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INTRODUCTION

INFORMATION CONTAINED IN THIS DOCUMENT

This document is a guide for the proper applications of the following Cummins MerCruiser Diesel engines for use in recreational, government service, and commercial applications:

- B/C
- QSB/QSC/QSL
- QSM 11
- QSD Inboard Recon

Within this document, the name Cummins MerCruiser Diesel (CMD) may be used interchangeably with "Cummins" or "Cummins Inc.". This is due to a large portion of the requirement statements and recommendations being shared with the marine high horsepower and auxiliary division, Cummins Marine.

This document is divided into subsections, based on engine system. Each subsection contains requirements that must be met in order to achieve an approved installation review. Installation reviews are to be conducted by qualified Cummins MerCruiser Diesel representatives.

The **requirements** for each system are denoted by the symbol "**!**" and highlighted with **bold text**. They must be adequately satisfied in order to obtain Cummins MerCruiser Diesel's approval of the installation. Failure to meet the installation requirements may result in noise, vibration, poor performance, reduced fuel economy, higher maintenance costs, shortened engine life, and engine/component failure. Installations that do not comply with Cummins Inc. requirements may also be excluded from warranty consideration.

Recommendations given in this document are provided to assist the installer in meeting the requirements of a particular system. The recommendations are intended as an aid, are not all encompassing, and their use is strictly optional; so long as the requirements are met. If you have questions concerning this document, contact a Marine Certified Application Engineer at your local Cummins MerCruiser Diesel distributor.

A Cummins MerCruiser Diesel approved installation confirms that all of the application requirements have been satisfactorily met. It is meant to provide assurance that the engine had been installed in a way to promote performance, reliability, and durability, within the engine's designed limits. An approved installation does not guarantee the following:

- Component quality, workmanship, assembly practices, and endurance characteristics of the installation.
- Acceptability to end users of subjective characteristics such as performance vibration, and noise levels.
- Conformance of the equipment to legislated or regulatory requirements regarding areas such as design, safety, and noise levels.
- Vessel application with regard to performance and type of service.

CMD realizes that marine installations are complex and all requirements may not be applicable, necessary, or attainable. Given this, a request for exemption may be made by properly filling out and submitting the "Request for Exemption of Marine Installation Requirement", which can be found in MAB 3.00.00-01/17/2001. The request must be approved by both a Cummins distributor and a factory application engineer, and be attached to the completed installation review to become valid.

SYMBOLS CONTAINED IN THIS DOCUMENT

❗ **This symbol and bold text indicates a requirement for the engine installation. Failure to comply with the requirement could void the engine warranty and result in engine damage or failure.**

Note: *A note provides additional helpful or important information*

△ **This symbol is an important point regarding the engine. When accompanied by the word “CAUTION”, this symbol indicates that failure to heed the caution could result in equipment damage or failure.**

⚠ **This symbol is an important point regarding safety. When accompanied by the word “WARNING”, this symbol indicates that there is a risk of personal injury or death.**

📖 **This symbol indicates that you should refer to the Operation and Maintenance manual or some other document for further information.**

☎ **This symbol indicates that you should consult your local Cummins Marine Certified Application Engineer, if needed.**

ADDITIONAL DOCUMENTS

The following documents will be referenced throughout the Installation Directions and are useful, if not required, to complete the installation. All documents are available on the Cummins MerCruiser Diesel website, www.cmdmarine.com, unless noted otherwise.

- Operation and Maintenance Manual, provided with the engine
- Engine Installation Drawing
- Engine Wiring Diagram
- General Engine Data Sheet
- Engine Performance Curves and Data Sheet
- Applicable Marine Application Bulletins (MAB), available from your local Marine Certified Application Engineer, or by logging onto http://marine.cummins.com

A NOTE TO THE BOATBUILDER REGARDING ENGINE ACCESSIBILITY

How the engine will be accessed for future service work is an important consideration. Hatches and removable decks sized and located to provide reasonable accessibility to all sides of the engine and drive system are indispensable to the technician for providing quality and timely maintenance and/or repairs to our mutual customers. They also allow the operator to more effectively complete the prescribed preventive maintenance and engine checks. Consideration for complete engine removal is also necessary. Many vessels will outlive the engine package, requiring a repower. Provisions for engine removal should be designed into the vessel. Most new construction vessels have the engines installed before the deck is added. After the deck is added, access for complete engine access becomes an afterthought until a major failure occurs. Having to cut permanent structures such as decks, bulkheads, supports, etc., and the use of elaborate rigging to remove an engine dramatically increases repair costs and chances for customer dissatisfaction.

CMD warranty repairs, including engine removal and installation, have published standard repair times (SRT) that are used to determine payment to our service providers. The standard repair times take into account the reduced access typical in marine applications, but assume reasonable access can be obtained to the entire engine. Note: Warranty work on applications that have restricted access that result in excessive repair time or additional costs to remove permanent structures may be subject, at CMD’s discretion, to denial of the portion of cost over the published SRT and/or what is normal and expected for that repair.

INSTALLATION QUALITY ASSURANCE PROCESS

INTRODUCTION

The Installation Quality Assurance (IQA) process is an eight (8) step process used to lead the application of marine engines from initial engine selection through installation and sea trial to final reporting. The eight steps are:

1. Define the Customer and Vessel Requirements.
2. Select an Engine and Rating.
3. Package the Engine in the Vessel.
4. Design the Engine Sub-Systems.
5. Construct the Engine Order.
6. Confirm Design Compliance During Vessel Construction.
7. Conduct the Sea Trial.
8. Document the Installation.

This IQA process should be used in the application of all marine engines and scaled according to the extent of the project. The purpose is to make sure of end user satisfaction, engine reliability, and engine durability; by selecting the correct engine(s) for the application and making sure all engine systems are designed and installed according to the requirements. An additional benefit is to capture and understand system costs to aid future installations.

DISCUSSION

The following describes in detail the eight IQA steps to be used in properly applying marine engines. All appropriate installation instructions should be referenced for specific details of the related installation requirements.

STEP 1 – Define the Customer and Vessel Requirements

1. Complete the installation profile.
    - Determine the vessel’s intended use profile.
    - Obtain and rank the customer’s requirements.
2. List major features and options required by the customer (noun name only)

STEP 2 – Select an Engine and Rating

1. Determine the marine rating.
    - Duty cycle analysis.
    - Operation time per year.
    - Vessel hull type and usage.
2. Define power demand.
    - Parasitic losses.
    - Corrections from standard.
    - Propulsion power.
    - Power take-off.
3. Select candidate engine(s).
4. Compare candidate engine(s) with customer requirements.
5. Select engine(s) (subject to Steps 3 and 4)

STEP 3 – Package the Engine in the Vessel

1. Define suppliers for critical components.
    - Who supplies data and hardware for isolators, PTOs, exhaust, etc.
2. Assess fixed interface points.
    - Location of prop shaft, companion flange, etc.
    - Vessel survey for repower.

  - Critical dimensions.
3. Specify owner and builder constraints.
4. Define mounting scheme.
  - Footprint of power train.
  - Overall clearances around powertrain.
  - Service accessibility.
    - Routine maintenance.
    - Major maintenance or repairs.
    - Engine removal.
5. Locate major vessel connections (points / zones).
  - Fuel
  - Water
  - Air
  - Exhaust
6. Finalize machinery layout.
7. Document the design and layout issues.
8. Communication with builder and designer.
9. Initiate preliminary engine option list for engine shop order.

STEP 4 – Design the Engine Sub-Systems

1. Specify engine sub-system design elements:
  - Mounting
  - Drivetrain
  - Accessory Drives
  - Exhaust
  - Cooling
  - Air Intake/Engine Room Ventilation
  - Fuel
  - Electrical
  - Starter
  - Electronic Controls
  - Controls, Gauges, and Alarms
  - Lubrication
2. Conduct a design review with the customer, by sub-system.
  - Include sea trial instrumentation test points (ref. Step 6-6).
3. Update the preliminary engine options list.
4. Initiate the installation review document.

STEP 5 – Construct the Engine Order

1. Choose the closest price specification. (based on preliminary option list from Step 4).
2. Edit and finalize CSL or COLS specification.
3. Compile specification in IMS or COLS.
  - Verify production availability and compare to customer delivery requirements.
4. Develop a list of the non-Marine Group supplied hardware (if applicable).
  - Distributor up-fit bill of material (all parts and components added by the distributor).

STEP 6 – Confirm Design Compliance During Vessel Construction

1. Establish a project team and work plan.
2. Up-fit the engine to customer specifications as required.
3. Make sure all hardware matches customer requirements prior to engine installation.
4. Update the installation review documentation.
5. Review the installation throughout the build phase.
6. Prepare for installation of sea trial instrumentation.

STEP 7 – Conduct the Sea Trial

1. Review or prepare the sea trial test plan.
2. Verify and calibrate instrumentation.
3. Install instrumentation and test equipment.
4. Conduct dock test – validate instrumentation and functional systems test.
5. Conduct sea trial.
6. Analyze measurements and validate data.
7. Resolve non-compliance issues when possible.
8. Confirm compliance via additional sea trials.
9. Update the installation review documentation.
10. Publish a preliminary sea trial report.
    - Witness sign off on sea trial.

STEP 8 – Document the Installation

1. Compile all documents from Steps 1 through 7.
2. Highlight issues of non-compliance with Marine Group installation requirements and customer expectations.
3. Make revisions to comply with Marine Group requirements.
4. Complete the Installation Review Report.
5. Review the final report with the customer and obtain sign-off.
6. Distribute copies of the Installation Review Report to CMC/CMD, the customer, distributor, shipyard, and naval architect.

ENGINE APPLICATION

SUMMARY OF REQUIREMENTS

! The engine must be used in accordance with the application guidelines for that particular rating.

GENERAL INFORMATION

Cummins MerCruiser Diesel develops engines to meet customer performance, reliability, and durability expectations; depending on the type of service. In order for the engine to perform as it is intended, it must be used in accordance with the published marine rating guidelines and corresponding duty cycle. Duty cycle is a measure of the annual operating time and severity of use, known as the power factor of the engine. MAB No. 2.05.00-11/13/2002, Marine Duty Cycle Analysis, provides further definition and methods for calculating the actual and/or anticipated power factor It is critical to use the calculated power factor and expected annual usage to select the proper engine rating for a given application. Using an engine beyond its designed duty cycle may, at Cummins MerCruiser Diesel's discretion, void the warranty coverage.

SERVICE ACCESSIBILITY

The following is a list of Engine Application service points that should be accessible:

- Engine dataplate
- Marine gear dataplate

INSTALLATION DIRECTIONS

Engine Application Guidelines

! **The engine must be used in accordance with the application guidelines for that particular rating.**

Proper application of the engine is important to make sure the engine is capable of providing the performance, reliability, and durability it was designed for. Table 3-1 lists the marine rating guidelines with annual usage, power factor, and typical usage information.

Rating	Description	Maximum Power Factor (Percent)	Annual Usage (hrs)
Prime Power	This power rating is intended for applications requiring unlimited use in variable load applications. Variable load must not exceed 70 percent of the rated power within any 250 hour operating period and full power operation must not exceed 500 hours annually.	70	Unlimited
Continuous	This power rating is intended for use in applications requiring uninterrupted and unlimited service at full power. Typical vessel applications include ocean-going displacement hulls such as deep water fishing trawlers, freighters, tugboats, pushboats, bottom drag trawlers, and towboats.	100	Unlimited
Heavy Duty	This power rating is intended for nearly continuous use in variable load applications, where full power is limited to eight hours out of every ten hours of operation. Also, reduced power operation must be at or below cruise rpm, which is 200 rpm below the maximum rated speed. This rating is for applications operating less than 5000 hours per year. Typical vessel applications include displacement hull vessels such as mid-water fishing trawlers, purse seiners, and towboats where frequent slowing is common and engine speed and load is stable. They may also be used in high speed vessels such as ferries and crewboats. Typical auxiliary applications include cargo pumps and thrusters in dynamic positioning modes.	75	<5000
Medium Continuous	This power rating is intended for moderate use in variable load applications, where full power is limited to six hours out of every twelve hours of operation. Also, reduced power operation must be at or below cruise rpm, which is 200 rpm below the maximum rated speed. This rating is for applications operating less than 3000 hours per year. Typical vessel applications include planing hull ferries, fishing boats designed for high speeds to and from fishing grounds, (non-cargo) displacement hull yachts, and short trip coastal freighters where engine load and speed are cyclical. Typical auxiliary applications include powerpacks and some cargo pumps.	60	<3000
Intermittent	This power rating is intended for intermittent use in variable load applications, where full power is limited to two hours out of every eight hours of operation. Also, reduced power operation must be at or below cruise rpm, which is 200 rpm below the maximum rated speed. This rating is for applications operating less than 1500 hours per year. Typical vessel applications include planing hulls such as customs, military and police vessels, charter fishing, and some non-net dragging fishing vessel applications. Typical auxiliary applications include hydraulic powerpacks, thrusters for maneuvering, and emergency fire pumps.	40	<1500
Government Service	This power rating is intended for infrequent use in variable load applications, where full power is limited to one hour out of every eight hours of operation. Also, reduced power operation must be at or below cruise speed (rpm). Cruise speed (rpm) is dependent on the engine rated speed (rpm): **Refer to Table 3-1.1** This rating is for applications operating less than 500 hours per year. Engines with this rating are restricted to non-revenue generating government service propulsion applications. It is not to be used in any revenue generating commercial applications, nor is it to be used in recreational/pleasure applications. Typical Government Service applications are patrol, rescue, fire, and assault vessels used by federal and state/local agencies such as military, coast guard, homeland security, research, police departments, fire departments, and departments of natural resources.	30	<500
High Output	This power rating is intended for infrequent use in variable load applications, where full power is limited to one hour out of every eight hours of operation. Also, reduced power operation must be at or below cruise speed (rpm). Cruise speed (rpm) is dependent on the engine rated speed (rpm): **Refer to Table 3-1.1** This rating is for applications operating less than 500 hours per year.Engines with this rating are intended for powering recreational/pleasure use vessels only. Commercial use is defined as any work or employment related use of the product, or any use of the product which generates income, for any part of the warranty period, even if the product is only occasionally used for such purposes. Typical High Output applications are sportfishers, motoryachts, and cruisers.	30	<500

Table 3-1

Rated Speed	Cruise Speed (reduction from rated)
2000 to 2800 rpm	200 rpm
2801 to 3500 rpm	300 rpm
3501 to 4500 rpm	400 rpm

Table 3-1.1

Table 3-2 illustrates typical power factors for a variety of applications with respect to the available marine engine ratings.

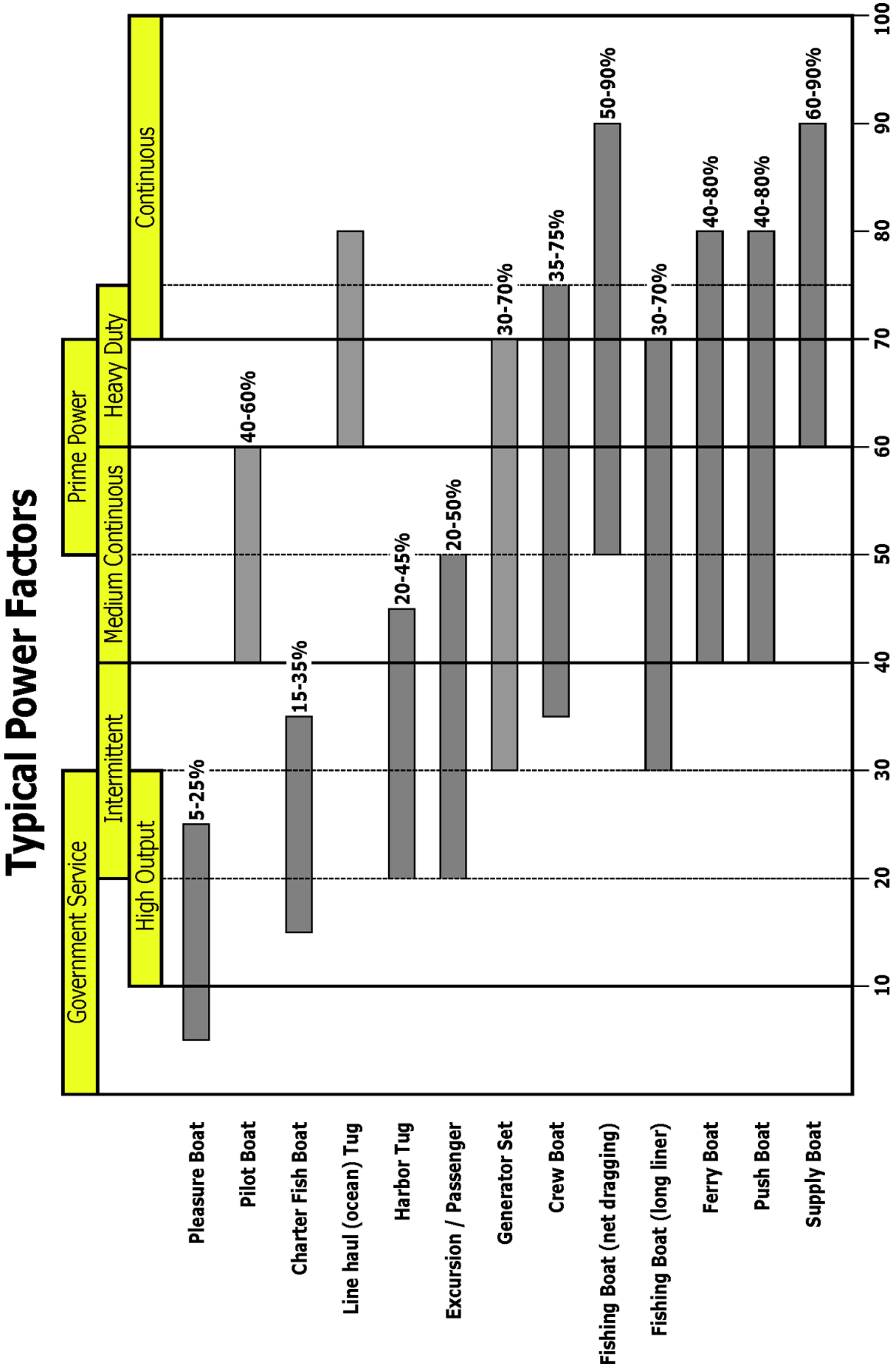


Table 3-2

ENGINE MOUNTING SYSTEM

SUMMARY OF REQUIREMENTS

! **The mounting system must be constructed so the supporting structure deflections do not overstress the engine castings.**
! **The engine must have sufficient clearance to prevent damage from physical contact between the engine components and adjoining vessel structures.**
! **The static installation angle of the engine in a waterborne vessel must not be less than the minimum, nor more than the maximum value given in the General Engine Data Sheet.**
! **Customer supplied mounts must meet manufacturer's load and alignment requirements.**
! **Vibration Isolators must be installed so their horizontal centerline is parallel to the crankshaft centerline and their vertical centerline is parallel to both the engine vertical centerline and to the rear face of the block.**
! **Vibration isolators must be free to deflect and not be fully compressed under static load.**
! **The engine must be installed so the static bending moment at the point where the flywheel housing is attached to the engine does not exceed the maximum value on the General Engine Data Sheet.**

GENERAL INFORMATION

The purpose of the engine mounting system installation directions is to lead to the development of a robust engine bed, and to mount the engine to it. The proper installation of the components discussed in this section is critical as they provide the foundation and framework for the rest of the engine installation. Oversights in design, construction, and installation of the engine mounting system may result in misalignment of the driveline, fatigue, and eventually failure of the components. They may also impact customer satisfaction due to excessive noise, vibration, and harshness.

SERVICE ACCESSIBILITY

The following is a list of Engine Mounting service points that should be accessible:

- Engine mounts
- Vibration isolators

INSTALLATION DIRECTIONS

Engine Foundation

! **The mounting system must be constructed so that the supporting structure deflections do not overstress the engine castings.**

The engine stringer and bed system in a vessel is the single most important structural component. It must be designed to withstand not only the weight of the engine, but also the thrust of the propeller, propeller torque reaction, and the stresses caused by the pitching and rolling of the vessel in the harshest of environmental conditions. Correctly constructed, the engine stringers and engine bed should absorb all of the vessel strain and stress, and not transfer it to the engine and driveline. In cases where the stringers and engine bed design have excessive flex, undue stress is transmitted to the supporting structure of the engine and driveline. The result is misalignment and stress upon the engine and driveline that leads to vibration and possible failure.

The foundation for the engine and driveline consists primarily of the longitudinal stringer sections and the engine bed. The stringers usually run the length of the boat, and are often built up the engine compartment to support the engine and the marine gear. The engine bed provides the attachment points for the engine and marine gear to the stringer framework (see Figure 4-1).

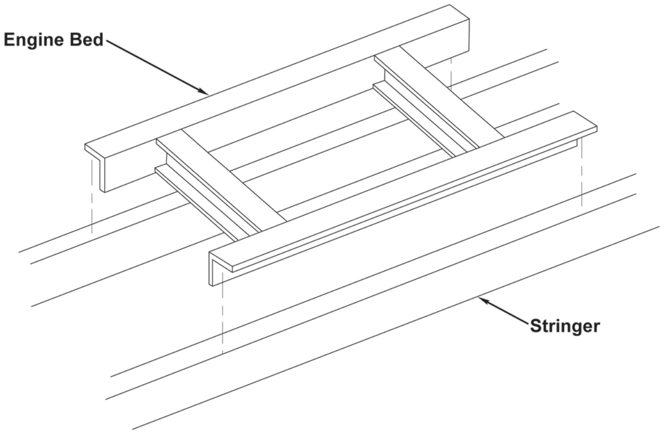


Figure 4-1: Typical Engine Foundation Arrangement

NOTE: *The angle of the installed engine foundation should match the required engine installation angle. Special recommendations are made in this section regarding the alignment of the engine and the position of the isolators. It is important that these be considered in the design process.*

Cross bracing on the engine bed and stringers may be needed to reduce transverse engine/support movement in some installations (see Figure 4-2). Doing so helps limit vessel structural deflections from being transmitted to engine castings and also limits the amount of transverse engine movement (causing vibration) that is transferred to the hull.

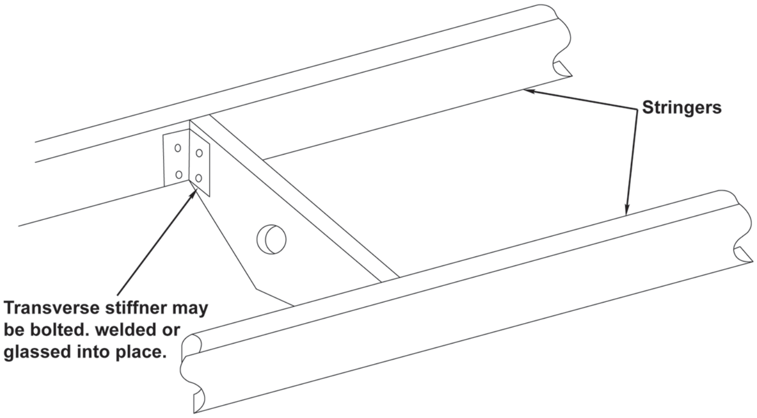


Figure 4-2: Typical Stringer Cross Bracing

Engine bed frames in steel or aluminum hulls should be of welded construction. The frame should be welded directly to the hull structure.

In fiberglass hulls, the engine bed can be molded and integral with vessel stringers or attached separately. Stringers should be built in a box section and filled with a material that is not affected by sea water, moisture, or oil. If the engine bed is integral to the stringer, a plate of steel or aluminum should be bedded into the top of the stringer to provide strong and positive mounting of the engine. Otherwise, a welded steel or aluminum engine bed that is securely fastened by through bolting should be used. Refer to Figures 4-1, 4-3, and 4-4.

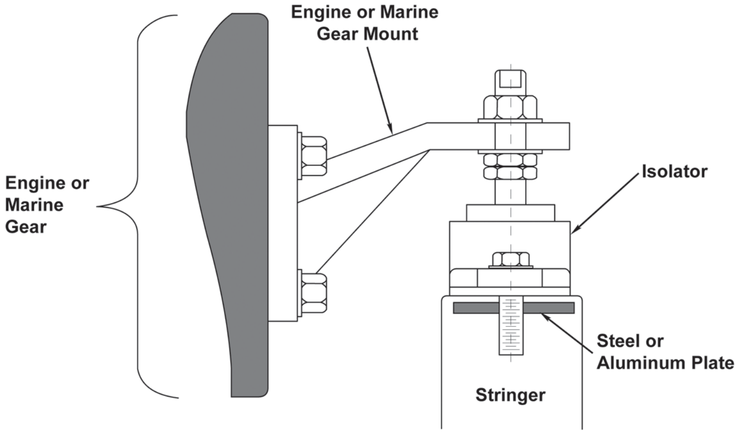


Figure 4-3: Engine Bed Integrated into Stringer

When an engine mounting support bracket or engine bed is fixed to the side of the wood or fiberglass stringer, the bracket should be through bolted with steel or aluminum backing plates or large flat washers used to sandwich the stringer and prevent crushing and failure of the area around the fastener (see Figure 4-3).

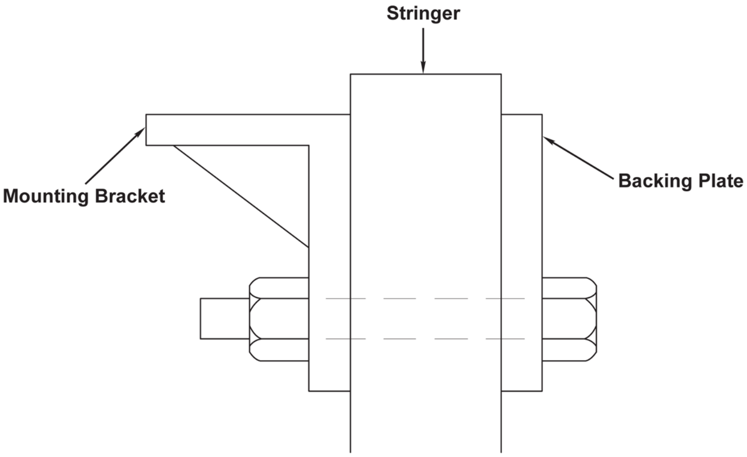


Figure 4-4: Side Mounted Engine Bed – Through Bolted with Backing Plate

NOTE: *Steel or stainless steel bolts should be used for all fasteners relating to the mounting system. Cummins recommends the use of fasteners that have been quenched and tempered for strength (SAE Grade 8 or equivalent). Lag bolts or other fasteners that do not thread into corresponding metal fasteners should not be used.*

! **The engine must have sufficient clearance to prevent damage from physical contact between the engine components and adjoining vessel structures.**

The engine must be installed with sufficient clearance on all sides to prevent damage from physical contact with the adjacent vessel structures. Cummins Inc. recommends a gap of at least 25 mm (1 in) between the engine and any vessel structures. Care must also be taken to make sure hoses, cables, and wires connecting the engine to the vessel structures are not damaged through engine movement. The attaching systems must have flexible sections with sufficient length to allow for the full range of engine movement. The attaching systems must also be routed and fixed in a way that prevents contact with the engine. In situations where this can not be avoided, adequate chafe protection must be provided. Additional requirements regarding the use of flexible sections are given in the respective system section that the flexible section supports (i.e. exhaust, fuel, cooling, electrical, etc.)

Engine Installation Angle

The static installation angle of the engine in a waterborne vessel must not be less than the minimum, nor more than the maximum value given in the Engine General Data Sheet.

The static installation angle is an angular measurement of the engine in reference to a level plane while the vessel is waterborne, loaded, and at rest. The measured angle is positive when the front of the engine is elevated or "nose up". The measured angle is negative when the front of the engine is dropped or "nose down". The static installation angle should be taken using an accurate inclinometer or angle finder placed longitudinally upon a flat surface on the engine that is parallel to the crankshaft centerline, such as the cylinder head or rocker box cover.

For a conventional in-line setup, 0 degrees is the minimum installation angle. Cummins Inc. recommends that the engine in a conventional in-line setup be installed as close as possible to 0 degrees. Marine gear manufacturers offer down angle gears to facilitate a low engine installation angle. For the maximum installation angle, refer to the General Engine Data Sheet (see Figure 4-5).

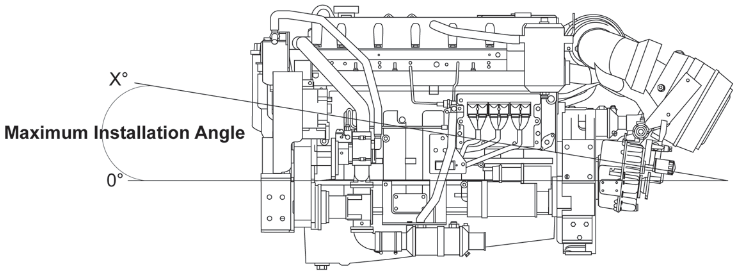


Figure 4-5: Conventional installation

For a vee drive setup, 2 or 3 degrees nose up is the minimum installation angle, depending on engine model. For the minimum and maximum installation angle, refer to the General Engine Data Sheet. Vee drive marine gears that allow the engine to be installed within the installation angle requirement are commonly available (see Figure 4-6).

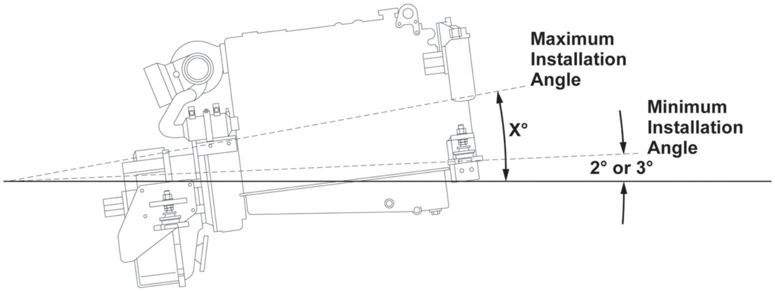


Figure 4-6: Vee Drive Installation

NOTE: *The front of an engine in a vee-drive installation faces the stern section of the vessel.*

The transverse installation angle of the engine for all applications should be 0°. Installation of the engine leaning to one side or the other can potentially overstress the mounting and isolation components. Additionally, it may also affect the supply of oil from the oil pan leading to oil pressure fluctuation or oil starvation (see Figure 4-7).

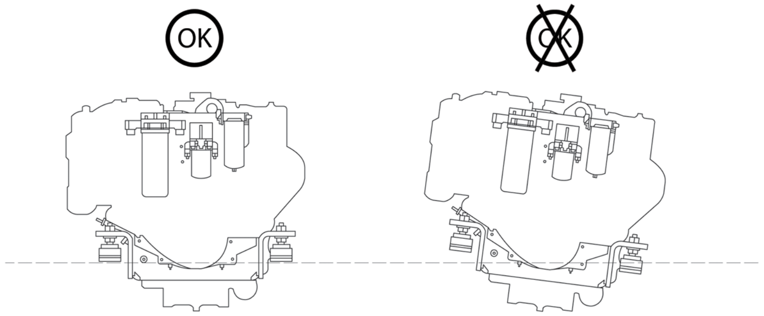


Figure 4-7: Transverse Installation Angle

The engine must be level or nose up during coolant fill and engine start-up so that the engine block, cylinder heads, and turbocharger will deaerate properly and completely fill with coolant. Operating an engine with the nose down (see Figure 4-8) can hinder proper venting and allow an air pocket to form at the rear of the cylinder head and/or turbocharger. This may cause localized overheating and possible engine damage.

CAUTION:Operating an engine with the front down may allow an air pocket to form at the rear of the cylinder head and/or turbocharger, causing localized overheating and possible engine damage.

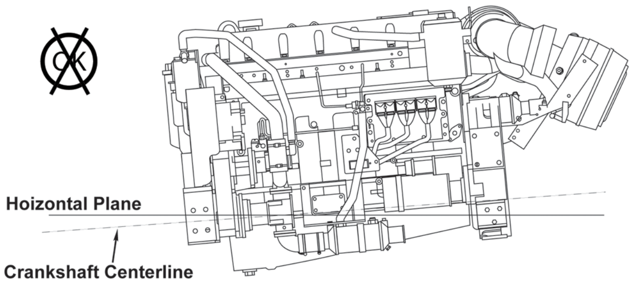


Figure 4-8: Nose Down Condition

Engine Mounting

Customer supplied mounts must meet manufacturer’s load and alignment requirements.

CAUTION: Failure to use proper mounts, support brackets, and hardware could result in premature failure of the mounts, which could result in damage to the engine or vessel.

Engine and gear mounts available from Cummins Inc. are recommended, as they have been designed and tested to provide the proper strength and rigidity. Non-Cummins Inc. supplied mounts for the engine and/or gear must meet that manufacturer’s load and alignment requirements. Some considerations that must be taken when sourcing non-Cummins Inc. mounts are:

- Must provide adequate strength to hold the static and dynamic load of the engine and/or marine gear.
- Must avoid resonant vibration with the normal operating range of the engine.
- Must have a mating surface for attaching to the engine or marine gear that is flat within 0.1mm (0.004”) and be unpainted. A machined surface is recommended.
- Must have adequate clearance and adjustability for installing and servicing the vibration isolator.

Solid Engine Mounting

NOTE: *Solid mounting the engine will increase the amount of resonance and vibration transmitted into the hull and drive system. Cummins Inc. recommends the use of a flexible mounting system.*

Typically, some commercial vessels use a solid mounting system, because it is the easiest to install, align, and requires less maintenance. Solid mounts are simple, durable, and generally inexpensive; but they do have disadvantages. A solid mounting system will transmit more noise and vibration to the hull structure than a flexible mounting system, making it less desirable in pleasure and passenger vessels.

If a solid engine mounting system is used, the proper support bracket locations must be used for mounting the engine and gear (see Figure 4-9). Use the mounting pads on the marine gear (1) and at the front of the engine (2) to absorb the propeller thrust.

The engine must not be mounted with brackets off the flywheel housing when using a direct mounted gear, unless they are used in conjunction with front and rear mounts for a six point mounting system; or when a saddle bracket is installed, which connects the engine flywheel housing and marine gear together for the purpose of reducing bending moment at the rear face of the block (see discussion on bending moment at the end of this subsection). When using a six point mounting system, the engine should be aligned initially using the front and rear mounts. Once the alignment is complete, the middle mounts attached to the flywheel housing are loaded and alignment is rechecked.

The use of the flywheel housing support as a rear mount location on some engines is only recommended with remote mounted gears or jet drives.

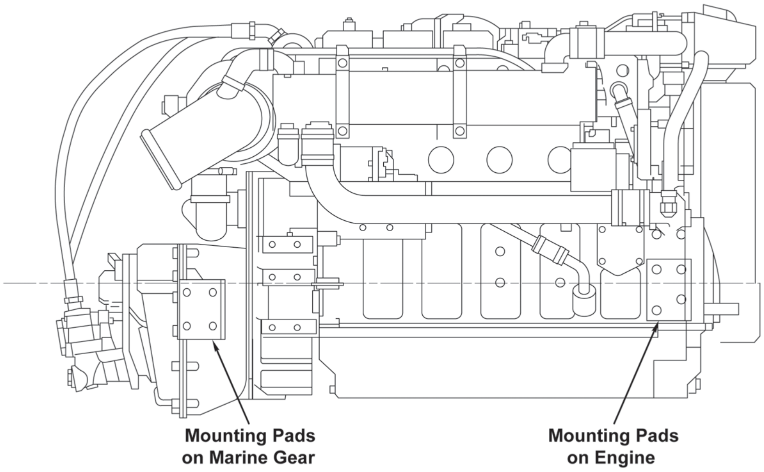


Figure 4-9: Engine Mounting Locations

Solid mounting an engine is typically done by using brass or steel shims, pourable chocking compound, or Fabreeka® type washers and pads. The use of pourable chocking compound is the simplest and preferred way to solid mount an engine. When using a chocking compound, the alignment of the marine gear and propeller shaft is accomplished using jacking screws between the mounts and the engine bed. The mounting bolts can be loosely installed at this point or a hole can be drilled through the chocking compound later. The jacking screws, mounting bolts, and bottom of the engine mount should be coated with grease or anti-bonding agent to allow them to be removed later. Temporary dams are put on the engine bed and should extend approximately 13 mm (0.5 in) above the bottom of the engine mounts. The chocking compound is poured in to fill the space between the mount and the engine bed. Once the compound has solidified, the mounting bolts are tightened to the proper torque value(see Figure 54-10).

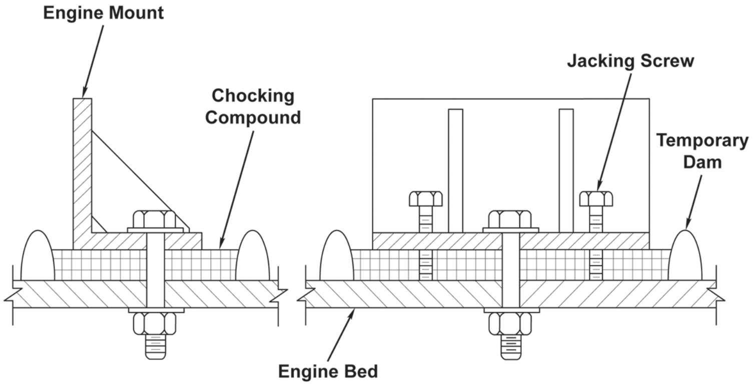


Figure 4-10: Solid Mount with Chocking Compound

Fabreeka® type washers and pads consist of layers of elastomer impregnated canvas vulcanized together. They provide some flexibility for minor misalignment and give a degree of shock loading protection to the engine. However, the spring rate is too high to provide isolation of the hull from the engine vibrations. A sample solid mounting using Fabreeka® type washers and pads is illustrated in Figure 4-11. It is still necessary to use brass or steel shims to align the engine and gear with the shafting.

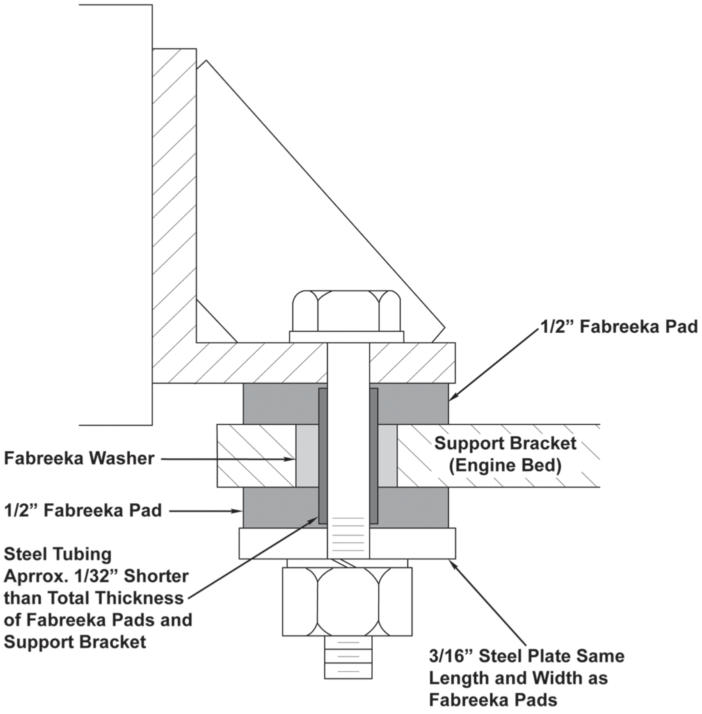


Figure 4-11: Solid Mounting Using Fabreeka® Type Washers and Pads

Flexible Engine Mounting and Isolators

NOTE: *CMD recommends the use of a flexible mounting system.*

Flexible engine mounting is commonly found on pleasure vessels, but it can be used on commercial vessels to reduce vibration and noise that is transmitted from the engine to the hull through the mounting system. Rubber isolators are typically used in a flexible mounting system. The term "rubber" is used to describe a wide range of commercially available elastomers that are used for vibration isolation.

Transmitted vibration is the primary source of noise in a boat. Therefore, efficient vibration isolation is the key to smooth and quiet operation, making the selection of vibration isolators very important. Vibration isolators available from CMD are recommended, as they are specifically designed for each engine model. (See Figure 5-12)

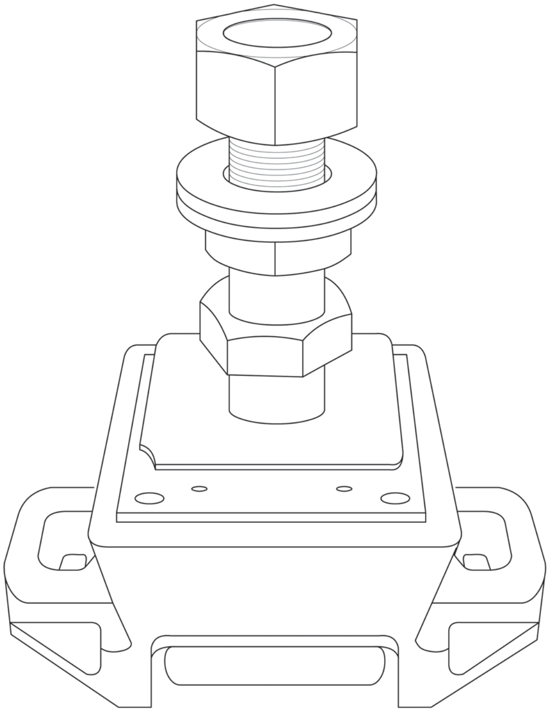


Figure 4-12: Typical CMD Supplied Vibration Isolator

If a flexible engine mounting system is used, the proper support bracket locations must be used for mounting the engine and gear (see Figure 4-8). Use the mounting pads on the marine gear (1) and at the front of the engine (2) to absorb the propeller thrust.

The engine must not be mounted with brackets off the flywheel housing when using a direct mounted gear, unless they are used in conjunction with front and rear mounts for a six point mounting system, or when a saddle bracket is installed, which connects the engine flywheel housing and marine gear together for the purpose of reducing bending moment at the rear face of the block (see discussion on bending moment at the end of this subsection). When using a six point mounting system, the engine should be aligned initially using the front and rear mounts. Once the alignment is complete, the middle mounts attached to the flywheel housing are loaded and alignment is rechecked.

The use of the flywheel housing support as a rear mount location on some engines is only recommended with remote mounted gears or jet drives.

NOTE: *The following instructions are specific to vibration isolators that are Cummins Inc. supplied. However, comparable vibration isolators will require similar installation techniques. Non-Cummins Inc. supplied isolators must meet that manufacturer's installation requirements.*

! **Vibration isolators must be installed so their horizontal centerline is parallel to the crankshaft centerline and their vertical centerline is parallel to both the engine vertical centerline and to the rear face of the block.**

Vibrations isolators are designed to provide the most efficient dampening of driveline vibrations when they are installed per the manufacturer's recommendations. If the vibration isolator is misaligned, it distorts and stresses the isolator element and adversely affects the dampening characteristics. Vibration isolator service life may also be significantly reduced if misaligned (see Figures 4-13 and 4-14).

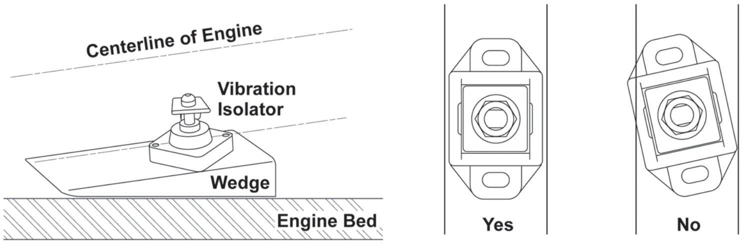


Figure 4-13: Horizontal Centerline of Isolator is Parallel with Crankshaft Centerline

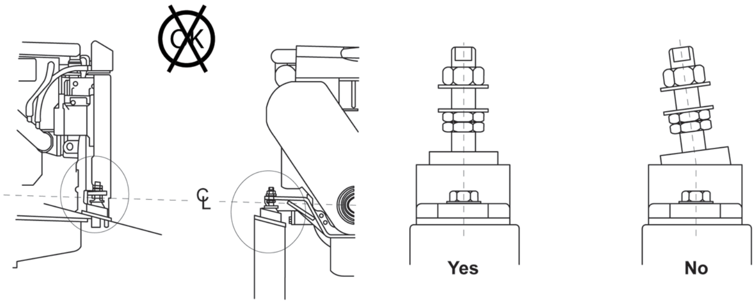


Figure 4-14: Vertical Centerline of Isolator is Parallel to Engine Vertical Centerline

When installing Cummins Inc. supplied vibration isolators, a maximum misalignment angle applies to the fore and aft, side to side (roll), and yaw orientation of the vibration isolator. The maximum misalignment angle may differ, depending on the generation of isolator used. Older generations of isolators all use cast aluminum or cast iron housings (see Table 4-1). Illustrations and instruction describing how to measure the misalignment angles are given later in this document, under the heading of Vibration Isolator Angle Determination.

Measure Cast Housing	Maximum Misalignment Angle
Fore and Aft Pitch Angle	4 degrees
Roll Angle	2 degrees
Yaw Angle	2 degrees

Table 4-1: Vibration Isolator Maximum Misalignment Angles

The bolt holes used to attach the vibration isolators to the engine bed must be drilled accurately to avoid building in stresses across the mounts. If the holes are drilled after the engine is lowered in position, the isolators can be used as a hole marking template. If the holes are drilled before the engine is installed, the hole pattern must be accurate to within 1.5 mm (0.06 inch) on all of the dimensions shown in Figure 4-15.

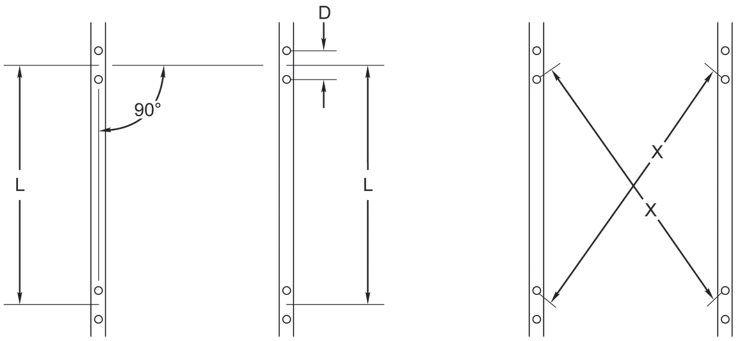


Figure 4-15: Dimensions L and D per Installation Drawings

! **Vibration isolators must be free to deflect and not be fully compressed under static load.**

Vessel structures, hoses, cables, wiring, etc. must be located or routed so as not to interfere with the vibration isolator's normal range of motion, due to interference, binding, and/or restraint. Under a static load, the isolators should be adjusted so that they are equally loaded and not fully compressed. See the instructions given under Vibration Isolator Adjustment to properly determine loading on the isolators.

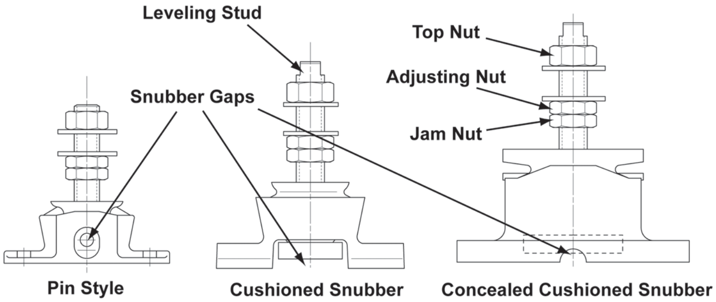


Figure 4-16: Vibration Isolator Snubber Gaps (Cast Housings)

Vibration Isolator Installation

1. The isolator base must be installed parallel to the crankshaft centerline to maintain the required range of motion, clearance, and isolation. It is also critical that the engine mount to isolator stud mating surfaces are parallel with the crankshaft centerline. The oil pan flange can be used as a visual reference to the crankshaft centerline. If the engine bed or stringer mounting system is not parallel to the engine mounts, the stringers must be leveled with shims or wedges installed under the isolators, to correct the misalignment (see Figure 4-13). Shims and wedges must be made of non-compressible material such as brass, aluminum, or steel.

   Assemble the isolators to the engine mounts. The proper orientation of the fastening hardware on the isolator stud from bottom to top is: jam nut, adjusting nut, washer, engine mount, washer, and top nut (see Figure 4-16). Position the nuts so that some thread adjustment is available both upward and downward. If the engine mount is slotted, position the leveling stud in the center of the slot. This will allow for adjustment in all directions when performing the engine alignment.

1. It is also necessary for the isolator stud to be perpendicular to the isolator base in all directions. Instructions on how to measure the misalignment and find the limits is included in the section titled Vibration Isolator Angle Determination.
2. Lower the engine into place so the four isolator bases rest in the desired position on the stringers. Bolt them lightly to the stringers. Do not remove the lifting hoist yet. Align the engine and marine gear with the propeller shaft to specification, and then begin to transfer the weight of the engine from the hoist to the mounts by using the adjusting nuts on all the isolators (see Figure 4-16). Do not move the adjusting nuts without assist from the hoist until the engine weight is close to evenly distributed. Failure to support the engine could result in damage to the stud and nut threads. Once the weight is evenly distributed, the hoist can be removed.

Vibration Isolator Adjustment

1. CMD supplied vibration isolators are height adjustable to allow for engine alignment. Adjusting the height also adjusts the share of the weight carried by each isolator. It is very important to equalize the weight of the engine and gear between the isolators. In some situations, the load will not be completely equalized between the front and rear isolators. However, the load should always be equalized between the sides of each engine.
2. On cast housing isolators with rubber snubber located between the cast housing and the stringer, the snubber serves as a load indicator. When the isolator is properly loaded, the rubber snubber should not be touching the housing or the stringer. If the snubber is touching the housing, the isolator is under-loaded. If the snubber is touching the stringer, the isolator is overloaded. Under static conditions, the snubber gap

should maintain a clearance of at least 1mm (0.040 in). The gaps above and below the snubber will vary from 1 to 5 mm (0.04-0.20 inch), depending on the load (see Figure 4-16).

On cast housing isolators with a concealed snubber, a feeler gage can be inserted through the half-moon opening under the base casting to get an approximate measurement of the gap. If the gap is 8 mm (0.312 in) or more, the isolator is under-loaded. If the gap is less than 1mm (.040in), the isolator is overloaded (see Figure 4-16).

On pin-style isolators, the pin serves as a load indicator. The isolator is correctly loaded when the pin is at least 3 mm (0.125 in) from the edge of the hole in the cast housing. If the pin is touching the top of the hole, the mount is under loaded and will not isolate well. If the pin is at the bottom, the mount is overloaded (see Figure 4-16).

1. To apply load to an isolator, turn the adjusting nut so that it moves upward. This lifts the engine at that corner, increases load, and compresses the isolator. You will see that when the nut goes up, the snubber goes down. To reduce load, turn the adjusting nut so that it moves downward. This lowers the engine at that corner and relieves load on the isolator. When the nut goes down, the snubber goes up. Adjust the isolator loads until the front isolators have similar snubber gaps and the rear isolators have similar snubber gaps.
2. Rotate the isolator housing, if necessary, to align its horizontal centerline parallel with the crankshaft centerline (see Figure 4-13). The yaw angle must not exceed 2 degrees. Tighten the isolators down to the stringers.
3. Adjusting the isolator snubber gaps may change the shaft flange alignment. Recheck alignment and repeat the process as necessary, to make sure that the isolators are properly loaded and the engine is aligned with the shaft. If major adjustments are needed to achieve proper loading and alignment, it may be necessary to add shims or modify the stringers to center the isolator studs to the engine mount. The vibration isolator top nut must not be more than 2 mm (.080in) above the flat on the stud. If the nut is too high on the stud, shims should be added under the vibration isolator to raise it.
4. Finally, the isolator stud lower nuts and upper nut must be tightened. Torque values are given below (see Table 4-2). Hold the adjusting nut and tighten the jam nut, then hold the stud with the flats or hex socket on the top of the stud (to prevent twisting) and tighten the top nut.

	Adjusting Nut / Jam Nut	**Top Nut**
.75 inch Diameter Stud	129 N•m (95 lb-ft)	195 N•m (144 lb-ft)
1 inch Diameter Stud	181 N•m (134 lb-ft)	285 N•m (210 lb-ft)

Table 4-2: Vibration Isolator Torque Values

1. The vibration isolators may settle slightly after installation. Re-check the engine/shaft alignment and snubber spacing after several days under full engine weight load. Minimum snubber gap is 1 mm (0.040 in) after 7-10 days.

NOTE: *The final alignment should not be done until after the vessel is waterborne and has been loaded to its normal operating condition for at least 24 hours. The alignment should be redone each time a flexible mounting system is disconnected from the propeller shaft.*

Vibration Isolator Angle Determination

Measuring the Fore and Aft Pitch Angle across the Isolator

Both methods shown (see Figure 4-17) are acceptable and give the same results, as long as the engine mount/bracket is flat and straight. If the engine mount/bracket is not flat and straight, use only Method 2.

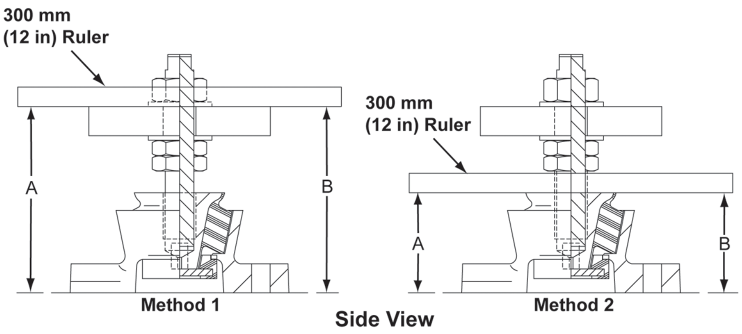


Figure 4-17: Method 1 and Method 2 - Side View of Isolator

1. With a 300 mm (12 in) ruler or straightedge centered on the isolator as shown, measure dimensions A and B at the ends of the ruler
2. Each degree of angle = 5 mm (.21in) of difference between A and B:

   Misalignment Angle = (A - B)/5mm or (A - B)/0.21in

1. The misalignment angle should not exceed 4 degrees or a 20.5 mm (0.84in) difference between A and B. If it does, realign the engine brackets or use wedges under the mount to get the angle below 4 degrees.

Measuring the Yaw Angle across the Engine Mount

The stringer edge can be used as a reference, if it runs in a straight line fore to aft in the hull. If it does not, find another reference that does run fore and aft in a straight line, and use that to make the following measurements: (see Figure 4-18)

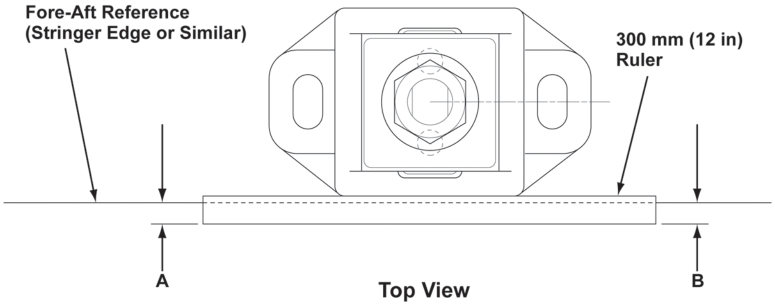


Figure 4-18: Top View of Isolator

1. With a 300 mm (12in) ruler or straightedge centered on the isolator as shown, measure dimensions A and B. Measure at the ends of the ruler.
2. Each degree of angle = 5 mm (.21in) of difference between A and B:

   Misalignment Angle = (A - B)/5mm or (A - B)/0.21in;

1. The misalignment angle should not exceed 2 degrees or a 10 mm (0.42 in) difference between A and B.

Measuring the Roll Angle across the Engine Mount

The vibration isolator housing is used as the reference (see Figure 4-19).

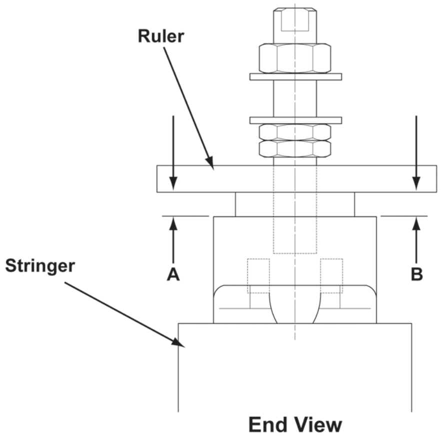


Figure 4-19: End View (Looking Forward)

1. With a short ruler or straightedge as shown, measure dimensions A and B at the edges of the mount's cast housing.
2. Each degree of angle = 1.5 mm (.06in) of difference between A and B:

   Misalignment Angle = (A - B)/1.5 mm or (A - B)/0.06 in

1. The misalignment angle should not exceed 2 degrees or a 3 mm (0.12 in) difference between A and B.

Bending Moment

The engine must be installed so that the static bending moment, at the point where the flywheel housing is attached to the engine, does not exceed the maximum value on the General Engine Data Sheet.

For assistance with calculating bending moments, contact your local Cummins Marine Certified Application Engineer.

Figure 4-20 illustrates the method for calculating the bending moment at the rear face of the block (M_{RFOB}) for a typical close coupled marine gear and four point mounting arrangement. The information needed for this calculation comes from the General Engine Data Sheet, installation drawing, marine gear manufacturer's information and the design of the mounting system. A bending moment calculator is also available in the Tools section of http://marine.cummins.com.

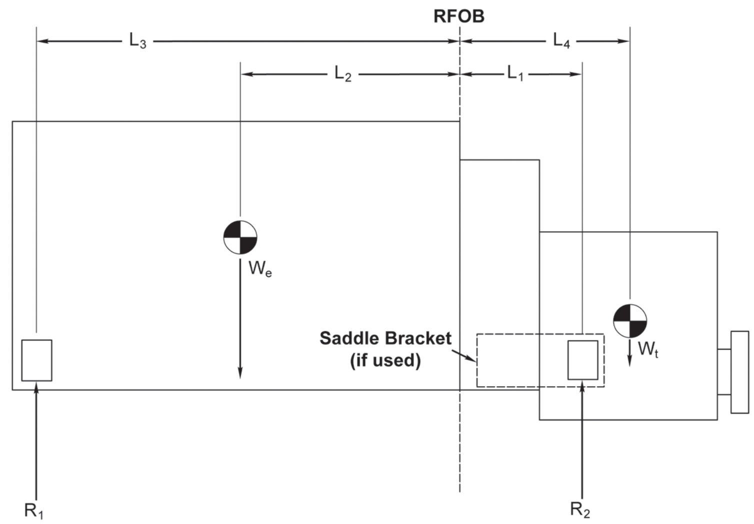


Figure 4-20: Measurements for Calculation Bending Moment at the Rear Face of the Block

W_e Is the location of the center of gravity and the wet weight of the engine in pounds (lb.) or kilograms (kg); made up from the dry weight of the engine plus the weight of water and oil in the engine.
W_t Is the location of the center of gravity and the wet weight of the marine gear package in pounds (lb.) or kilograms (kg); made up from the dry weight of the marine gear plus oil in the marine gear, weight of the flexible connection, and other mounted equipment.
R_1 Is the front mount reaction in pounds (lb.) or kilograms (kg).
R_2 Is the rear mount reaction in pounds (lb.) or kilograms (kg).
RFOB Is the plane of the rear face of the block about which bending moment is being calculated.
L_1-L_4 Are the horizontal distances between supports, centers of gravity, and the rear face of the block as illustrated in the diagram in units of inches (in) or millimeters (mm).
MRFOB Is the calculated bending moment at the rear face of the block.
L_1(Ideal) Is the ideal location of the rear mount where MRFOB = 0.
The engine mount reactions, R_2 and R_1, must first be determined:
$R_2 = (W_e*(L_3-L_2)+W_t*(L_3+L_4)) / (L_3+L_1)$ lb. (kg)
Then
$R_1 = W_e + W_t - R_2$ lb. (kg)
The bending moment, M_x, can then be calculated using:
MRFOB = W_tL_4 in $R_2L_{1 = 0}$ lb.in. (kg mm)
To convert to units used on the General Engine Data Sheet:
When using English units: MRFOB(lb.in.)/12 = MRFOB(lb.ft.)
When using SI units: MRFOB(kg.mm)(9.8/1000) = MRFOB(N•m)
The ideal L_1 where MRFOB = 0 can be calculated using:
$L_{1(}$Ideal) = $W_t*L_3*L_4 / (W_t*X_3+ (W_e*(L_3-L_2))$ in (mm)

If the static bending moment at the rear face of the block is found to be excessive, a decision must be made on how to reduce the bending moment to within acceptable limits. Three options exist:

1. Move the rear mounts towards the rear face of the block

This may be possible if there are alternate mounting locations on the marine gear. The use of swept mounts to move the mounting location towards the rear face of the block is not recommended, as they are inherently less rigid and can impose excessive forces upon the marine gear case mounting pad.

2. Use a six point mounting arrangement

If a six point mounting arrangement is to be used, the third set of engine mounts must be located on the flywheel housing. The requirements given previously in the solid engine mounting or flexible engine mounting section must be followed. Special care should be taken to make sure even loading between the front, middle, and rear engine mounts is achieved. Aligning the propeller shaft and distributing the load evenly across the mounts with a six point mounting arrangement is more difficult than with a four point mounting arrangement.

3. Use a saddle bracket (recommended)

A saddle bracket connects the flywheel housing and marine gear mounting pads together, providing a rigid pad that allows the mount to be located virtually anywhere along its length (see Figure 4-21). For a saddle bracket to be most effective, the location of the mount should be placed where the bending moment is at or near zero. This measurement is calculated above as the value $L_{1(Ideal)}$. Another advantage of using a saddle bracket is that it maintains a four point mounting arrangement, which simplifies propeller shaft alignment and provides better distribution of load on the mounts.

NOTE: *Moving the rear mount towards the rear face of the block to achieve a reduced bending moment will increase the load on the rear mount. Therefore, consideration must be taken to make sure the bending moment is within the acceptable limit, while maintaining a near equal distribution of load between the front and rear mounts.*

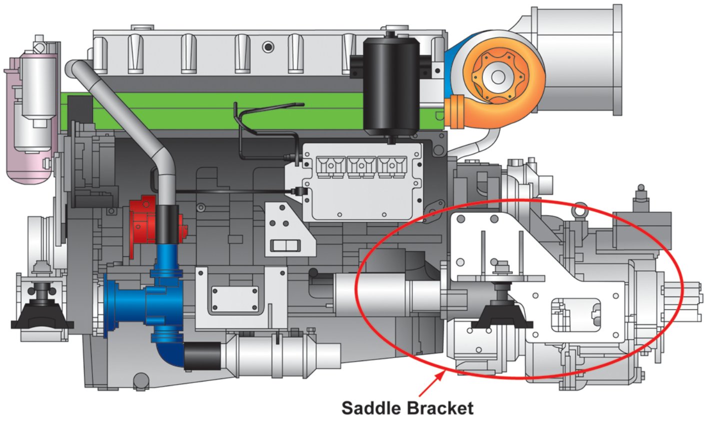


Figure 4-21: Saddle Bracket Example

DRIVETRAIN

SUMMARY OF REQUIREMENTS

- ! **The results from a Torsional Vibration Analysis (TVA), performed as required in Marine Application Bulletin No. 2.03.00-3/23/2000, must be within acceptable limits.**
- ! **A TVA must be performed on all new engine installations with a front power takeoff.**
- ! **A TVA must be performed on all new engine installations with remote mounted reduction gears.**
- ! **A torsional coupling must be used between the engine and a marine gear/jet.**
- ! **The angular alignment of the torsional coupling must be within the coupling and gear manufacturer's specified limits.**
- ! **The engine crankshaft end clearance must be within specifications after installation of the marine gear or any accessory that imposes an axial load on the crankshaft.**
- ! **The calculated axial load on the crankshaft must not exceed the values specified on the General Engine Data Sheet.**
- ! **The propeller shaft flange bore and face alignment must be within the gear manufacturer's limits.**

GENERAL INFORMATION

The purpose of the drivetrain is to transmit the power of the engine to the propulsion device at the proper speed, efficiently, and without excessive noise, vibration, or harshness. To accomplish this, proper selection and installation of the marine gear, torsional coupling, and propeller shaft is required. With any new or unique installation, a Torsional Vibration Analysis (TVA) must be performed. A TVA provides a mathematical approximation of whether the driveline components will operate in unison, or develop irritating or possibly damaging vibrations.

SERVICE ACCESSIBILITY

The following is a list of the Drivetrain service points that should be accessible:

- Propeller shaft coupling/marine gear output flange
- Service points identified by the marine gear/jet manufacturer
- Shaft seal/stern tube
- Jack shaft cardon or constant velocity joints

INSTALLATION DIRECTIONS

Torsional Vibration Analysis

! **The results from a Torsional Vibration Analysis (TVA), performed as required in Marine Application Bulletin No. 2.03.00-3/23/2000, must be within acceptable limits.**

As an engine translates reciprocal motion of the pistons into rotational motion of the crankshaft, the output is delivered to the flywheel and drive system. The crankshaft can be thought of as a torsional spring constantly winding and unwinding. Weights attached to the crankshaft counteract the torsional forces. However, as additional components are attached to the crankshaft, such as gears, shafts, props, power takeoffs, etc., the torsional equilibrium can be disrupted. A TVA will help to predict where this can occur.

Cummins Inc. requires that a TVA be conducted on new installations. A new installation is defined as an installation for which a TVA has not been conducted on the same installation or similar installation, or has a configuration specifically called out in the following requirements.

Cummins Inc. does not require a TVA when the installation is a sister vessel or a similar to a vessel that has received a TVA. An example of a similar installation is one that is uses the same engine, gear model, torsional coupling, shaft diameter, roughly the same shaft length, and roughly the same propeller.

! **A TVA must be performed on all new engine installations with a front power takeoff.**

This applies to any installation where a mass is directly attached to the front of the engine, such as a power takeoff clutch, heavy coupling, or heavy pulley.

! **A TVA must be performed on all new engine installations with remote mounted reduction gears.**

Note: *This includes any large rotating mass connected to the engine, such as shaft brakes.*

A TVA is recommended on all new marine installations to minimize the risk of encountering potentially destructive vibratory forces. Although a TVA is required on the above-mentioned installations, a TVA will not predict linear vibration problems. Generally, these problems are identified after installation and can be quantified through field vibration measurements. The resolution of linear vibration is sometimes achieved through the installation of resilient engine mounts/isolators.

The TVA should predict heat load and temperature of the engine vibration damper. The operating temperature can also be measured during a sea trial, while operating at full throttle.

Note: *The maximum operating temperature for viscous fluid type vibration dampers is 100° C (212° F).*

Cummins Marine recommends (as primary contact) utilizing the services of Renold Power Transmission Corporation for TVA and vibration testing needs. Renold was previously known as Holset Engineering - Coupling Division, and in 1973 was acquired by Cummins Inc. In 1997, Holset Engineering - Coupling Division was sold to Renold PLC. Renold has offices in both the USA and UK, and has an extensive background of performing TVAs on Cummins Inc. installations.

Renold is recommended because:
(1) They have demonstrated to Cummins Inc. that they can perform a valid TVA.
(2) They have access to Cummins Inc. proprietary data, including crankshaft limits and cylinder pressure excitation.
(3) They maintain a database of completed TVAs to aid in system evaluation.

For further information regarding TVAs, contacting Renold, and TVA request forms, refer to Marine Application Bulletin (MAB) No. 2.03.00-3/23/2000 or contact your local Cummins Marine Certified Application Engineer.

Marine Gear Installation

! **A torsional coupling must be used between the engine and a marine gear/jet.**

! **The angular alignment of the torsional coupling must be within the coupling and gear manufacturer’s specified limits.**

If installing a marine gear, water jet, and/or other component for transferring power from the flywheel of the engine, a torsional coupling must be used. The torsional coupling must be installed so that the angular alignment is within the torsional coupling and gear manufacturer's specified limits. Consulting the gear manufacturer, coupling manufacturer, and/or completing a Torsional Vibration Analysis (TVA) will help determine the appropriate torsional coupling for the application.

The engine crankshaft end clearance must be within specifications after installation of the marine gear or any accessory that imposes an axial load on the crankshaft.

CAUTION: The engine should not be run without sufficient end clearance. Doing so may result in damage to the engine.

The installation of a marine gear, water jet, or other component that may impose an axial load on the crankshaft requires the verification of sufficient crankshaft end clearance. Without crankshaft end clearance, the crankshaft will be turning in solid contact with the engine thrust bearing surface and may damage the thrust bearing and the crankshaft (see Figure 5-1).

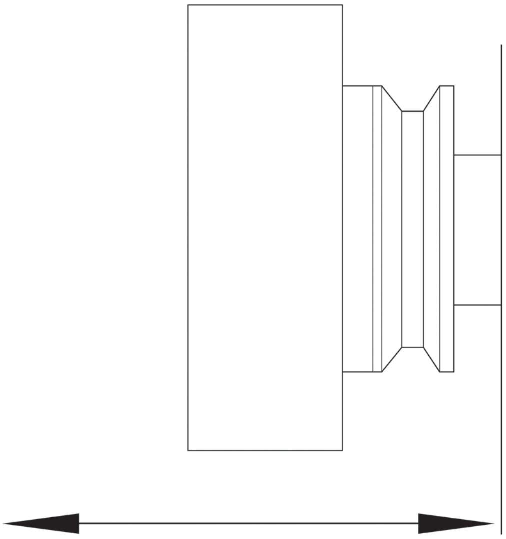


Figure 5-1: Crankshaft End Clearance

Table 5-1 provides the minimum and maximum values for crankshaft end clearance, depending on engine family. The appropriate service manual should be consulted for how and where to take the measurements.

Refer to the appropriate service manual for the proper procedure.

Engine Family	Minimum Clearance	Maximum Clearance
B, QSB	.127mm (.005")	.254mm (.010")
C, QSC/L	.157mm (.006")	.334mm (.013)
M	.10mm (.004")	.50mm (.022")
N	.10mm (.004")	.58mm (.023")

Table 5-1: Crankshaft End Clearance Specifications

The calculated axial load on the crankshaft must not exceed the values specified on the General Engine Data Sheet.

If installing a marine gear, water jet, and/or other component for transferring power from the engine crankshaft that imposes an axial load, the calculated axial load must not exceed the value specified on the General Engine Data Sheet. Marine gears and water jets typically do not transmit axial thrust loads to the engine crankshaft, as they usually have a self contained thrust bearing capable of absorbing all of the driveline thrust.

When using a remote mounted marine gear or water jet and the engine and/or marine gear is flexibly mounted, constant velocity joints or universal joints with a slip joint must be used to allow for relative motion between the engine and marine gear. When using universal joints, for the system to work properly and minimize vibration, it is necessary to align the shaft so that each joint has the same angle at all operating conditions (see Figure 5-2). Cummins Inc. recommends that shafts with universal joints be angled only in one plane. Using compound angles with universal joints is not recommended due to the possibility of torsional vibration. Constant velocity joints should be used if compound or unequal angles are expected.

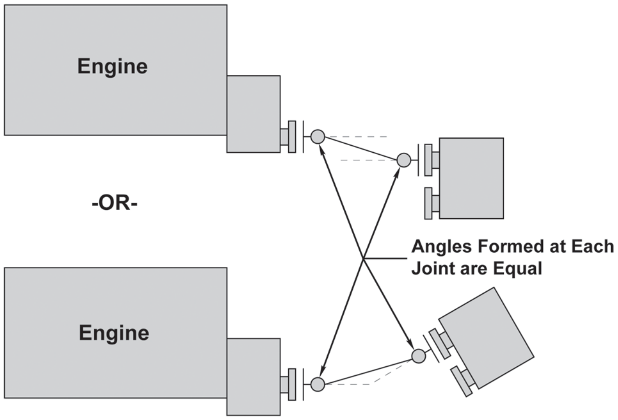


Figure 5-2: Remote Mount Gear Using a Shaft with Universal Joints

Driveline/Propeller Shaft

The driveline of a vessel typically consists of the following components: A companion flange which attaches the propeller shaft to the output flange of the marine gear; the propeller shaft to transfer power from the marine gears to the propeller; the stuffing box which provides a watertight hull penetration for the propeller shaft; the strut(s) which are mounted rigidly to the hull along the propeller shaft's length and provide support to the propeller shaft; and the propeller. Proper component selection and installation is essential to minimize vibration, noise, power loss, and stress in the driveline.

If using a fixed shaft support bearing or rigid stuffing box, CMD recommends that the distance from the marine gear output flange to the first fixed bearing or rigid stuffing box be a minimum of 20 times the shaft diameter. This will allow the propeller shaft to flex allowing for some engine movement and reducing vibration transmitted to the hull. If the distance is less than 20 times the diameter, a flexible coupling between the gear and propeller shaft may be necessary (see Figure 5-3). Shaft seals that use a flexible bellows or length of hose for attachment to the hull reduce the transmitted vibration and may be preferred based on the intended use.

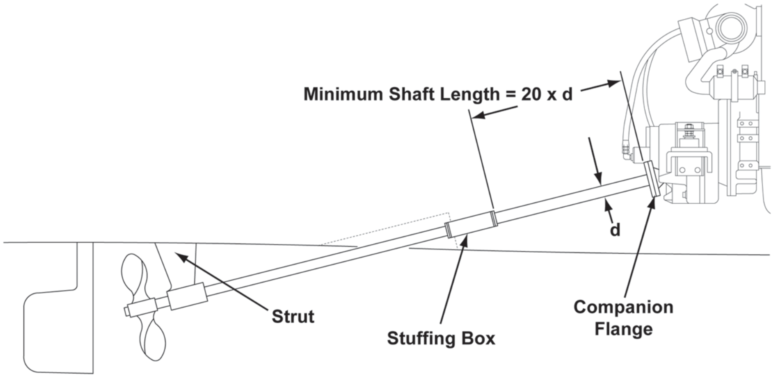


Figure 5-3: Driveline Vibration Isolation

Selection of the propeller shaft is dependent on the engine and marine gear selection. Other components of the driveline will be selected by the vessel manufacturer, based on the propeller shaft selection.

The propeller shaft is typically manufactured from alloys that have the key properties of resistance to corrosion, strength, and toughness. Different grades of shaft materials are available and the selection of the right material depends on the specific needs and cost. Most widely available propeller shaft materials will provide adequate service in most applications. However, for special applications that require superior corrosion resistance, strength, and/or toughness, the propeller shaft manufacturer should be consulted.

The required propeller shaft diameter can vary significantly, depending on the material used, strut and bearing arrangement, shaft length, engine power, and shaft RPM. Information is available from the propeller shaft manufacturer and in marine handbooks for selecting the proper diameter. Sufficient shaft diameter is critical for durability and to minimize vibration. The following calculation can be used to determine the required propeller shaft diameter. A propeller shaft diameter calculator is also available in the Tools section of http://marine.cummins.com.

In general, the required propeller shaft diameter can be calculated using the equation:

$D^3 = (321{,}000 \times P \times S.F.) / (St \times N)$

Where:
D = Shaft Diameter (inches)
P = Power (BHP)
S.F. = Safety Factor (5 for Recreational and Intermittent Duty Ratings; 10 for all other Commercial Duty Ratings)
St = Material Yield Strength in Torsional Shear (psi)
N = Propeller Shaft Speed

Table 5-2 lists the material yield strength (St) of the commonly available propeller shaft materials.

Material	Yield Strength in Torsional Shear (psi)				
Aquamet 22	0.75 in to 1.25 in = 86,600	Over 1.25 in to 2.0 in = 70,000	Over 2.0 in to 2.5 in = 63,000	Over 2.5 in to 3.0 in = 50,000	Over 3.0 in to 12.0 in = 36,600
Aquamet 19	Up to 1.5 in = 70,000	Over 1.5 in to 2.0 in = 57,000	Over 2.0 in to 2.5 in = 40,000	Over 2.5 in to 3.0 in = 36,000	Over 3.0 in to 12.0 in = 33,000
Aquamet 18	Up to 1.75 in = 60,000	Over 1.75 in to 2.5 in = 47,000	Over 2.5 in to 5.0 in = 40,000		
Aquamet 17	70,000	70,000	70,000	70,000	70,000
Monel 400	40,000	40,000	40,000	40,000	40,000
304 Stainless Steel	20,000	20,000	20,000	20,000	20,000

Table 5-2: Common Shaft Material Yield Strength (St)

It is recommended that propeller shaft diameter be calculated for each unique application. Care should be taken to use the correct Yield Strength (St) value, depending on the selected propeller shaft material and the assumed diameter.

Since the material Aquamet 17 is widely used in recreational and commercial applications and has a consistent Yield Strength (St), it can be used as a starting point to help determine an approximate diameter and corresponding Yield Strength (St) value to use for other materials that do not have a consistent Yield Strength (St) with respect to diameter. The recommended propeller shaft diameter, depending on duty cycle for Aquamet 17 is given in Tables 5-3 and 5-4. The values are given in the units of inches. Use of the larger propeller shaft diameter is recommended when the selection falls between sizes.

Aquamet 17 - Recreational and Intermittent

	HP	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Shaft Speed																
500		1.75	2.00	2.00	2.25	2.50	2.50	2.50	2.75	2.75	3.00	3.00	3.00	3.00	3.25	3.25
700		1.50	1.75	1.75	2.00	2.25	2.25	2.25	2.50	2.50	2.75	2.75	2.75	2.75	3.00	3.00
900		1.375	1.50	1.75	1.75	2.00	2.00	2.25	2.25	2.25	2.50	2.50	2.50	2.50	2.75	2.75
1100		1.25	1.50	1.50	1.75	1.75	2.00	2.00	2.25	2.25	2.25	2.25	2.50	2.50	2.50	2.50
1300		1.25	1.375	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.25	2.25	2.25	2.25	2.50	2.50
1500		1.125	1.375	1.50	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.25	2.25	2.25	2.25
1700		1.125	1.25	1.375	1.50	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.00	2.25	2.25
1900		1.125	1.25	1.375	1.50	1.50	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.00	2.25
2100		1.00	1.25	1.25	1.375	1.50	1.50	1.75	1.75	1.75	1.75	1.75	2.00	2.00	2.00	2.00
2300		1.00	1.125	1.25	1.375	1.50	1.50	1.50	1.75	1.75	1.75	1.75	1.75	2.00	2.00	2.00
2500		1.00	1.125	1.25	1.375	1.375	1.50	1.50	1.50	1.75	1.75	1.75	1.75	1.75	2.00	2.00
2700		1.00	1.125	1.25	1.25	1.375	1.50	1.50	1.50	1.50	1.75	1.75	1.75	1.75	1.75	2.00
2900		1.00	1.00	1.125	1.25	1.375	1.375	1.50	1.50	1.50	1.75	1.75	1.75	1.75	1.75	1.75
3100		0.875	1.00	1.125	1.25	1.25	1.375	1.50	1.50	1.50	1.50	1.75	1.75	1.75	1.75	1.75
3300		0.875	1.00	1.125	1.25	1.25	1.375	1.375	1.50	1.50	1.50	1.50	1.75	1.75	1.75	1.75

Table 5-3: Propeller Shaft Diameter in Inches

Aquamet 17 - Medium Continous, Heavy, Heavy Duty and Continous Duty

	HP	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Shaft Speed																
500		2.00	2.50	2.75	2.75	3.00	3.00	3.50	3.50	3.50	4.00	4.00	4.00	4.00	4.00	4.00
700		1.75	2.25	2.50	2.50	2.75	2.75	3.00	3.00	3.00	3.50	3.50	3.50	3.50	3.50	3.50
900		1.75	2.00	2.25	2.25	2.50	2.75	2.75	2.75	3.00	3.00	3.00	3.50	3.50	3.50	3.50
1100		1.50	1.75	2.00	2.25	2.25	2.50	2.50	2.75	2.75	3.00	3.00	3.00	3.00	3.00	3.00
1300		1.50	1.75	2.00	2.00	2.25	2.25	2.50	2.50	2.75	2.75	2.75	2.75	3.00	3.00	3.00
1500		1.375	1.75	2.00	2.00	2.00	2.25	2.25	2.50	2.50	2.50	2.75	2.75	2.75	2.75	3.00
1700		1.375	1.50	1.75	2.00	2.00	2.00	2.25	2.25	2.50	2.50	2.50	2.50	2.75	2.75	2.75
1900		1.375	1.50	1.75	1.75	2.00	2.00	2.25	2.25	2.25	2.50	2.50	2.50	2.75	2.75	2.75
2100		1.250	1.50	1.75	1.75	2.00	2.00	2.00	2.25	2.25	2.25	2.50	2.50	2.50	2.50	2.50
2300		1.250	1.50	1.50	1.75	1.75	2.00	2.00	2.00	2.25	2.25	2.25	2.25	2.50	2.50	2.50
2500		1.250	1.375	1.50	1.75	1.75	2.00	2.00	2.00	2.25	2.25	2.25	2.25	2.25	2.50	2.50
2700		1.250	1.375	1.50	1.50	1.75	1.75	2.00	2.00	2.00	2.00	2.25	2.25	2.25	2.25	2.50
2900		1.125	1.375	1.50	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.25	2.25	2.25	2.25
3100		1.125	1.250	1.375	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.25	2.25	2.25	2.25
3300		1.125	1.250	1.375	1.50	1.50	1.75	1.75	1.75	2.00	2.00	2.00	2.00	2.25	2.25	2.25

Table 5-4: Propeller Shaft Diameter in Inches

Engine/Propeller Shaft Alignment

The alignment of the engine and marine gear with the propeller shaft is essential to minimize vibration, noise, power loss, and stress to the driveline components.

The propeller shaft flange bore and face alignment must be within gear manufacturer’s limits.

Proper alignment of the propeller shaft flange (commonly referred to as the companion flange) and gear output flange is critical. Misalignment and the associated vibration causes the following: discomfort to the operator and passengers, reduced efficiency, accelerated wear of bearings, stuffing boxes, and vibration isolators, leaking shaft seals, stress and fatigue upon the propeller shaft, and possible damage to the engine and gear.

While aligning the engine and gear, check the bore and face alignment of the mating flanges. The bore or parallel alignment must be within the gear manufacturer's recommendations, to allow the companion flange and marine gear output flange to mate properly. The angular or face alignment must be within the gear manufacturer's recommendation when checked with a feeler gauge at the top, bottom, and each side of the flanges (see Figure 5-4). Both fixed and flexible mounting arrangements must meet these specifications. If alignment recommendations can not be obtained from the gear manufacturer, Cummins Inc. recommends that flanges up to 200 mm (8 in) in diameter are aligned to within 0.01 mm (0.004 in) for face alignment and 1.0 mm (0.020 in) for parallel/bore alignment.

The final alignment should not be done until after the vessel is in the water and has been loaded to its normal operating condition for at least 24 hours. The alignment must be redone each time a flexible mounting system is disconnected from the propeller shaft.

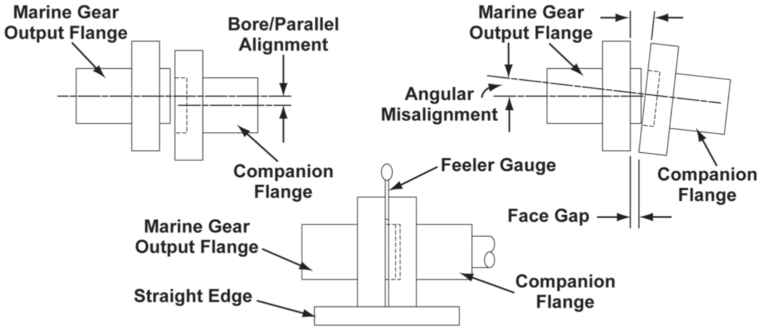


Figure 5-4: Flange Face and Bore Alignment

There are many ways to align the engine and transmission. The methods discussed here are only a recommendation on how to accomplish this task. Please consult a trained professional for further assistance and advice.

The most accurate method of initially aligning the engine is to use a laser alignment tool fitted into the strut bearing, before the shaft is installed, to shoot a perfectly straight line of reference. This allows the center of the gear output flange to be aligned with the strut bearing to make sure the shaft will be straight between the two points.

If aligning the engine with the propeller shaft in the vessel, it may be necessary to temporarily support the propeller shaft at the companion flange, to counteract the unsupported weight of the end of the shaft. The diameter of the shaft, the method it is supported, and the length that is unsupported will all affect how much the shaft will sag or droop (see Figure 5-5).

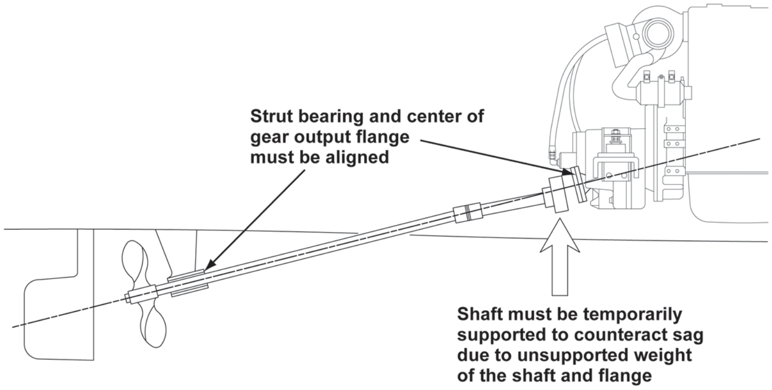


Figure 5-5: Shaft Alignment

On a solid mounted engine, temporary alignment is made with jacking screws (if available in the engine supports) or with temporary jacks and lifts (see Figure 5-6). Chocking compound or shims are made to fit exactly between the engine mounts and the engine bed. With the engine aligned and the mounting bolts installed, the jacking screws are backed off or the temporary jacks removed. On wood or soft engine beds, steel plates must be used under the jacking screws to prevent damage to the engine bed. See the Engine Mounting section for more detail on solid engine mounting and adjustment.

A flexibly mounted engine "moves" on the engine mounts. Therefore, the propeller shaft connected to the marine gear output flange must be free to move with the engine. As illustrated in Figure 5-6, most recreational boat installations use a flexible stuffing box (1) and a single strut bearing (2) to support the propeller shafting while allowing for freedom of movement in the shafting.

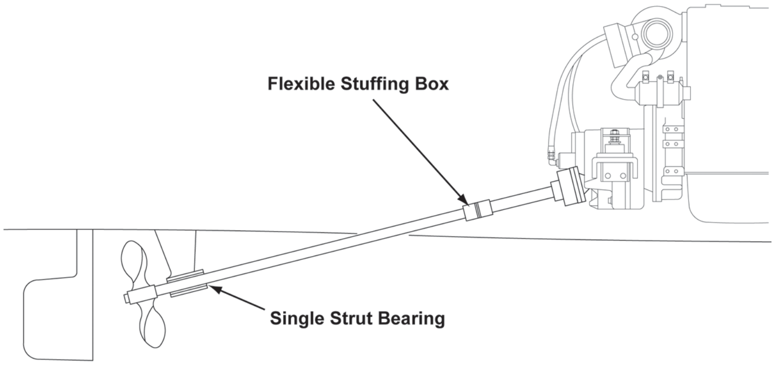


Figure 5-6: Propeller Shaft for a Flexibly Mounted Engine

On flexibly mounted engines, the engine is aligned using the adjusting nuts on the vibration isolators. Isolator studs are not designed for major adjustments. They are limited to the length of the threaded section on the stud. It is very important to equalize the weight of the engine and gear to the isolating mounts as much as possible. Shimming should be used when additional height is needed. See the Engine Mounting System section for more detail on flexible engine mounting and adjustment.

Propeller Rotation in Twin Engine Applications

The convention used to specify engine or propeller rotations is:
Right Hand (RH) = Clockwise (CW)
Left Hand (LH) = Counter Clockwise (CCW)

The direction of engine rotation is viewed from the front of the engine, looking at the engine damper. The direction of propeller rotation is viewed from behind the boat, looking forward at the propeller. Therefore, a RH rotation engine and a LH rotation propeller are turning in the same direction.

Cummins engines are available in right hand rotation only. Twin engine installations should have the propellers turning in opposite directions. The typical recreational boat arrangement has the right hand (clockwise) turning propeller on the starboard (right) side of the boat and the left hand (counterclockwise) turning propeller on the port (left) side of the boat. This is known as outboard turning and provides the best propeller efficiency (see Figure 5-7). Some commercial applications may have the opposite configuration (inboard turning) for the primary purpose of minimizing the pulling of debris between the propeller and hull in shallow water applications and/or improved close quarters maneuvering.

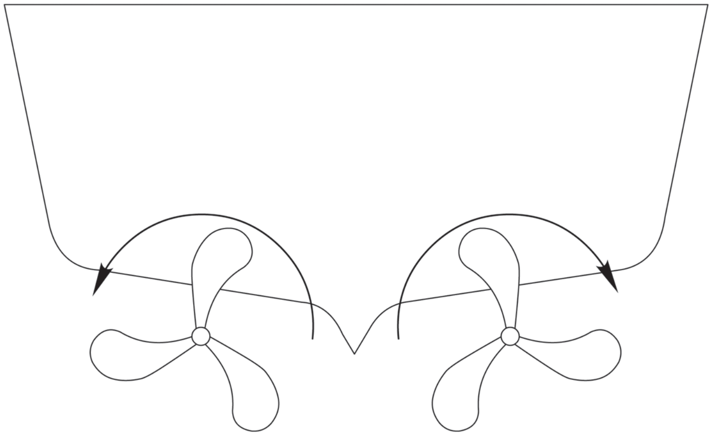


Figure 5-7: Twin Engine Propeller Rotation

The propeller rotation is determined by the marine gear. Most gears allow for full power in either direction of rotation. Direction of rotation is controlled mechanically by the shift lever position or electrically by selecting the correct shift solenoid valve, depending on how the gear is equipped. Gears that are designed for a specific direction of rotation must be installed on the proper side of the boat and cannot be used for extended periods of time in the reverse rotation or under heavy loads.

Propeller Tip Clearance

Adequate tip clearance is important for maximum propeller performance and for reduced vibration, noise, and cavitation (see Figure 5-8). The tip clearance is specified by the builder. Tip clearance is expressed as a percentage of the propeller diameter. In most applications, Cummins Inc. recommends that it not be less that 10-15 percent. The use of a propeller with a higher number (5 or more) and/or high skew blades may significantly reduce the onset of vibration, noise, and cavitation at less that the recommended tip clearance.

The maximum propeller diameter that can be used on vessel can be calculated using the following equation:

Maximum Allowable Propeller Diameter = Max Diameter w/o Clearance / 1 + [2(Specified Tip Clearance/100)]

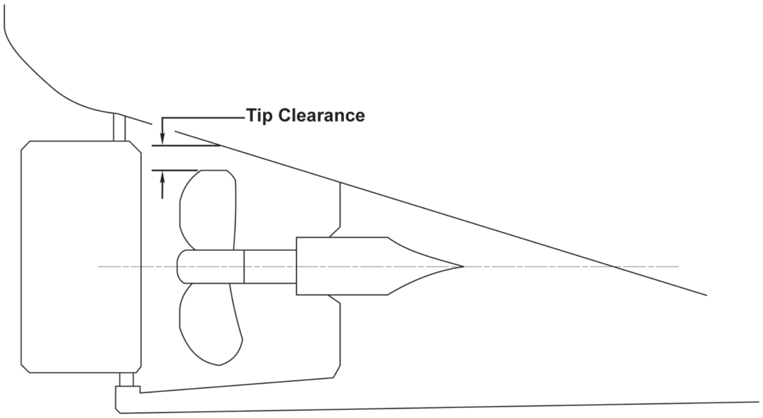


Figure 5-8: Propeller Tip Clearance

ENGINE DRIVEN ACCESSORIES AND POWER TAKE-OFFS

Summary of Requirements

All Applications

! The total power taken off the front of the crankshaft must not exceed the value listed in the Engine Performance Curve and Data Sheet.
! Brackets used to mount accessories must provide adequate strength to hold the static and dynamic load of the accessory and avoid resonant vibration within the normal operating range of the engine.
! All exposed rotating components must have a protective guard.

Belt Driven Accessories

! The calculated radial load on the crankshaft must not exceed the values specified in the Engine General Data Sheet.
! Belt driven accessories must be mounted on the engine when a flexible mounting system is used.
! Belt driven equipment must be held in alignment to a tolerance of 1 mm in 200mm (1/16 inch in 12 inches).

Front Power Take-off

! The calculated axial load on the crankshaft must not exceed the values specified in the Engine General Data Sheet.
! The engine crankshaft end clearance must be with specifications after installation of the marine gear or any accessory that imposes an axial load on the crankshaft.
! Front power take-off (FPTO) accessories driven from the crankshaft must have sufficient axial clearance to allow for thermal expansion of the crankshaft.

GENERAL INFORMATION

An engine driven accessory refers to any component, driven by mechanical link from the engine, that is not supplied by Cummins Inc. Examples of engine driven accessories are hydraulic pumps for power steering, deck machinery, roll stabilizers, water pumps for deck wash down, livewells, or firefighting, bilge pumps, additional alternators, freon compressors, and air compressors. This section provides instructions on how to apply an engine driven accessory so that it will not negatively impact the engine's operation, reliability, or durability.

Cummins engines are equipped, depending on engine family, configuration, and rating, with provisions for accessory drives. Common drive options that are available are belt pulleys from the front of the crankshaft, additional pulley locations on the front of the gear case, and front power take-offs (FPTO) from the nose of the crankshaft. For some keeled cooled engines, a direct drive SAE A or B flange becomes available in the location normally reserved for the sea water pump.

Not all engine and/or ratings are suitable for non-factory supplied accessories or power take-offs. Check the Engine Performance Curves and Data Sheet to see if an engine is suitable and the amount of power which may be used.

☎ **For assistance in determining what accessory drive options and their capability are available for a specific engine family, configuration, and rating, contact your local Cummins Marine Certified Application Engineer.**

Additional accessory drive locations can be obtained by using a marine gear with PTO capability. Many marine gear manufacturers offer models that have accessory PTO drives.

SERVICE ACCESSIBILITY

The following is a list of Engine Driven Accessory and Power Take-off service points that should be accessible:

- Mounting brackets
- Belt guards
- Brackets used for adjusting belt tension
- PTO mounting flanges and associated fastening hardware
- PTO shafts and couplings

INSTALLATION DIRECTIONS

All Applications

The total power taken off the front of the crankshaft must not exceed the value listed in the Engine Performance Curve and Data Sheet.

The total power taken from the front of the crankshaft must not exceed the value listed in the Engine Performance Curve and Data Sheet. This limit is in place to maintain the structural integrity of the crankshaft and the bolted joint at the front of the crankshaft.

The maximum torque capacity from the front of the crankshaft is given in the Performance Curve and Data Sheet in units of N•m (lb-ft.). To convert the design HP load of the accessory to a corresponding torque value, use the following equations, depending on metric or standard units:

Torque (N•m) = HP x 7120 / n

Torque (lb-ft.) = HP x 5252 / n

Where: HP Is the design horsepower of the accessory and n Is the speed of the accessory at rated engine speed.

The following are formulas for estimating accessory HP/kW draw (if unknown):

Pumps

$$\text{Hp} = \frac{\text{Flow Rate (GPM)} \times \text{Pressure (PSI)} \times \text{Design Service Factor}}{1714 \times \text{Efficiency}}$$

$$\text{Hp} = \frac{\text{Flow Rate (GPM)} \times \text{Head (Feet)} \times \text{Specific Gravity} \times \text{Design Service Factor}}{3960 \times \text{Efficiency}}$$

$$\text{Hp} = \frac{\text{Flow Rate (Liters/Min)} \times \text{Pressure (kPa)} \times \text{Design Service Factor}}{59950 \times \text{Efficiency}}$$

$$\text{Hp} = \frac{\text{Flow Rate (Liters/Min)} \times \text{Head (M)} \times \text{Specific Gravity} \times \text{Design Service Factor}}{6124 \times \text{Efficiency}}$$

$$\text{Efficiency} = \frac{\text{Output Hp}}{\text{Input Hp}} = \frac{\text{Output kW}}{\text{Input kW}}$$

Typical Efficiency = .60 to .90

Specific Gravity = 1.00 for Water
0.85 for Hydraulic Oil

Alternators

$$\text{Hp} = \frac{\text{Volts} \times \text{Amps} \times \text{Design Service Factor}}{746 \times \text{Efficiency}}$$

Volts = 13.7 for 12 V System
= 27.4 for 24 V System
= 36.5 for 32 V System

Typical Efficiency = .40 to .50

Figure 6-1

Since engine driven accessories will experience fluctuations in load during normal operation, the rated load of the accessory should be multiplied by a design service factor to determine the actual load imposed on the engine by the accessory (see Table 6-1).

Accessory Type	Design Service Factor
Bilge Pumps and Alternators	1.3
Air Compressors	1.4
Hydraulic Pumps	2.0

Table 6-1: Accessory Design Service Factor

For example, if a hydraulic pump is rated at 20 HP, using the design service factor from Table 6-1 determines the actual load to be 40 HP (20 HP * 2.0 = 40 HP).

In addition to the above, the following must also be considered before applying an engine driven accessory:

Impact on Achieving Rated Speed

An engine must be able to meet or exceed rated speed at full throttle under any steady state operating condition; except for engines in variable displacement vessels, which must achieve not less than 100 rpm below rated speed at full throttle during a dead push or bollard pull. Additional parasitic loads from engine driven accessories will affect the ability of an engine to meet this requirement. The power draw of the accessory and how it is used while underway (in conjunction with the propulsion load) will determine the need to adjust the propeller, to ensure the engine can not be operated in an overloaded condition.

Impact on Partial Throttle Operation

A propulsion engine will operate along a relatively fixed load curve dictated by the propulsion device (propeller, water jet, etc). With the addition of engine driven accessories, the demand on the engine throughout the operating range will be increased, depending on the power draw of the accessory and when it is used. Accessories with relatively low power demands such as an alternator, wash down pump, and other belt driven devices typically have little impact on the engine. However, larger accessories such as hydraulic pumps, fire pumps, and other PTO devices can pull a significant load from the engine. A large accessory load, either on its own or in combination with the propulsion demand, must be limited to allow the engine to operate within its design limits.

When a large accessory load is added, either on its own or in combination with the propulsion demand, the result can be a load curve that is elevated above the normal and expected fixed load curve from the propulsion device. Depending on severity, the increase in load can impact the performance (ability of the engine to maintain speed or accelerate), durability (the engine is working harder, therefore less life will be achieved), and overall reliability of the product. Other factors such as increased noise, smoke, and soot may also be experienced.

Impact on Power Factor

For applications with engine accessories that operate continuously or frequently for extended periods of time, the additional load placed on the engine may appreciably increase the power factor. For these applications, the effect of the accessory upon power factor should be considered when determining the proper engine rating. This also applies to any other accessory driven by the engine, including, but not limited to, an accessory drive from a marine gear PTO.

Note: *Accessory loads placed on the engine in combination with the propulsion load will decrease the engine performance with respect to acceleration and load stability.*

Brackets used to mount accessories must provide adequate strength to hold the static and dynamic load of the accessory and avoid resonant vibration within the normal operating range of the engine.

Brackets used to mount accessories must provide adequate strength to hold the static and dynamic load of the accessory. This is critical for maintaining proper alignment of the accessory. If the accessory is to be mounted on the engine, the bracket must be designed and constructed to avoid resonant vibration within the normal operating range of the engine. In other terms, the natural frequency of any engine mounted accessory must be outside the normal operating range of the engine. Operation in the engine natural frequency range may cause accessory bracket, component, or engine casting failure.

! **All exposed rotating components must have a protective guard.**

Installation of engine driven accessories must be accompanied by the addition of protective guards that cover all exposed rotating components. Protective guards should meet local regulations where the vessel will be operated.

Most Cummins engines are provided with a protective belt/pulley guard. They may be modified to install accessory drives. The installer is responsible for the modifications and any failures resulting from these modifications.

Belt Driven Accessories

! **The calculated radial load on the crankshaft must not exceed the values specified in the General Engine Data Sheet.**

Belt driven accessories will place a radial load upon the crankshaft, due to the tension of the belt. Excessive tension in a belt drive system can overstress the engine drive components The maximum allowable radial load is dependent on the direction of load, with relation to the engine crankshaft, while looking at the front of the engine. Values for the maximum allowable radial load are located in the General Engine Data Sheet. Values are given at directions of 0°, 90°, 180°, and 270°, looking toward the front of the engine.

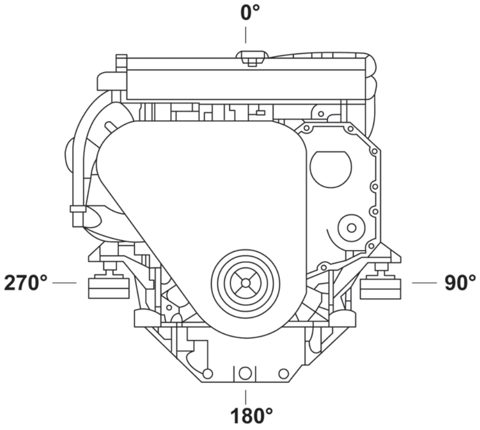
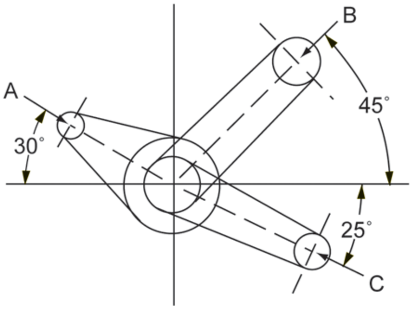
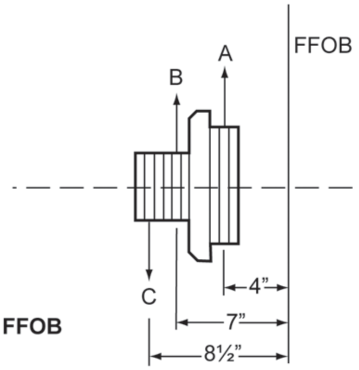


Figure 6-2

If two or more accessories are being driven from the front of the crankshaft, the accessories should be arranged to have opposing belt pulls, so the resulting force on the crankshaft is kept to a minimum. Figure 6-3 provides an example of the process for calculating the resulting radial load and direction.





Belt Pull **Distance from FFOB**

F_A = 100 lb. L_A = 4 in

F_B = 220 lb. L_B = 7 in

F_C = 150 lb. L_C = 8.5 in

Moment to FFOB

$M_A = F_A \times L_A$ = 400 in.lb. @ 300°

$M_B = F_B \times L_B$ = 1540 in.lb. @ 45°

$M_C = F_C \times L_C$ = 1275 in.lb. @ 115°

Solve for x and y component values

A_x = 400 cos 30° -346

A_y = 400 sin 30° = +200

B_x = 1540 sin 45° = +1089

B_y = 1540 cos 45° = +1089

C_x = 1275 cos 25° = +1156

C_y = 1275 sin 25° = -539

Total_x = +1899

Total_y = +750

Use absolute values for all the below:

Vector Magnitude = (Total$_x$^2 + Total$_y$^2) ^-2 = 2042 in.lb

Vector Direction = tan^-1(Total$_y$ Total$_x$) = <u>21.5°</u>

Radial Load (lb.ft.) = Vector Magnitude x (($M_A+M_B+M_C$)/($F_A+F_B+F_C$))/144 = <u>97lb.ft.</u>

Graphic Solution

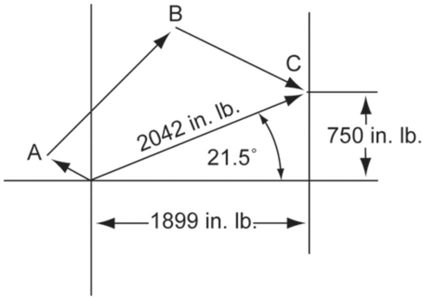


Figure 6-3: Calculating Radial Load and Direction

Belt driven accessories must be mounted on the engine when a flexible mounting system is used.

When a flexible engine mounting is used, the belt driven accessories must be mounted on the engine. If accessories are mounted to the vessel, the relative motion between the engine and vessel may cause the belt to become misaligned, slip, fail, and/or jump off the pulley.

Belt driven equipment must be held in alignment to a tolerance of 1 mm within 200mm (1/16 in within 12 inches).

Misalignment between the belt driven accessory and the engine will result in bending forces on the shafts that can result in bearing and/or shaft failures. Misalignment will also cause greatly increased belt wear. Alignment must be held to within a tolerance of 1 mm over a run of 200 mm or 1/16 in over a run of 12 inches (see Figure 6-4).

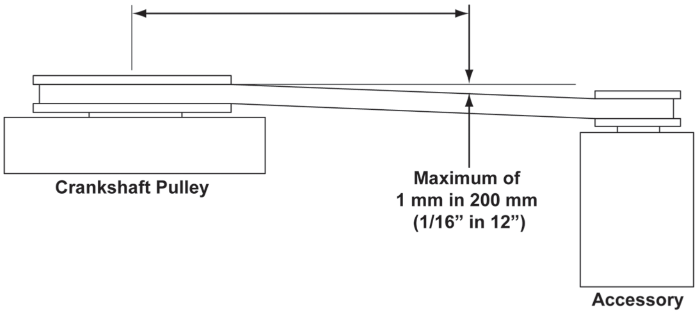


Figure 6-4: Belt Alignment

EXHAUST SYSTEM

SUMMARY OF REQUIREMENTS

All Applications

! The exhaust back pressure must not exceed the value specified in the General Engine Data Sheet.
! The exhaust system components must not impose excessive load or bending moment on the exhaust manifold or turbocharger due to weight, inertia, relative motion of the components, or dimensional change due to thermal growth.

  - **The bending moment at the turbocharger outlet mounting flange must not exceed the maximum value specified in the General Engine Data Sheet.**
  - **The direct load at the turbocharger outlet mounting flange must not exceed the maximum value specified in the General Engine Data Sheet.**
  - **A flexible connection must be installed directly to the engine exhaust outlet connection.**

! The exhaust system must prevent the entrance of water into the engine.
! The exhaust gas must be dispersed so that it does not detrimentally affect the air cleaner function and the crew and passengers.
! Exhaust system surfaces that persons or gear may come in contact with must not exceed 93 C (200 F).
! Exhaust system surfaces which may be impinged upon by a flammable liquid leak must not exceed 220 C (428 F).
! Piping must not be installed near combustible material.
! A service port must be provided in the exhaust system.

Wet Exhaust System – Height Above Loaded Waterline

! Wet exhaust systems installed with the exhaust manifold or turbocharger outlet greater than 305 mm (12 in) above the loaded waterline must meet the following requirements:

  - **The highest point in the exhaust system must be dry and at least 305 mm (12 in) above the loaded waterline.**

! Wet exhaust systems installed with the bottom of the exhaust manifold or turbocharger outlet less than 305 mm (12 in) above the loaded waterline must meet the following additional requirements:

  - **The highest dry point of the exhaust system before the water injection must be dry and at least 305 mm (12 in) above the loaded waterline, or any other waterline created by standing water within the exhaust system.**
  - **If using a water lift muffler or similar component, a riser in the exhaust system must be installed on the outlet of the water lift muffler, with the bottom of the riser at least 305 mm (12 in) above the loaded waterline and the exhaust outlet at least 12” below the bottom of the riser.**

Wet Exhaust System – Exhaust Connections and Plumbing

! The injected water must not be able to flow back into the engine.
! The point of water injection is downstream of and at least 203 mm (8 in) from or 51 mm (2 in) below the highest dry point.
! The down angle of the exhaust connection after the highest dry point, including the water injection and downstream plumbing immediately thereafter, must be at least 15 degrees from horizontal.
! If the point of the water injection is below the loaded waterline (LWL), the sea water plumbing to the water injection must be routed at least 305 mm (12 in) above the LWL, with a siphon break installed.
! The location of the water injection must be at least 305 mm (12 in) from any downstream bends in the exhaust system.
! Wet exhaust piping must have a continuous downward slope of no less than 2 degrees or 12.7 mm over a 305 mm run (0.5 in over a 12 in run), with exception given to sections of piping used as a riser after a water lift muffler or similar component.

GENERAL INFORMATION

The purpose of the exhaust system is to carry the heat and exhaust gases from the engine to the exterior of the vessel. The system must provide minimal flow restriction, prevent entry of water into the engine, and not impose excessive mechanical loads on the engine exhaust outlet connection. Marine applications may use wet or dry exhaust systems, or a combination of wet and dry.

Dry exhaust systems use materials that are capable of withstanding high temperatures, such as steel, stainless steel, and/or iron piping. Because dry systems operate at high temperatures, they must be shielded or insulated to prevent convection or radiation of heat from damaging nearby vessel structures or injury to personnel from contact with the hot surfaces.

A wet exhaust system injects water into the exhaust gas stream to significantly lower the exhaust temperatures. The lower temperature allows the use of lightweight, corrosion resistant materials such as rubber, silicone, and fiberglass for the exhaust system plumbing. The surface temperature of the piping is also greatly decreased for increased safety and reduced radiant heat. Exhaust water injection uses sea water from the engine's sea water cooling system outlet, or from a separate sea water pump. Any noncooled exhaust piping between the engine exhaust outlet and the point of water injection must be treated as a dry system.

Definition of Exhaust System Terms

Water Intrusion – The entrance of water, in any physical state, into the engine by way of the exhaust system.

Loaded Waterline – The highest static waterline (i.e. heaviest displacement) the vessel is expected to be operated at. If actual vessel loading is unknown, Cummins recommends that the loaded waterline be defined as full fuel, full water, full waste, plus 10 percent of the vessel’s dry weight.

Water Injection or Diffuser Ring – a series of holes or slots positioned around the internal periphery of the exhaust piping, which sprays water into the exhaust gas stream to greatly reduce its temperature.

Exhaust Connection – The section of pipe that connects directly to the turbocharger or exhaust manifold outlet. Exhaust connections range from a single wall steel elbow for a dry system to an insulated/jacketed stainless steel pipe with integrated water injection for a wet system.

Riser – A raised section of piping used to increase the height of the exhaust system above a waterline, to reduce the possibility of water intrusion. The term riser is often used to describe an exhaust connection that is designed to increase the distance above a waterline.

Water Lift Muffler – A muffler that maintains a predetermined level of water, during operation, that is independent of the loaded waterline. They are useful for installations where the exhaust outlet of the engine is not sufficiently above the loaded waterline, but may be used in any application and are common because of their quieting capabilities. Water lift mufflers require a riser with proper dimensions to be installed at their outlet.

SERVICE ACCESSIBILITY

The following is a list of Exhaust System service points that should be accessible:

- Service port for exhaust gas temperature, pressure, and emissions.
- Any exhaust system drains
- Engine to exhaust system connection points

INSTALLATION DIRECTIONS

Back Pressure

The exhaust back pressure must not exceed the value specified in the General Engine Data Sheet.

The exhaust back pressure must not exceed the value specified In the General Engine Data Sheet. Excessive exhaust back pressure can lead to a decrease in a power and economy, as well as an increase in smoke/soot and exhaust gas temperature. Cummins Inc. recommends designing the exhaust system to keep exhaust back pressure as low as reasonably possible, since it enhances engine performance and life.

The exhaust gas flow and temperature for each specific engine rating is listed in the Engine Performance Data Sheet. These values should be used for piping design and muffler selection.

The exhaust back pressure of a given engine installation will depend on the size of pipe, number and type of bends and fittings, muffler selection and location, and flow rate of water injection (if used). Tight bends, undersized piping, and mufflers are typically the highest contributors to back pressure within a system.

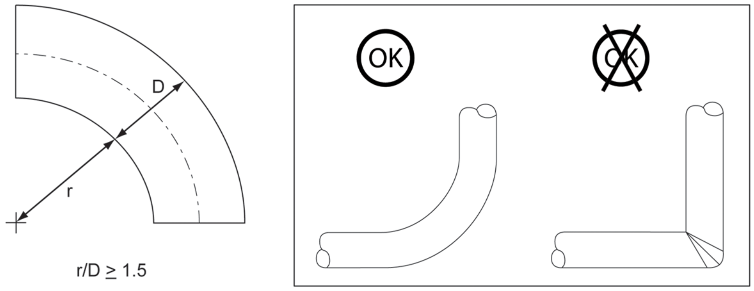


Figure 7-1: Bend Radius

The minimum bend radius of any piece of exhaust piping should not be less than one and one half times the pipe diameter. All bends in the exhaust system should be made as smooth as possible. Sharp, mitered bends can drastically increase the exhaust back pressure and should be avoided (see Figure 7-1).

The diameter of the exhaust piping will have a large effect on the exhaust back pressure in the system. The minimum exhaust pipe diameter for the various engine models and ratings will be at least as large as the exhaust connection outlet diameter. The actual exhaust piping or hose size may vary, depending upon the complexity of the routing and the muffler used in the system. An increase of one standard pipe diameter size can dramatically reduce the pressure restriction caused by the piping.

Muffler design is highly specialized. Therefore, it will not be discussed in this document. The muffler manufacturer is the best source of information for details on muffler construction, type, recommended size, and location in the piping system. Factors influencing muffler selection include restriction level, desired noise reduction, available space, and cost.

An approximation of back pressure in an exhaust system can be obtained by using the back pressure calculator available in the Tools section of http://marine.cummins.com. In all cases, the calculated back pressure is an estimate. The actual value must be verified by test measurements under sea trial conditions. If mufflers are to be used in the calculation, the back pressure imposed by the muffler(s) must be obtained from the muffler manufacturer. The tool includes both a back pressure calculator and a reference chart showing back pressure vs. flow vs. pipe size.

Wet exhaust system back pressure is generally higher than in a dry exhaust system, because of the addition of water and steam in the exhaust gas flow. To approximate the wet system back pressure, calculate the dry system back pressure value, then double it. (Note: double the dry system value only for the portion downstream of the water injection point.) Wet exhaust systems are typically one standard pipe size larger than dry exhaust systems to meet the back pressure requirements.

The exhaust system components must not impose excessive load or bending moment on the exhaust manifold or turbocharger due to weight, inertia, relative motion of the components, or dimensional change due to thermal growth.

! **The bending moment at the turbocharger outlet mounting flange must not exceed the maximum value specified in the General Engine Data Sheet.**

! **The direct load at the turbocharger outlet mounting flange must not exceed the maximum value specified in the General Engine Data Sheet.**

△ **CAUTION: Failure to maintain bending moment and direct load within limits can cause the turbocharger to fail.**

The turbocharger outlet mounting flange is designed to support only very short sections of piping attached to it. The exhaust system must be designed to limit the load or bending moment on the exhaust manifold or turbocharger due to weight, inertia, relative motion of the components, or dimensional change due to thermal growth. Exceeding the limits may result in warped mounting flanges on both the inlet and outlet of the turbine housing, turbocharger malfunction, and exhaust leaks. The value for the maximum allowable bending moment and direct load is given in the General Engine Data Sheet. Due to the variety and complexity of exhaust systems, calculation of the bending moment and direct load on the exhaust connection must be done for each unique installation.

Exhaust connections with riser sections, due to their larger dimensions and weight, are recommended to be directly supported with a brace or stanchion from the engine flywheel housing or close coupled marine gear. Under most circumstances, the support should be orientated vertically and be attached as close as possible to the center of gravity of the exhaust riser to minimize both bending moment and direct load (see Figure 7-2).

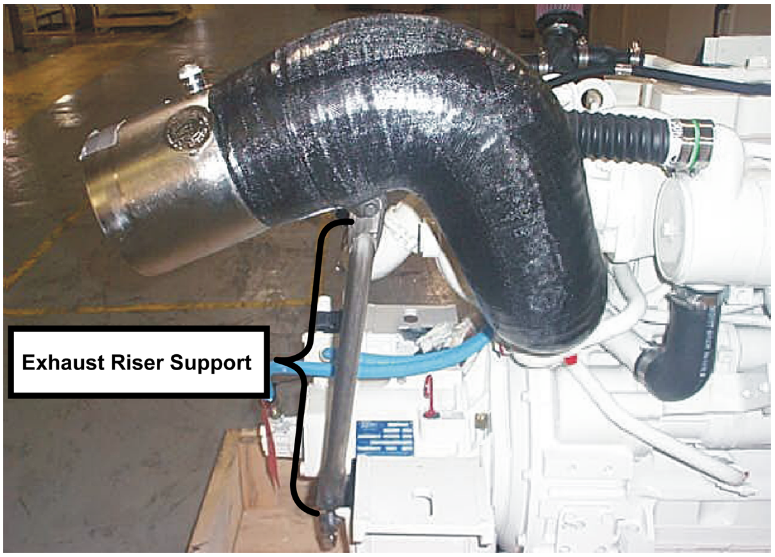


Figure 7-2: Exhaust Riser Support

Calculating Bending Moment and Direct Load

Bending moment is the rotational force applied to the exhaust outlet flange. Bending moment must be calculated in two directions. First is the bending moment about the X axis and second is the bending moment about the Z axis. Both are with respect to the center point of the exhaust outlet flange (see Figure 7-3).

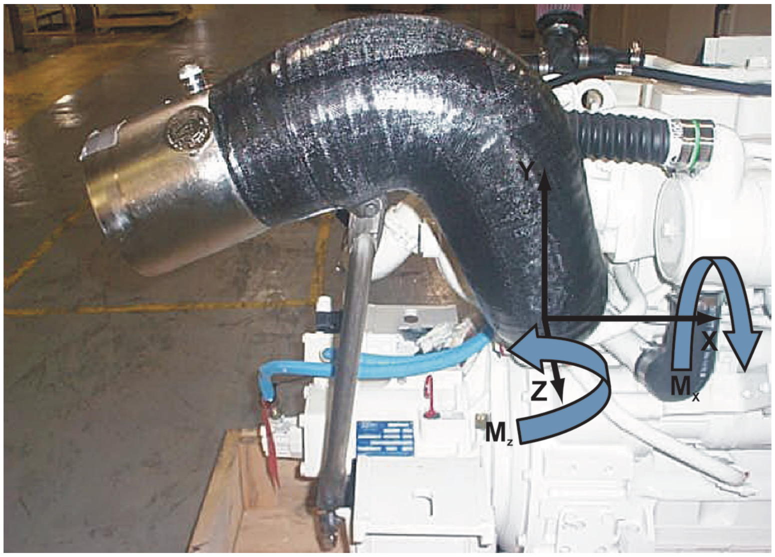


Figure 7-3: Bending Moment – X and Z Axis

Bending moment is a greater concern when using an exhaust connection that does not have a support. When using a support, the bending moment can be reduced to near zero for both X and Z axis, if it is located under the exhaust connection center of gravity and oriented vertically.

The direct load is the vertical force applied at the exhaust outlet flange in either a downward or upward direction. Direct load is affected by the weight of the exhaust connection and if using a support, the location of the support in relation to the center of gravity of the exhaust connection. The location of the support can affect the direct load significantly. As discussed previously, it is recommended that the support be placed as close to the exhaust connection center of gravity as possible.

The following illustrates the method for calculating the bending moment (M_X and M_Z) and direct load (R_f) upon the exhaust outlet flange for an exhaust connection with a single support or without a support. If not using a support, enter zero “0” for all inputs relating to the support.

An exhaust connection bending moment and direct load calculator is available in the Tools section of http://marine.cummins.com.

Note: *The following calculations will determine the load upon the exhaust connection support. It is critical that the calculated load on the support is duplicated during installation. When installing an exhaust connection with a support, Cummins Inc. recommends that the exhaust connection mounting flange initially is installed loosely to allow for movement and prevent binding. Next, adjust and secure the support while checking for proper alignment of the joint. The exhaust connection mounting flange can be tightened when the flange faces can be met squarely by hand. This will ensure that no additional loads are generated due to misalignment of the bolted joint and the calculated load upon the support is achieved.*

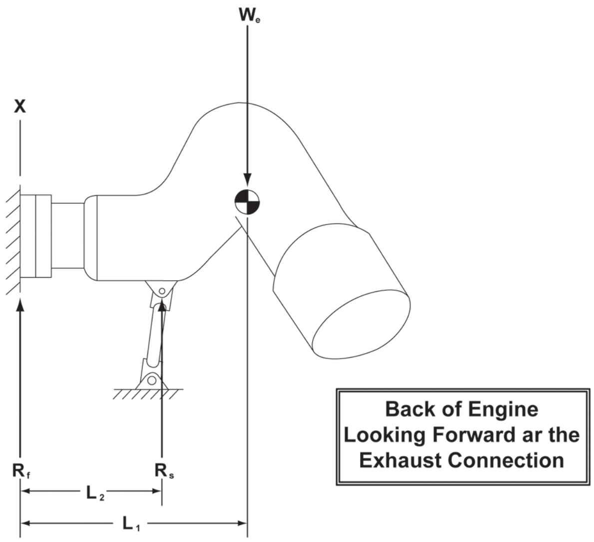


Figure 7-4

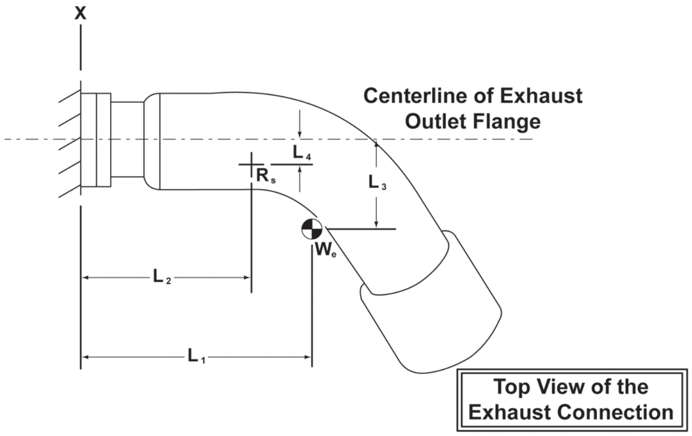


Figure 7-5

W_e	The location of the center of gravity and the wet weight of the exhaust connection in pounds (lb.) or kilograms (kg); made up from the dry weight of the exhaust connection plus the weight of the volume of water inside the exhaust connection. This information is provided by the exhaust connection manufacturer.
R_f	The direct load upon the exhaust outlet flange in pounds (lb.) or kilograms (kg).
R_s	The exhaust connection support location and reaction in pounds (lb.) or kilograms (kg). Enter a value of zero if not using a support.
X	The plane of the exhaust outlet flange.
L_1 - L_4	The horizontal distances between supports, centers of gravity, and the exhaust outlet flange, as illustrated in the diagram in units of inches (in) or millimeters (mm).
M_x	Bending moment about the X axis as illustrated in Figure 8-5.
M_z	Bending moment about the Z axis as illustrated in Figure 8-5.

The exhaust connection support reaction, R_s, must first be determined:

$Rs = (W_e L_1) / L_2$ lb. (kg)

Then find the direct load on the exhaust outlet flange

$R_f = W_e – R_s$ lb. (kg)

The bending moment about the Y and Z axis, M_y and M_z respectively, can then be calculated using:

$M_x = W_e L_1 – RsL_2$

$M_z = W_e L_3 – RsL_4$

To convert to units used in the General Engine Data Sheet:

Mx or $_z$(lb.in.) / 12 = M_x or $_z$(lb.ft.) when using English units

M_x or $_z$(kg.mm)*9.8 / 1000 = M_x or $_z$(N•m) when using metric units

- Both bending moments, M_x and M_z, must not exceed the value specified in the General Engine Data Sheet
- The direct load on the exhaust outlet flange, R_f, must not exceed the value specified in the General Engine Data Sheet

A flexible connection must be installed directly to the engine exhaust outlet connection.

CAUTION: Failure to isolate relative motion between the exhaust connection and vessel may cause the turbocharger or exhaust plumbing to fail.

A flexible connection must be installed between the exhaust connection outlet and the vessel exhaust piping. A flexible connection protects the exhaust connection, exhaust manifold, and turbocharger from the stresses due to relative motion and thermal expansion between the engine and vessel mounted exhaust components. It also minimizes the transmission of noise and vibration from the engine to the vessel structures for crew/passenger comfort.

For wet exhaust systems, the flexible connection is located directly after the exhaust connection. A silicone or EPDM hump hose is recommended as the flexible connection, because they provide excellent isolation of vibration and free range of movement (see Figure 7-6). When using a hump hose, the tubes that are being connected should have ends that are inline, at the same angle, and are spaced appropriately apart. This prevents the hump hose from being bent, offset, or under compressive/tensile load stress, which may place excessive loads upon the turbocharger and reduce the vibration isolation qualities.

Wire-reinforced black exhaust hose is significantly stiffer than a silicone or EPDM hump hose. Therefore, if wire reinforced hose is used as the flexible connection, a length equal to at least 5 times the diameter of this hose is recommended. Incorporating a slight bend in the hose will allow it to flex if subjected to compressive or tensile loads.

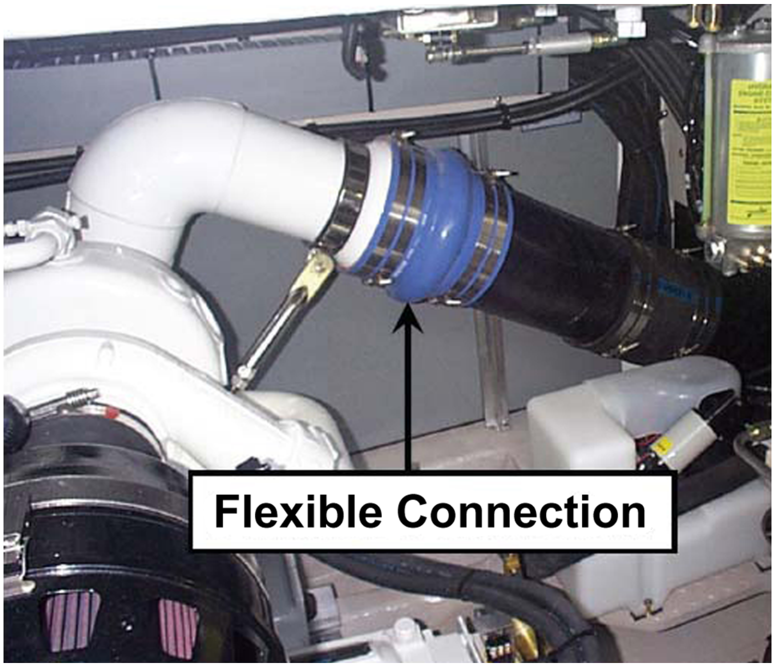


Figure 7-6: Flexible Connection (Silicone Hump Hose)

For dry exhaust systems, connection is made directly to the turbocharger outlet flange or after a short exhaust connection. If the engine design incorporates a rigidly-supported elbow or adapter after the turbo connection, it is not necessary to use a flex section at the exhaust flange; however, a flex section must still be incorporated within 1.2 meters (4 feet) of this point. Flexible stainless steel bellows are recommended (see Figure 7-7). Metal bellows are relatively stiff and therefore a minimum bellows length of 305 mm (12 in) should be used. Stiffness data from the bellows manufacturer should be used to calculate the load imposed on the turbo due to misalignment of the piping at the bellows. Flexible exhaust connections should be installed per the manufacturer's requirements and should be installed without bends, offset, or under compressive/tensile loads (see Figure 7-8).

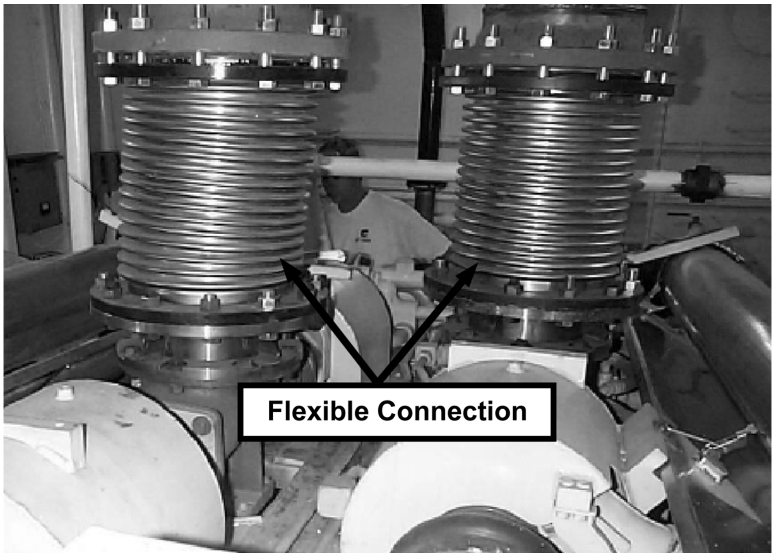


Figure 7-7: Stainless Steel Bellows – Flexible Connections

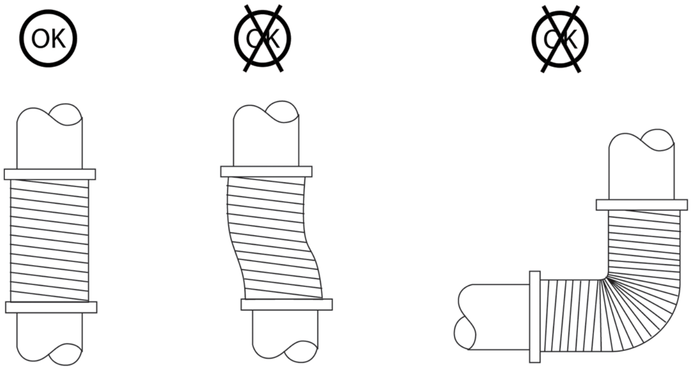


Figure 7-8: Flexible Connection “Metal Bellows” Installation

Thermal Expansion Considerations

All exhaust systems must be designed to accommodate the thermal expansion of the piping without over stressing any components in the exhaust system or the engine. However, particular attention should be paid to dry exhaust systems, because the materials used and a large change in temperature create significant expansion. One method, as illustrated in Figure 7-9, is to use a fixed support at the engine end and let the other end float. All supports, except the fixed support must be flexible to allow for thermal expansion of the exhaust piping.

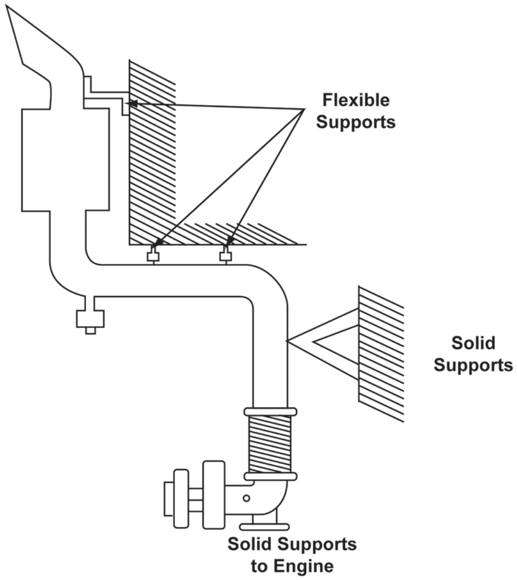


Figure 7-9

The previous method is not suitable for systems that have long horizontal and vertical sections of piping in the same system, as illustrated in Figure 7-10. Separate flexible exhaust connections must be used to absorb the thermal expansion in each direction. The horizontal flexible connection should be installed as close to the engine or as far away from the vertical piping as possible, to avoid collecting soot and condensation in the bellows.

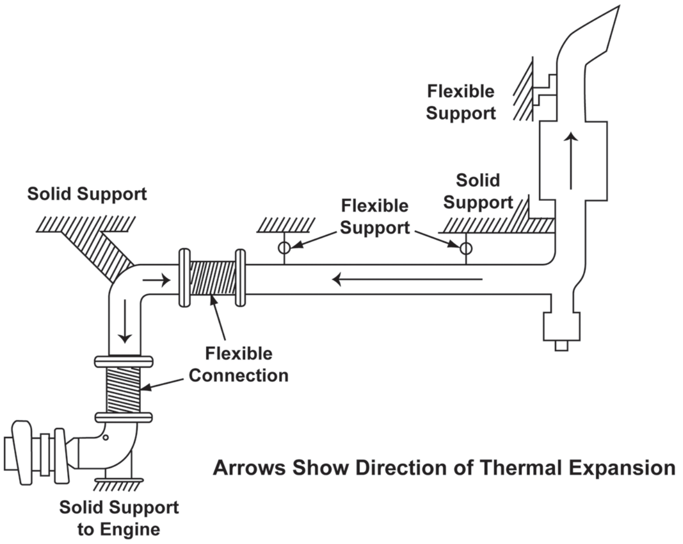


Figure 7-10

! The exhaust system must prevent the entrance of water into the engine.

The exhaust system must prevent entrance of water (water intrusion) into the engine during both operating and non-operating conditions, whether it is from spray, rain, washing, wave action, boat motion, or any other source.

In a dry system with vertical stacks, water intrusion protection is typically accomplished by using a 45 degrees or greater bend with the top edge of the pipe having a slight overhang. The exhaust outlet must face toward the stern of the vessel to prevent forward motion from driving spray or rain into the opening. Angling an exhaust outlet outboard to improve dissipation of the gases is permissible, given that it also faces in the aft direction. Cummins Inc. recommends using a condensation trap and drain at the bottom of any vertical section. These characteristics are illustrated in Figure 7-11.

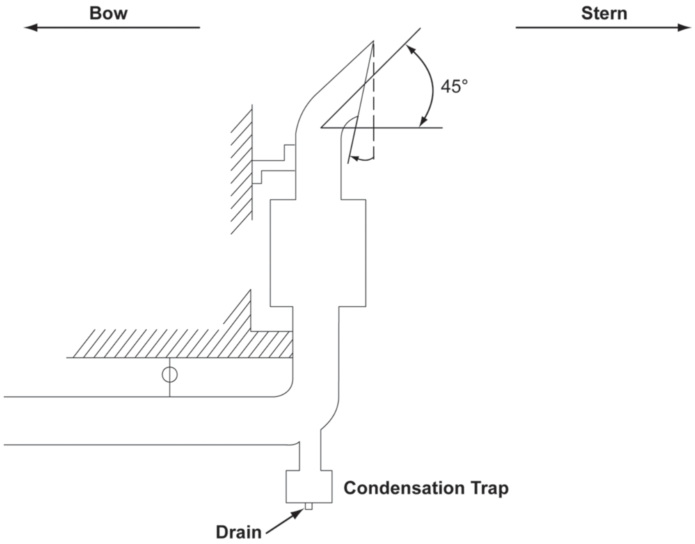


Figure 7-11

For wet exhaust systems, Cummins Inc. requires the design and installation of the exhaust system to meet specific measures. Requirements for wet exhaust systems are covered in detail later in this section.

The exhaust gas must be dispersed so that it does not detrimentally affect the air cleaner function.

The exhaust outlets must be a sufficient distance from all air ventilation intake openings, including engine room and crew/passenger spaces, to prevent adversely affecting the air cleaner function, the engine ambient environment, and personnel spaces. The longitudinal placement of the exhaust outlets should be aft of the air intake, so that the forward motion of the vessel supplies fresh air to the intake before carrying away the exhaust gases (see Figures 7-12 and 7-13).

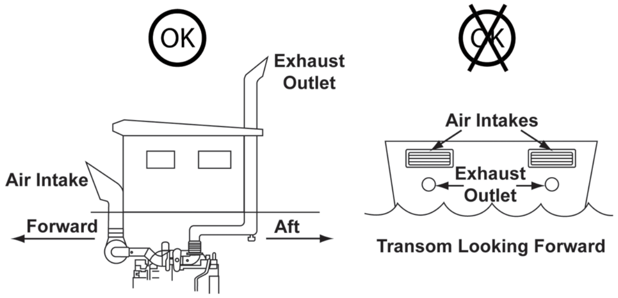


Figure 7-12: Exhaust Outlet Placement

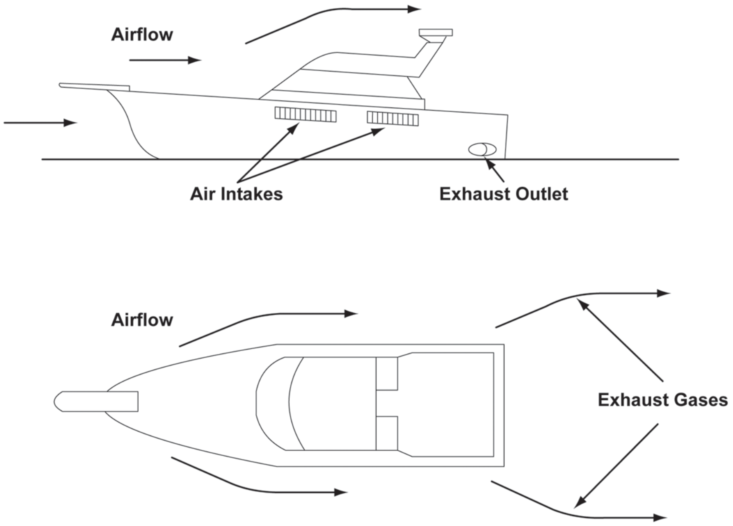


Figure 7-13: Exhaust Outlet Placement

Other consideration that should be taken into account when locating the exhaust outlets are:

- Airflow around the vessel structures which can draw exhaust gases into engine and personnel spaces.
- Placement of through transom exhaust outlets, depending on airflow characteristics, around the aft section of the vessel to minimize soot deposits on the transom.
- Placement of the exhaust outlets to prevent noise reflection from stern or quarter waves back toward the vessel.

WARNING: In order to prevent personal injury from contact with a hot surfaces and to protect the vessel from the possibility of fire, all exhaust system surfaces that persons or gear may come in contact with must not exceed 93° C (200° F) and all exhaust system surfaces which may be impinged upon by a flammable liquid leak must not exceed 220° C (428° F).

For safety reasons, any exhaust system surface that persons or gear may come in contact with must not exceed 93° C (200° F). Additionally, due to Marine Classification Societies adopting the Safety of Life at Sea (SOLAS) requirements, any exhaust system components which may be impinged upon by a flammable liquid leak must not exceed 220°C (428° F) (see Figure 7-14). Insulation, covers, shields, or a combination thereof may be used to limit surface temperatures or prevent contact with the surface. Insulation or any other materials used to limit surface temperature must be fireproof and resistant to absorbing fuel, oil, and coolant.

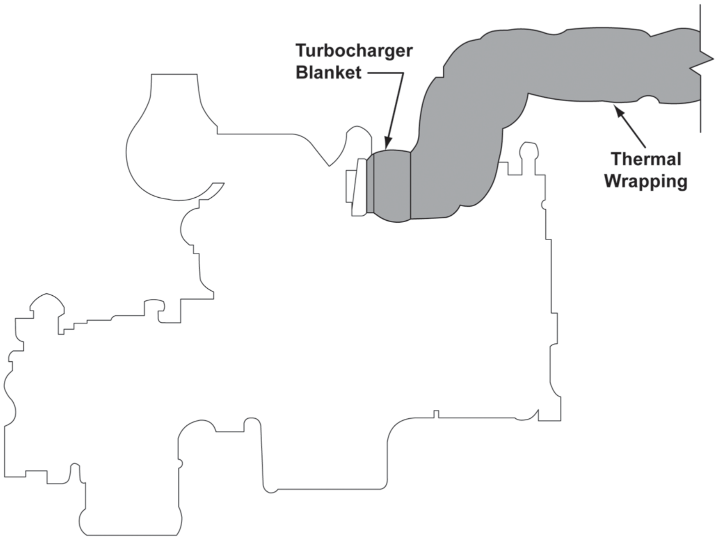


Figure 7-14: Insulation on Exhaust System Components Exceeding 93° C (200° F)

Piping must not be installed near combustible material.

CAUTION: Exhaust piping installed near combustible materials could exceed the material specifications, causing damage, including the risk of fire.

Due to the high temperature of a dry exhaust system, piping must not be installed near combustible materials. Cummins Inc. recommends that insulated dry exhaust piping be at least 15 cm (6 in) from any combustible materials.

Wet exhaust system surface temperatures are much lower and therefore routing of the piping around combustible materials is less critical. However, in the event of a water injection failure, the exhaust will become dry and rapidly heat up. In this case, materials and components that can be sensitive to brief periods of high heat, such as plastics, foam insulation, and tanks holding flammable liquids may be affected. Therefore, routing of a wet exhaust around these materials and components with sufficient clearance should be considered.

A service port must be provided in the exhaust system.

All engines subject to EPA emissions standards must be equipped with a service port in the exhaust system for the temporary attachment of gaseous and/or particulate emissions sampling equipment.

-Also-

Cummins Inc. requires a service port to measure exhaust gas temperature and back pressure.

The service port must be internally threaded with standard pipe threads of a size no larger than 12.7 mm (0.5 in). The port must be located in the exhaust connection and accessible to industry standard pyrometer probes.

Note: *Cummins Inc. recommends the service port not be installed in the radius of a bend. Doing so can cause inaccurate back pressure measurements. The ideal location for the port is in a straight section of pipe directly after the outlet of the turbocharger.*

Wet Exhaust Systems - Height Above Loaded Waterline

The most important consideration when designing and installing a wet exhaust system is protecting the engine from water intrusion. Many designs exist to accomplish this. However, the basic configuration of a wet exhaust system depends on one critical measurement; the distance between the bottom of the exhaust manifold or turbocharger outlet and the loaded waterline, as illustrated in Figure 7-15. For Cummins Inc., the minimum acceptable distance is 305 mm (12 in).

Wet exhaust systems installed with the bottom of the exhaust manifold or turbocharger outlet greater that 305 mm (12 in) above the loaded waterline must meet the following requirements:

The highest point in the exhaust system must be dry and at least 305 mm (12 in) above the loaded waterline.

Having the distance between the bottom of the exhaust manifold or turbocharger outlet and the LWL greater than 305 mm (12 in) allows for the simplest of exhaust system designs, using a down turned exhaust connection as illustrated in Figure 7-15. The highest point of this system must be dry.

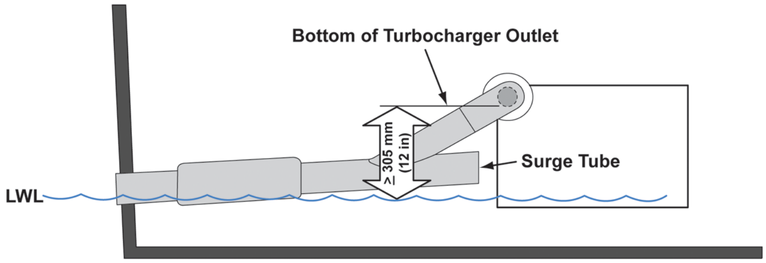


Figure 7-15: Height above LWL without Riser

Note: *If using a water lift muffler, follow the directions for wet exhaust systems installed with the exhaust manifold or turbocharger outlet less than 305 mm (12 in) above the loaded waterline (LWL).*

The customer has the option of installing a riser, as illustrated in Figure 7-16 for greater height above the LWL, allowing more protection against water intrusion. Installation of a surge tube as seen in Figures 7-15 and 7-16 can also be used to assist in keeping water from entering the engine. The function of the surge tube is to trap a momentary surge of water up the exhaust before it can enter the engine. Vessels that are likely to encounter heavy seas and/or aggressive backing maneuvers such as vessels traveling offshore, long range trawlers, pilot boats, and fishing vessels are recommended to have greater than the minimum height above waterline and surge tubes. A flapper valve at the termination of the exhaust system may also be used to reduce the entrance of water.

Wet exhaust systems installed with the bottom of the exhaust manifold or turbocharger outlet less than 305 mm (12 in) above the loaded waterline must meet the following requirements:

The highest dry point of the exhaust system before the water injection must be dry and at least 305 mm (12 in) above the loaded waterline or any other waterline created by standing water within the exhaust system.

If the bottom of the exhaust manifold or turbocharger is less than 305 mm (12 in) above the loaded waterline, two options exists to be able to obtain the required distance.

The first option is to install a riser on the engine exhaust outlet, as illustrated in Figure 7-16 to elevate the highest dry point. The highest dry point will be at the bottom of the internal riser pipe at the riser apex and must be at least 305 mm (12 in) above the loaded waterline.

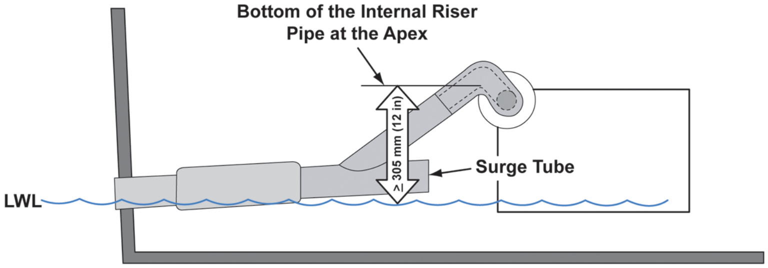


Figure 7-16: Height above LWL with Riser

The second option is to install a water lift muffler as illustrated in Figure 7-17. Special attention should be paid to the location of the waterline created by standing water in the water lift muffler during static conditions. At least 305 mm (12 in) of distance must be maintained from the bottom of the exhaust manifold or turbocharger outlet to the static waterline level in the water lift muffler. If there is insufficient distance between the exhaust manifold or turbocharger outlet, then an exhaust riser must be installed directly to the exhaust manifold or turbocharger outlet as depicted in Figure 7-17 to obtain adequate distance.

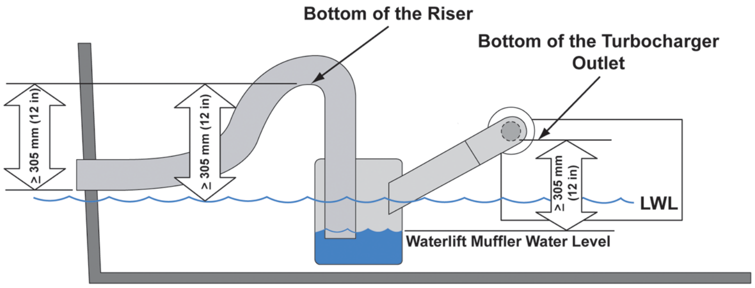


Figure 7-17: Water Lift Muffler Arrangement

If using a water lift muffler or similar component, then a riser in the exhaust system must be installed on the outlet of the water lift muffler, with the bottom of the riser at least 305 mm (12 in) above the loaded waterline and the exhaust outlet at least 305 mm(12 in) below the bottom of the riser.

If using a water lift muffler or similar component that holds a volume of standing water that will not passively drain and maintain a nominal water level if additional water is added during stopped engine conditions, a riser that is at least 305 mm (12 in) above the loaded waterline measured from the bottom of the riser must be installed on the outlet of the water lift muffler. The bottom of the exhaust outlet must be at least 305 mm (12 in) below the bottom of the riser.

It is recommended that the upward and downward slope of the riser is as close to a vertical orientation as possible. This will minimize the volume of water within the riser section during operation and maximize the protection against water intrusion (see Figure 7-17).

Note: *Cummins Inc. recommends that drains are installed in any exhaust system component that collects water and does not passively drain, such as a water lift muffler. Installation of a drain facilitates emptying the system for maintenance, seasonal storage, and/or transportation of the vessel. During transportation and the associated lifting of the vessel, the vessel may encounter conditions whereby it is tilted or moved in such a way that allows trapped water to enter the engine.*

Wet Exhaust Systems – Exhaust Connections and Plumbing

The injected water must not be able to flow back into the engine.

The point of water injection is downstream of and at least 203 mm (8 in) from or 51 mm (2 in) below the highest dry point.

The down angle of the exhaust connection after the highest dry point, including the water injection and downstream plumbing immediately thereafter, must be at least 15 degrees from horizontal.

The design and installed orientation of the exhaust connection or riser must meet the following: The point of water injection is downstream of and at least 203 mm (8 in) from or 51 mm (2 in) below the highest dry point of the exhaust system. The highest dry point of the exhaust system before the water injection will be one of two locations: If a standard exhaust connection with no riser is used, the bottom of the exhaust manifold or turbocharger outlet will be the highest point (see Figure 7-15). If an exhaust riser is used to obtain greater height above the LWL or any other waterlines, the highest point will be at the bottom of the internal riser pipe at the riser apex (see Figure 7-16). The down angle of the exhaust connection after highest dry point, including the water injection and downstream plumbing immediately thereafter, must be at least 15 degrees from horizontal. Figure 7-18 illustrates how to measure for these requirements. In all cases, the injected water must not be able to flow back into the engine.

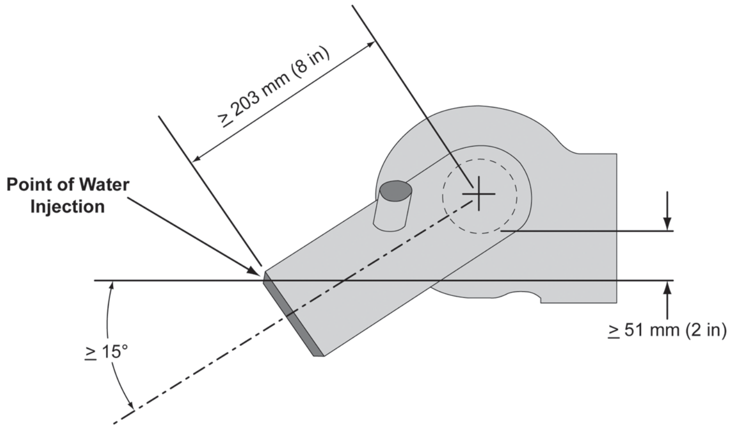


Figure 7-18

If the point of the water injection is below the loaded waterline, the sea water plumbing to the water injection must be routed at least 305 mm (12 in) above the loaded waterline, with a siphon break installed.

If the point of the water injection is below the loaded waterline, siphoning may occur through the sea water system and flood the exhaust, causing water intrusion. To prevent siphoning when the point of the water injection is below the loaded waterline, the sea water plumbing must be routed at least 305 mm (12 in) above the loaded waterline, with a siphon break installed (see Figure 7-19). Follow the manufacturer's instructions when installing the siphon break.

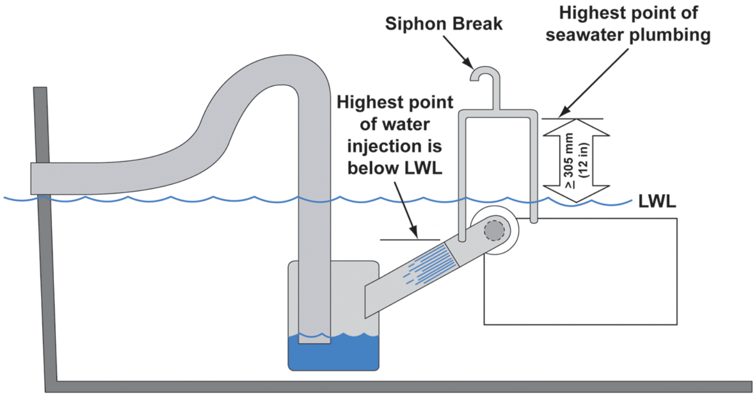


Figure 7-19: Water Injection Below LWL with Siphon Break

The location of the water injection must be at least 305 mm (12 in) from any downstream bends in the exhaust system.

The location of the first bend in the exhaust system must be at least 305 mm (12 in) downstream of the point of water injection. When measuring the distance, measure from the point of water injection to the beginning of the inside radius of the bend (see Figure 7-20). Having a bend too close to the water injection may disrupt the mixing of water and exhaust gases, and create hot spots that may exceed the temperature limits of the materials commonly found in wet exhaust systems.

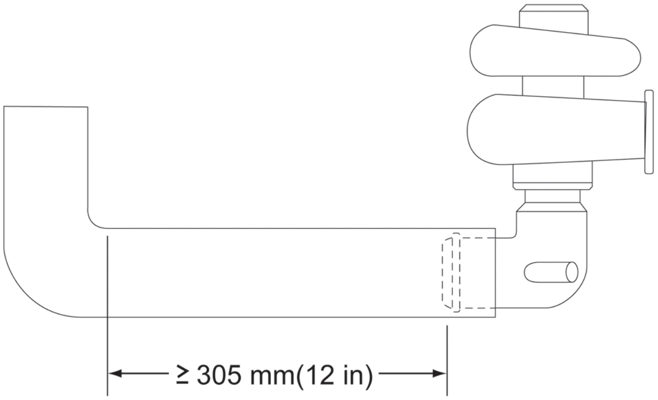


Figure 7-20

Wet exhaust piping must have a continuous downward slope of no less than 2 degrees or 12.7 mm over a 305 mm run (0.5 in over a 12 in run) with exception to sections of piping used as a riser after a water lift muffler or similar component.

To facilitate the passive removal of water from the exhaust system, the piping must have a continuous downward slope of no less than 2 degrees or 12.7 mm over a 305 mm run (0.5 in over a 12 in run) (see Figure 7-21). Flat runs of pipe, dips, and low spots within the exhaust system can collect water and increase the possibility of water intrusion into the engine, especially during heavy seas and stopped engine conditions. The exception to this requirement applies to sections of piping used as a riser after a water lift muffler or similar component (see Figure 7-22).

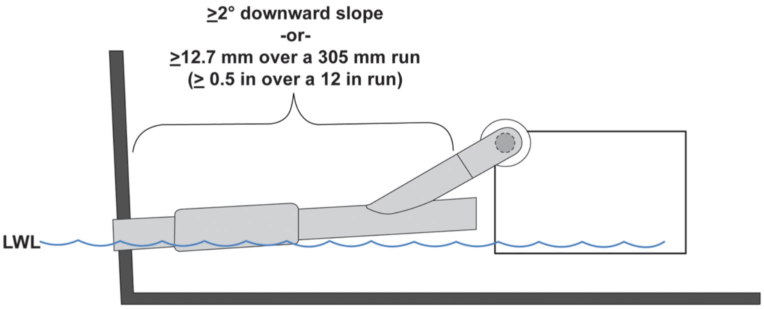


Figure 7-21

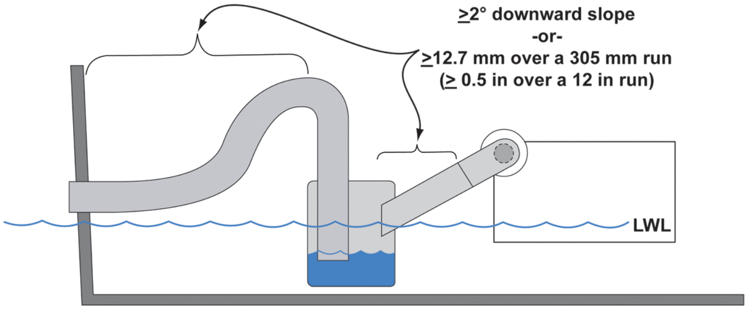


Figure 7-22

Water Injection Considerations

When water is injected into the exhaust system, it is important that an even spray pattern is achieved. If the spray pattern is uneven, parts of the exhaust piping may not be sufficiently cooled. This can result in failure of the exhaust piping such as deterioration, delamination, and/or melting due the temperature exceeding the material limits. The surface temperature of the exhaust piping should not exceed 93° C (200° F) under any operating conditions. For through transom or through hull exhausts, hoses used shall comply with the performance requirements of SAE J2006 or UL 1129. All other exhaust system components shall meet the performance requirements of UL 1129.

Spray holes too large may not allow the water to form an effective spray and sufficiently cool the exhaust hose. Holes that are too small may increase the sea water cooling system pressure, restrict water flow, and are more prone to clogging.

As a general rule, the use of evenly distributed 8mm (0.31 in) diameter holes will provide adequate cooling and acceptable sea water system pressure. The number of holes is dependent upon the sea water flow rate of the engine.

For determining the number spray holes, the following can be used:

The number of 8 mm (0.31 in) diameter spray holes required equals

Liters per minute (LPM) of sea water flow / 10
-Or-
Gallons per minute (GPM) of sea water flow / 2.6

Note: *When using a customer supplied wet elbow, the maximum allowable discharge pressure at the seawater pump outlet must not exceed the limits given in MAB 0.08.17-07/16/2001, Sea Water Pump Performance, and the temperature of the exhaust after the water injection must not damage the exhaust system components.*

Note: *In all cases, the water injection spray holes must be larger than the sea strainer hole diameter (2 mm (0.079 in) maximum) to prevent plugging.*

Cummins Inc. recommends that wet exhaust connections are self draining (preferred) or at least equipped with a drain plug. This reduces the risk of internal corrosion (pitting) due to the stagnation of trapped water during shutdown. Internal corrosion of the exhaust connection can go undetected and if the inner tube fails, water may drain back into the engine.

COOLING SYSTEM

Summary of Requirements

All Applications

- Marine engine coolants must contain at least a minimum of 25 percent antifreeze concentration.
- Marine engine coolants using less than 40 percent antifreeze concentration must maintain higher minimum SCA levels, as prescribed in Service Bulletin No. 3666132, Section 8, except engines with parent bore blocks (non-liner engines) that do not require SCA.
- Separate cooling circuits must be used for each engine, such that coolant is not shared between engines.
- No modifications are to be made to any factory supplied cooling systems.
- The cooling system must be designed and installed so that the maximum jacket water temperature does not exceed 96° C (205° F) at any operating condition.
- All joints, components, piping, and connections must be leak free.
- Flexible lines must be installed between the engine and vessel piping to allow for relative motion.
- All plumbing must be free from chafing points.
- Customer supplied hoses and fittings connected to the engine must comply with SAE J1942 for coolant hoses.
- Customer supplied hose type connections must have a circumferential hose bead or barb.
- Customer supplied hoses must be installed with two stainless steel hose clamps or equivalent at each connection point for sea water systems.
- The engine must have a closed cooling system that will maintain the system pressure between 103 kPa and 138 kPa (15 psi and 20 psi). The overflow line from the pressure cap must be routed to safely drain excess coolant.
- Remote mounted expansion tanks must be mounted with the low coolant alarm level above the highest point in the cooling system.
- The coolant level sensor must be installed in the expansion tank, not in a coolant recovery bottle.
- The expansion tank volume must provide a minimum excess coolant volume that is equal to 20 percent of the engine coolant capacity listed in the General Engine Data Sheet plus 5 percent of the total coolant system volume.
- The coolant makeup line from the expansion tank must be at least 6 times the combined cross-sectional area of all the vent lines.
- Customer supplied vent lines must be routed to the top air gap section of the expansion tank.
- Customer supplied vent lines must be routed continuously upward and must not be teed together.
- The system must vent during initial fill to allow filling of the total cooling system volume to 95 percent of its full capacity.
- The cooling system must remove entrained air at engine start-up, and must continuously remove air that enters the cooling system during normal operation.
- All cooling system accessories must have a minimum pressure rating of 414 kPa (60 psi).
- All cooling system accessories must be located below the coolant level in the expansion tank.

Heat Exchanger Cooled

- The sea water pump inlet restriction at rated engine speed must not exceed the limit specified in MAB 0.08.17-07/16/2001.
- The sea water pump discharge pressure at rated engine speed must not exceed the limit specified in MAB 0.08.17-07/16/2001.
- Customer supplied sea water cooling systems must not allow the heat exchanger sea water outlet temperature to exceed 54° C (130° F).
- Fittings and components used in sea water systems must be made of corrosion resistant materials.
- The location of the sea water pickup must be below the waterline at all operating conditions.
- A seacock valve must be installed before the sea water pump and strainer.
- A full flow sea water strainer must be installed upstream of the sea water pump and the maximum strainer hole size must not exceed 2.0 mm (0.079 in).
- The sea water pump inlet plumbing must be installed such that sea water is retained inside the pump when the engine is not running.

Keel Cooled

- **! Keel coolers must be submerged in sea water at all operating conditions.**
- **! Manufactured keel cooler specified heat rejection capacity (including loss due to fouling) at maximum coolant flow must meet or exceed the value specified in the Engine Performance Data Sheet.**
- **! Fabricated keel cooler heat rejection capacity (including 50 percent loss due to fouling/painting) at maximum coolant flow must meet or exceed the value specified in the Engine Performance Data Sheet.**
- **! The engine coolant pressure drop across any external coolers, measured from the engine coolant outlet to the engine coolant inlet connections, must not exceed 34.5 kPa (5 psi).**
- **! The coolant inlet temperature from the Low Temperature Aftercooler (LTA) must be less than the value specified in the Engine Performance Data Sheet.**
- **! For Low Temperature Aftercooled (LTA) engines, auxiliary coolers are to be installed only in the LTA supply line from the keel cooler.**

GENERAL INFORMATION

Cummins engines must have a closed cooling system. A closed cooling system circulates chemically treated water (coolant) through the engine. Open systems, which are not approved, circulate sea water or raw water through the engine. In this section, sea water refers to any untreated water source such as salt, brackish, or fresh water from an ocean, river, lake, pond, etc. Tap water is also considered an untreated water source.

Two closed cooling systems are offered with Cummins engines; heat exchanger cooled and keel cooled.

A heat exchanger cooling system uses the engine water pump to circulate the coolant through an engine mounted heat exchanger. Within the heat exchanger, the coolant flows around a series of tubes or plates before returning to the water pump inlet. Also equipped with the engine is an independent, open loop sea water system that draws sea water in from a through hull fitting. The sea water is pumped through adjacent but segregated passages within the heat exchanger before being discharged. Heat is rejected from the engine coolant to the sea water through the tube or plate walls. An advantage of heat exchanger cooling is that it facilitates the use of sea water aftercooling to greatly reduce intake manifold temperatures and thereby allow higher output ratings.

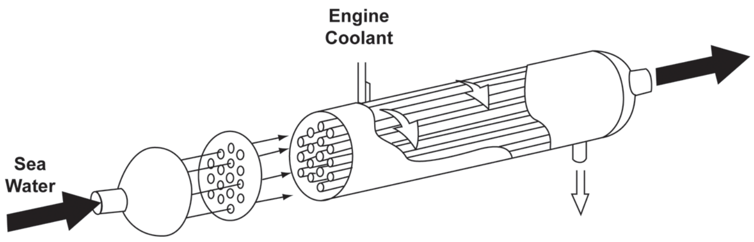


Figure 8-1

A keel cooled system has a group of tubes, pipes, or channels attached to the exterior of the hull that is connected to the engine closed cooling system. Engine coolant is circulated by the engine water pump through the keel cooler, where excess heat is conducted through the cooler walls to the surrounding water. Keel cooling is popular in commercial applications that have heavy silt, debris, or ice in the water that would clog and/or erode a heat exchanger system. An advantage of a keel cooled system is that it greatly reduces the maintenance and corrosion protection needed with a sea water system.

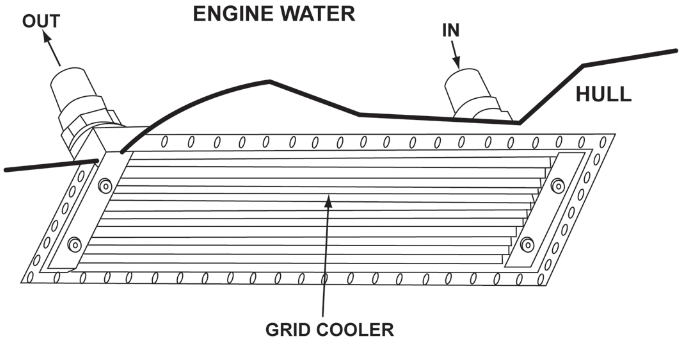


Figure 8-2

SERVICE ACCESSIBILITY

The following is a list of Cooling System service points that should be accessible:

All Applications

- Cooling system fill/pressure cap
- Thermostat housing
- Cooling system sensors
- Any installed petcocks
- Coolant level sight glass (if used)

Heat Exchanger Cooled

- Seacock
- Sea water strainer
- Sea water pump impeller
- Sacrificial anodes

Installation Directions

Coolant Requirements

Marine engine coolants must contain at least a minimum of 25 percent antifreeze concentration.

Marine engine coolants using less than 40 percent antifreeze concentration must maintain higher minimum SCA levels as prescribed in Service Bulletin No. 3666132-02, Section 8, except engines with parent bore blocks (non-liner engines) that do not require SCA.

WARNING: Check the coolant level only when the engine is stopped. Wait until the temperature is below 50° C (120° F) before removing the pressure cap. Failure to do so can cause personal injury from heated coolant spray.

Cummins engines are designed to use a coolant that is a mix of 50% water and 50% ethylene or propylene glycol based antifreeze. The coolant mixture raises the boiling point, lowers the freezing point, and helps to prevent scaling and corrosion. In areas where operation in temperatures below -37° C (-34° F) is expected, the antifreeze concentration may be increased to 60% for additional freeze protection.

To help reduce the fill and maintenance cost of high volume cooling systems, a minimum antifreeze concentration of 25% can be used when maximum freeze protection is not required. When using lower antifreeze concentrations, higher minimum Supplemental Coolant Additives (SCA) levels are required. Service Bulletin No. 3666132-02, Section 8, contains the provisions for using reduced levels of antifreeze.

Note: *Cummins engines with parent bore blocks (non-liner engines) do not require the addition of SCA*

For a copy of Service Bulletin No. 3666132-02, contact your local Cummins Marine Certified Application engineer.

DCA2 and DCA4 are supplemental coolant additives, specifically designed for Cummins engines by Cummins Filtration, that provide additional corrosion protection and inhibit cylinder liner cavitation. Cummins engines built with cylinder liners (C-series and larger) are required to have the specified SCA concentration in the coolant. SCA is added to the system as a liquid, powder, or as a spin on cartridge filter, if so equipped.

Figure 8-3

The required SCA concentration levels are as follows in Table 8-1.

Antifreeze Concentration	SCA Requirements	Coolant Filter (If Applicable)
40-60% Ethylene/Propylene Glycol	1.2 - 5.0 Units per Gallon of Cooling System Volume	Chemical Filter or Chemical Free Filter as Required
25-40% Ethylene/Propylene Glycol	3.0 - 5.0 Units per Gallon of Cooling System Volume	Chemical Free Filter ONLY

Table 8-1: SCA Concentration

During normal operation the SCA protection will gradually deteriorate. Periodically, the SCA concentration must be checked and additional SCA added if necessary. SCA test kits are available from Cummins Filtration to determine the initial and subsequent maintenance of the SCA concentration. The test is a simple nitrate color test that can be done in a few minutes with a small coolant sample. Refer to the instructions included with the test kit for the proper testing procedure.

Cummins Inc. recommends that the desired antifreeze concentration is mixed with the water prior to filling the engine. This ensures the proper ratio of antifreeze to water and prevents difficulties with filling and venting of the engine, due to the higher viscosity of undiluted antifreeze. For convenience, premixed coolants are available from Cummins Filtration.

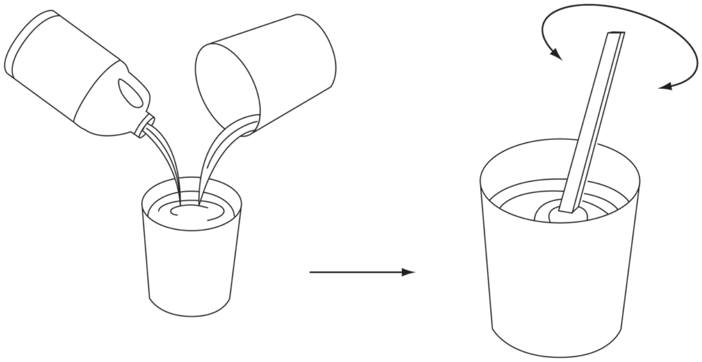


Figure 8-4

Note: *Cummins Inc. requires that the water used in coolant solutions must meet the requirements in Service Bulletin 3666132, Section 9. Excessive levels of calcium, chloride, and sulfate can lead to cooling system scaling, corrosion, and reduced service life. Cummins Inc. recommends the use of deionized or distilled water. If deionized or distilled water is not available, the water used must be tested for suitability and must meet allowable limits for dissolved minerals and other characteristics given in Service Bulletin 3666132.*

Separate cooling circuits must be used for each engine, such that coolant is not shared between engines.

Each engine must have a dedicated closed cooling system that does not share coolant with any other engine. Separate cooling systems are important for several reasons:

1. They maintain the ability to troubleshoot the system effectively.
2. Flow throughout the system is unpredictable when cooling circuits are combined, potentially causing inadequate flow to the block and/or low temperature aftercooler.
3. Dearation may not occur effectively.
4. In the event of a situation such as an engine overheating, the overheated engine will not affect the other installed engines with separate cooling systems. This requirement includes the use of coolant recovery bottles; they are not to be shared between engines.

General Installation

No modifications are to be made to any factory supplied cooling systems.

Cooling systems supplied with the engine by the factory have been developed and tested to ensure proper operation. Modifications to these systems can have an adverse effect and therefore are not approved. Any modifications made to the system will become the responsibility of the installer.

The cooling system must be designed and installed so that the maximum jacket water temperature does not exceed 96° C (205° F) at any operating condition.

Cummins engines are designed to operate within a specified coolant temperature range. The minimum warm engine coolant temperature is given in the General Engine Data Sheet. The maximum coolant temperature is 96° C (205° F) for all engines. The coolant temperature must not exceed 96° C (205° F) at any operating condition. Operating the engine with excessively high engine coolant temperatures can result in reduced engine life and possible engine or component failure.

All joints, components, piping, and connections must be leak free.

All joints, components, piping, and connections used in the cooling system must be leak free. Robust methods for joining components should be used to make sure leaks do not develop over time. A suitable pipe sealant compatible with coolant should be used on tapered fit threaded connections. Teflon® tape and other wrap type thread sealants must not be used because of the risk of the material entering the cooling system.

If using hose clamps, they should be positioned behind the hose bead and tightened to the clamp manufacturer's specifications. Excessively tightening clamps and positioning them over the hose bead can cause failure of the clamp and/or hose material.

Flexible lines must be installed between the engine and vessel piping to allow for relative motion.

All lines installed between the engine and the vessel must have flexible sections that allow for relative motion. Flexible sections should be of sufficient length to allow for unrestricted movement in all directions. Hard wall and/or reinforced hose commonly used for sea water pump suction applications are relatively stiff and should be installed with a length of least 5 times the hose diameter and a sweeping bend to minimize stress on the connections.

All plumbing must be free from chafing points.

Proper installation techniques must be observed to make sure hoses and piping are securely fastened and routed to prevent chafing. Additionally, hoses and piping must not be routed near or on hot surfaces. If the routing can not avoid chafing points or hot surfaces, adequate chafe protection and/or insulating sleeves must be used.

Customer supplied hoses and fittings connected to the engine must comply with SAE J1942 for coolant hoses.

Non-factory supplied hoses and fittings connected to the engine must comply with SAE J1942, Hose and Hose Assemblies for Marine Applications.

Customer supplied hose type connections must have a circumferential hose bead or barb.

Customer supplied hose type connections must have a circumferential hose bead or barb for added security against leaks and the possibility of the hose slipping off the connection. Hose beads should meet the dimensional requirements specified in Table 3, Figure 1 of SAE J1231, or equivalent.

Customer supplied hoses must be installed with two stainless steel hose clamps or equivalent at each connection point for sea water systems.

Customer supplied hoses must be installed with two stainless steel hose clamps or equivalent at each connection point for sea water systems (see Figure 8-5). Marine grade stainless steel (type 304 or 316) clamps are recommended. The clamps must be installed behind the hose bead and should be orientated so that the bolt head is accessible for service considerations.

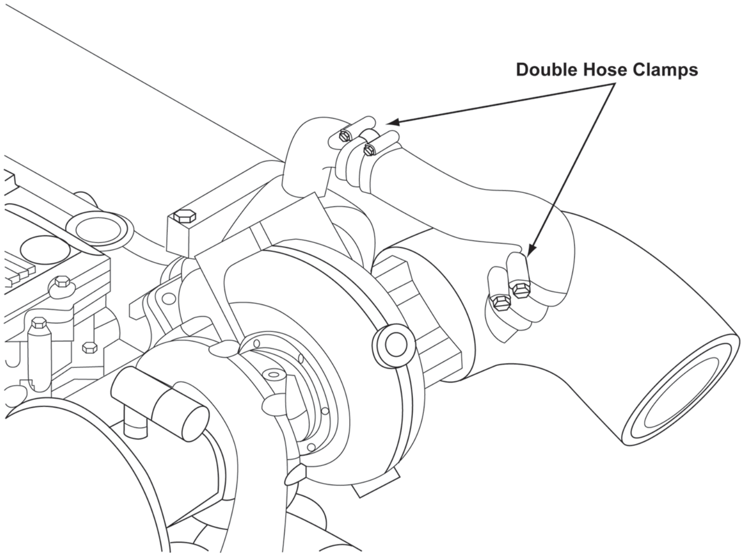


Figure 8-5: Installation of Double Hose Clamps

Pressure Caps

The engine must have a closed cooling system that will maintain the system pressure between 103 kPa and 138 kPa (15 psi and 20 psi).

The engine must have a closed cooling system that will maintain the system pressure between 103 kPa (15 psi) and 138 kPa (20 psi). A pressure cap rated for 103 kPa (15 psi) must be installed, unless the water level in the expansion tank is more than 1.5 meters (5 feet) above the engine crankshaft. Doing so will maintain the proper pressure in the engine for boilover and water pump cavitation protection. For installation where the water level in the expansion tank is more than 1.5 meters (5 feet) above the engine crankshaft, the required pressure cap rating will change, depending on the height. Table 8-2 shows the combination of pressure caps and expansion tank water level heights.

Expansion Tank Water Level Height above Crankshaft	**Minimum Pressure Cap**
meters (feet)	kPa (PSI)
0 to 1.5 (0 to 5)	103 (15)
1.5 to 4 (5 to 13)	48 (7)
3 to 7 (10 to 23)	28 (4)
6 to 9 (20 to 30)	Fill Cap & Vent

Table 8-2: Expansion Tank Water Level Height vs. Pressure Cap Rating

Expansion tanks with a water level more than 9 meters (30 feet) above the engine crankshaft are not recommended.

Note: *Expansion tanks that are high enough not to require a pressure cap must have a fill cap and a vent tube from the top of the tank to allow for the air and gases to escape from the cooling system. The vent must be designed to prevent dust and debris from contaminating the cooling system. A gooseneck vent is recommended for simplicity and effectiveness.*

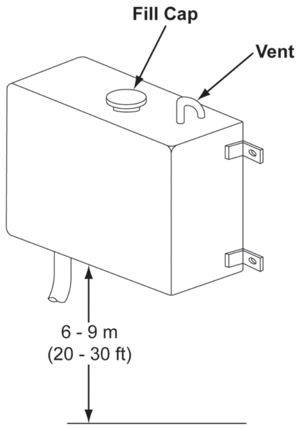


Figure 8-6

Note: *Cummins Inc. recommends that the expansion tank be located no more that 6 meters (18 feet) horizontally from the front of the engine.*

! **The overflow line from the pressure cap must be routed to safely drain excess coolant.**

Excess coolant escaping the expansion tank due to initial overfilling or an overheat condition is a potential impact upon safety. The overflow line from the pressure cap must be routed in a way to safely drain excess coolant, so that it does not impact personnel accessible areas and/or contact hot surfaces. Cummins Inc. recommends the line be terminated into either a suitable coolant recovery bottle or catch tank.

Expansion Tanks

Cummins engines with keel cooling require the installer to fabricate or source an expansion tank to meet the needs of the system. The following installation requirements describe the design and installation criteria to ensure proper operation of the expansion tank.

Cummins engines with heat exchanger cooling will be equipped with an integral, engine mounted expansion tank. Additions and modifications to the expansion tank are not required by the installer and will not be approved by Cummins Inc. If modifications are made to the expansion tank, the installer will assume the component liability and any progressive damage that may be attributed to the component.

! **Remote mounted expansion tanks must be mounted with the low coolant alarm level above the highest point in the cooling system.**

! **The coolant level sensor must be installed in the expansion tank, not in a coolant recovery bottle.**

When using a remote mounted expansion tank, the low coolant sensor must be installed into the expansion tank so that the alarm level is above the highest point of the cooling system, including the engine and cooling system accessories. The low coolant level sensor must be installed in the expansion tank (engine mounted or remote mounted). Installation of the coolant level sensor in the coolant recovery bottle is not approved.

! **The expansion tank volume must provide a minimum excess coolant volume that is equal to 20 percent of the engine coolant capacity listed in the General Engine Data Sheet plus 5 percent of the total coolant system volume.**

The expansion tank must have sufficient excess volume after the initial fill to account for the increase in coolant volume as the engine warms to operating temperature. Cummins Inc. requires that the minimum excess coolant volume is equal to 20 percent of the engine coolant capacity listed in the General Engine Data Sheet plus 5 percent of the total coolant system capacity. The following can be used to calculate the minimum required expansion tank volume.

$V = T/18 + E/4.5$

Where:

V = Minimum Expansion Tank Volume

T = Total Cooling System Volume (including engine)

E = Engine Coolant Volume

Note: *When designing an expansion tank, Cummins Inc. recommends the use of vertical and vent baffles to prevent aerated coolant from being drawn into the engine. A vertical baffle prevents the coolant from sloshing as the vessel pitches and rolls in a seaway. A vent baffle assists with removing the entrained air from the coolant entering from the vent lines. Vent baffles are situated at an angle at the top of the tank so that coolant from the vent flows over the baffle allowing the entrained air to escape.*

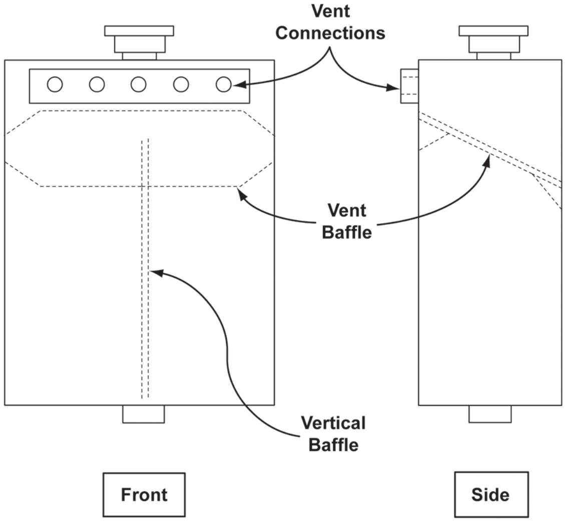


Figure 8-7

! The coolant makeup line from the expansion tank must be at least 6 times the combined cross-sectional area of all of the vent lines.

The cross sectional area of the coolant makeup line from the expansion tanks must be at least six (6) times the combined cross sectional area of all of the vent lines. The makeup line connection is located at the bottom of the expansion tank. As aerated coolant is being removed through the engine vents, deaerated coolant is being added to the cooling system through the makeup line. When the system is initially filled, the coolant must flow through the makeup line to fill the engine. If an insufficiently sized line is used, the time required to fill the engine may be excessive. The expansion tank may also fill faster from the vents than the coolant can flow back to the engine.

Note: *An example of a properly designed expansion tank with dimensions is provided in Figure 8-24 at the end of the Cooling System section. Dimensions for 38 L (10 gal), 76 L (20 gal), and 114 L (30 gal) tanks are given to meet multiple capacity requirements. Included in the drawing are tank connection sizes and locations to satisfy most installations.*

☎ **For assistance with designing and applying expansion tanks, contact your local Cummins Marine Certified Application Engineer.**

Coolant Recovery Bottle

A coolant recovery bottle or overflow bottle should be used to supplement the normal coolant expansion space on engines with an integrated heat exchanger. A coolant recovery system is defined as an external volume of coolant, connected to the main system by a single connection, through which coolant, air, and vapor are free to expand as temperature rises, and through which only coolant returns.

Note: *The cooling system must be filled by pouring coolant through the fill/pressure cap on the engine mounted expansion tank. Do not assume, because there is coolant in the reservoir bottle, that the engine cooling system is full. Coolant can be added to the reservoir when the system is cold to maintain at least a 50 mm (2 in) level.*

The ideal position for the reservoir is above the expansion tank. Mounting the reservoir below the expansion tank, but above the crankshaft centerline, is acceptable. The reservoir should be mounted within 10 ft [3.5 m] of the expansion tank. The hose connecting the expansion tank to the reservoir must be leak free and not have kinks or sharp bends to ensure proper operation of the coolant recovery system.

Properly sized expansion tanks may not require a coolant recovery system, but they can be used to provide a simple visual check of the coolant level on vessels that have limited access around the engine.

Vent Lines

! **Customer supplied vent lines must be routed to the top air gap section of the expansion tank.**

! **Customer supplied vent lines must be routed continuously upward and must not be teed together.**

Engine vents provide a continuous flow of water from the engine to the expansion tank as a method of removing air and gases from the engine coolant. The highest points in the engine coolant circuit are the best vent locations. All Cummins engines have venting provisions at the thermostat housing. Other vent locations depending on engine family and configuration are shown in the Installation Drawings. These may include turbocharger, exhaust manifold, and aftercooler. Additional vents are also required at the top of the keel cooler, if so used, to allow air to escape during initial coolant fill.

All customer supplied vent lines must be routed to the top air gap section of the expansion tank. Cummins Inc. recommends that vent lines enter the expansion tank parallel to the water level or flow over a vent baffle to minimize aeration within the tank.

All customer supplied vent lines must be routed continuously upward. Any loops or sags in the vent line may prevent the cooling system from properly venting. Vent lines must not be teed together. Since vent lines run from points of different pressure, teeing the vent lines together may result in reduced flow and inadequate venting of the system (see Figure 8-8). The exception is vent lines that are routed to a properly designed manifold. The manifold must be sized to have a flow area greater than the sum of all the individual supply or return lines attached to it (see Figure 8-9).

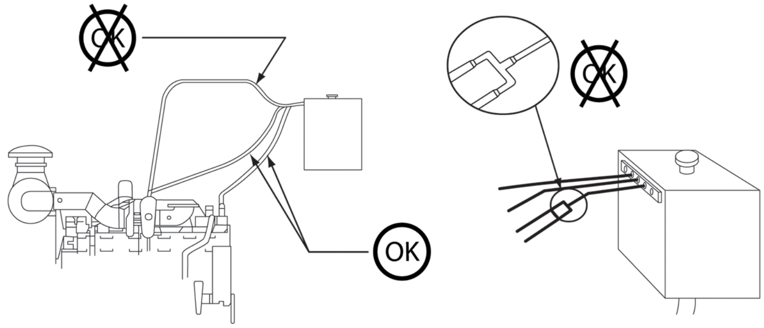


Figure 8-8

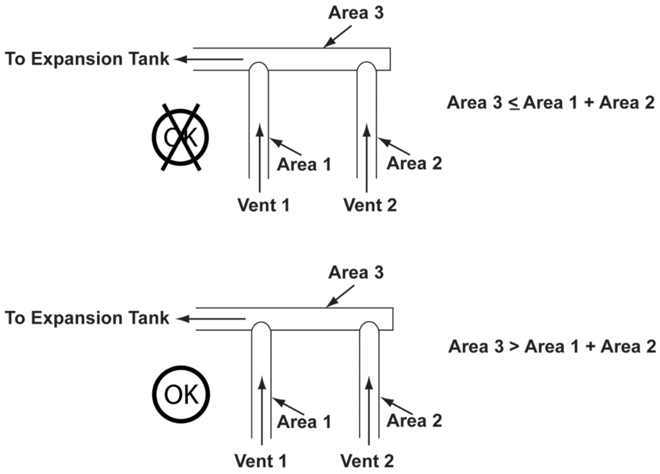


Figure 8-9

The system must vent during initial fill to allow filling of the total cooling system volume to 95 percent of its full capacity.

The cooling system must remove entrained air at engine start-up, and must continuously remove air that enters the cooling system during normal operation.

CAUTION: Improper filling of the cooling system can create air pockets that may cause localized overheating and damage.

The system must be equipped with adequate venting to allow the cooling system to fill 95 percent of its volume during the initial fill. The system should be filled slowly at a rate of less than 19 lpm (5 gpm). Filling too quickly may overwhelm the ability of the vents to deaerate the system and air pockets could form. Air pockets left in the system may cause localized overheating and damage. The system must also remove entrained air at engine start-up and must continuously remove air that enters the cooling system during normal operation.

The system should never be filled with antifreeze and then topped off with water. Antifreeze at full concentration may prevent proper filling of the system due to the higher viscosity restricting the venting system. The desired antifreeze concentration should be mixed with high quality water before being added to the system.

All petcocks must be open during the fill process, especially those on the keel cooler and keel cooler plumbing, if so equipped.

For engine fill and startup procedures, consult the Owner's Operation and Maintenance Manual.

Cooling System Accessories

All cooling system accessories must have a minimum pressure rating of 414 kPa (60 psi).

The cooling system becomes dependent upon the integrity of the added accessory when a cabin heater, water heater, auxiliary coolers, or any other cooling system accessory is added to the cooling system,. Failure of an accessory can lead to progressive or catastrophic damage due to coolant loss. Cummins Inc. is not responsible for any engine damage caused by the failure of these accessories. All cooling system accessories must have a minimum pressure rating of 414 kPa (60 psi).

All cooling system accessories must be located below the coolant level in the expansion tank.

All cooling system accessories must be installed so that they are located below the coolant level in the expansion tank. Cooling system accessories that have multi-pass flows or large internal volumes that may trap air, such as cabin and water heaters, should be equipped with a properly routed vent line to the expansion tank (see Figure 8-10).

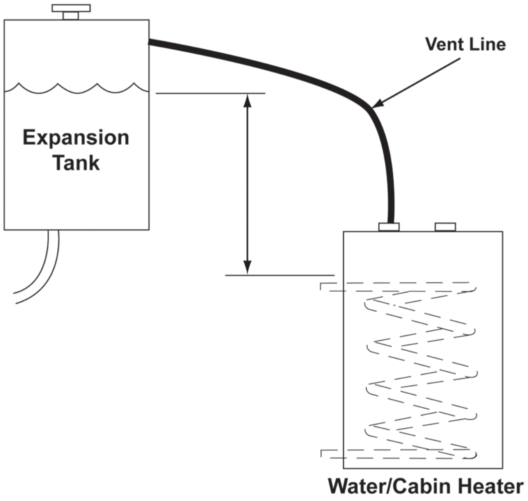


Figure 8-10: Cooling System Accessory Arrangement

Note: *To prevent overcooling and to make sure of sufficient water flow to the engine when using a water/cabin heater, the water circulated to the water/cabin heater should be less than 5 percent of the engine coolant flow. This is accomplished with the proper sizing of the lines and the use of restriction fittings. For information where to connect the supply and return lines for water/cabin heaters to the engine, refer to the Installation Drawing.*

Heat Exchanger Cooled

The sea water pump inlet restriction at rated engine speed must not exceed the limit specified in MAB 0.08.17-07/16/2001.

The sea water pump discharge pressure at rated engine speed must not exceed the limit specified in MAB 0.08.17-07/16/2001.

For proper sea water pump durability and cooling system performance, the inlet restriction and discharge pressure must not exceed the limits specified in MAB 0.08.17-07/16/2001. There are many factors that can affect the sea water pump inlet restrictions and discharge pressure. Consideration must be given to each of these and their individual and combined effects. These include, but are not limited to the following:

Inlet Restriction:

- Through hull inlet scoop type or location
- Seacock and/or strainer restriction
- Hose size, routing and/or connections

Discharge Pressure:

- Internal restriction through the engine’s integral sea water cooling circuit, including the piping, fuel cooler, aftercooler, gear oil cooler, heat exchanger, and exhaust elbow.
- Customer supplied coolers, exhaust elbows, and discharge circuit plumbing and connections.
- Exhaust back pressure

The plumbing from the sea water pickup to the sea water pump inlet should be as short and as free of sharp bends as possible. Wide, sweeping bends will minimize restriction. Excessively sharp bends increase restriction and can kink (see Figure 8-11). Hard wall, wire reinforced hose rated for suction applications or suitable pipe should be used. Hoses that are not rated for suction applications can collapse and severely restrict flow.

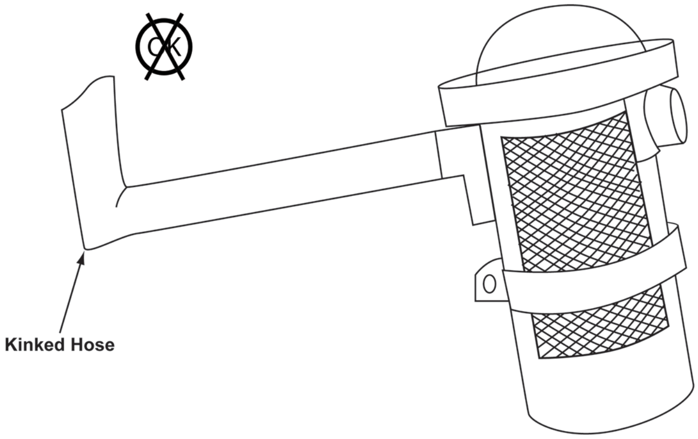


Figure 8-11

The hoses, through hull connection, and sea cock internal diameter should be at least the same diameter as the sea water pump inlet connection. Using the next larger standard internal diameter size is often necessary to stay within inlet restriction limits.

Each engine should have a dedicated sea water pickup. Sea chests are acceptable, if engines do not share sea water inlet plumbing. Doing so prevents overheating of more than one engine if the sea water inlet plumbing becomes restricted.

Verification of sea water pump inlet restriction and discharge pressure must be made during the sea trial of the completed installation to make sure they are within specified limits.

Customer supplied sea water cooling systems must not allow the heat exchanger sea water outlet temperature to exceed 54° C (130° F).

In instances where the customer will be supplying the sea water cooling system or any part thereof, the heat exchanger sea water outlet temperature must not exceed 54° C (130° F). Excessive heat exchanger sea water outlet temperatures can cause scaling and plugging within the heat exchanger and any downstream plumbing and components; particularly the exhaust connection water injection passages.

Fittings and components used in sea water systems must be made of corrosion resistant materials.

The sea water system supplied with the engine is designed with materials that resist corrosion. Customer supplied fittings and components must also be made of corrosion resistant materials suited for the marine environment.

When dissimilar metals are in contact in the presence of sea water or any other untreated water source, galvanic corrosion can result. Galvanic corrosion is an electrochemical process in which one metal corrodes preferentially when it is in contact with a different metal. Basically a battery is created that facilitates the transfer of ions from one metal to another. The metal that loses ions and corrodes is referred to as the anode. The metal that gains ions and remains stable is referred to as the cathode. Which material corrodes and at what rate depends largely on the relative potential difference as shown in the galvanic series (see Figure 8-12). Metals that are more likely to be anodes are referred to as “Less Noble” and are located toward the top of the table. Conversely, metals that are more likely to be cathodes are “More Noble” and are located toward the bottom of the table. As long as one metal is paired with another that is less noble, it will tend to resist corrosion. This is the basis for using sacrificial anodes or “zincs” to control corrosion. Zinc and aluminum alloys commonly used for sacrificial anodes are some of the least noble materials and therefore provide the most protection against corrosion. Sacrificial anodes must be inspected and/or changed frequently to provide good corrosion protection.

In order for the sacrificial anodes to protect the metal parts of the sea water system, all of the metal parts must be touching or connected by bonding wires. Any metal part not physically connected to the sacrificial anodes may be subject to galvanic corrosion. Additionally, threaded engine zincs should not be installed with Teflon® tape or other wrap type pipe sealants, since they prevent metal to metal contact and isolate the zinc from the system.

	Material
Less Noble - Anode End	MAGNESIUM
	MAGNESIUM ALLOYS
	ZINC
	ALUMINUM 5052, 3004, 3003, 1100, 6053
	CADMIUM
	ALUMINUM 2117, 2017, 2024
	MILD STEEL (1018), WROUGHT IRON
	CAST IRON, LOW ALLOY HIGH STRENGTH STEEL
	STAINLESS STEEL, 430 SERIES (ACTIVE)
	302, 303, 321, 347, 410, 416, STAINLESS STEEL (ACTIVE)
	316, 317, STAINLESS STEEL (ACTIVE)
	ALUMINUM BRONZE (CA687)
	INCONEL 625 (ACTIVE), TITANIUM (ACTIVE)
	LEAD
	TIN
	INCONEL 600 (ACTIVE)
	NICKEL (ACTIVE)
	60 NI-15 CR (ACTIVE)
	80 NI-20 CR (ACTIVE)
More Noble - Cathode End	BRASSES
	COPPER (CA102)
	MANGANESE BRONZE (CA675), TIN BRONZE (CA903, 905)
	SILICON BRONZE
	NICKEL SILVER
	COPPER - NICKEL ALLOY 90-10
	COPPER - NICKEL ALLOY 80-20
	430 STAINLESS STEEL
	NICKEL, ALUMINUM, BRONZE (CA630, 632)
	MONEL 400, K500
	NICKEL (PASSIVE)
	60 NI-15 CR (PASSIVE)
	INCONEL 600 (PASSIVE)
	80 NI-20 CR (PASSIVE)
	302, 303, 304, 321, 347, STAINLESS STEEL (PASSIVE)
	316, 317, STAINLESS STEEL (PASSIVE)
	SILVER
	TITANIUM (PASSIVE), INCONEL 625 (PASSIVE)
	GRAPHITE
	GOLD

Figure 8-12: Galvanic Series

When selecting materials for use in sea water cooling systems, galvanic corrosion can be minimized by using materials that are toward the noble end of the table and closely grouped. Cummins Inc. recommends components and fittings made from bronze, cupronickel, Monel, and passive 300 series stainless steel. Do not use commercially available iron or steel fittings in sea water systems.

The location of the sea water pickup must be below the waterline at all operating conditions.

Proper placement of the sea water pickup is important to make sure there is a continuous and non-aerated water flow to the sea water pump. The location of the sea water pickup must be below the waterline at all operating conditions. It should be in a location of smooth, undisturbed water flow. Installation close to lifting strakes or behind other hull fittings should be avoided, since they can cause disturbances and aeration that negatively affects flow (see Figure 8-13).

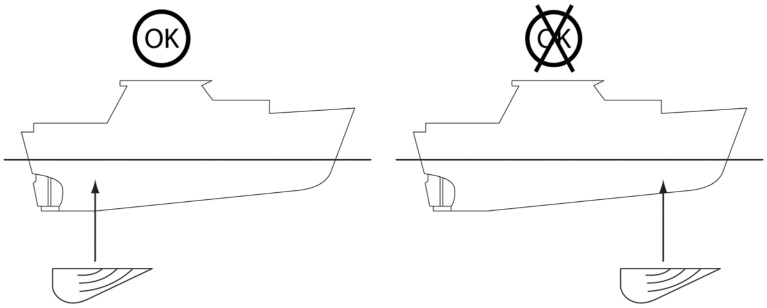


Figure 8-13

The orientation of the sea water pickup should be such that the openings in the pickup are facing the bow of the vessel (see Figure 8-14). The forward motion of the vessel will assist in forcing sea water into the pickup and increase flow at higher speeds. Incorrect installation can cause significant reduction in flow and unacceptable restriction.

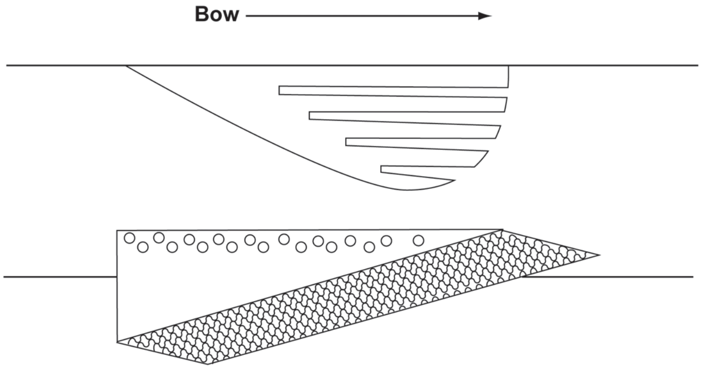


Figure 8-14

A seacock valve must be installed before the sea water pump and strainer.

A full flow sea water strainer must be installed upstream of the sea water pump and the maximum strainer hole size must not exceed 2.0 mm (0.079 in).

A seacock valve must be installed before the sea water pump and strainer (see Figure 8-15). Installing the seacock directly to the sea water pickup connection is preferred. To minimize restriction, a seacock with an internal flow area equal to at least that of the sea water pump inlet is recommended. Seacocks stop the flow of water for servicing of the sea water system components, without having to remove the vessel from the water. Seacocks are also safety related as they can prevent the ingress of sea water in the event of a malfunction of any of the sea water cooling system components.

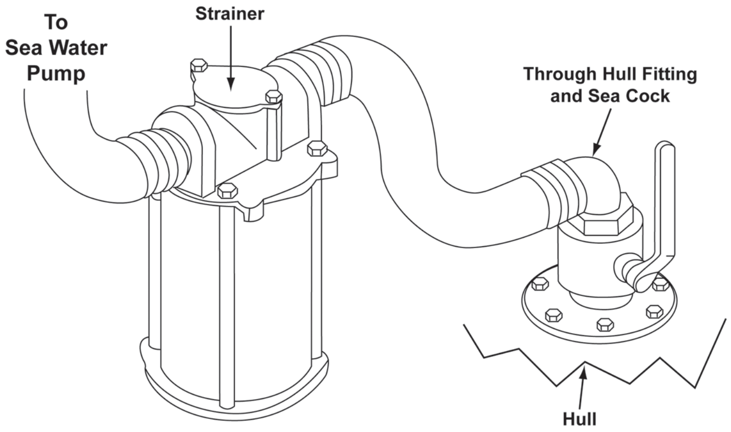


Figure 8-15

Sea water strainers are critical for preventing debris from entering the sea water system (see Figure 8-16). Debris can damage the sea water pump impeller and clog cooling system passages. A full flow sea water strainer must be installed before the sea water pump. The maximum strainer hole size must not exceed 2.0 mm (0.079 in). To minimize restriction, the strainer inlet and outlet connection internal diameter should be at least the same as the sea water pump inlet.

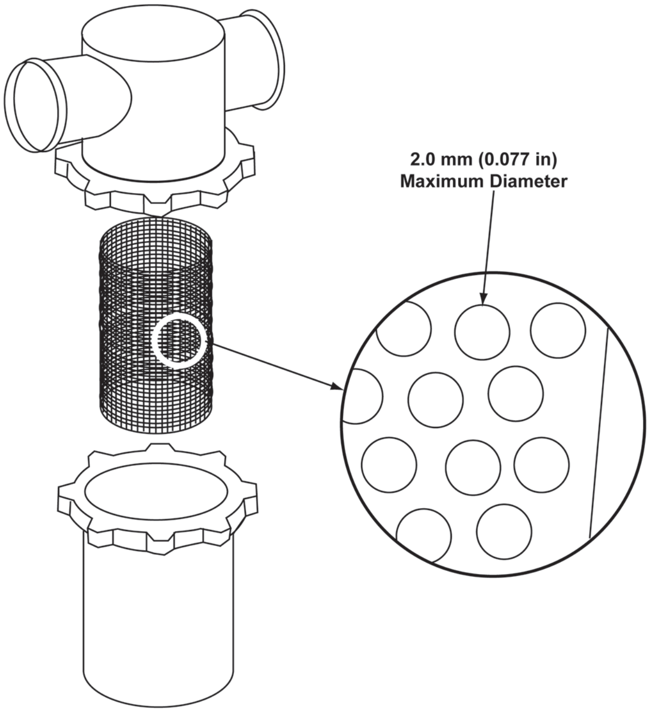


Figure 8-16

Note: *Both the seacock and strainer should be accessible for service and safety considerations.*

Sea water pumps with rubber impellers are subject to damage when operated dry. Dry operation causes accelerated wear on the impeller and mechanical seal, causing leaks, reduced flow rate, and reduced pressure. Cummins Inc. recommends that the sea water pump inlet piping is installed such that sea water is retained inside the pump when the engine is not running. This is especially important if the sea water pump is located above the waterline or if the vessel will be stored out of the water.

Retention of water inside the sea water pump can be accomplished by either adding a small rise in the inlet plumbing before the sea water pump or installing the strainer outlet connection above the sea water pump inlet (see Figure 8-17). It is important to remember that only a small distance above the sea water pump inlet is needed. The pump requires only a small amount of water to lubricate it while prime is achieved. Excess height above the sea water inlet will only serve to increase unwanted inlet restriction.

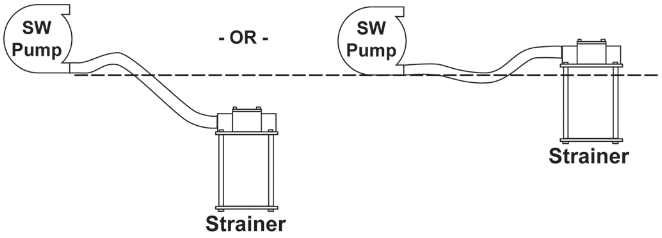


Figure 8-17: Sea Water Pump Inlet Plumbing

Keeled Cooled

Keel coolers may be manufactured units purchased complete or fabricated on-site.

Commercially manufactured keel coolers or grid coolers are generally much more compact and efficient than fabricated units. They are made of corrosion resistant materials and have a grid of specially designed and positioned tubes to increase heat rejection (see Figure 8-18). They should not be painted as it reduces the efficiency. Protective guards should be installed to prevent damage to the tube grid.

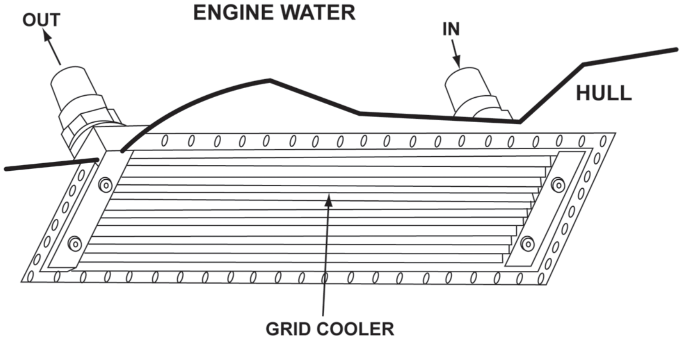


Figure 8-18

Fabricated keel coolers are manufactured by the vessel builder as part of the hull construction. Structural steel or aluminum shapes are usually used with 4.8 mm (0.187 in) to 12.7 mm (0.500 in) wall thicknesses (see Figure 8-19). They tend to be less efficient and therefore larger than a commercially manufactured unit. They are generally painted or coated in the same manner as the hull.

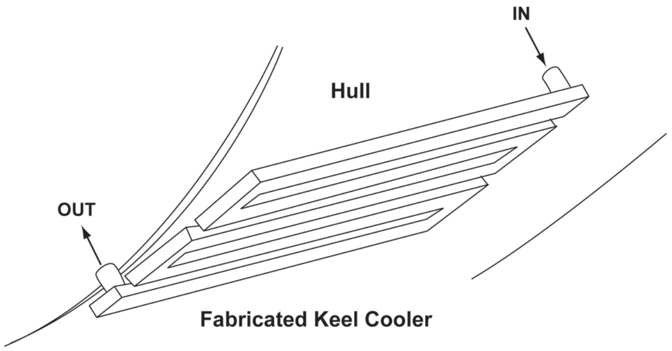


Figure 8-19

Another type of keel cooler is a box cooler. This type uses a box or sea chest that sits inside the hull with openings that allow sea water to flow through it. A tube bundle sits inside the box with engine coolant circulated through it (see Figure 8-20). These units are useful since they can be serviced without pulling the vessel from the water and the cooler is protected from any impact with foreign objects or due to grounding.

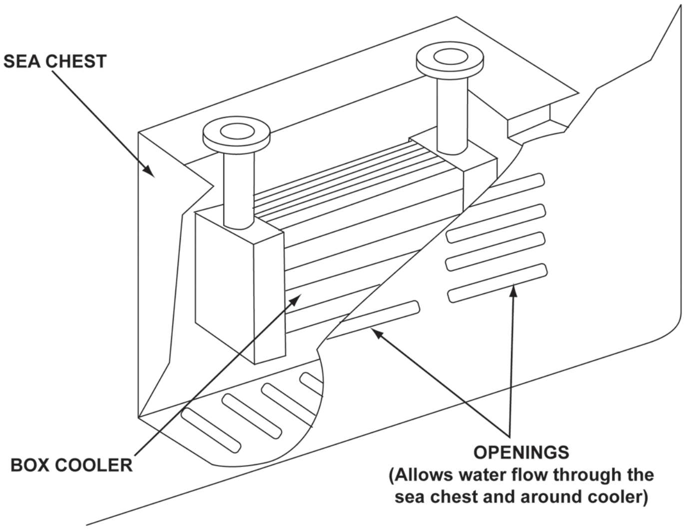


Figure 8-20

! **Keel coolers must be submerged in sea water in all operating conditions.**

Good keel cooler performance requires a constant water flow over the cooler. The keel cooler should be installed far enough below the waterline to avoid aerated water close to the surface. Locations that are in the water flow and flush on the hull are preferred over side locations and recessed installations. Recessed and/or shielded installations must allow for unobstructed sea water flow in and out of the cooler. Slow moving vessels should have the keel cooler installed behind the propeller, to benefit from the increased flow from the propeller wash. Dredges and other vessels with little movement through the water should have the keel cooler installed on an incline or vertically, to promote water circulation by convection.

Keel coolers should not be located in areas that are exposed to pounding seas, hull flexing, or excessive vibration. The bow of the vessel is subjected to tremendous water forces and is generally a poor location for a keel cooler. The area of the vessel bottom adjacent to the keel is the strongest and is the best keel cooler location.

Manufactured keel cooler specified heat rejection capacity (including loss due to fouling) at maximum coolant flow must meet or exceed the value specified in the Engine Performance Data Sheet.

If using a commercially available manufactured keel cooler, the specified heat rejection capacity of the cooler, including losses due to fouling at maximum coolant flow, must meet or exceed the heat rejection value specified in the Engine Performance Data Sheet. The manufacturer of the cooler will need to be consulted to determine the size and configuration needed to meet the specified heat rejection requirements. In addition to the engine heat rejection requirements, the keel cooler manufacturer will also need the following information

Coolant Flow	Engine Performance Data Sheet
Coolant Temperature Out of Engine	Engine Performance Data Sheet
Coolant Inlet and Outlet Size	Installation Drawing
Maximum System Pressure Drop	35 kPa (5 psi)
Minimum Vessel Speed at Full Throttle	Consult the Designer/Builder of Vessel
Maximum Ambient Sea Water Temperature	Local Information

-

Fabricated keel cooler heat rejection capacity (including 50 percent loss due to fouling/painting) at maximum coolant flow must meet or exceed the value specified in the Engine Performance Data Sheet.

If using a fabricated keel cooler, the heat rejection capacity of the cooler must meet or exceed 150 percent of the heat rejection value in the Engine Performance Data sheet. The additional 50 percent capacity is to account for the painting and fouling of the cooler. The size and configuration of a fabricated keel cooler to achieve proper heat rejection and have acceptable pressure drop should be determined by a qualified person(s).

The engine coolant pressure drop across any external coolers, measured from the engine coolant outlet to the engine coolant inlet connections, must not exceed 34.5 kPa (5 psi).

The total engine coolant pressure drop across any external coolers, including the keel cooler, measured from the engine coolant inlet and outlet connections must not exceed 34.5 kPa (5 psi). Pressure drops greater than 34.5 kPa (5 psi) may result in insufficient coolant flow through the engine and possible overheating. Any external cooling system component should be sized to keep the pressure drop to a minimum. Refer to the Installation Drawing for the pressure test port locations.

On some systems, it may be necessary to bypass some of the coolant flow around an external cooler (gear oil, fuel, etc.) to stay within the 34.5 kPa (5 psi) restriction limit. This may be done with a bypass line with a valve to control flow. The valve is opened gradually until the pressure drop is within limits. The valve handle is then removed or locked to prevent the valve position from being changed. An orifice may also be installed in place of a valve to obtain the proper amount of bypass flow.

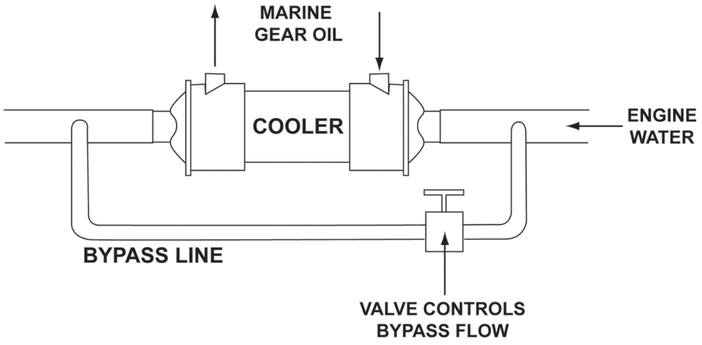


Figure 8-21

Note: *When adjusting flow, care must be taken to make sure the temperature of the component cooled by the auxiliary cooler is maintained within the manufacturer's limits.*

Cummins Inc. has developed a tool to calculate the coolant pressure drop across a single external cooler system. It covers a range of nominal pipe sizes based on engine coolant inlet and outlet connections, diameters, and coolant flows for the whole range of Cummins engines, from 4B to QSK60. It assumes constant pipe sizes from the engine to and from the external cooler connections. Although designed primarily for keel cooler systems, this tool may also be used for pressure drop calculations in other piping systems meeting the constraints of the tool. The tool can be accessed through the Tools section of http://marine.cummins.com. Due to the multitude of available designs for external coolers, the value for the pressure drop across the cooler must be obtained from the manufacturer, or in the case of a fabricated cooler, the naval architect designing the system. The system pressure drop values obtained from the tool are estimates only. Actual values must be verified by sea trial tests.

! **The coolant inlet temperature from the Low Temperature Aftercooler (LTA) must be less than the value specified in the Engine Performance Data Sheet.**

The coolant inlet temperature entering the water pump from the Low Temperature Aftercooler (LTA) must be less than the value specified on the Engine Performance Data Sheet. This requirement ensures that the Low Temperature Aftercooler (LTA) is properly cooling the intake air, to provide optimum engine output and durability.

! **For Low Temperature Aftercooled (LTA) engines, auxiliary coolers are to be installed only in the LTA supply line from the keel cooler.**

Auxiliary coolers including marine gear coolers must be installed only in the LTA supply line from the keel cooler. Coolant flow to the LTA is always present to make sure of heat rejection from the cooler. Coolant flow in the main engine cooling circuit is variable, depending on engine temperature. At times when the engine thermostat is closed or partially opened, the cooler will not receive proper flow. Insufficient heat rejection will occur and damage may result. Installing auxiliary coolers before the keel cooler is not approved (see Figure 8-22).

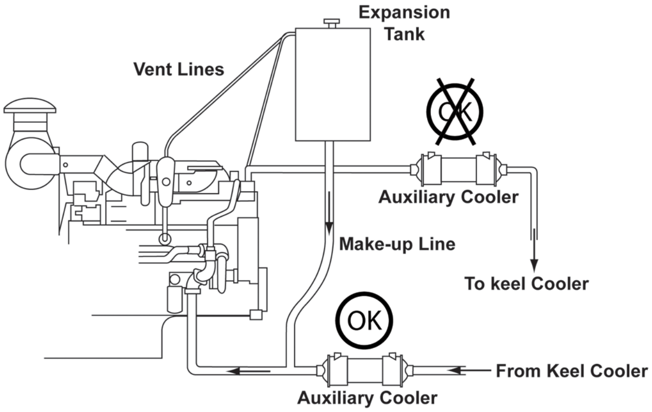


Figure 8-22: Auxiliary Cooler Location

Shaft Seal Water Supply

Dripless shaft seals have become commonplace in the marine market. They use a mechanical seal with a carbon seal ring and a stainless steel mating surface. The proper operation of a mechanical seal relies upon a thin film of water to cool and lubricate the sealing surface. Insufficient water supply to the seal quickly leads to wear and failure of the seal. The method for providing sufficient water depends on the hull design and vessel speed.

Slow Speed Displacement Hulls – Suction Venting

Slow speed (<12 knots) displacement vessels usually require a venting arrangement that vents trapped air from the seal face, allowing water to reach the seal though the shaft log or stern tube. Depending on the manufacturer, a provision for a vent fitting or line may or may not be incorporated into the seal assembly.

Shafts seals without a provision for a vent fitting or line will provide instructions for manually venting the shaft seals by momentarily compressing the seal bellows manually to allow any trapped air to escape.

For those with a vent fitting or line supplied, it should be connected per the manufacturer’s instructions. For engines with heat exchanger cooling, the vent may be connected to the suction side of the sea water pump.

High Speed Planing Hulls – Positive Pressure Flow

High speed (>12 knots) semi-displacement or planing hulls require an injection line to supply water to the seal due to water being drawn out of the shaft log or stern tube at planing speeds. Connection to the engine sea water cooling system after the sea water pump is the most convenient means to provide a positive pressure (typically a 15 psi/103 kpa maximum) to the shaft seal. Cummins recommends using the service port as shown on the Installation Drawing. Typically this will be the sea water pump discharge pressure test port. If necessary, a tee fitting should be used to maintain the service port to measure pressure.

For keel cooled systems, since these are closed systems, the shaft seal water injection line must not be connected into the engine coolant circuit. If dripless shaft seals are installed, in conjunction with keel cooled engine installations, the installer must provide a separate sea water source for the injection/vent line, as recommended by the vessel designer and shaft seal manufacturer.

Air vent or water injection fittings that may be included as part of the dripless shaft seal from the manufacturer must be used with the shaft seal (not the engine). They are unique and compatible only with the specific shaft seal design of the manufacturer. Appropriate fittings to connect the water injection line must be sourced separately. Due to the inherently small size of the fitting, Cummins recommends using marine grade (type 316) stainless steel fittings for their strength and resistance to corrosion.

The above does not pertain to the installation of the dripless shaft seals themselves. Refer to the installation instructions provided by the manufacturer of the shaft seal.

Note: *If using water lift mufflers in a twin engine application, the shaft seal water supplies should not be teed together. If an engine becomes disabled, not teeing the supply lines together will prevent water back-feeding into the disabled engine's exhaust system and causing water intrusion damage.*

Fuel Coolers/Marine Gear Oil Coolers/Accessory Coolers

Cummins Inc. optionally supplies fuel and gear oil coolers that have been integrated into the cooling system and validated for proper operation on many engine models. Location and fitting size and type of the coolers can be found on the Installation Drawing. If a customer chooses to supply the fuel and gear coolers and integrate them into the engine cooling system, they must meet the applicable cooling system requirements:

- Sea water pump inlet restriction, if installed before the sea water pump (Heat Exchanger Cooled).
- Sea water pump discharge pressure, if installed after the sea water pump (Heat Exchanger Cooled).
- Pressure drop for auxiliary coolers (Keel Cooled)

In addition, coolers must meet the following to ensure performance and durability of the system:

- Required heat rejection including losses due to fouling.
- Maximum Allowable Working Pressure (MAWP) of the cooler meets or exceeds the operating pressure of the fluids.
- Cooler is compatible for use with sea water (Heat Exchanger Cooled)

Expansion Tank - Design Example

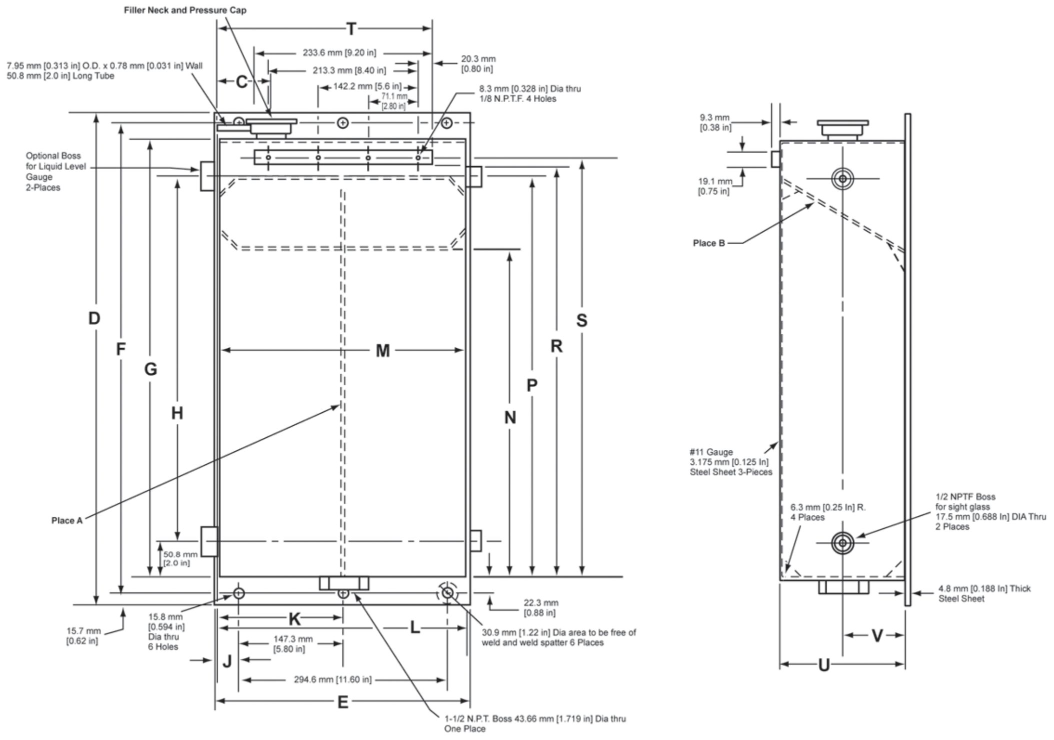


Figure 8-23

Dimension	Reservior Capacity		
	38 Liter [10 Gallon]	78 Liter [20 Gallon]	114 Liter [30 Gallon]
C	76 mm [3 in]	102 mm [4 in]	102 mm [4 in]
D	686 mm [27 in]	838 mm [33 in]	965 mm [38 in]
E	362 mm [14.25 in]	514 mm [20.25 in]	572 mm [22.25 in]
F	654 mm [25.75 in]	806 mm [31.75 in]	933 mm [36.75 in]
G	610 mm [24 in]	762 mm [30 in]	889 mm [35 in]
H	508 mm [20 in]	660 mm [26 in]	787 mm [31 in]
J	34 mm [1.33 in]	110 mm [4.33 in]	135 mm [5.33 in]
K	178 mm [7 in]	254 mm [10 in]	279 mm [11 in]
L	356 mm [14 in]	508 mm [20 in]	559 mm [22 in]
M	350 mm [13.76 in]	502 mm [19.76 in]	553 mm [21.76 in]
N	457 mm [18 in]	559 mm [22 in]	686 mm [27 in]
P	559 mm [22 in]	711 mm [28 in]	838 mm [33 in]
R	575 mm [22.62 in]	727 mm [28.62 in]	854 mm [33.62 in]
S	584 mm [23 in]	737 mm [29 in]	864 mm [34 in]
T	305 mm [12 in]	381 mm [15 in]	406 mm [16 in]
U	178 mm [7 in]	203 mm [8 in]	229 mm [9 in]
V	89 mm [3.5 in]	102 mm [4 in]	114 mm [4.5 in]
W	499 mm [19.64 in]	651 mm [25.64 in]	778 mm [30.64 in]
X	124 mm [4.88 in]	149 mm [5.88 in]	175 mm [6.88 in]
Y	401 mm [15.78 in]	553 mm [21.78 in]	680 mm [26.78 in]
Z	350 mm [13.76 in]	502 mm [19.76 in]	553 mm [21.76 in]

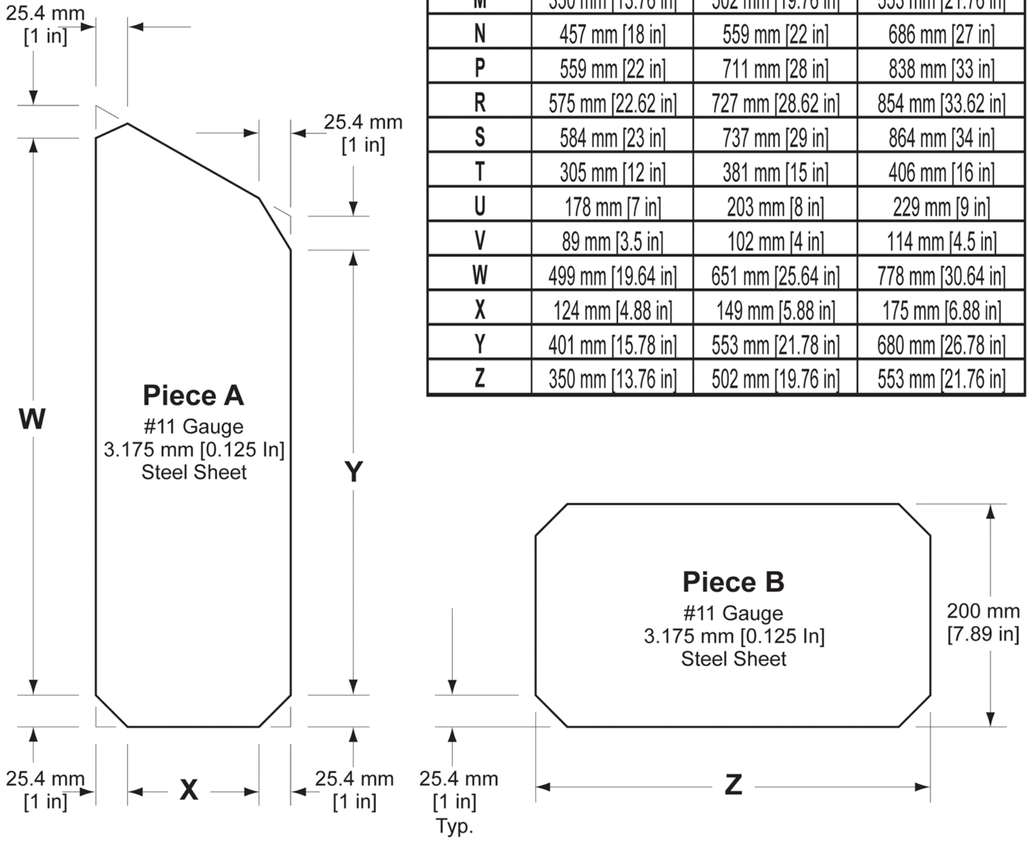


Figure 8-24

Air Intake System

Summary of Requirements

All Applications

- **The inlet air temperature is not more than 17° C (30° F) above the outside ambient temperature at rated speed and load.**
- **Forced ventilation systems, if needed, must operate continuously any time the engine(s) are running.**
- **The air inlet, in combination with the vents, must be located or shielded to prevent direct ingestion of water, snow, ice, debris, dust, exhaust gases, blowby gases, and any combustible vapors.**

Air Cleaners – Remote Mounted

- **The air intake system restriction must not exceed the value specified in the Engine General Data Sheet.**
- **All ducts, components, and connections must be free from leaks.**
- **All ducts, components, and connections must be capable of operating continuously in a maximum ambient temperature of 92° C (200° F).**
- **All ducts, components, and connections must withstand a negative pressure (vacuum) of -8kPa (-32 in H_2O) without collapsing.**
- **All remote mounted air cleaner plumbing must be routed away from high heat sources.**
- **All plumbing must be free from chafing points.**
- **Remote mounted air cleaner plumbing must allow for relative motion between the engine and the vessel plumbing.**
- **Hoses that connect directly to the turbocharger compressor inlet must be rated for a continuous temperature of 177° C (350° F).**
- **Remote mounted air cleaner plumbing must allow for thermal expansion.**

Air Cleaners – Customer Supplied

- **The air cleaner must have an initial efficiency of 99.5%, an overall efficiency of 99.9%, and a dirt holding capacity of 6.4 g/l/s (3.9 g/cfm) per SAE J726b test specifications.**
- **The air cleaner media must be reinforced to prevent media from being ingested by the engine.**
- **Oil bath air cleaners are not approved for use on turbocharged engines.**

Crankcase Ventilation

- **For open crankcase ventilation, the crankcase gases must be vented to atmosphere (not to the air intake system).**
- **Only factory installed closed crankcase ventilation systems can be used. Aftermarket closed crankcase systems are not approved.**

General Information

The purpose of the air intake system is to:

- Provide sufficient combustion air to the engine.
- Provide combustion air that is not overly heated.
- To remove water, dirt, debris, salt, or any other foreign object(s) from the combustion and ventilation air.
- Ventilate the engine compartment of radiated heat and fumes for the engine and other installed machinery.

Vessel vent type, location, and sizing, as well as remote air cleaner plumbing (if used) are critical to achieve the above. If the air intake system fails in its purpose, increased maintenance cost, loss of performance/efficiency, and operating difficulties can result.

Service Accessibility

The following is a list of Air Intake System service points that should be accessible:

- Air cleaner
- Restriction indicator / test port
- Any installed drains

Installation Directions

All Applications

The methods for supplying ventilation to the engine compartment are varied. For engines that are supplied with intake air from within the engine compartment, the ventilation must provide combustion air for the engine as well as carry away heat and fumes generated by the engine and any other auxiliary equipment. For engines that are supplied with intake air from outside the engine compartment via a remote air cleaner, only ventilation to carry away heat and fumes is necessary. The maximum engine compartment temperature should not exceed 66° C (150° F); temperatures exceeding this may cause deterioration of the hoses and/or wiring of the engine.

Adequate ventilation, depending on vessel configuration, can be achieved from natural (unforced) circulation, forced circulation (fans, blowers, etc), or a combination of natural and forced circulation. Determining the size and configuration of the system prior to the engine installation is recommended. MAB No. 0.23.00-03/28/2001 provides instructions on how to calculate the total air flow required for combustion air and ventilation, how to apply the flow requirements to a method of ventilation, and how to measure the system for compliance. Within the referenced MAB there are links and instructions for a computer run ventilation calculator in both English and SI units. The MAB and calculator can be accessed through http://marine.cummins.com or by contact with your local Cummins Marine Certified Application Engineer.

A restriction indicator may be installed to signal when maximum air inlet restriction has been exceeded and the air cleaner element requires servicing. Two types of indicators are commercially available. One is a trip/lock device with a window which indicates that either the air cleaner is satisfactory or requires service. The second type has a dial that provides a progressive indication of increasing air cleaner restriction to the point of maximum permissible restriction. Either type can be mounted directly at its sensing location or remotely, using appropriate tubing and connectors. The preferred connection point for restriction indicators is in a straight section of pipe approximately 305 mm (12 in) upstream of the engine inlet connection.

Note: *The set point of the indicator should match the maximum inlet restriction as specified in the Engine General Data Sheet.*
-AND-
The restriction indicator is a tool to determine if filter maintenance is required. It should not be used as a measuring device to determine if inlet restriction is within acceptable limits.

! **The inlet air temperature is not more than 17° C (30° F) above the outside ambient temperature at rated speed and load.**

High air inlet temperatures will reduce an engine’s performance and increase heat rejection to the engine coolant. Temperatures above 38°C (100°F) can reduce engine power output by as much as 1% for each 5.5°C (10°F) above 38°C (100°F). The heat rejection to the coolant increases up to 1.5% for each 5.5°C (10°F) above 38°C (100°F). Ultimately, excessive air inlet temperatures may lead to high thermal stresses, high exhaust temperatures, poor engine performance, decreased fuel economy, and shortened engine life.

To minimize the above effects, the air inlet connection, air piping, and engine room ventilation must be designed so that the air inlet temperature is not more than 17° C (30° F) above the outside ambient air temperature at rated speed and load. This is known as the #T. As illustrated in Figure 9-1, the ambient air temperature (T_1) is measured at the exterior of the vessel in an area of good air circulation. Inlet air (T_2) is measured directly at the air cleaner, with the temperature probe located on the side away from the engine to minimize the effect of radiated heat. Subtraction of T_1 from T_2 yields the #T value.

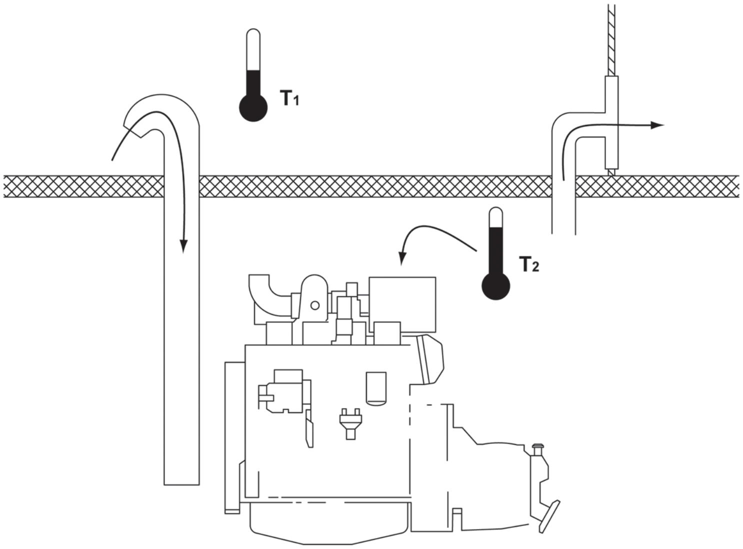


Figure 9-1: Ambient Air (T_1) and Air Inlet (T_2) Measurement Locations

EXCEPTIONS:

It is known that the heat rejection of the engine to the engine compartment increases as the ambient temperature decreases. In cooler environments, achieving the 17° C (30° F) requirement may be difficult. The following equation can be used to correct the allowable inlet air temperature above ambient, when the ambient temperature is less than 35° C (95° F).

Corrected $\Delta T°C$ = (35-Ambient Temperature) x 0.2 +17

Corrected $\Delta T°F$ = (95-Ambient Temperature) x 0.2 +30

Table 9-1 is provided as a quick reference for determining the allowable ΔT below 35° C (95° F):

Ambient Temperature °C (°F)	Max Allowable Delta T °C (°F)
-18 (0)	28 (49)
-15 (5)	27 (48)
-12 (10)	26(47)
-9 (15)	26 (46)
-7 (20)	25 (45)
-4 (25)	25 (44)
-1 (30)	24 (43)
2 (35)	24 (42)
4 (40)	23 (41)
7 (45)	23 (40)
10 (50)	22 (39)
13 (55)	21 (38)
16 (60)	21 (37)
18 (65)	20 (36)
21 (70)	20 (35)
24 (75)	19 (34)
27 (80)	19 (33)
32 (90)	18 (31)
35 (95)	17 (30)

Table 9-1

For vessels operating in polar climates, this requirement may not apply, due to the need to keep the air inlet temperature and/or engine space significantly warmer than the ambient condition for the purpose of maintaining the minimum engine operating temperature, protecting other vessel systems, and/or crew comfort. In these conditions, the task of elevating the air temperature with the compartment should be accomplished by managing waste heat and not by reducing ventilation and thereby restricting air flow to the engine. If the vessel is ever to be operated in warmer climates, this requirement must be able to be met.

If an exception is made, it must be noted on the installation review form with the reason for the exception.

! **Forced ventilation systems, if needed, must operate continuously any time the engine(s) are running.**

If forced ventilation systems are needed to maintain a temperature difference of less than 17° C (30° F), the forced ventilation systems must operate continuously any time the engine(s) are running.

! **The air inlet, in combination with the vents, must be located or shielded to prevent direct ingestion of water, snow, ice, debris, dust, exhaust gases, blowby gases, and any combustible vapors.**

The air inlet, in combination with the vents, must be located or shielded to prevent direct ingestion of water, snow, ice, debris, dust, exhaust gases, blowby gases, and combustible vapors.

In most marine applications the air cleaner is in the engine room where there is little debris and dust. Protection from water is usually the biggest factor when designing the system. The exception to this is when the installation is in a new boat. It is common to find dust and debris attributed from the build process in sufficient quantities to clog an air cleaner.

For applications with an engine mounted filter or remote mounted filter within the engine compartment, vents supplying air to the engine compartment should be positioned so that air does not flow directly onto the air inlet (see Figure 9-2). Cummins Inc. recommends ducting intake vents to the bottom of the engine compartment to 1. Promote natural air circulation carrying away heat and blow by gases, 2. Remove vapors and moisture from the bilge area, and 3. Help to keep any water vapor and salt entrained with the intake air off the engine and air inlet.

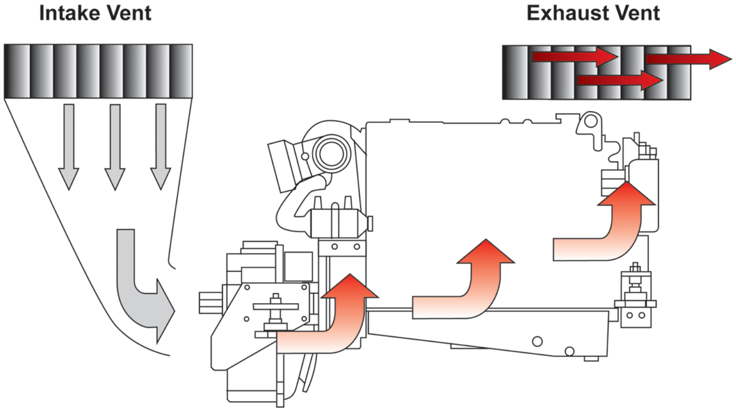


Figure 9-2

Intake vents that are located on the hull sides should be baffled to help prevent and remove any entrained water, such as sea spray (see Figure 9-3). Louvers over the vent can also help prevent the entrance of water. The opening of the louvers should be orientated away from the most prevalent direction of water from rain, washing, sea spray, etc.

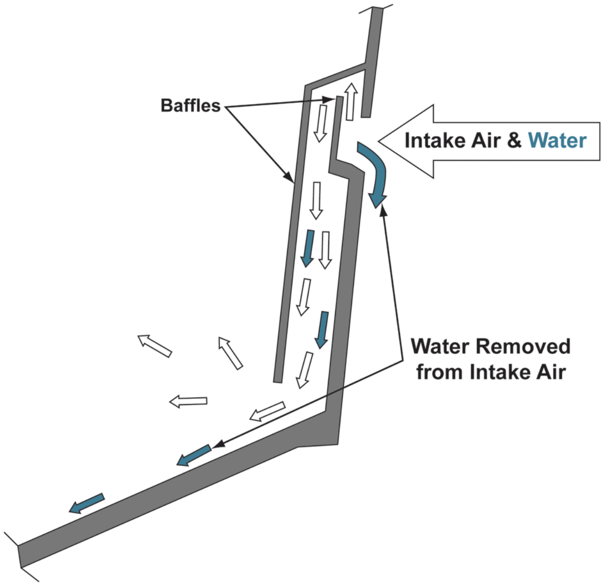


Figure 9-3

Deck hatch seams that are exposed to the weather or any other possible leak path must not be located directly above the engine air inlet unless they are properly sealed and/or drains are installed to prevent the entrance of water under all conditions including, but not limited to rain, sea spray, and/or washing (see Figure 9-4).

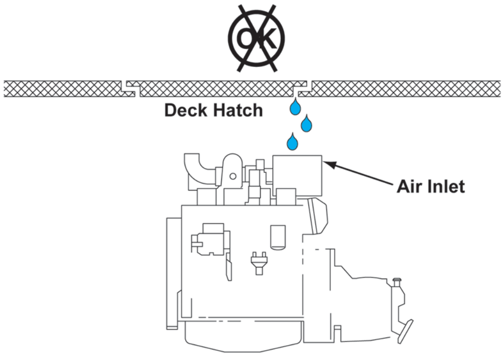


Figure 9-4

For engines with a remote mounted air cleaner outside the engine compartment, the remote air cleaner housing must be designed and located so that water, snow, dust and debris can not directly enter the filter element. Areas that are exposed directly to the weather and/or sea spray should be avoided. For vessels operating in freezing climates, the air cleaner must be protected from water freezing on the element or over the air cleaner inlet. A drain incorporated into the remote filter housing to remove the collection of any water or condensation is recommended.

The inlet to an air cleaner, especially remote mounted cleaners mounted outside the engine compartment, must not be located near fuel vents or any other source that may allow combustible vapors to be drawn into the air inlet (see Figure 9-5). Combustible vapors entering the engine may cause an overspeed/runaway condition.

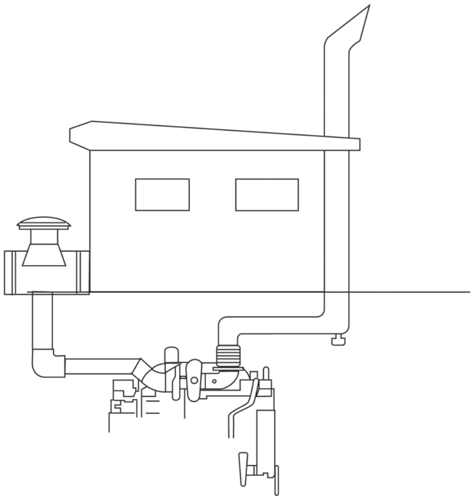


Figure 9-5

The location of the air inlet and exhaust outlet must be orientated so that exhaust gases are not drawn into the air inlet (see Figure 9-6). Also refer to the Exhaust System section for more detail.

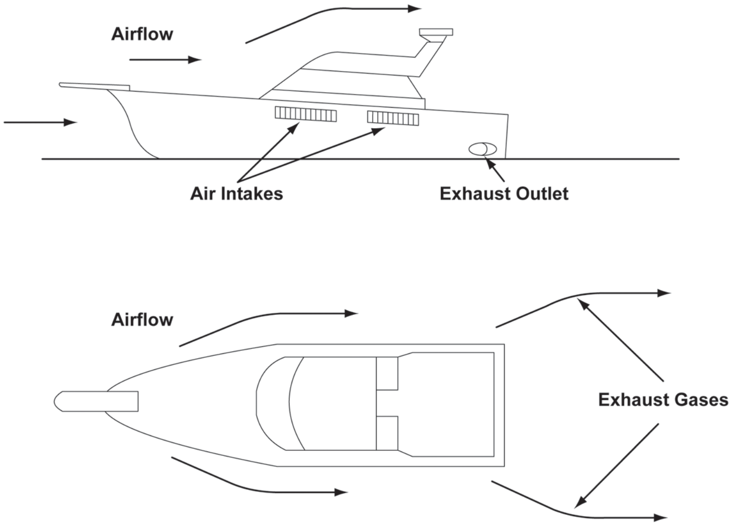


Figure 9-6

Remote Mount Air Cleaner

!

The air intake system restriction must not exceed the value specified in the Engine General Data Sheet.

Applications with remote mount air cleaners must have the air intake system restriction checked due to the additional plumbing. Excessive air inlet restriction will lead to decreased air flow to the engine for combustion. This has a negative impact on engine performance, fuel economy, and smoke. The total air intake system restriction must not exceed the value specified in the Engine General Data Sheet. The air inlet restriction must be measured at the air inlet to the engine (see Figure 9-7).

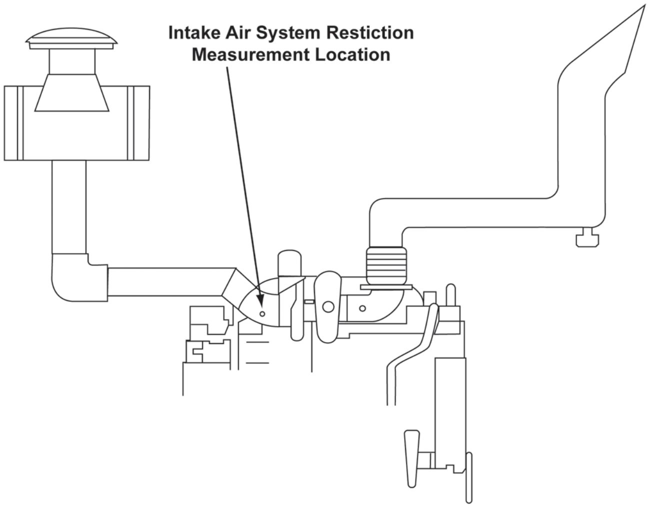


Figure 9-7

When designing a remote mounted air cleaner, the following equations should be used to determine if the restriction limits will not be exceeded. Air restriction graphs for smooth pipe, two elbows, and a reducer are also provided at the end of the Air Intake System section (see Figures 9-10, 9-11, 9-12, and 9-13).

1. Obtain the air cleaner restriction from the air cleaner manufacturer based on intake air flow at rated speed and load from the Engine Performance Curve and Data Sheet.

2. Calculate the air flow resistance through the combined length of straight pipe, assuming a smooth internal diameter:

Restriction (in H_2O) = Length of Pipe (ft) x 0.000502 x [Flow^2 (cfm) / Dia^5 (in)]
Conversions:
l/s = 0.472 x cfm
mm = in x 25.4
mm H_2O = in H_2O x 25.4

3. Calculate the air flow resistance for any 45 degree elbows:

Restriction (in H_2O) = 0.0003183 x [Flow^2 (cfm) / Dia^4 (in)]

4. Calculate the air flow resistance for any 90 degree elbows:

Restriction (in H_2O) = 0.0008367001 x [Flow^2 (cfm) / Dia^4 (in)]

5. Calculate the air flow resistance for any reducers:

Restriction (in H_2O) = Flow^2 x [10 x [[-2.90334+1.9909 x Log[Larger Dia (in)]] / Log10] x [5.30696 x Log[Smaller Dia (in)] / Log10]]]

6. Add up the restriction from each component to establish the total restriction.

! **All ducts, components, and connections must be free from leaks.**

! **All ducts, components, and connections must be capable of operating continuously in a maximum ambient temperature of 92° C (200° F).**

! **All ducts, components, and connections must withstand a negative pressure (vacuum) of -8kPa (-32 in H_2O) without collapsing.**

Generally, only applications using a true remote mount air filter will require the fabrication of a duct system to route air directly into the engine. However, some applications using an engine mounted air cleaner may require slight modifications for additional air cleaner clearance, for airflow and service considerations.

Many materials exist that are suitable for use in intake air systems. Reinforced plastic, fiberglass, and stainless steel are common materials for pipe used in long runs. Pipe or tubing must have sufficient rigidity to prevent crushing and/or collapsing the tube when tightening the clamps and mounting brackets. Flexible rubber connections for connecting inlet pipes are available from most air cleaner manufacturers. These connections include hump hoses, reducers, elbows, and a variety of special shapes and sizes. Metal materials are not recommended unless they are inherently corrosion resistant or specially coated to prevent corrosion. The moisture-laden air and salt common in the marine environment will cause unprotected metals such as steel and aluminum to corrode, producing abrasive oxides that can be ingested into the engine and cause accelerated wear.

All ducts, components, and connections must be free from leaks. Any breaks or leaks in the air system after the air cleaner may allow unfiltered air into the engine and cause accelerated wear. All connection points must have a smooth finish. Rough or uneven surfaces can cut or abrade hose connections. Hose clamps which provide a 360 degree seal should be used at connection points where pipe and hose meet. Either “T” bolt type or SAE F is recommended. Wire reinforced hose should be avoided as this type of hose does not clamp evenly, which can cause leaks.

All ducts, components, and connections must be capable of operating continuously in an ambient temperature of 92° C (200° F). Be sure to check the suitability of any reinforced plastics used. Rubber components (commonly referred to as EPDM) are suitable for temperatures up to 120° C (250° F).

All ducts, components, and connections must withstand a negative pressure (vacuum) of -8kPa (-32 in H_2O) without collapsing. Collapsing of ducts, components, and connections can drastically increase air restriction and cause significant power loss and excessive smoke.

! **All remote mounted air cleaner plumbing must be routed away from high heat sources.**

All plumbing associated with the remote mount air cleaner plumbing must be routed away from high heat sources such as exhaust piping, mufflers, boilers, auxiliary engines, air conditioning and refrigeration condensers, etc. Locating air intake plumbing near these components will increase the air temperature of the air entering the engine and may exceed the 17° C (30° F) temperature difference limit between the intake air and the ambient air.

! **All plumbing must be free from chafing points**

Proper installation techniques must be observed to make sure hoses and piping are securely fastened and routed to prevent chafing. Additionally, hoses and piping must not be routed near or on hot surfaces. If the routing can not avoid chafing points or hot surfaces, adequate chafe protection and/or insulating sleeves must be used.

Remote mounted air cleaner plumbing must allow for relative motion between the engine and the vessel plumbing.

Connections made between the engine and the remote mounted air cleaner plumbing must allow for relative motion between the two. A silicone or EPDM hump hose connection is recommended because it provides excellent isolation of vibration and free range of movement. Connections that are stiff can impose excessive loads upon the engine inlet connection.

The location of the flexible connection must be between the engine inlet connection and the first support for the remote air cleaner plumbing. Cummins Inc. recommends installing the flexible connection directly to the engine inlet connection. The first fixed support should be no more than 1.5 meters (5 feet) from the engine inlet connection (see Figure 9-8 and 9-9).

Applications with remote mount air cleaners must have the air intake system restriction checked due to the additional plumbing. Excessive air inlet restriction will lead to decreased air flow to the engine for combustion. This has a negative impact on engine performance, fuel economy, and smoke. The total air intake system restriction must not exceed the value specified in the Engine General Data Sheet. The air inlet restriction must be measured at the air inlet to the engine (see Figure 9-7).

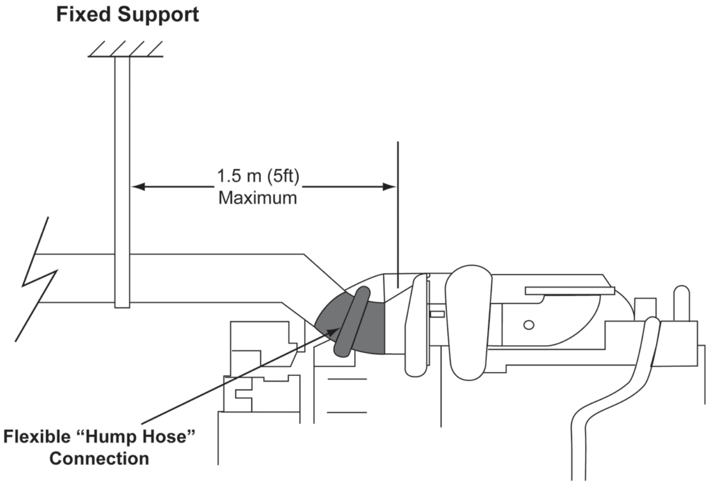


Figure 9-8: Remote Air Cleaner Plumbing to Engine Flexible Connection

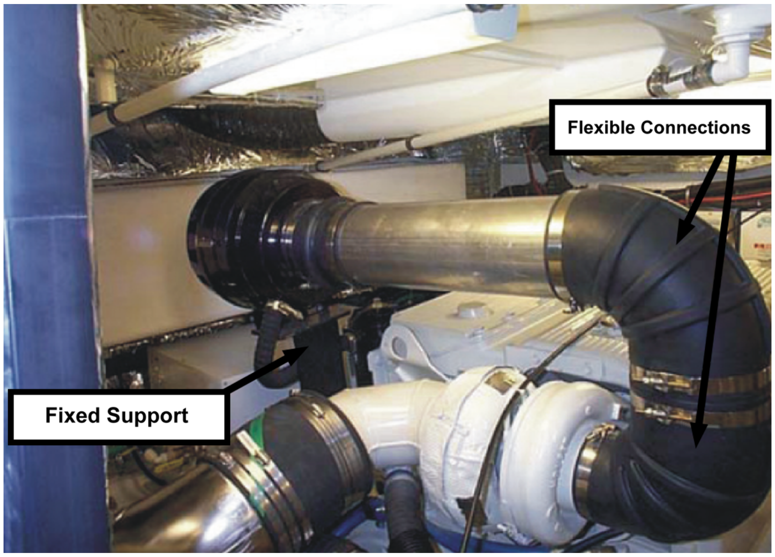


Figure 9-9: Remote Air Cleaner Installation

! **Hoses that connect directly to the turbocharger compressor inlet must be rated for a continuous temperature of 177° C (350° F).**

Hoses connected directly to the turbocharger compressor inlet are subject to high temperature. Materials used must be rated for a continuous temperature of 177° C (350° F). Cummins Inc. recommends silicone hose for this type of service. Commercially available silicone type hoses have a continuous temperature rating of 177° C (350° F), with higher temperature ratings also available.

! **Remote mounted air cleaner plumbing must allow for thermal expansion.**

Plumbing for a remote mounted air cleaner must be designed to accommodate thermal expansion without overstressing components in the air intake system. One method is to use a fixed support at the engine end and let the end toward the air cleaner float on flexible mounts. Otherwise, the use of flexible rubber or silicone connectors between each fixed section of piping is recommended.

Air Cleaners – Customer Supplied

! **The air cleaner must have an initial efficiency of 99.5%, an overall efficiency of 99.9%, and a dirt holding capacity of 6.4 g/l/s (3.9 g/cfm) per SAE J726b test specifications. SAEJ726b may have been superseded by ISO 5011.**

Dirt is the major cause of wear in an engine. Minimizing the amount of dirt that enters the engine will increase engine life. The use of an air cleaner that meets a minimum initial efficiency of 99.5%, an overall efficiency of 99.9%, and a dirt holding capacity of 6.4 g/l/s (3.9 g/cfm) is required. Air filters are tested per SAE J726b or ISO 5011 standards.

Although no universal standard for rating air cleaners has been established, the following ratings in Table 9-2 are widely accepted:

Rating	Initial Efficiency at 15% to 100% Air Flow	Dirt Holding Capacity g/l/s (g/cfm)	Construction Type
Normal Duty	99.5%	6.4 (3)	Single Stage
Medium Duty	99.7%	21 (10)	Single Stage
Heavy Duty	99.9%	53 (25)	Two Stage

Table 9-2: Air Cleaner Ratings

Most recreational boat applications have engine rooms that are relatively free of dirt and therefore normal duty air cleaners are sufficient. Commercial engines that operate in a protected, clean environment are recommended to use a medium duty air cleaner. For commercial engines that operate in an environment that contains debris that can clog the air filter (coal/grain dust, any dry bulk items, fish scales, etc), or where a longer service interval is required, a heavy duty air cleaner should be used.

! **The air cleaner media must be reinforced to prevent media from being ingested by the engine.**

Over the life of the air cleaner, the restriction through the filter media will increase as it collects dirt and debris. This restriction causes the air cleaner media to be pulled inward toward the engine inlet. The air cleaner must be constructed to prevent the media from being ingested into the engine. Typically expanded wire mesh is used to reinforce the interior of the air cleaner media and prevent it from collapsing into the engine inlet.

! **Oil bath air cleaners are not approved for use on turbocharged Cummins engines.**

Oil bath air cleaners are not approved for use on turbocharged Cummins engines. Potential carryover of the oil used in oil bath air cleaners can form deposits on the turbocharger compressor wheel and aftercooler core (if equipped) that cause a decrease in engine performance and efficiency.

Note: *When not using a factory supplied air cleaner option, Cummins Inc. recommends consulting with an air cleaner manufacturer before making a selection. Cummins Filtration is a division of Cummins Inc. that can supply air cleaners and technical support for most marine applications. The website www.cumminsfiltration.com has contact information for the local Customer Service location.*

Crankcase Ventilation

! **For open crankcase ventilation, the crankcase gases must be vented to atmosphere (not to the air intake system).**

Open crankcase ventilation (OCV) systems allow combustion gases that accumulate in the crankcase to vent to the atmosphere, either directly or through an intermediate oil trap device. Routing the crankcase gases to vent directly into the air intake system, either before or after the air cleaner is not approved, since it can cause oil contamination and/or coking of the turbocharger, aftercooler, and intake valves.

Note: *Exceptions to this require apply only to engines that are factory supplied with crankcase ventilation systems that route the crankcase gases to the dirty side of the air filter.*

! **Only factory installed closed crankcase ventilation systems can be used. Aftermarket closed crankcase systems cannot be used are not approved.**

Closed crankcase ventilation (CCV) systems use an oil separating filter to remove entrained oil mist from the combustion gases so that it can be vented into the air intake system. The apparent advantage of a closed crankcase system is that combustion gases and entrained oil are not allowed to enter the engine compartment, thereby keeping it cleaner. However, closed crankcase systems that are not properly designed and applied can have detrimental effects. Inefficient oil separating filters can cause oil contamination and/or coking of the turbocharger, aftercooler, and intake valves. Improper pressure regulation can cause either crankcase overpressure or excessive vacuum, leading to seal failure. Therefore, only factory installed closed crankcase ventilation systems can be used. Customer supplied closed crankcase systems are not approved.

For more information, reference MAB 0.03.03 - 06/05/2000, Crankcase Ventilation Components.

Air Flow Resistance Charts

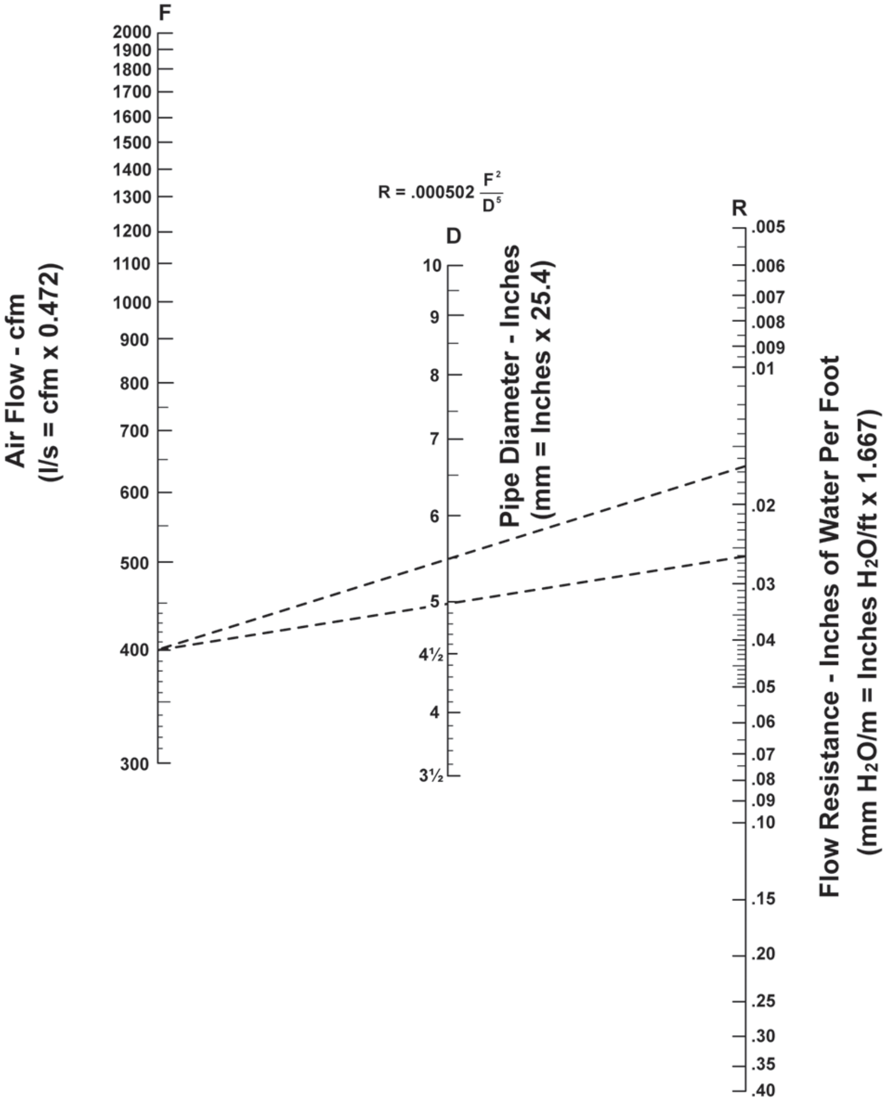


Figure 9-10: Air Flow Resistance of a Smooth Pipe

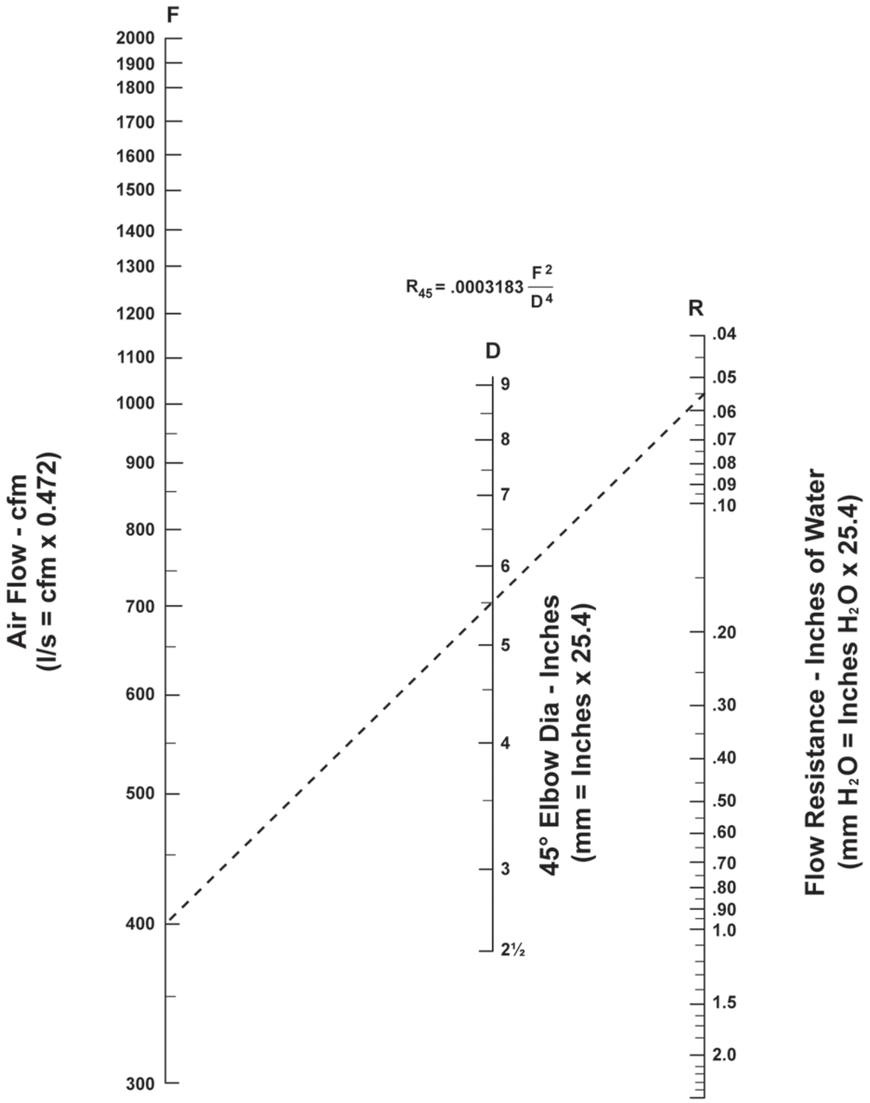


Figure 9-11: Air Flow Resistance of a 45° Elbow

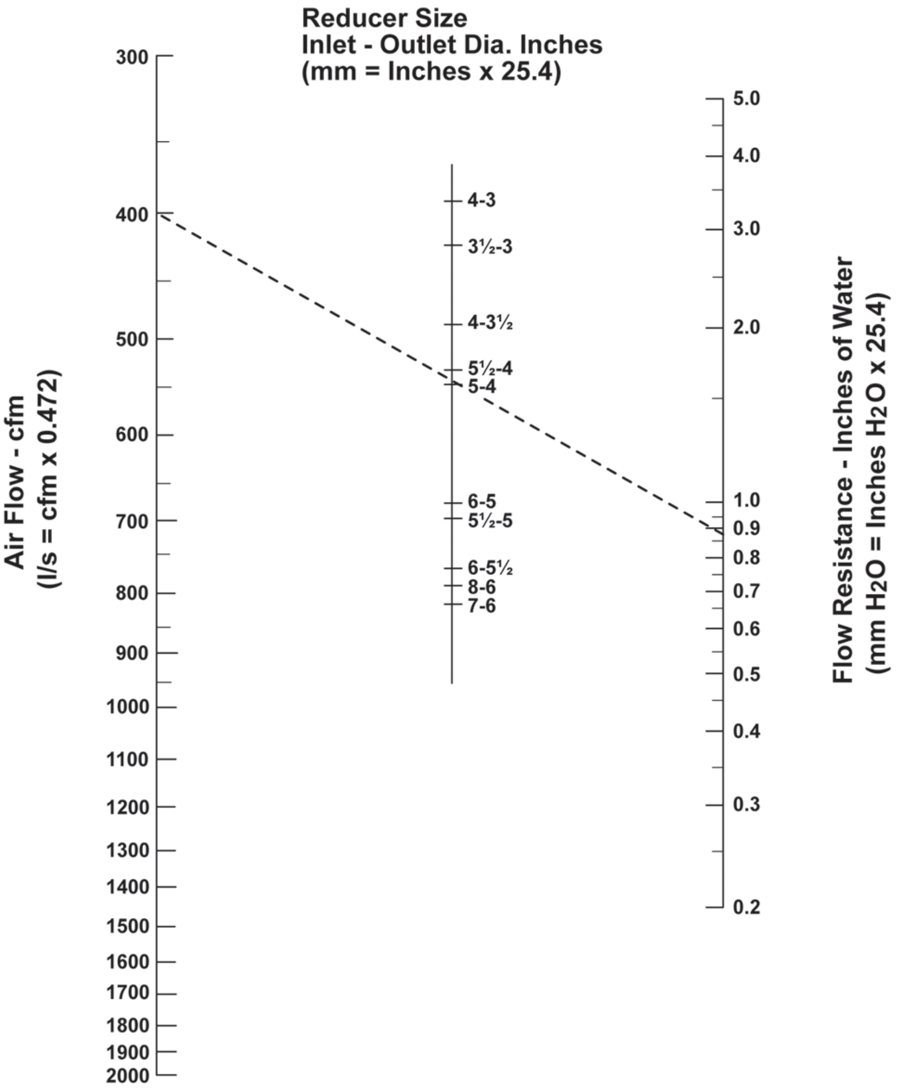


Figure 9-12: Air Flow Resistance of a 90° Elbow

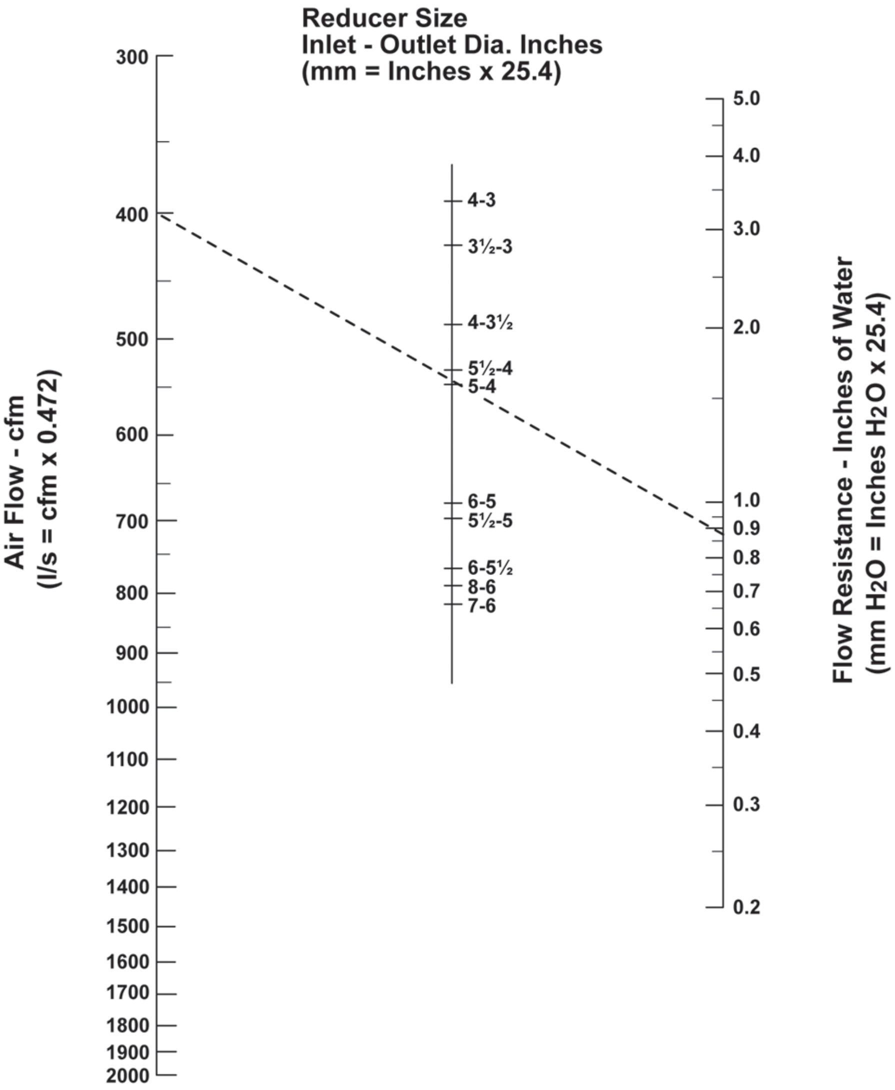


Figure 9-13: Air Flow Resistance of a Reducer

Fuel System

Summary of Requirements

- **! The fuel used in Cummins engines must meet the requirements specified in Cummins Service Bulletin 3379001.**
- **! The maximum fuel inlet restriction must not exceed the value specified in the Engine General Data Sheet.**
- **! The maximum fuel return line restriction must not exceed the value specified in the Engine General Data Sheet.**
- **! The maximum fuel supply to pump temperature must be below the value specified in the Performance Curves and Data Sheet.**
- **! Non-Cummins supplied hoses and fittings connected to the engine or marine gear must comply with SAE J1942/J1527.**
- **! All joints, components, and connections must be leak free.**
- **! The fuel system must not contain any zinc, zinc plated, or galvanized components.**
- **! Fittings and threaded connections must be free from Teflon tape or wrap type thread sealants.**
- **! Fuel lines must be routed away from heat sources.**
- **! Flexible lines must be installed between the engine and vessel plumbing to allow for relative motion.**
- **! All hoses must be adequately protected from chafing and clipped to appropriate pieces on the engine/vessel structure such that there is not overhanging load on connections.**
- **! The fuel supply line must be routed to prevent pressure surges and must be free from vertical loops.**
- **! A shut off valve must be installed in the fuel supply line.**
- **! If dual skin fuel lines are used, a 6.35mm (0.250 in) I.D. return line from the fuel collection tank overflow drain must be routed to the top of the vessel fuel tank, to an oily waste tank, or other suitable secondary collection device.**
- **! If dual skin fuel lines are used, the electrical leads from the fuel collection tank must be connected to a suitable alarm device that can notify the operator of a fuel line leak.**
- **! The engine must be installed with the secondary fuel filter supplied with the engine.**
- **! For engines with the High Pressure Common Rail Fuel System (HPCR), a water separating primary fuel filter with 10 micron filter media must be installed before the fuel inlet connection on the engine.**
- **! For engines without the High Pressure Common Rail Fuel System (HPCR), a water separating primary fuel filter with 30 micron filter media must be installed before the fuel inlet connection on the engine.**
- **! If used, duplex fuel filters must be mounted off the engine**
- **! For High Pressure Common Rail Fuel Systems (HPCR) only, a water in fuel (WIF) sensor must be installed with each water separating primary fuel filter; each WIF sensor must be connected to the Engine Control Module (ECM).**
- **! The fuel tank must be equipped with a vent; the vent must be designed and installed to prevent the entry of water and/or dirt.**
- **! The fuel return line must be routed to the top of the tank and be located at least 305 mm (12") horizontally from the fuel supply inlet. Additionally the fuel return line outlet must terminate above the maximum fuel level for engines with PT, HPI, and HPCR fuel systems, and below the minimum fuel level for all other fuel systems.**

General Information

Diesel engines are sensitive to the quality of the fuel and fuel system. The precise metering and timing of the injection event into the cylinders requires finely machined, close tolerance fuel system components. The inherent precision of these components makes them susceptible to failure or disruption of operation from a variety of fuel problems. To ensure proper and long lasting performance, the installed fuel system in a vessel must be able to supply an unrestricted supply of quality fuel that is free of air, water, and contaminants such as dirt, debris, microbes, etc. to the engine. Additionally, the fuel must not exceed specified temperature limits for proper cooling and lubrication.

Service Accessibility

The following is a list of Fuel System service points that should be accessible:

- Primary water separating fuel filter, drain valve, and water in fuel sensor (if installed)
- Water in Fuel (WIF) sensor
- Secondary, on engine fuel filter
- Fuel supply and return restriction test ports
- Any fuel shut-off or tank selection valves
- Any installed drains
- Fuel tank level sensor

Installation Directions

General

The fuel used in Cummins engines must meet the requirements specified in Cummins Service Bulletin 3379001.

There are three major functions that diesel fuel performs in a Cummins engine.

- It supplies the energy for the engine.
- It cools and lubricates the precision parts of the engine’s fuel pump and injectors.
- It enables emissions controlled engines to meet regulated emission levels.

Fuel quality, therefore, is extremely important for maintaining proper performance, reliability, durability, and emissions. To define fuel quality, Cummins publishes the service bulletin, number 3379001, “Fuels for Cummins Engines”. This document provides the required diesel fuel specifications and contains discussion regarding the use of contingency fuels, blended fuel, and biodiesel fuel. Fuel used in Cummins engines must meet the requirements specified in this document.

To obtain the latest revision of “Fuels for Cummins Engines”, Service Bulletin 3379001, contact your local Cummins Marine Certified Application Engineer.

The maximum fuel inlet restriction must not exceed the value specified in the Engine General Data Sheet.

The maximum fuel inlet restriction must not exceed the value specified in the Engine General Data Sheet. The test port location and fitting size for measuring the fuel inlet restriction can be found on the Installation Drawing.

High fuel inlet restriction causes reduced fuel flow to the fuel pump leading to increased fuel temperature, cavitation, and reduced lubrication. Short term effects of excessive fuel restriction are reduced power and possibly smoke. Long terms effects are fuel system wear and component failure.

Fuel inlet restriction is affected by the following:

1. Pump lift (static head)
2. Plumbing length, diameter, number of fittings/elbows, and radius of bends; collectively known as Friction Head
3. Filters and valves between the tank and engine

Each of these contributors should to be estimated during the design of the fuel system to meet the maximum inlet restriction requirement. The actual fuel inlet restriction must be verified during the sea trail. A fuel restriction calculator has been developed by Cummins. It allows users to estimate fuel inlet and return restriction, based on fuel characteristics, flow, pipe and hose size, valves, incremental restriction devices such as filters and flow meters, and static head. The calculator can be found in the Tools section of the http://marine.cummins.com website.

1. Pump Lift (Static Head)

Static head is the vertical distance between the fuel level in the tank and fuel pump inlet. For installations that have the fuel tank level located below the fuel pump inlet, the engine fuel pump must lift the fuel, creating a negative pressure or restriction. Conversely, a fuel tank level that is located above the fuel pump inlet will cause fuel to gravitate to the inlet, creating a positive pressure. All Cummins engines have a published maximum fuel inlet restriction. Some Cummins engines also have a published maximum fuel inlet positive pressure; typically High Horsepower engines with open injection nozzles (PT fuel system).

Ideally, the fuel tank high and low level should straddle the fuel pump inlet height. Doing so keeps the static head near zero and minimizes the chance of both air leaks into and fuel leaks out of fittings and connections.

Static head is easily calculated using the vertical difference and the density of fuel being used. It is important to calculate for both the expected high and low levels of fuel in the tank.

English units:

Static head = height difference * 0.8859 * SG

Where:
Static head = Pressure in units of inches of Mercury (in. Hg.)
Height difference = Distance in feet (ft) from engine fuel pump inlet to fuel tank level. Fuel tank level below the fuel pump inlet is negative; positive when above.
SG = specific gravity (or “density") of fuel used (this value is available from the fuel supplier)
0.8859 = conversion factor

Metric units:

Static head = height difference * 9.949 * SG

Where:
Static head = Pressure in units of inches of kilopascals (kPa)
Height difference = Distance in meters (m) from engine fuel pump inlet to fuel tank level. Fuel tank level below the fuel pump inlet is negative; positive when above.
SG = specific gravity (or “density") of fuel used (this value is available from the fuel supplier)
0.8859 = conversion factor

Example: Fuel low level is 7 ft. below the fuel inlet fitting. Standard diesel fuel is used.

7 ft. fuel * 0.8859 * 0.831 = 5.2 in. Hg static head

Specific gravity (or density in grams/cc) for typical fuels is shown below in Table 10-1:

Fuel	Specific Gravity
Standard diesel DF-2 (nominal value)	0.831
Acceptable range for standard diesel	0.816-0.876
DMA (marine distillate oil)	0.89
DMX (marine distillate oil)	0.89

Table 10-1: Specific Gravity for Typical Fuels

If the fuel's specific gravity is unknown, or the source of fuel varies, it is recommended that the worst case value (highest SG) be used in the calculation.

Intermediate tanks or day tanks may be required in some installations, based on the above static head calculations. Figures 10-1 and 10-2 illustrate typical fuel system arrangements using a day tank.

Use of day tanks, mounted near the same level as the engine crankshaft centerline, are a means to reduce the restriction (vacuum) or positive pressure caused by static head. If the main fuel tank is well below the engine (such as a double bottom tank), a transfer pump will be required to transfer the fuel to the day tank (see Figure 10-1). Main fuel tanks well above the engine can gravitate fuel to the day tank, but should have a shut off valve to stop flow when the day tank is full (see Figure 10-2). Day tanks should be sufficiently sized so that the heated fuel returned from the engine does not raise the tank temperature above the maximum allowable temperature specified in the Performance Curves and Data Sheet. Fuel coolers may be required to cool the fuel below allowable limits.

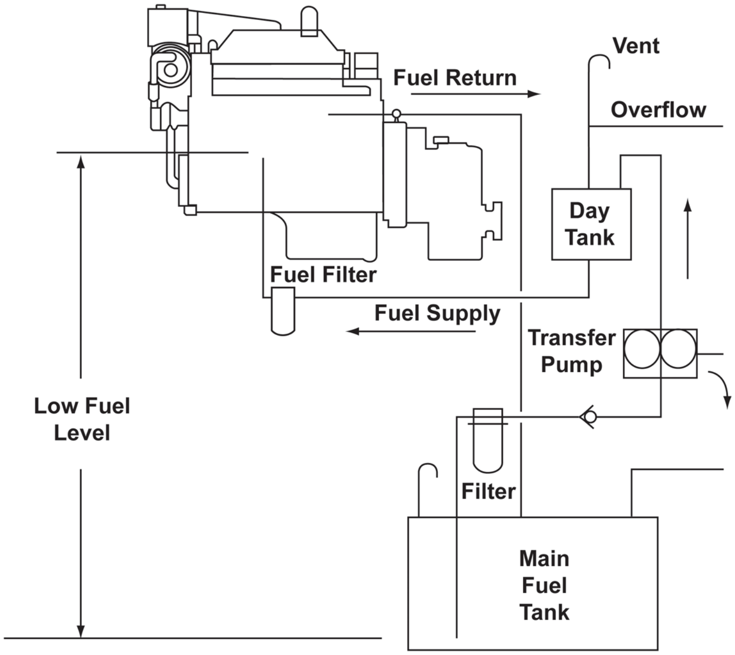


Figure 10-1: Example schematic of fuel system with tank below engine inlet

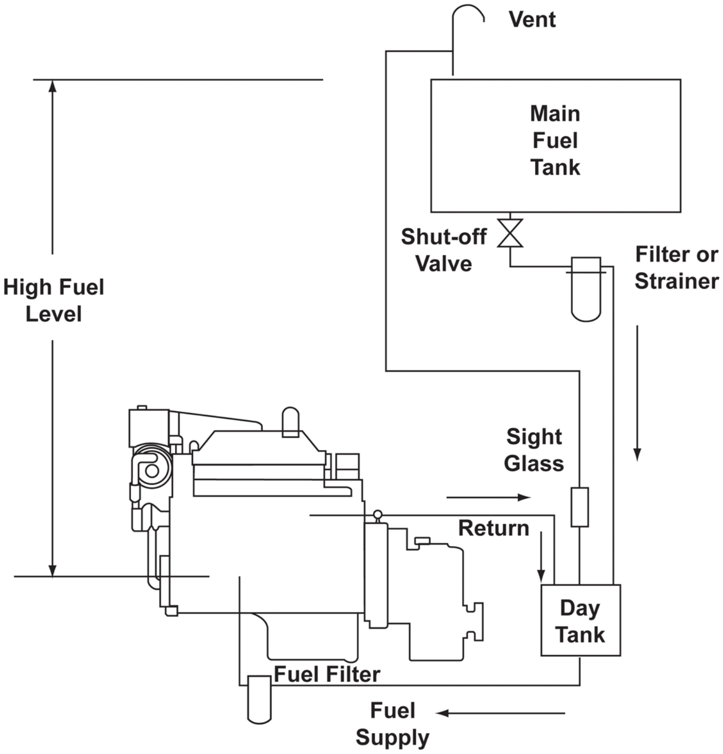


Figure 10-2: Example schematic of fuel system with tank above engine inlet

2. Plumbing Length, Diameter, and Number of Fittings/Elbows (friction head)

Fuel flowing through tubing, fittings, and elbows creates resistance to flow, referred to as Friction Head.

The fuel line size (inside diameter) required for an engine will depend on the length of piping and number of fittings and elbows used. In general, the minimum recommended supply and discharge pipe sizes are the same as the fuel inlet fitting size and fuel discharge fitting size, respectively. The line size may need to be increased depending on the length of hose, number of bends, valves, or fittings in the fuel plumbing.

Keep the radius of elbows and bends as wide as possible to minimize restriction.

3. Filters and valves between the tank and engine

The primary water separating fuel filters (typically customer supplied), shutoff valves, flow meters, and other components in the fuel system all contribute to flow restriction. The flow vs. pressure drop characteristic of each of these components is available from their respective suppliers and should be included in the calculation of total inlet restriction.

Note: *Anti-siphon valves are not required in diesel applications and are not recommended by Cummins. Anti-siphon valves, due to their design, are restrictive and may cause the specified maximum fuel inlet restriction to be exceeded.*

Fuel Inlet Restriction

The total fuel inlet restriction is a sum of the values from sections 1, 2, and 3 above. Note that if the fuel tank is below the fuel pump inlet, the value from step 1 will add to the total restriction. If the fuel tank is above the fuel pump inlet, the value from step 1 will subtract from the total restriction. The total fuel inlet restriction must not exceed the value specified in the Engine General Data Sheet. This must be verified during the sea trial of the vessel. Refer to the appropriate installation drawing for the correct restriction measurement location and fitting size.

! **The maximum fuel return line restriction must not exceed the value specified in the Engine General Data Sheet.**

The maximum fuel return line restriction must not exceed the value specified in the Engine General Data Sheet. If the fuel return restriction is excessive, fuel injection metering and timing can be altered possibly leading to high cylinder and exhaust temperatures, increased smoke, reduced performance, and decreased engine life. The factors contributing to return line restriction are generally the same as the fuel inlet, except that there may be a fuel cooler installed and no filters. The contributors to fuel return line restriction can be estimated in the same way as inlet restriction and must be verified during the sea trail. The test port location and fitting size for measuring the fuel return line restriction can be found on the Installation Drawing.

△ **CAUTION: Excessive return restriction may damage fuel system components such as the fuel cooler.**

△ **CAUTION: Closing of a valve installed in the fuel return line while the engine is running can cause immediate and severe damage to the engine’s fuel system.**

Note: *Care should be taken when installing valves into the fuel return line. Closing of a valve in the return line while the engine is running can cause immediate and severe damage to the engine’s fuel system. Cummins Inc. recommends that valves used to switch tanks are designed to maintain full flow when operated. Shutoff valves are not recommended in the fuel return. If installed, they should be protected to prevent accidental closing and accompanied with a label stating that damage will occur if it is closed when the engine is running.*

! **The maximum fuel supply to pump temperature must be below the value specified in the Performance Curves and Data Sheet.**

The maximum fuel supply to pump temperature must be below the value specified in the Performance Curves and Data Sheet. Excessive fuel temperature may cause a reduction in performance and can reduce fuel lubricity, leading to premature wear of the fuel system components. Fuel coolers are standard on many Cummins engines and are effective for reducing the temperature of the fuel returning to the tank. Fuel coolers, if included as standard equipment with the engine, must not be removed without prior approval from a Cummins Marine Certified Application Engineer.

Applications with large fuel tanks and/or have steel or aluminum hulls in contact with the fuel tank may not require a fuel cooler, as these installations are more efficient at removing heat from the fuel. The application should be analyzed prior to the start of build to determine the need for a fuel cooler.

Fuel Plumbing

Materials suitable for the fuel system plumbing are iron, steel, stainless steel, cupronickel, copper, and/or flexible hose. Copper and cupronickel lines are not recommended where they will be subject to bending and vibrations, due to their tendency to work harden and crack. Copper, cupronickel and copper alloy lines are not recommended for use with biodiesel fuels, because they can cause catalytic degradation of the biodiesel fuel. Zinc, zinc plated, or galvanized components must not be used in any part of the fuel system.

Fittings and connections may be made of iron, steel, stainless steel, and/or brass. Brass fittings and connections should be heavy wall/hydraulic grade for strength.

! **Non-Cummins Inc. supplied hoses and fittings connected to the engine or marine gear must comply with SAE J1942/J1527.**

All fuel hoses must meet the flame resistance, burst pressure limits and other requirements of SAE J1942/J1527. MAB 0.07.06 - 02/19/2002, Lube Oil and Fuel Hose Requirements, gives further guidance on selection of hoses and fittings.

A number of factors must be considered when choosing the correct hose in order to meet the requirements of the application and achieve the maximum life of the hose assembly. A systematic review of each application, based on these factors, should be made in order to select the hose that best meets the requirements. The following are some factors for consideration:

- Pressure: The system pressure should be determined. A hose with a maximum operating pressure equal to or greater than the system pressure should be selected. Pressure surges which exceed the system pressure should also be considered. Hoses used on marine engines, which are approved by Marine Classification Societies must have a maximum operating pressure at least 1.5 times the system pressure.
- Fluid Compatibility: The hose selected must be compatible with the fluid being used. This includes the hose material, the fittings, and cover (when used).
- Flow Requirements (Size): the size of the hose and fittings must be chosen to allow adequate flow and keep pressure losses to a minimum. Supplier catalogs provide charts for recommended velocities and flows.
- Environment: Consideration must be given to the environment in which the hoses will operate. Environmental conditions such as heat, ultraviolet light, ozone, salt water, chemicals, and air pollutants can damage the hose and shorten its life.
- Mechanical Loads: Excessive flexing, twist, kinking, tensile or side loads, bend radius, and vibration are all external forces which can reduce hose life. Fitting types and hose routings must be selected to avoid these problems. Bend radius must not be less than the minimum provided in the supplier catalog.
- Space Availability: The amount of space should be considered for ease of assembly, serviceability, and to accommodate allowable bend radius.
- Dual Seat Fittings: If the choice is made to use conical seat type fittings, they should be of the dual seat design. Dual seat fittings are available in both JIC 37.5 and SAE 45 degree conical seating surfaces.

! **All joints, components, and connections must be leak free.**

! **Fittings and threaded connections must be free from Teflon tape or wrap type thread sealants.**

All joints, components, piping, and connections used in the fuel system must be leak free. Robust methods for joining components should be used to make sure leaks do not develop over time. A suitable pipe sealant compatible with diesel fuel should be used on tapered fit threaded connections. Teflon® tape and other wrap type thread sealants must not be used, because of the risk of the material entering the fuel system.

Cummins Inc. recommends the use of compression, dual seat JIC 37.5/SAE 45 conical, and/or o-ring face seal fittings wherever possible in the fuel system. These fittings provide a robust connection that facilitates easy and repeated removal and installation. Fittings that are hydraulically crimped to the hose ends are preferred to the use of barb fittings with hose clamps.

If using hose clamps, the clamp should be positioned behind the hose bead or barb and tightened to the clamp manufacturer’s specifications. Excessively tightening clamps and positioning them over the hose bead can cause failure of the clamp and/or hose material.

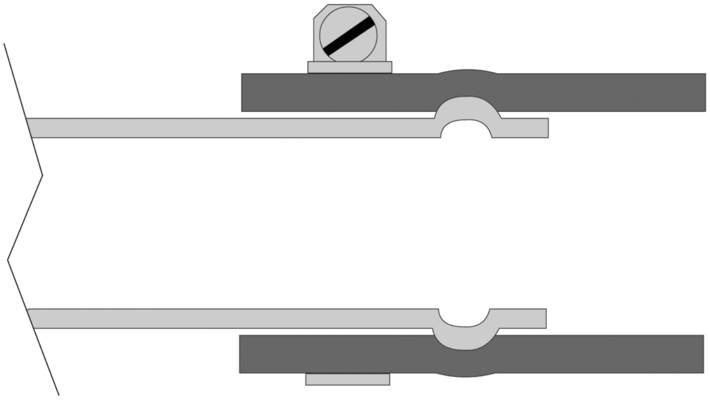


Figure 10-3

! **The fuel system must not contain any zinc, zinc plated, or galvanized components.**

Zinc, zinc plated, or galvanized components must not be used in any part of the fuel system including, but not limited to fuel lines, tanks, fittings, connections, and accessories. Zinc reacts with the fuel to produce compounds that can wear and clog fuel pumps and injectors. Coatings and primers that contain zinc to control corrosion, such as zinc phosphate and zinc chromate, may only be used on the exterior of fuel plumbing and tanks and must not come in contact with the fuel.

! **All hoses must be adequately protected from chafing and clipped to appropriate pieces on the engine/vessel structure such that there is not overhanging load on connections.**

! **All plumbing must be free from chafing points.**

! **Fuel lines must be routed away from heat sources.**

Proper installation techniques must be observed to make sure fuel lines are securely fastened and routed to protect from damage due to vibration, excessive load, and chafing. Fuel lines should be secured at regular intervals using chafe protected clips (see Figure 10-4). Electrical wire ties are not designed to secure fuel plumbing and are not recommended.

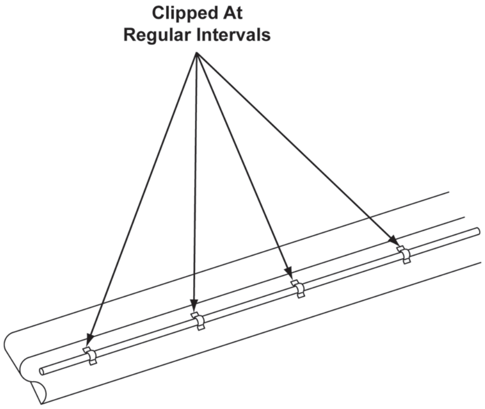


Figure 10-4

Routing fuel lines away from heat sources, such as exhaust plumbing, is done primarily for safety reasons. In the event that a fuel leak develops, fuel must not impinge on any hot surfaces. The secondary reason is to prevent the unnecessary heating of the fuel, which can affect engine performance.

If the routing can not avoid chafing points or hot surfaces, adequate chafe protection and/or insulating sleeves must be used.

For agency classed vessels, fittings/flanges/connections on fuel and oil lines shall be screened or otherwise suitably protected to avoid spray or leakage onto hot surfaces or machinery intakes. The Safety of Life at Sea (SOLAS) requirements regarding fuel lines and fuel fittings are described in detail in MAB 5.00.00 - 07/14/2003, SOLAS Fire Prevention Requirements.

! **Flexible lines must be installed between the engine and vessel plumbing to allow for relative motion.**

All fuel line connections from the vessel to the engine or any components that may have relative motion must have a flexible section (see Figure 10-5). Engine vibration, thermal growth, and flexure of the vessel when pitching and rolling in heavy seas may cause a rigid fuel line to fail. If hose is used for the flexible section, it must meet the requirements set forth in this document. It is recommended the hose is installed with a sweeping bend to provide the best isolation of movement and protect the hose from tensile and compressive loads.

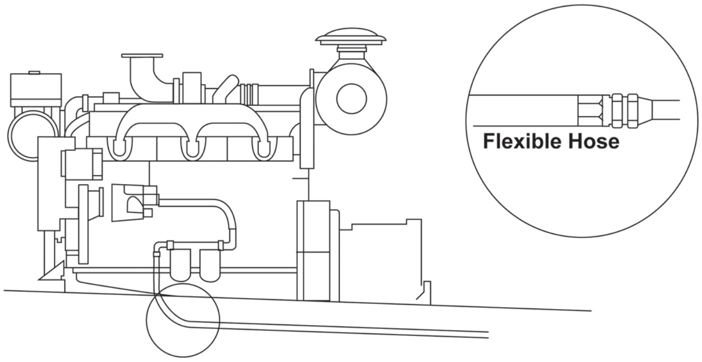


Figure 10-5

The fuel supply line must be routed to prevent pressure surges and must be free from vertical loops.

Routing of the fuel supply and return lines should be as direct as possible. Vertical loops must be avoided. Vertical loops and bends can trap air and cause pressure surges (see Figure 10-6).

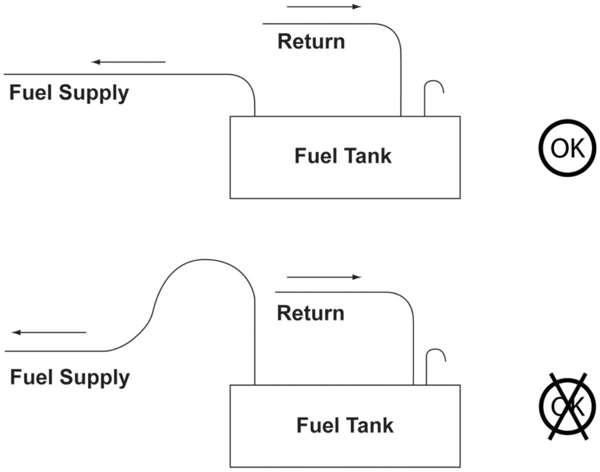


Figure 10-6

Whenever multiple engines are installed, each engine should have separate fuel supply and return lines. Running two or more engines with common fuel lines can result in idle surge and instability problems. Common supply and return manifolds must be sized to have a flow area equal to or greater than the sum of all the individual supply or return lines attached to it (see Figure 10-7).

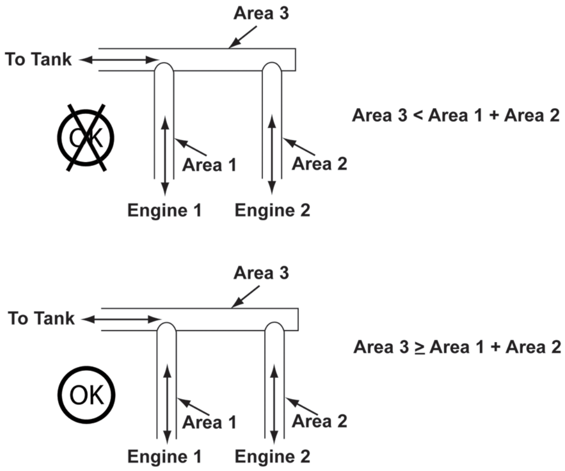


Figure 10-7: Fuel Manifold Sizing

A shutoff valve must be installed in the fuel supply line.

The engine fuel pump may incorporate an electrically actuated fuel shutoff valve (FSOV) that opens and closes based on the key switch operation. In addition, a shut off valve must be installed in the fuel supply line to facilitate maintenance and to make sure fuel can be shut off in event of a major leak. Shutoff valves should be installed at the fuel tank, allowing the entire fuel system to be secured.

Note: *Shutoff valves are not recommended in the fuel return. Closing of a valve installed in the fuel return line while the engine is running can cause immediate and severe damage to the engine’s fuel system. If installed, they should be protected to prevent accidental closing and accompanied with a label stating that damage will occur if it is closed when the engine is running.*

Dual Skin Fuel Lines

If dual skin fuel lines are used, a 6.35mm (0.250 in) I.D. return line from the fuel collection tank overflow drain must be routed to the top of the vessel fuel tank, to an oily waste tank, or other suitable secondary collection device.

If dual skin fuel lines are used, the electrical leads from the fuel collection tank must be connected to a suitable alarm device that can notify the operator of a fuel line leak.

Dual skin fuel line options are available on certain Cummins engines. Usage of these options requires additional consideration by engine installers in providing fuel drain and alarm connection provisions from the fuel collection tank included in the option.

According to Safety of Life at Sea (SOLAS), "All external high pressure fuel delivery lines between the high pressure fuel pumps and fuel injectors shall be protected with a jacketed piping system capable of containing fuel from a high pressure line failure. A jacketed pipe incorporates an outer pipe into which the high pressure fuel pipe is placed, forming a permanent assembly. The jacketed piping system shall include a means for collection of leakage and arrangements shall be provided for an alarm to be given of a fuel line failure." This means that fuel lines must have two skins, enough space between the two skins to allow leaking fuel to drain into a collection device, and an alarm, triggered by the collection device, that will alert the operator of a fuel leak.

The dual skin fuel supply lines, and associated manifolds and drain tubes, have been designed to collect any leakage from the high pressure fuel lines and return it to a self-contained fuel collection tank. This tank has an internal, normally open, float switch, which, when properly connected to an alarm device, will notify the operator of a high pressure fuel line leak. Any continuing leakage will drain from the fuel collection tank through the overflow drain tube. The overflow drain tube must be 6.35mm (0.250 in) I.D. and connected to the vessel fuel tank, an oily waste tank, or other suitable secondary collection tank to prevent spillage of fuel in the event of a high pressure fuel line leak. This secondary collection tank must be vented to atmosphere to prevent back pressure or backflow of fuel into the fuel collection tank. The return line must meet the fuel hose requirements specified in the previous subsection. A suitable alarm device must be connected to the fuel collection tank electrical leads (UL-1007, AWG 22) so that, in the event of a high pressure fuel line leak, the operator is aware of the accumulating fuel and can take appropriate action (see Figure 10-8).

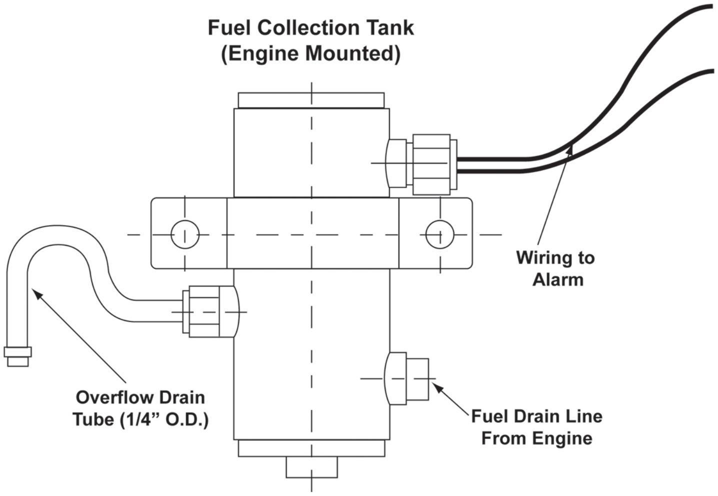


Figure 10-8: Fuel Collection Tank

Fuel Filters

Cummins Inc. requires a minimum of a two-stage fuel filtering for all engine installations. The primary filter (the first filter after the tank) is mounted off-engine. The secondary filter (the filter just before the engine fuel injection pump) is Cummins-supplied and can be either engine-mounted or remotely mounted for some duplex filter options (see Figure 10-9). The primary filter uses a relatively coarse media with a larger capacity compared to the secondary filter and includes a water separator. Using the proper size primary filter media will extend the life of the secondary filter without adding excessive inlet restriction to the system.

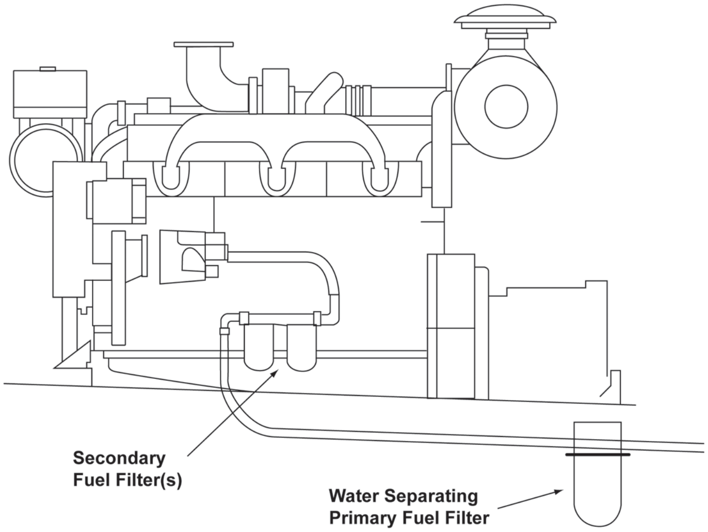


Figure 10-9

All fuel systems used on Cummins engines are fuel lubricated. Water in the fuel dramatically decreases lubrication and can cause failure of the pump and/or injectors. Therefore, it is necessary to remove any water from the fuel before it reaches the fuel pump, by using a water separating primary fuel filter.

! **For engines without the High Pressure Common Rail Fuel System (HPCR), a water separating primary fuel filter with 30 micron filter media must be installed before the fuel inlet connection on the engine.**

Cummins Inc. requires the use of a water separating primary fuel filter with a 30 micron filter media size for all engines, except those with High Pressure Common Rail (HPCR) fuel systems. Using a 30 micron filter media size with non-HPCR engines provides the best balance of filtration and filter life. The use of a finer filter media size may cause excessive fuel inlet restriction and unnecessarily frequent primary filter plugging. The use of a coarser filter media size may cause ineffective filtration and frequent secondary filter plugging.

The water separating primary filter must be installed before the fuel inlet connection on the engine.

! **For engines with the High Pressure Common Rail Fuel System (HPCR), a water separating primary fuel filter with 10 micron filter media must be installed before the fuel inlet connection on the engine.**

Cummins Inc. requires the use of a water separating primary fuel filter with a 10 micron filter media size for all engines with High Pressure Common Rail (HPCR) fuel systems. HPCR fuel systems require a finer filter media due to tighter tolerances needed to achieve the high injection pressures. Using a 10 micron filter media size with these engines provides the best balance of filtration and filter life. The use of a finer filter media size may cause excessive fuel inlet restriction and unnecessarily frequent primary filter plugging. The use of a coarser filter media size may cause ineffective filtration and frequent secondary filter plugging.

The water separating primary filter must be installed before the fuel inlet connection on the engine.

! **For High Pressure Common Rail Fuel Systems (HPCR) only, a water in fuel (WIF) sensor must be installed with each water separating primary fuel filter; each WIF sensor must be connected to the Engine Control Module (ECM).**

High Pressure Common Rail fuel systems (HPCR) are very sensitive to water in the fuel, due to the tight tolerances of the components and the extremely high pressures produced. Therefore, HPCR engines require a water in fuel (WIF) sensor be installed in each water separating primary fuel filter. WIF sensors are integrated into the engine control system via a WIF harness. Refer to the Wiring Diagram for the location to connect the WIF harness to the engine control system.

Cummins offers several WIF sensor and harness options to meet customer needs. WIF harnesses have provisions for two WIF sensors for dual water separating primary filter installations. If only one primary filter is installed, a 220 k Ohm resistor plug, supplied with the appropriate WIF harness option, must be installed in the vacant WIF harness sensor plug. Failure to terminate both WIF harness sensor plugs with either a WIF sensor or resistor plug will result in WIF related fault codes and alarms.

! **The engine must be installed with the secondary fuel filter supplied with the engine.**

All Cummins engines are supplied with a secondary fuel filter assembly (on engine or remote mounted) to remove contamination from the fuel. The secondary fuel filter works in conjunction with the water separating primary fuel filter. The water separating primary filter removes water and larger particles to prevent excessive plugging of the secondary filter. The secondary fuel filter uses a finer filter media that is specifically sized to protect the engine's fuel system components.

The secondary filter supplied with the engine must be installed.

! **If used, duplex fuel filters must be mounted off the engine**

Duplex secondary fuel filters are offered on some Cummins products. Duplex filters are configured to allow changing one filter at a time, while the engine is running, with no loss in filtration capability. Some marine agencies require duplex fuel filters on marine engines. MAB 0.06.01 - 02/15/2002, Duplex Fuel Filters, further describes some of these available options.

It is necessary to remote mount these filters when they are required on marine engines. The mounting bracket and filters are not designed to withstand the vibration and possible resonance conditions associated with engine mounting. The bracket should be firmly attached to a nearby rigid structural member within the length limitations of the supplied hoses.

Fuel Tanks

Proper fuel tank design and construction is very important to make sure of proper and long lasting performance of the engine. A well thought out tank facilitates organized fuel plumbing connections, efficient filling and venting, effective control of sloshing and aeration, and ease of maintainability.

Fuel tanks may be constructed of phosphate coated steel, stainless steel, aluminum, or fiberglass. Recently, plastic fuel tanks have been made available. Plastic offers the advantages of lighter weight, seamless construction, and corrosion resistance. The main disadvantage of plastic is being the least resistant to heat. Plastic tanks should not be used with fuel temperatures exceeding 65.6° C (150° F).

In general, the temperature of the fuel within the fuel tank should not exceed 60° C (140° F) for the following reasons:

- To remain below the flash point temperature of diesel fuel
- To reduce tank breathing which aids in the formation of condensation.
- To limit scalding temperatures when having to change fuel filters.

The use of carbon steel or black iron is prohibited. Galvanized or zinc plated steel should never be used as the zinc reacts with the fuel to produce compounds that can wear and clog fuel pumps and injectors. The use of terneplate is prohibited by United States federal law, unless it is coated with an inorganic sacrificial coating. However, inorganic sacrificial coatings that contain zinc must not be allowed to come in contact with the fuel.

Standard fittings on a fuel tank include fill, vent, fuel supply, fuel return, and bottom drain. Other fittings sometimes used are an equalizer line to balance fuel levels between tanks and a fuel gauge/sounding tube to measure the fuel level (See figure 10-5).

! **The fuel tank must be equipped with a vent; the vent must be designed and installed to prevent the entry of water and/or dirt.**

! **The fuel return line must be routed to the top of the tank and be located at least 305 mm (12") horizontally from the fuel supply inlet. Additionally the fuel return line outlet must terminate at above the maximum fuel level for engines with PT, HPI, and HPCR fuel systems, and below the minimum fuel level for all other fuel systems.**

! **Anti-siphon valve(s) must not be installed on fuel tanks.**

The tank should have at least 5 percent of its capacity above the maximum fill level to allow for expansion. Fuel tanks must be equipped with a vent. The vent allows for filling, expansion, and air/combustion gases in the return fuel to escape. Fill and vent lines normally terminate above deck in a protected location. They must not allow water and/or dirt to enter the tank. Vents should have a gooseneck or loop installed above the termination point as a means to prevent the entrance of water.

If using a fuel vent that exits the hull sides or bulkhead horizontally, a vertical loop in the fuel vent line must be installed to inhibit water from draining into the fuel tank. The holes in the fuel vent should also be pointed down and aft to prevent water from forcibly being pushed into the vent during underway operation. (See Figure 10-10)

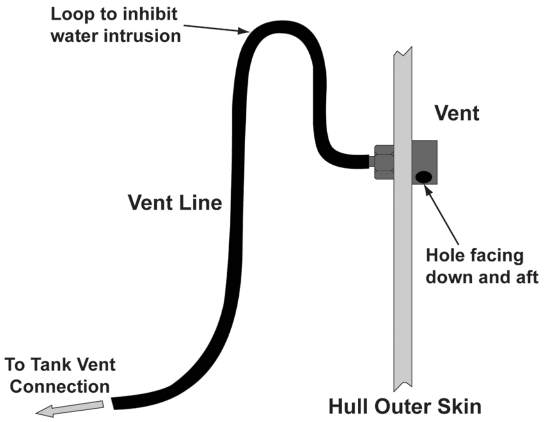


Figure 10-10: Vent Installation

The recommended minimum fuel fill line size is 38 mm (1.5 in) I.D and the minimum fuel vent line is 13 mm (.5 in) I.D. For larger fuel fill lines, the vent size should be at least 1/3 the fill line diameter.

The fuel supply line may use a drop tube or standpipe through the top of the tank or may be installed through the side or bottom of the tank. In either case the supply line should terminate at least 25 mm (1 in) from the bottom of the tank to prevent water, dirt, and sludge from entering the fuel system. Drop tubes or standpipes must be rigid and well supported to prevent cracking due to vibration. Manual shut off valves must be installed in the supply line and should be installed between the tank and the inlet to the water separating primary fuel filter.

The fuel return connection must be in the top of the fuel tank. For engines with Pressure Time (PT), High Pressure Injection (HPI) and High Pressure Common Rail (HPCR) systems, the fuel return outlet must terminate above the maximum fuel level in the tank. For all other engines, the fuel return outlet must terminate below the minimum fuel level in the tank, by using a drop tube or standpipe to prevent fuel from siphoning out of the system and causing hard starting/smoke. In all applications, the fuel return outlet must be separated from the fuel supply inlet by at least 305 mm (12 in) of horizontal distance. This is to prevent warm fuel and entrained air and/or combustion gases from the fuel return from entering the fuel supply. Small tanks that can not achieve at least 305 mm (12 in) of separation are recommended to have a baffle(s) installed between the supply and return (see Figure 10-11).

The use of anti-siphon valves is not approved. They must not be installed on the fuel tank or anywhere else in the fuel system. Anti-siphon valves can create excessive fuel supply restriction.

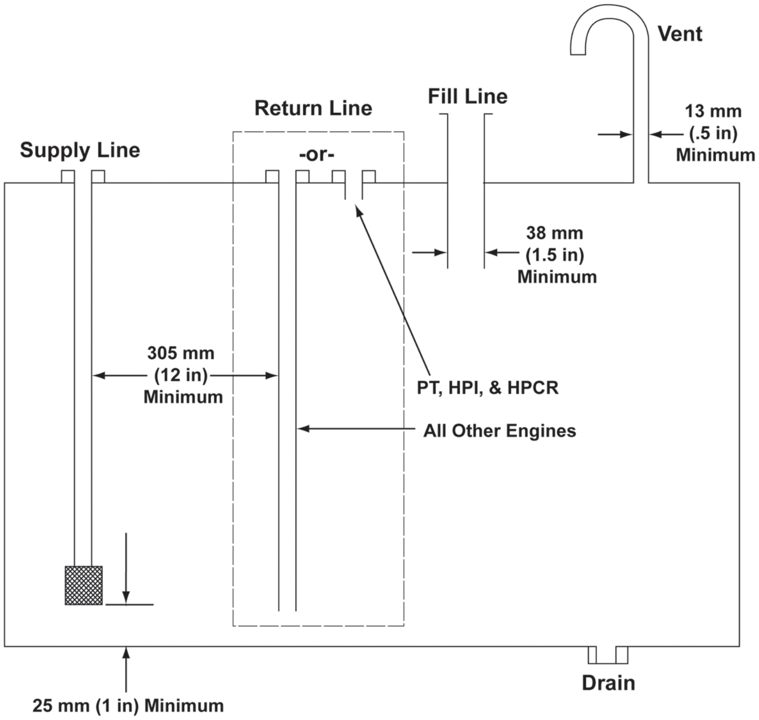


Figure 10-11: Sample Fuel Tank

Electrical System

Summary of Requirements

Batteries

! The battery bank cranking ampere rating must be greater than the value specified in the Engine General Data Sheet.
! The battery bank reserve capacity must not be less than the value specified in the Engine General Data Sheet.
! The voltage at the battery must exceed the minimum voltage specified in the General Engine Data Sheet.

General Electrical System Installation

! All DC electrical components must match the rated voltage of the respective power source.
! All electrical harnesses must be loomed and/or covered, clamped securely, and routed away from water and sources of heat.
! The wiring must use protective grommets at clamp points.
! All powered circuits must include wiring and overcurrent protection that complies with governing standards of the intended application.
! Cummins supplied wiring harnesses must be installed without modifications or splices.
! All ground connections to the engine must be to a common point.

Alternators

! The minimum regulated charging voltage must be greater than the rated voltage of the battery.
! The maximum regulated charging voltage must be less than or equal to 15.5V for 12V systems or 31V for 24V systems or the battery manufacturer's recommended maximum.
! The combined voltage drop across the positive negative wires and connections must be less than or equal to 0.5V for 12V systems or 1.0V for 24V systems between the alternator and battery.
! The alternator negative must be connected directly to the starter or battery negative terminal.
! The sensing wire for externally regulated alternators must be 0.75mm^2 / 18 gauge or larger.
! If the alternator is not supplied with the engine, the installer must assume responsibility for adequate mounting.

General Information

The electrical system consists of the batteries, charging circuits, harnesses, and general installation of the engine related wiring.

Inadequate sizing and/or installation of these components can create a number of starting and engine operational problems. When dealing with electrical circuits, care should be taken to ensure that good installation practices are observed and all connections make good contact, are secure, and protected against water and corrosion.

△ **If welding on the vessel or engine, the following must be performed to protect the engine: 1. Disconnect the battery positive and negative conndductors from the battery 2. Turn off circuit breakers or remove fuses in all the power supplies to the engine and any engine associated electrical equipement, and 3. Disconnect and pull back the OEM interface connector from the engine control module and any other engine related electronic control modules.**

Service Accessibility

The following is a list of Electrical and Starting System service points that should be accessible:

- All circuit breakers and/or fuses
- Alternator
- Battery terminals

- All wiring connection points
- Switches

Installation Directions

Batteries and Battery Installation

The battery bank cranking ampere rating must exceed the value specified in the Engine General Data Sheet.

The battery bank reserve capacity must exceed the value specified in the Engine General Data Sheet.

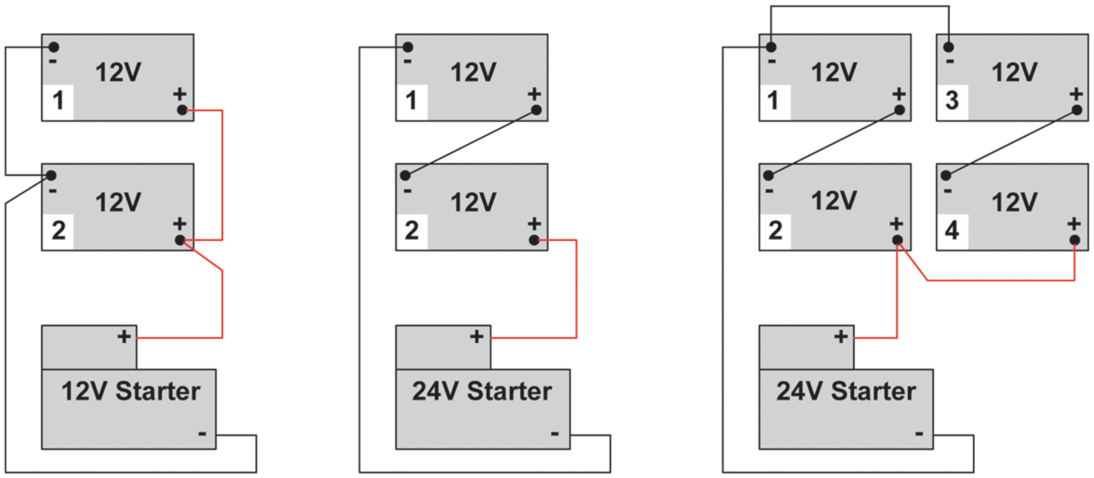
The voltage at the battery must exceed the minimum voltage specified in the General Engine Data Sheet.

The sizing of the battery banks used for starting the engines is critical for ensuring quick, reliable starts over the range of conditions likely to be encountered. For each battery bank, the cranking ampere rating and reserve capacity both must exceed the values specified in the Engine General Data Sheet.

Cranking ampere rating is the amperage a battery can supply at a given temperature for 30 seconds before falling below 7.2 volts. Ratings are typically given in Cold Cranking Amperes (CCA) or Marine Cranking Amperes (MCA). The difference between CCA and MCA is the temperature at which the battery is tested; -17.8° C (0° F) for CCA and 0° C (32° F) for MCA. Reserve capacity (RC) is the duration of time that the battery can maintain at least 10.5 volts with a 25 ampere draw.

The voltage at the battery while the engine is running must exceed the minimum voltage specified in the Engine General Data Sheet.

To obtain the proper system voltage and meet minimum cranking ampere and reserve capacity requirements, multiple batteries may need to be connected to one another. Parallel, series, and series-parallel battery circuits and the respective effect on voltage (V) and amperage (I) are illustrated in Figure 11-1.



Parallel Circuit
$V_{system} = V_1 = V_2$
$I_{system} = I_1 + I_2$

Series Circuit
$V_{system} = V_1 + V_2$
$I_{system} = I_1 = I_2$

Series-Parallel Circuit
$V_{system} = V_1 + V_2 = V_3 + V_4$
$I_{system} = I_1 + I_3 = I_2 + I_4$

Figure 11-1: Battery Circuits

Cable ends attaching to the battery bank, battery switch, starter, etc. should have quality tinned copper lugs that have been properly attached to the cable end. Battery post clamps that are molded to the end of the cable are a good choice, if available.

When connecting multiple cables to a battery post, care should be taken to ensure that the lugs are in good contact with the battery post clamp. The cables should be paired with the flat side of the lugs toward each other. Washers on either side of the lugs will increase contact area and strengthen the connection. The battery post clamp should fit squarely on the battery post, be clean, and securely fastened. Stacked terminal connections which have only point or line contact are not satisfactory.

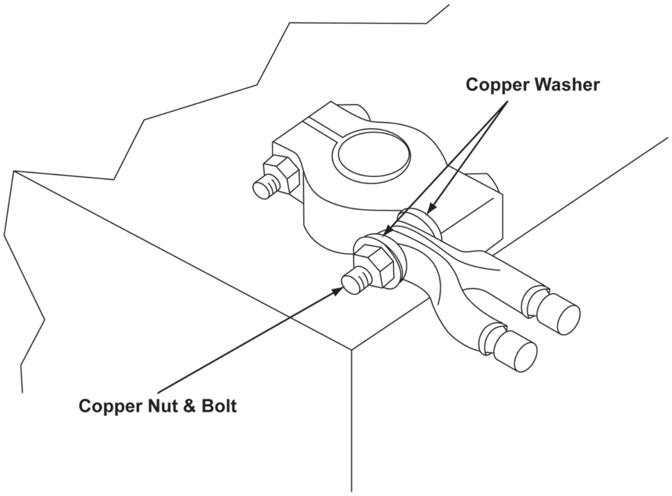


Figure 11-2

Battery terminals in vessels are susceptible to corrosion due the presence of electrical current, sulfuric acid within the battery, and the marine environment. Battery post clamps with tinned copper or stainless steel hardware are recommended for corrosion resistance. The use of dielectric grease on the connections will also help prevent corrosion.

Note: *Cummins Inc. recommends that a dedicated starting battery bank is used for each engine installed. Starting multiple engines from a single battery bank can cause surges in voltage to the Engine Control Module (ECM), which may cause fault codes, engine shut down, or damage to the ECM.*

Electrical System Installation

! **All DC electrical components must match the rated voltage of the respective power source.**

All DC electrical components, including, but not limited to starters, alternators, solenoids, magnetic switches, relays, and gauges, whether factory installed or customer supplied, must match the rated voltage of their respective power source.

! **All electrical harnesses must be loomed and/or covered, clamped securely, and routed away from water and sources of heat.**

! **The wiring must use protective grommets at clamp points.**

Because of the unique environmental conditions and for safety reasons, wiring on marine applications requires special considerations. Along with following, the American Boat and Yacht Council (ABYC) guidelines, section E11 “AC and DC Electrical Systems on Boats” is a good reference. ABYC published guidelines are widely accepted and/or paralleled by other boat building standards groups.

All electrical harnesses must be loomed and/or covered to prevent damage to the wire(s) (see Figure 11-3). Popular options for wire looms are split convolute tubing and expandable braided sleeve. It is important to select a loom material that at a minimum is rated as “Fire Retardant” and has passed the UL 94 V2 flame test. For large and/or multiple harnesses, cable trays and similar products offer greater size and easier access.

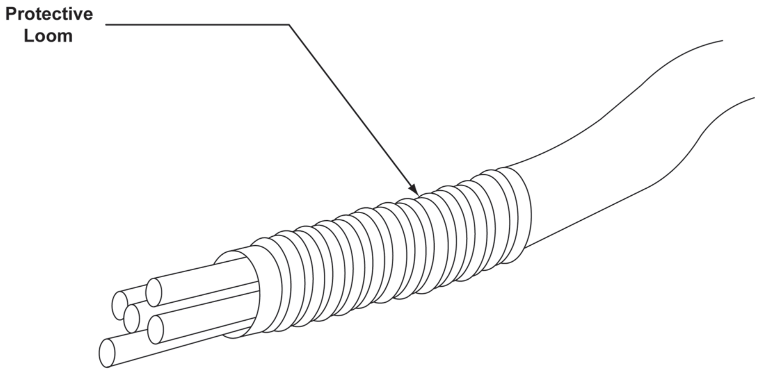


Figure 11-3

All wires and harnesses must be routed away from heat sources. Cummins Inc. recommends a distance of at least 127 mm (5 in) away from an exhaust pipe, turbocharger, turbocharger crossover tubes, or other sources of heat. Ideally, wires and harnesses should be kept as far as possible from heat sources (see Figure 11-4).

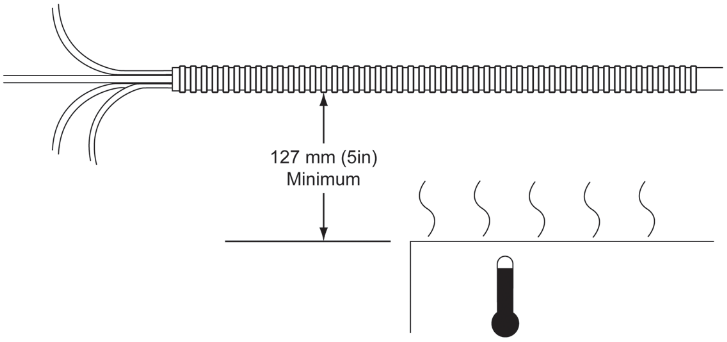


Figure 11-4

All electrical harnesses must be clamped, clipped, banded, etc., securely with protective grommets at each securing point to prevent chafing. Some type of support should be used at least every 450 mm (18 in) (see Figure 11-5). On any surface likely to see movement from vibration or normal deflections, such as a frame or stringer, wires must not rub against surrounding parts or each other. If they must touch a surface, they should be properly secured to it.

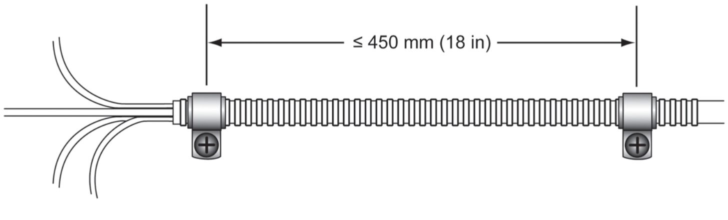


Figure 11-5

Harnesses should not be secured to equipment such as engines, marine gears, generators, or other machinery, except where required.

Under no circumstances should wires or harnesses contact sharp edges, screws, bolts, nuts, etc. (see Figure 11-6).

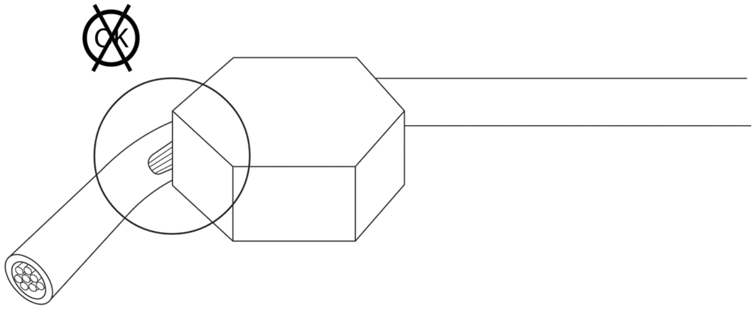


Figure 11-6

Electrical connection points should be made with corrosion resistant hardware and must be installed to prevent contact with water. Again, ABYC guidelines, section E11 “AC and DC Electrical Systems on Boats” is a good reference. Cummins Inc. recommends that all crimped/swaged terminal connections are covered and sealed with adhesive lined heat shrink tubing, providing an environmentally sealed wire end to prevent corrosion. Heat shrink tubing will also provide strain relief to the wire where it enters the connection, preventing breaks due to fatigue.

! **All powered circuits must include wiring and overcurrent protection that complies with governing standards of the intended application.**

All powered circuits must have wiring that is sufficiently sized and/or rated depending on the load, length of circuit, and intended area of use. Overcurrent protection in the form of fuses and/or circuit breakers must be properly installed in all powered circuits to comply with the governing standards of the intended application.

! **Cummins Inc. supplied wiring harnesses must be installed without modifications or splices.**

Wiring harnesses supplied by Cummins must be installed without modifications or splices. Modifications and splices to Cummins supplied harnesses are not approved. Failure of customer modified or spliced harnesses and any associated progressive damage will not be warranted by Cummins.

! **All ground connections to the engine must be to a common point.**

All customer supplied DC ground connections to the cylinder block must be to a common point. Cummins Inc. recommends the flywheel housing as the common grounding connection point. In multiple engine installations, Cummins Inc. recommends that a grounding cable is installed between each engine and must be sized to carry the full cranking load of the starter.

Note: *Proper grounding is particularly important for electronically controlled engines. Improper grounding can cause differences in voltage between engines that may affect ECM operation.*

It is important to understand the DC grounding circuits and vessel bonding system are separate, but may be shared at points, and are both connected to the battery negative terminal. DC grounding circuits are current carrying conductors for motors, relays, inverters, etc. that are sized appropriately, based on the electrical load they serve.

The bonding system provides a low resistance electrical path between metal components to 1. Prevent the buildup of a voltage differential and protect against galvanic corrosion 2. Create a redundant ground path for AC components 3. Create a ground path for lightning strikes 4. Prevent the buildup and discharge of static electricity and 5. Help to minimize radio frequency interference. It is beyond the scope of this document to discuss bonding in further detail and industry standards should be followed to design a proper bonding system.

Alternators

A properly selected and applied alternator will provide substantial battery charging at all engine speeds and prevent battery life shortening deep discharge with subsequent fast recharge cycles. Lead acid storage batteries will provide significantly longer service if they are kept near full charge. To assure an adequate charging capability, the electrical rating of the alternator should be at least 25 percent greater that the maximum continuous load upon it. The maximum continuous load can be determined by listing all the lights, heaters, windshield wipers, instruments, solenoid valves, appliances, etc. that may be operated at the same time. Nameplate data or manufacturer's literature may be used to determine the current draw of each component.

Cummins provides alternators as options for 12 and 24 volts systems. Factory supplied alternators are recommended as the alternator itself and the mounting including belt arrangement, alignment, and loading have been engineered and validated for reliability and durability. Customer supplied alternators are acceptable for use, but must meet the requirements given in the Engine Driven Accessories section of the Installation Directions. Regardless, failure of a customer supplied alternator and any associated progressive damage will not be warranted by Cummins.

The minimum regulated charging voltage must be greater that the voltage of the battery bank.

The maximum regulated charging voltage must be less than or equal to 15.5V for 12V systems / 31V for 24V systems or the battery manufacturer's recommended maximum.

The regulated charging voltage of an alternator must be within both a minimum and maximum value.

The minimum regulated charging voltage of an alternator must be greater than the rated voltage of the battery bank it supplies. The typical reasons for an alternator not being able to supply adequate voltage to the battery bank are:

- Excessive load on the battery bank and/or alternator not properly sized to provide sufficient amperage
- High resistance or poor connection of the conductor from the alternator to the battery.
- Normal or abnormal voltage drop due to any installed battery isolators.
- Failed or misadjusted alternator voltage regulator.

The maximum regulated charging voltage must be less than or equal to 15.5 V for 12 V systems / 31V for 24 V systems or the battery manufacturer's recommended maximum. With the increasing popularity of gel cell batteries and other battery technologies, following the manufacturer's maximum charging voltage is very important for preventing damage and/or failure of these batteries, as well as maximizing battery life.

Note: *The minimum and maximum regulated charging voltage should be measured at the battery bank.*

The combined voltage drop across the positive and negative wires and connections must be less than or equal to 0.5V for 12V systems or 1.0V for 24V systems between the alternator and battery.

To prevent excessive voltage drop and thereby maximize charging capability, the combined voltage drop across the positive and negative wires and connections from the alternator to the battery bank must be less than or equal to 0.5V for 12V systems or 1.0V for 24V systems.

Voltage drop in the charging system will vary, depending on the load placed upon it. The voltage drop measurement should be taken when the charging system is loaded to the expected maximum continuous load. This can be accomplished by turning on accessories, lights, heaters, windshield wipers, instruments, solenoid valves, appliances, etc., that are expected to be operated simultaneously. Figure 11-7 illustrates where to take measurements and how to calculate the voltage drop. When dealing with a charging system that has a battery isolator (diode) installed, the voltage drop of the isolator should not be included. However, it should be understood that battery isolators do create a significant voltage drop which may affect the ability for the alternator to provide sufficient voltage to charge the batteries under high loads. Typical battery isolator voltage drop is 0.7 volts. Recently, automatic charger relays, which allow the isolation of multiple batteries without the voltage drop associated with conventional diode isolator technology, have become widely available.

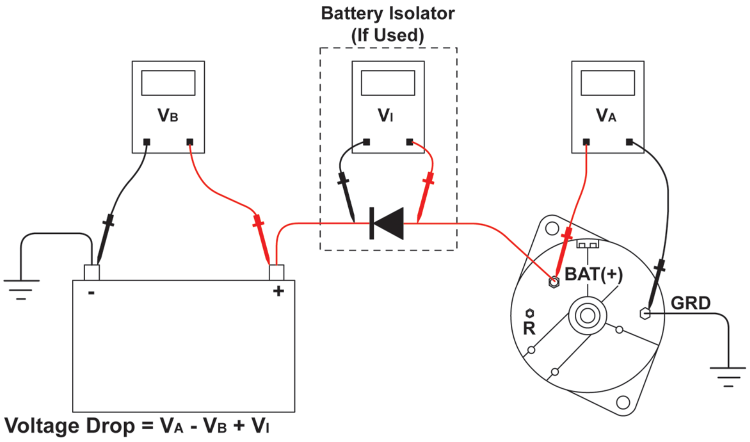


Figure 11-7: Alternator Wiring Voltage Drop Measurement

The alternator negative must be connected directly to the starter or battery negative terminal.

The alternator negative terminal must be connected directly to the starter or battery negative terminal. Connection of the alternator negative terminal to the engine block is not approved.

The sensing wire for externally regulated alternators must be 0.75mm^2 / 18 gauge or larger.

Externally regulated alternators use a sensing wire to read voltage at the battery bank or other point in the charging system. Sensing wires must be a wire size 0.75 mm^2 / 18 gauge or larger.

Starting System

Summary of Requirements

- **! Starter(s) must be connected directly to the battery or to a common connection point (bus), which is connected directly to the battery.**
- **! A battery disconnect switch must be installed.**
- **! The engine must achieve a minimum cranking speed of 150 RPM (tested in no run condition)**
- **! The total combined voltage drop in the paths to and from the starter must be less than 1V/2V for 12V/24V starters respectively.**
- **! An auxiliary magnetic switch must be installed between the key switch and the starter solenoid. It must be mounted horizontally and wired directly to the "S" terminal of the starter solenoid, without any additional electrical loads/connections.**
- **! The engine must be prevented from starting when in gear.**

General Information

The Starting System consists of wiring and associated components to connect the battery bank to the engine/starter and to control the operation of the starter.

Proper starter performance begins with an adequate power source. The requirements for selecting a properly sized battery bank and making secure, low resistance connections to it is covered in the Electrical System section.

Inadequate sizing and/or installation of these components can create starting problems. When dealing with electrical circuits, always make sure that good installation practices are observed and all connections make good contact, are secure, and are protected against water and corrosion.

△ **If welding on the vessel or engine, the following must be performed to protect the engine: 1. Disconnect the battery positive and negative conductors from the battery 2. Turn off circuit breakers or remove fuses in all the power supplies to the engine and any engine associated electrical equipement, and 3. Disconnect and pull back the OEM interface connector from the engine control module and any other engine related electronic control modules.**

Service Accessibility

The following is a list of Starting System service points that should be accessible:

- Battery disconnect switch
- Starter mounting bolts and electrical connections
- Auxiliary magnetic switch
- All wiring connection points

Installation Directions

Starting

! **Starter(s) must be connected directly to the battery or to a common connection point (bus), which is connected directly to the battery.**

! **A battery disconnect switch must be installed.**

The starter positive and negative conductor(s) must be connected directly to the battery or to a common connection point (bus), which is connected directly to the battery.

A battery disconnect switch must be installed in the positive conductor(s) from each battery or battery bank. The switch should be mounted in an accessible location as close, as possible to the battery.

The purpose of a battery disconnect switch is to:

- Protect the unfused starting circuit when not in use.
- Provide a means to disconnect electrical power for maintenance or in the event of failure.
- Prevent battery drain during periods of storage or non-usage.

At the time this document was published, battery disconnect switch manufacturers, although UL listed, do not use a standard method for rating the switch in an intermittent amperage condition. Ratings such as “intermittent”, “cranking”, and “momentary” all exist to describe a condition where a maximum current is limited by time and repetition. However, all will have a continuous duty rating. When selecting a switch that can withstand the current of starting the engine, the method of how the manufacturer rated the switch must be understood. As a general guideline, Cummins Inc. recommends that the switch has a continuous rating that satisfies the larger amperage value of the two following statements:

- One third of the minimum battery capacity (CCA) as specified on the General Engine Data Sheet.

-or-

- The total ampacity of the overcurrent devices connected to the switch or the ampacity of the feeder cable to the switch, whichever is less.

Cummins further recommends that battery disconnect switches with tin plated copper terminals are used, rather than brass alloys. Tin plated copper offers superior corrosion resistance and much better conductive properties than brass, reducing resistance across the switch for improved starter performance.

The engine must achieve a minimum cranking speed of 150 RPM (tested in no run condition)

Diesel engines require a minimum cranking speed to generate cylinder temperatures high enough to support combustion and facilitate starting. In addition, electronically controlled engines will not begin the injection of fuel during start conditions until a minimum speed is achieved.

Cummins Inc. requires that the engine must achieve a minimum cranking speed of 150 RPM. The engine must be tested with the fueling disabled so that the speed of the engine is generated only by the starter, and is not assisted by combustion.

The ability for the engine to meet the minimum cranking speed requirements is largely dependent on battery capacity and starter circuit voltage drop.

The total combined voltage drop in the paths to and from the starter must be less than 1V/2V for 12V/24V starters respectively.

The starter motor needs to receive an adequate supply of electrical energy from the batteries to be able to start the engine throughout the expected range of ambient conditions while in service. A substantial part of starting difficulties can be traced to excessive voltage loss in the wiring to the starting motor because of high resistance. It is essential that the wire sizes and connections are such that the energy losses are within allowable limits initially, and do not change appreciably over time.

Cummins validates the starting circuit by measuring voltage drop. The total combined voltage drop from the positive and negative conductors to the starter must be less than 1V/2V for 12V and 24V systems respectively.

When measuring voltage drop in the starting circuit, the engine fueling must first be disabled. This will allow the engine to crank continuously without starting. Voltage readings are taken directly at the battery bank and at the starter using a digital Volt Ohm Meter (VOM). (see Figure 12-1) Readings from the VOM should be taken manually after the crank cycle is initiated and the voltage has stabilized. Automatic MIN/MAX function on the VOM should not be used, as it will capture the voltage drop during to the initial high current “in rush” to the starter, and not the steady state current draw.

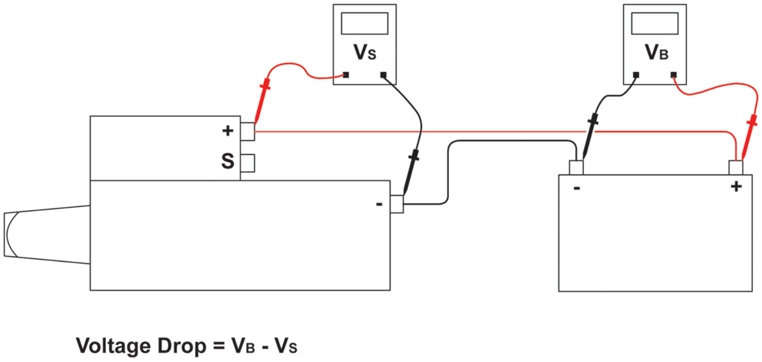


Figure 12-1: Starter Circuit Voltage Drop Measurement

Note: *The resistance in the starting circuit should be limited to .001 ohms for 12V systems and .002 ohms for 24V systems, to be able to meet the voltage drop requirement.*

It should be understood that the resistance of the starting circuit will degrade over the life of the vessel. Steps should be taken to limit this degradation and ensure the circuit resistance does not significantly impact the starter motor cranking performance. The following should be considered in developing a robust starting circuit:

- Determine proper cable size to meet resistance guidelines for the necessary wire lengths.
- Avoid running “taut’ cables between connection points.
- Select insulation to meet use and routing requirements.
- Choose proper terminals for all cables. Terminal connectors should be sealed to prevent corrosion.
- Do not use star or toothed type lock washers, as they can promote corrosion.
- Secure and protect the cables with items such as clamps, conduit, terminal boots, and sleeves.
- Determine protection requirements from exposure to water and heat sources.
- Limit the number of cables attached to a terminal, preferably 2. Multiple connections on a single terminal are more likely to loosen over time due to the relative softness and compression of the terminal lugs after the connection is tightened.
- Corrosion protection.

Calculating Starting Circuit Resistance

When designing a starting circuit, the total resistance can be calculated by summing the resistance of the cables (positive and negative), the connection points in the system, and the use of additional components such as disconnect switches. The resistance in the starting circuit should be limited to .001 ohms and .002 ohms for 12V and 24V systems respectively, to be able to meet the voltage drop requirement. Table 12-1 gives the typical resistance values for connections, disconnect switches, and marine grade battery cable. The graphs in Figures 12-2 and 12-3 can be used to determine battery cable resistance, based on length and size.

When multiple batteries are used, the resistance of the cables connecting the batteries must also be considered. Depending on how the batteries are connected, series or parallel, will dictate how their resistance is added.

- For batteries that are in parallel, the connection cables only carry a portion of the full amperage of the system, depending on their location. The resistance of each connection cable must be multiplied by the fraction of amperage carried with respect to the total amperage of the system, before being added to the system resistance (see Figure 12-4).
- For batteries that are in series, the connection cables carry the same amperage as the batteries they connect (see Figure 12-5).

- For batteries that are in series-parallel, the resistance of all connection cables must be multiplied by the fraction of amperage carried by the cable with respect to the total amperage of the system, before being added to the system resistance (see Figure 12-6).

☎ **For assistance in calculating the starting circuit resistance, contact your local Cummins Marine Certified Application Engineer**

Item	Resistance, Ohms
Connection, each	0.00001
Disconnect Switch, each	0.0002
1/0 Cable, per meter (foot)	0.00032 (0.000099)
2/0 Cable, per meter (foot)	0.00025 (0.000077)
3/0 Cable, per meter (foot)	0.00020 (0.000062)
4/0 Cable, per meter (foot)	0.00016 (0.000049)

Table 12-1: Typical Resistance Values

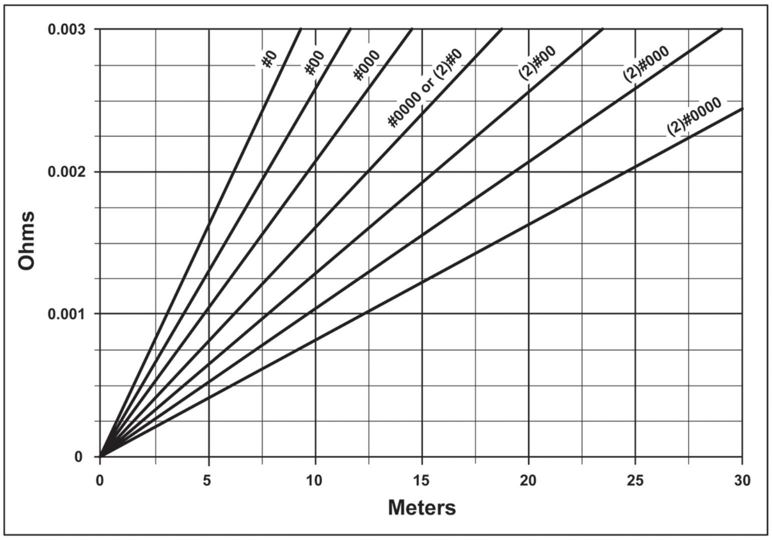


Figure 12-2: Resistance vs. Cable length (Meters)

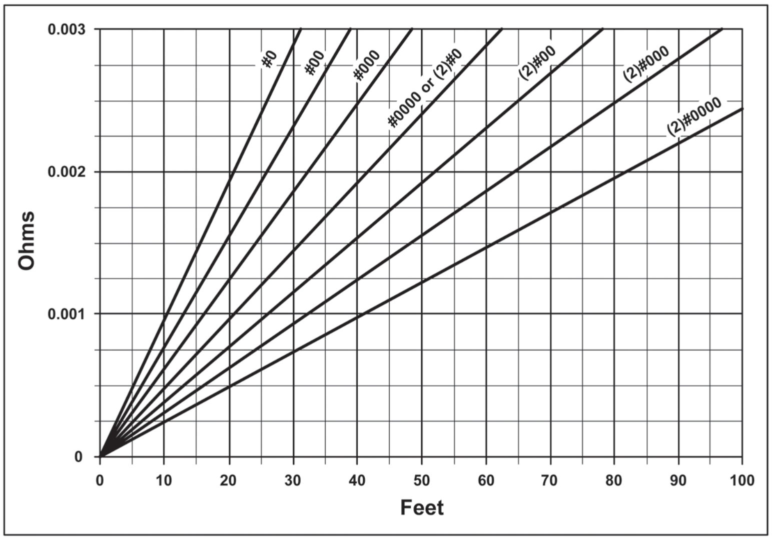


Figure 12-3: Resistance vs. Cable Length (Feet)

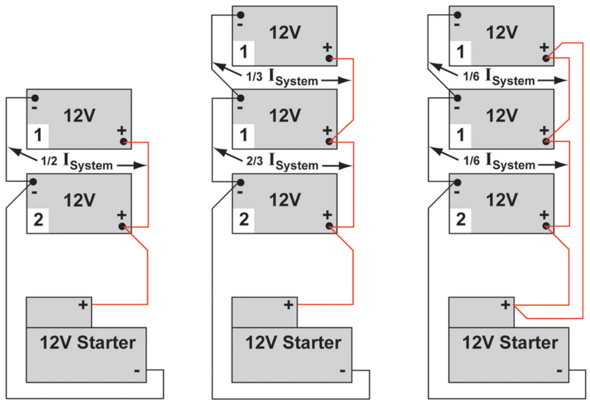


Figure 12-4: Parallel Battery Connection Cables – Carried Current

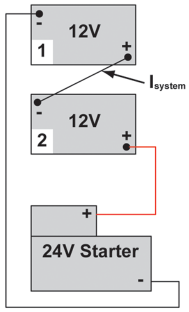


Figure 12-5: Series Battery Connection Cables - Carried Current

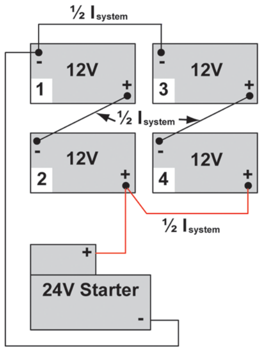


Figure 12-6: Series-Parallel Battery Connection Cables - Carried Current

An auxiliary magnetic switch must be installed between the key switch and the starter solenoid. It must be mounted horizontally and wired directly to the "S" terminal of the starter solenoid, without any additional electrical loads/connections.

An auxiliary magnetic switch, also referred to as a starter relay, must be installed between the key switch and the starter solenoid. Key switch circuits are not sized to carry the current draw from the starter solenoid and therefore should not be connected directly. Instead, the use of an auxiliary magnetic switch that is controlled by the key switch will allow the starter solenoid to be wired directly to the battery through the starter positive terminal.

The auxiliary magnetic switch must be wired such that the switched terminal is connected directly to the starter solenoid "S" terminal. In addition, there must not be any additional electrical loads and/or connections added to this circuit. For proper starter solenoid operation, the circuit should be sized to have no more than a 1V drop for

12V systems or a 2V drop for 24V systems, as measured between the starter "S" terminal and battery negative, when both the starter solenoid pull in and hold coils are energized. (See Figure 12-7)

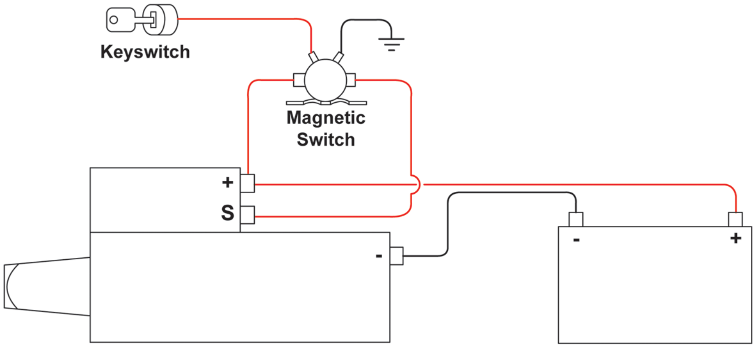


Figure 12-7: Magnetic Switch Installation

Auxiliary magnetic switches must be mounted with the axis of the plunger horizontal with respect to the waterline, and should be perpendicular to the axis of travel of the vessel. Doing so ensures that the motion of the vessel does not inadvertently activate the switch. (see Figure 12-8)

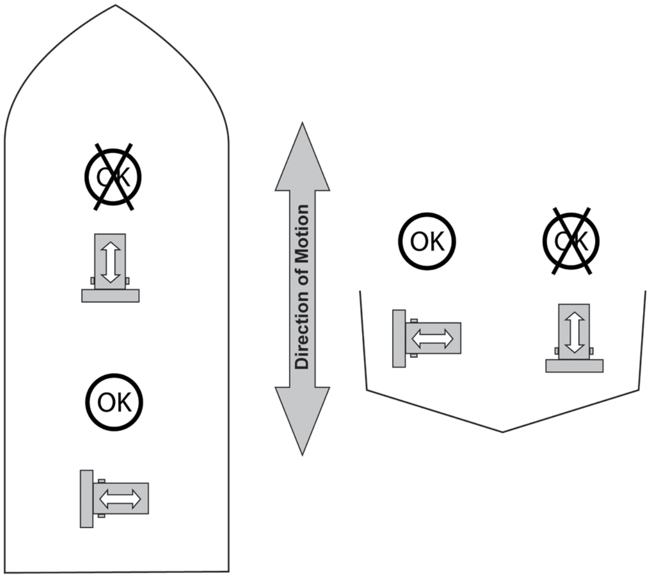


Figure 12-8: Auxiliary Magnetic Switch Installation

! **The engine must be prevented from starting when in gear.**

Starting an engine while the marine gear is engaged will cause excessively high loads upon the starting system, and can be a safety issue. Therefore, the engine must be prevented from starting when in gear. Neutral safety lockout switches are available through the marine gear and throttle supplier. These switches are closed in the neutral position and open in the ahead or astern positions. When wired in series with the engine crank circuit (see Figure 12-7), the engine will crank in the neutral (switch closed) position and will not crank in the ahead or astern (switch open) position. All Cummins engines have a provision to integrate a neutral safety lockout switch. See the Wiring Diagram for location and connection type.

Electronic Control System

Summary of Requirements

Electronic Engine Applications

- **! Cummins Inc. supplied Electronic Control Systems must be “as delivered” and must not be modified.**
- **! The ECM positive and negative power cables must be connected to the engine battery so that the power to the ECM will not be interrupted during operation.**
- **! The ECM power cable must be a dedicated power supply to the ECM. No additional loads may be connected to the ECM power cable.**
- **! The ECM power cable must have proper overcurrent protection.**
- **! The ECM power cable circuit resistance must not exceed 50 milliohms.**
- **! If a battery charger is connected to the battery, it must be independent of the ECM power supply cable, such that they do not share a conductor.**
- **! Wiring used for SAE J1939 and/or SAE J1708 connections must comply with applicable communications standards.**
- **! The data link diagnostic connector must be installed in a technician accessible location.**
- **! The throttle device must comply with the requirements defined in MAB 0.19.06-07/31/2001 & MAB 0.19.06-04/24/2001.**
- **! Twisted triple wires at the rate of one twist per 25.4 mm (1 in) must be used on throttle input wiring.**
- **! The throttle signal must be 0% when the hand lever is in the idle position and 100% when the hand lever is in the full throttle position, both forward and reverse.**

General Information

The electronic control system encompasses the power supply to the Engine Control Module (ECM) and ECM inputs and outputs such as electronic throttle, communications (data links), and switched inputs.

The ECM is continuously reading information via inputs, processing those signals, and then adjusting outputs to control fueling, gauges, etc. to meet the needs of the operator in an effective and efficient manner. Like any electronic component, a robust power supply is critical for ensuring its proper operation.

Both analog (voltage, resistance, mA) and digital (data links, controlled area networks) signals are used on the engine. When installing or integrating electronic control system components, the most important considerations are proper initial setup and protecting the signal from degradation or interference.

! **If welding on the vessel or engine, the following must be performed to protect the engine: 1. Disconnect the battery positive and negative conductors from the battery 2. Turn off circuit breakers or remove fuses in all the power supplies to the engine and any engine associated electrical equipement, and 3. Disconnect and pull back the OEM interface connector from the engine control module and any other engine related electronic control modules.**

Service Accessibility

The following is a list of Electronic Control System service points that should be accessible:

- ECM power supply overcurrent protection
- Data link Diagnostic Connector
- Electronic throttle adjustment points

Installation Directions

! **Cummins Inc. supplied Electronic Control Systems must be “as delivered” and must not be modified.**

Cummins Inc. supplied Electronic Control Systems must be “as delivered” and must not be modified. Modifications including splices, removal and/or addition of hardware, and any other changes are not approved. Failure of a customer modified electronic control system and any associated progressive damage will not be warranted by Cummins.

! **The ECM positive and negative power cables must be connected to the engine battery so that power to the ECM will not be interrupted during operation.**

! **The ECM power cable must be a dedicated power supply to the ECM. No additional loads may be connected to the ECM power cable.**

! **The ECM power cable must have proper overcurrent protection.**

! **The ECM power cable circuit resistance must not exceed 50 milliohms.**

! **If a battery charger is connected to the battery, it must be independent of the ECM power supply cable, such that they do not share a conductor.**

△ **CAUTION: Improper wiring of the ECM power supply may damage the ECM.**

The ECM is continuously reading information via inputs, processing those signals, and then adjusting outputs to control fueling, gauges, etc. to meet the needs of the operator in an effective and efficient manner. Like any electronic component, a robust power supply is critical for ensuring its proper operation. The following are the requirements for designing and applying a power supply that will provide the needs of the ECM:

The ECM positive and negative power cables must be connected to the engine battery so that the electrical connection will not be interrupted during operation. Cummins Inc. recommends that the ECM power cables be connected directly to the battery or a bus fed directly from the battery. This is because the battery acts as a filter capacitor, reducing voltage fluctuations. It is acceptable to connect the ECM positive power cable either before or after the battery disconnect switch. However, cable length to the battery switch should be kept at a minimum, to limit voltage drop due to line loss during engine cranking. (see Figure 13-1) It is not acceptable for the power supply to the ECM to be controlled by the keyswitch, either directly or by a relay.

Note: *If the ECM positive power cable is connected after the battery disconnect switch, that switch should remain closed for at least 30 seconds after shut down of the engine(s), to allow the ECM to perform a proper shutdown cycle. Otherwise, ECM historical information may be missing and/or faults may occur.*

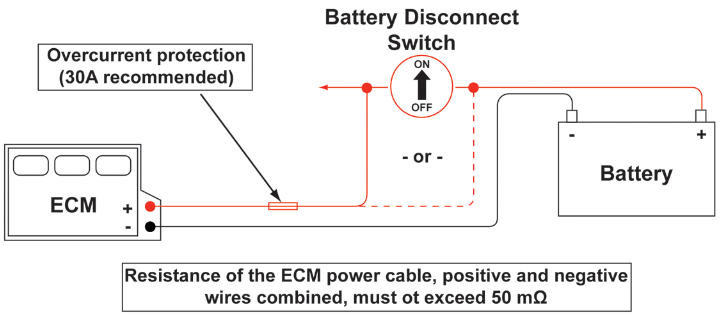


Figure 13-1: ECM Power Supply

It is important that the voltage to the ECM remains constant with respect to battery voltage and is free of surges. To accomplish this, the ECM power cable must be a dedicated power supply to the ECM. No additional loads may be supplied by the ECM power cable.

The ECM power cable must have proper overcurrent protection installed. The recommended ECM power cable overcurrent protection is 30 amps. Some engines may have ECM power circuit overcurrent protection already integrated into the engine harnessing. However, overcurrent protection is still required in the ECM power cable, to protect the cable itself. The location of the overcurrent protection device may depend on the local regulations and/or the standards the builder is complying to.

The resistance of the ECM power cable must not exceed 50 milliohms. This is for both the positive and negative conductors combined. This ensures a permissible voltage drop to the ECM. Table 13-1 shows the Cummins recommended conductor size for given harness lengths to safely remain within the allowed cable resistance.

Harness Length m (ft)	**Wire Gauge** AWG
3 (10)	12
4.5 (15)	10
6 (20)	10
7.6 (25)	8
9.1 (30)	8
10.6 (35)	6
12.1 (40)	6
13.7 (45)	6
15.2 (50)	6

Table 13-1: Recommended ECM Power Cable Conductor Size

When connecting a battery charger to the battery bank, the connections must not be installed between the battery and the ECM. The connection of a battery charger and the ECM power supply to the battery must be independent and not share a common conductor. (see Figure 13-2) This method of connection is important because the battery acts as a filter capacitor to dampen any voltage fluctuations or spikes, caused by the battery charger, that may be potentially harmful to the ECM. If the battery charger and ECM power supply were to share a common conductor and the battery was disconnected, power could be supplied directly from the battery charger, possibly causing damage to the ECM.

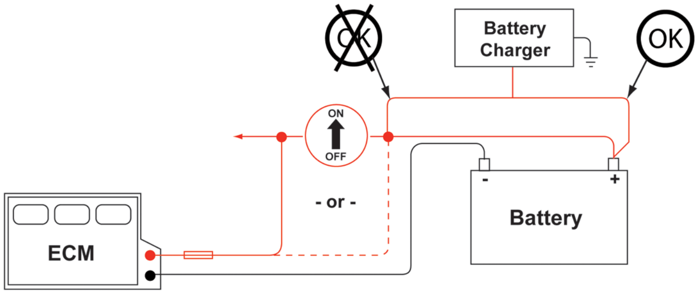


Figure 13-2: Battery Charger Connection

Wiring used for SAE J1939 and/or SAE J1708 connections must comply with applicable communications standards.

SAE J1939 and/or SAE J1587/J1708, and recently CAN Kingdom (Smartcraft) are data links that provide a means for the engine and related electronic devices on the vessel to communicate with each other. Some typical functions performed are sharing of sensor data, sharing of calculated information, allowing subsystems to influence each other's operations, and communication of subsystem operation state. Data links also provide a means for diagnostic work to be done by way of electronic service tools.

Electronic Cummins engines are supplied with one or more data links that provide the necessary communication needs. Depending on the number of engines and helm stations, some configuration of the data link system may be necessary. Additionally, the customer may choose to interface other compatible components that require proper installation practices. Gauges and displays for engine information is a typical example of these components. Specifics regarding configuration and integration into the data links can be obtained through Cummins Inc. published Application Engineering Bulletins (AEBs), Marine Application Bulletions (MABs) and Wiring Diagrams.

For assistance with obtaining Cummins published AEBs and MABs, contact your local Cummins Marine Certified Application Engineer.

- The data link is a high speed network which operates at 250k baud.
- The topology of J1939 is a linear bus, meaning, in simple terms that it has a beginning and an end. (see Figure 13-3) The main wires of the data link are referred to as the backbone. Devices communicating on the data link are referred to as nodes. The wires connecting the backbone to the nodes are referred to as stubs
- Both ends of the backbone must be terminated with a 120 ohm resistor.
- J1939 cable used for the backbone is color coded. J1939+ (CAN_H) uses a yellow and J1939- (CAN_L) uses green. All added connections should utilize this color scheme to avoid misconnections and promote easier troubleshooting.
- The backbone wires are twisted and may be shielded to prevent radio frequency (RF) interference.
- The backbone shield (if used) is connected to a drain wire, which in turn is connected to the nodes and backbone interconnects. The shield/drain wire should be grounded only at one point to the battery negative.
- The maximum length of the backbone is 40 m (131 ft).
- The maximum number of nodes connected to the backbone is 30.
- The maximum length of a stub is 1 m (3.3 ft).

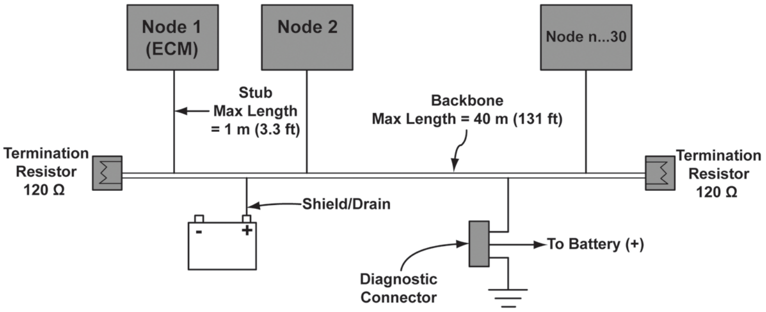


Figure 13-3: Example of J1939 Topology

Recently, Cummins MerCruiser Diesel engines have been equipped with Smartcraft, which communicates using CAN Kingdom protocol. Smartcraft allows the engine and vessel controls and information to be intregrated into a single network. The topology of CAN Kingdom is essentially the same as J1939, but they are not able to directly communicate. It is important to understand that engines equipped with Smartcraft still retain a J1939 data link for communication with the ECM. A System Integration Module (SIM) is used to communicate between the CAN Kingdom (Smartcraft) and J1939.

J1708

- The data link is much slower than J1939, operating at 9600 baud.
- The topology of J1708 is described as “free”, compared to the linear bus topology of J1939. (see Figure 13-4) The terms backbone, stubs, shield, and termination resistors do not apply to J1708.
- The J1708 cable is a twisted pair.
- The maximum length of the cable is 40 m (131 ft).

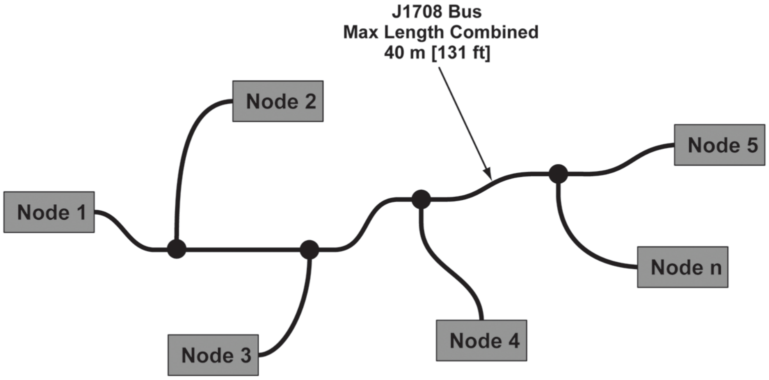


Figure 13-4: Example of J1708 Topology

The data link diagnostic connector must be installed in a technician accessible location.

The data link diagnostic connector will be located either as a stub off the main station harness, on the engine, or on the Vessel Interface Panel (VIP). Regardless of its location, the diagnostic connector must be accessible for connection to Cummins diagnostic service instruments by a technician.

Throttle – Electronic Engines

The throttle device must comply with requirements defined in MAB 0.19.06-07/31/2001 & MAB 0.19.06-04/24/2001.

Twisted triple wires at the rate of one twist per 25.4 mm (1 in.) must be used on throttle input wiring.

The Cummins MerCruiser Diesel product line includes a growing number of electronically controlled engines. These were developed with several different fuel control systems and for use in diverse market applications. The product complexity has resulted in non-uniform throttle interfaces. It can be difficult to understand what throttle signal is required for each product. CMD does supply pre-engineered throttle solutions. However, for customer supplied throttles, the following, which is taken from MAB 0.19.06-07/31/2001, will clarify the different requirements and establish a consistent approach for new products.

☎ **For assistance with obtaining Cummins published AEBs and MABs, contact your local Cummins Marine Certified Application Engineer.**

Summary of Installation Requirements for Electronic Throttles

Cummins Inc. installation requirements for throttles are summarized below, and explained in detail in the Discussion section.

Throttle devices must be connected to the engine according to the circuit definition specified in the Marine System Wiring Diagram and the throttle wiring must comply with the following:

- Gold plated terminals must be used at all connections.
- Power, signal, and ground wires must be twisted at least once for every inch of length.

The electrical ground for the throttle device must be common with the engine electronic control module (ECM) ground.

The minimum and maximum voltage values of the throttle signal input to the engine harness connection must be within the upper and lower limits specified in Table 13-3. The signal values in Table 13-3 are applicable when the input signal is exposed to an input impedance of 47K ohm +/- 5% and electrically connected as shown in Figure 14-11.

The idle validation switch (IVS) input signals must comply to the following, relative to the values specified in Table 14-4.

- The switch must change states when the throttle signal is within the indeterminate range or within .050 seconds following a signal transition beyond the upper or lower range limits.
- The switch position must be "on idle" when the throttle input signal is below the lower range limit.
- The switch position must be "off idle" when the throttle input signal is above the upper range limit.
- Open circuit impedance > 10 M Ohms
- Closed circuit impedance < 10 Ohms

Throttles with Idle Validation (IVS) must be calibrated immediately following installation.

The throttle signal must exhibit the following characteristics:

- Linearity - maximum +/- 2 percent of the voltage span.
- Hysteresis - maximum +/- 1 percent whenever the hand lever is returned to the same position from any other position.
- Smoothness - such that it does not vary by more than 0.5 percent within any 2.0 percent change of hand lever rotation.

Discussion

This discussion includes the following topics:

1. Marine Controls

2. Throttle Interface Types
3. Throttle Interface Requirements
4. Back-up Throttles

Marine Controls

Vessel owners have many options for throttle controls. Their choice generally depends upon how much they are willing to spend and how much control function they want. A basic system consists of one or more hand levers and a device that converts hand lever motion to an electrical signal for throttle control, and sometimes gear shift control. Some options are generally described below, and contact information for common suppliers are included in the References section.

- Fully electronic - This system is similar to an electro-mechanical one, but provides a direct electric signal (either voltage or current) to the engine and electronically controlled marine gear. A multi-function hand lever controls both engine and marine gear. This system also commonly features enhanced clutch control, including variable engagement time and clutch modulation (simulated trolling valve) for incremental propeller speed reduction. ZF Mathers & Twin Disc are common suppliers.
- Electro-mechanical - This is a system that converts electronic signals from a microprocessor device into mechanical actuation to rotate a potentiometer. It most often is applied when an electronically controlled engine is matched with a mechanical marine gear. A multi-function hand lever controls both engine and marine gear for enhanced operation. ZF Mathers and Twin Disc are common suppliers of this equipment, which may be used with the Cummins electronic throttle option described above.
- Mechanical-electric - This system typically involves cable, pneumatic, or hydraulic actuation to rotate a potentiometer that outputs an electric voltage signal. Single function hand levers are commonly used, such that the engine and gear are controlled independently. Cummins Inc. offers an electronic throttle option for this purpose.

Throttle Interface Types

Cummins Marine throttle interfaces vary, based on the type of engine electronic control system and the type of throttle device (or source of the electric signal). Specifically, the throttle interfaces are classified by the following, and summarized in Table 13-2.

1. CENTRY engine control - used on K-Series engines.
2. Non-CENTRY engine control - applies to various engines with other types of electronic fuel systems.
3. Voltage driver - throttle device that outputs DC voltage.
4. Current driver - throttle device that outputs 4-20 mA current.
5. Idle validation - throttle device that outputs a switch signal to indicate when the hand lever is in the idle position.

Throttle Interface Name	Engine Control System	Throttle Device
Type 1	CENTRY	Voltage driver **without** idle validation switch (IVS).
Type 8	CENTRY	4-20 mA current driver and 226 ohm +/-1% shunt resistor, **without** idle validation switch (IVS).Can also be used with a voltage driver, but is not recommended.
Quantum Marine	Non-CENTRY	Voltage driver **with** idle validation switch (IVS).Preferred for use with **single function** hand levers.
Quantum Marine	Non-CENTRY	Voltage driver **without** idle validation switch (IVS).Preferred for use with **multi-function** hand levers.
Quantum Marine	Non-CENTRY	4-20 mA current and 200 ohm +/-1% shunt resistor, **without** idle validation switch (IVS).Preferred for use with **multi-function** hand levers.Production availability planned for August '02

Table 13-2: Throttle Interface Types

For CENTRY engines, the throttle interface type is determined by the engine calibration (FQ option). Therefore, it is important to specify the correct calibration option within the engine order to attain the desired interface. Otherwise, recalibration in the field using INSITE (service ESDN) may be required.

The 4-20 mA current driver interfaces should typically be used for installations involving the following:

- The throttle signal is generated from micro-processor type controllers. The 4-20 mA current drivers are commonly used to control many types of machinery used in marine applications. So compared to less standard voltage driver interfaces, it can be more easily specified and understood by the many different controller manufacturers.

- The throttle signal is subject to high resistance or noise. When a voltage driver device is used with lengthy or junctioned wiring harnesses, throttle signal errors can result from excessive voltage drop. A 4-20 mA current driver is not subject to the voltage drop problem.
- A wiring harness adapter containing the correctly sized shunt resistor is installed at the throttle connection on the engine. This serves to convert the 4-20 mA current to a DC voltage signal input to the ECM. The conversion from current to voltage must occur at the engine harness connection (not at the current source) using a Cummins Inc. supplied wiring harness adapter with shunt resistor (available as an engine wiring harness EC or EA option). CENTRY and Non-CENTRY engines use different adapter harnesses containing different connectors and resistors.

The idle validation interfaces are characterized as follows:

- Interfaces with idle validation switch (IVS) input are intended for use with mechanically actuated potentiometers. IVS usage is recommended whenever single function controls (independent throttle and gear levers) are used.
- Interfaces without IVS are intended for use with multi-function controls (combined throttle and gear lever) which directly output a voltage signal from an electronic control source. Multi-function controls may exclude use of IVS because they allow an operator to easily respond to a faulty throttle signal by engaging neutral gear.
- The Non-IVS throttle interface is established by not connecting to the IVS connector on the marine engine harness. Without sensing an IVS signal, the engine control module (ECM) defaults to a non-IVS interface. Once the ECM senses IVS activity, it establishes the IVS throttle interface and an IVS signal must always be present to avoid a fault condition. When an IVS throttle interface is established, the only way to change to a non-IVS interface is to completely calibrate the engine ECM using INSITE™ electronic service tool (service ESDN). Therefore, whenever testing the engine without vessel controls (such as on a dynamometer, or when troubleshooting) always use the same interface as that on the vessel.
- The IVS interface includes an auto scaling feature that automatically adjusts the 0 and 100 precent throttle break points based on the actual minimum sensed voltage value. This can help to minimize dead band (unresponsiveness) and improve the overall "feel" of the throttle.

The various throttle interfaces are graphically represented by Figures 13-5 through 13-9.

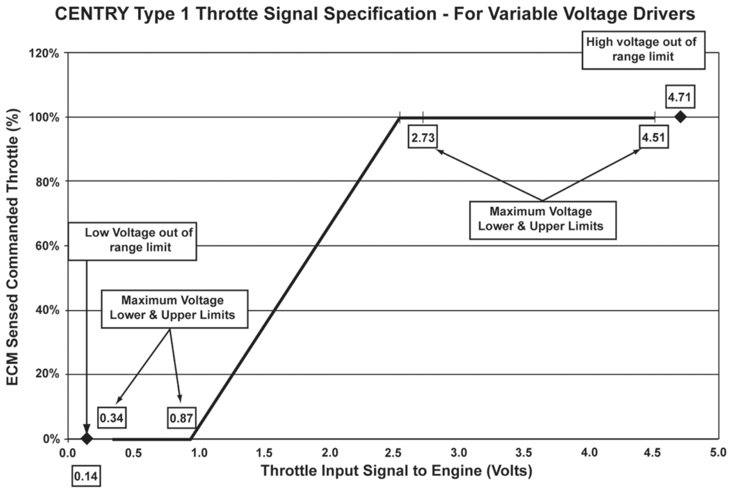


Figure 13-5: CENTRY Type 1

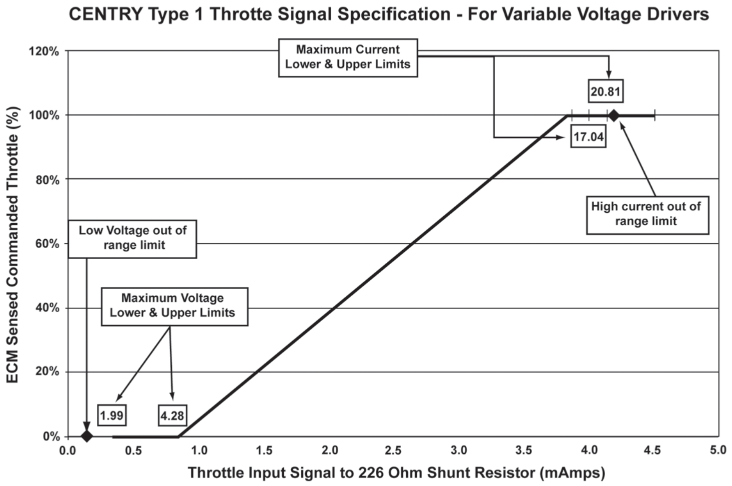


Figure 13-6: CENTRY Type 8

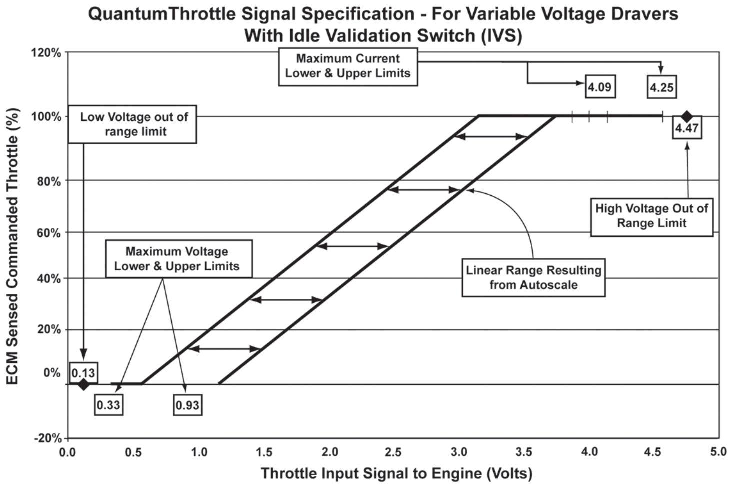


Figure 13-7: Quantum Marine with IVS

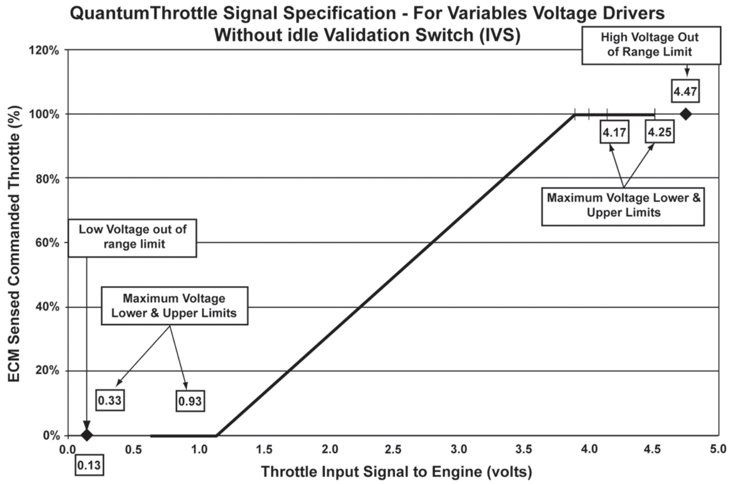


Figure 13-8: Quantum Marine without IVS

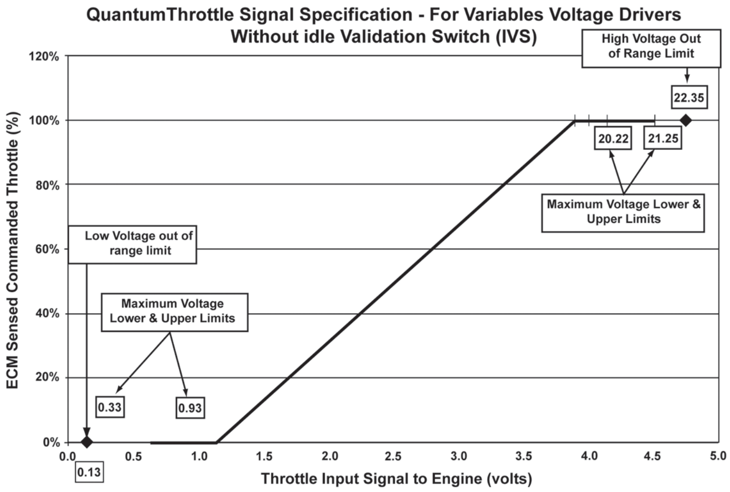


Figure 13-9: Quantum Marine for 4-20 mA

Throttle Interface Requirements

The technical requirements for the throttle interfaces described above are detailed as follows:

Throttle devices must be connected to the engine according to the circuit definition specified in the Marine System Wiring Diagram and throttle wiring must comply to the following:

- Gold plated terminals must be used at all connections.
- Power, signal, and ground wires must be twisted at least once for every inch of length.

Marine engine wiring harnesses contain either one or two 3-pin Packard style connectors containing throttle circuits. The details of these connections are described in the Wiring Diagrams.

A general schematic of the throttle circuitry is shown in Figure 13-10 below.

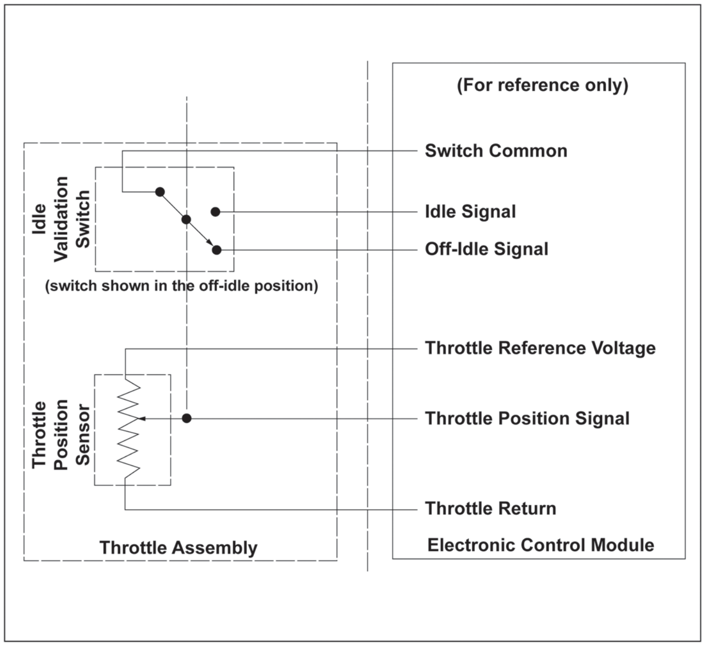


Figure 13-10: Example of Throttle Circuitry

The electrical ground for the throttle device must be common with the engine electronic control module (ECM) ground.

A common ground can be achieved by connecting the throttle device to the throttle ground wire supplied within the throttle connector on the marine engine harness. The power source for the throttle device can be independent or it can use power supplied by the engine ECM. A power wire, (providing 5.0 VDC), is also supplied in the throttle connector. If ECM power is used, it is important to know that CENTRY ECMs have an internal 470 ohm resistance on the power output circuit, as shown in Figure 13-11. So for CENTRY engines only, the actual reference voltage supplied to the throttle device will be somewhat less than 5.0V and dependent upon the sum of the internal 470 ohm and undetermined throttle device resistances. Power output from ECMs on non-CENTRY engines is 5.0V.

Always comply to manufacturers' instructions when installing their throttle devices. Special instructions for bonding may also be required, particularly for installation in fiberglass vessels.

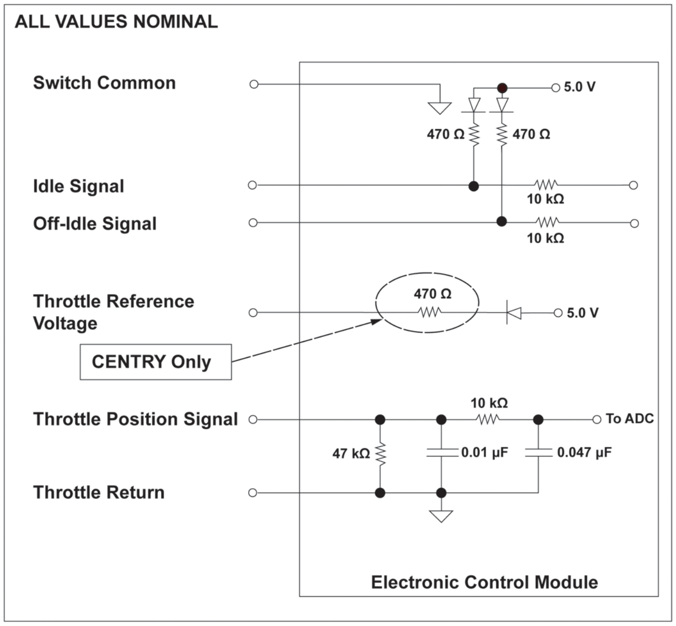


Figure 13-11: Throttle Circuitry Internal to the ECM

The minimum and maximum voltage values of the throttle signal input to the engine harness connection must be within the upper and lower limits specified in Table 13-3. The signal values in Table 13-3 are applicable when the input signal is exposed to an input impedance of 47K ohm +/- 5% and electrically connected as shown in Figure 13-11.

To minimize dead band (unresponsive regions of hand lever travel), it is recommended that the throttle devices be adjusted to achieve the target values also listed in Table 13-3, if possible.

A 47K ohm impedance internal to the engine ECM (shown in Figure 13-11) can significantly affect the throttle input signal and complicate troubleshooting. Therefore, comparison of a measured throttle signal to the Table 13-3 limits requires connection of the complete throttle circuit (from the voltage source to the ECM). Because a volt meter cannot easily be used at the closed engine harness connection, the following troubleshooting tips are recommended:

1. Disconnect the circuit at the engine throttle input connector and measure the voltage from signal to ground, on the throttle source side of the connector. Reference power may need to be applied to the throttle device. If the measured throttle signal voltage is within the Table 13-3 specified range by at least 10%, discount the effect of the input impedance. Otherwise, troubleshoot using tip #2 or #3.
2. Install jumper connections (or "break out" adapter P/N 3823255) across the engine throttle input connector, such that a volt meter measurement can be made with the circuits complete. Figure 13-12 illustrates this test set up.
3. With the throttle connected, use INSITE™ electronic service tool software version 6.1.18 or later to monitor ECM sensed throttle voltage. This is the most accurate method to compare the input signal against the requirements.

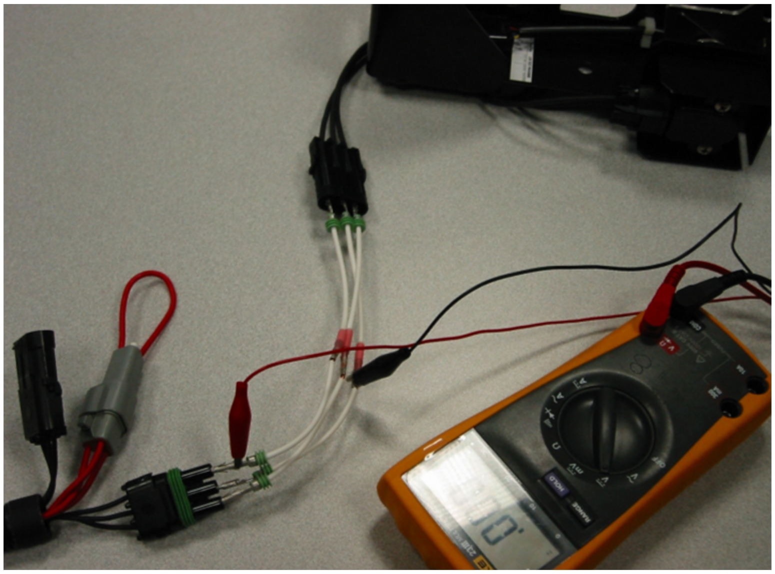


Figure 13-12 - Example of Voltage Test with Break Out Jumper Wires

Interface Type	Throttle Input Signal	Lower Limit	Target	Upper Limit
CENTRY Type 1	Minimum Voltage	0.34	0.86	0.87
	Maximum Voltage	2.73	2.78	4.51
CENTRY Type 8	Minimum Voltage	0.0020	0.0042	0.0043
	Maximum Voltage	0.0170	0.0174	0.0208
	Minimum Voltage	0.45	0.95	0.97
	Maximum Voltage	3.85	3.93	4.70
Quantum Marine without IVS	Minimum Voltage	0.33	0.91	0.93
	Maximum Voltage	4.17	4.20	4.25
Quantum Marine with IVS	Minimum Voltage	0.33	0.63	0.93
	Maximum Voltage	4.09	4.17	4.25
Quantum Marine for 4-20mA	Minimum Voltage	0.0017	0.0048	0.0049
	Maximum Voltage	0.0202	0.0206	0.0228
	Minimum Voltage	0.33	0.95	0.97
	Maximum Voltage	4.04	4.13	4.55

Table 13-3 - Throttle Signal Requirements

Note: *Interfaces with an idle validation switch (IVS) are available on some engines. If equipped, the IVS interface is established by either connecting or not connecting the IVS connector on the engine. It is important to remember that once the ECM senses an IVS installed, it establishes the IVS interface and will continue to require an IVS signal to be present to avoid a fault condition. After an IVS interface is established, the only way to change to a non IVS interfaces is to calibrate the ECM. Therefore, the engine should be operated only with the same interface intended for use on the finished vessel. The IVS interface is not active on engines with the CM850 control module.*

The idle validation switch (IVS) input signals must comply to the following, relative to the values specified in Table 13-4:

- The switch must change states when the throttle signal is within the indeterminate range or within .050 seconds following a signal transition beyond the upper or lower range limits.
- The switch position must be "on idle" when the throttle input signal is below the lower range limit.
- The switch position must be "off idle" when the throttle input signal is above the upper range limit.
- Open circuit impedance > 10 M Ohms
- Closed circuit impedance < 10 Ohms

Indeterminent Range of IVS	Throttle Input Signal (volts)
Lower Limit	Actual minimum sensed voltage +0.10
Upper Limit	Actual minimum sensed voltage +0.40

Table 13-4 - IVS Signal Requirements

The indeterminate range represents the condition of throttle position when it is acceptable for the IVS to change states between "on idle" and "off idle". As shown in Table 14-4, this range varies, based on the actual minimum sensed voltage (corresponding to the hard stop idle position of the hand control lever).

Throttles with Idle Validation (IVS) must be calibrated immediately following installation.

The IVS interface features an auto zero scaling feature that minimizes throttle dead band (or unresponsiveness). Auto zero scaling requires that the ECM be calibrated to the throttle signal as soon as the throttle is installed. To calibrate the ECM, first provide power to the ECM by turning the key switch on (engine not running). Then, quickly exercise the throttle lever from idle to full throttle and back to idle, three consecutive times,

The throttle signal must exhibit the following characteristics:

- Linearity - maximum +/- 2 percent of the voltage span
- Hysteresis - maximum +/- 1 percent whenever the hand lever is returned to the same position from any other position
- Smoothness - such that it does not vary by more than 0.5 percent within any 2.0 percent change of hand lever rotation.

The smoothness constraint only applies over the useable range of hand lever rotation. Exclude rotation corresponding to zones of dead band (unresponsiveness).

Back-Up (Remote) Throttles

Cummins Marine does not have a unique throttle interface requirement for applications that use a back-up throttle. In this case, installers may choose one of three options for a back-up throttle.

- Use a Cummins Marine back-up throttle option, available for use on non-CENTRY engines.
- Use two or more throttle devices that satisfy one of the standard interface requirements and incorporate a multi-pole switch device to change the connection between the main and back-up throttle circuits.
- Maintain a spare, but unconnected, throttle device on board the vessel.

Compliance Measures

- INSITE™ electronic service tool readings that demonstrate the ability to achieve 0% and 100% throttle values corresponding to the appropriate hand lever positions.
- INSITE™ electronic service tool readings that demonstrate the ability to achieve stable % throttle values for any given hand lever position.
- Measured input signal voltage within the limits specified in Table 13-3. Voltage must be measured as described in the Discussion section.
- Absence of engine fault codes relating to throttle function.
- Wiring diagrams illustrating complete throttle system circuitry.

References

Cummins Engineering Standard 14118.

Cummins Marine Application Bulletin No. 0.19.06-04/24/2001, Cummins Electronic Throttle.

Below is a list of contact information for some marine controls manufacturers that have demonstrated capability to provide a reliable throttle interface.

1. ZF-Mathers - Offer a variety of marine society approved, multi-function electronic controls. Phone 800 546-5455, Internet link http://ZF-Marine.com/Company/ZF_Mathers_LLC/index.cfm

2. Twin Disc Electronics - Offer multi-function electronic controls. Phone 414-638-4000, Internet link http://www.twindisc.com/plma_powercomm.html
3. Williams Controls - Offer potentiometer type throttles; Phone 877-330-9820. Examples include model WM 532 Remote Sensor Assembly - Internet link http://www.wmco.com/Products/html/wm531.html and model WM 526 Air/Electronic Remote Sensor Assembly - Internet link http://www.wmco.com/Products/html/wm526_air_electronic.html

CAUTION: Unless specified by the supplier of the throttle interface, do not mount the throttle interface system to the engine. Vibration and/or environmental conditions may cause failure.

The throttle signal must be 0 percent when the hand lever is in the idle position and 100 percent when the hand lever is in the full throttle position, both forward and reverse.

To ensure a proper throttle interface, the throttle signals must be 0 percent when the hand lever is in the idle position and 100 percent when the hand lever is in the full throttle position, both forward and reverse. These readings may be confirmed by the diagnostic service tool or a digital display if installed.

CONTROLS, GAUGES, AND ALARMS

SUMMARY OF REQUIREMENTS

Controls, Gauges, and Alarms

- **Instrument panels and wiring must be installed according to Cummins installation instructions.**
- **There must be no additional electrical devices connected to the instrument panels.**
- **The 2nd station panel must be used only with a main station panel and must be connected using the appropriate “Y” harness.**
- **Main station and 2nd station panels in a dual-station installation must be of the same voltage.**

Controls, Gauges, and Alarms – Customer Supplied

- **Each engine installation must include the following mandatory controls, gauges, and alarms: Start and stop switches and/or buttons, engine running hour indicator, tachometer, engine oil pressure, engine coolant temperature, and battery voltage.**
- **Fault indicators must be located at the operator location.**
- **All audible and visual alarms must have test and acknowledge/reset capability.**
- **The engine oil pressure alarm must be set to activate at 20 kPa (3 psi) below the minimum idle value specified in the Engine General Data Sheet, with a persistence time of 5 seconds.**
- **The engine coolant temperature alarm must be set to activate at 96° C (205° F), with a persistence time of 5 seconds.**
- **For non-electronic engines, the tachometer must be driven by a magnetic pickup installed in the flywheel housing and properly calibrated, depending on the number of ring gear teeth.**
- **For electronic engines, tachometers must be driven by the ECM, not the Alternator “R” terminal.**
- **Wiring harnesses and hoses must be secured to the vessel where the harness will not be subjected to physical damage or high temperatures, and will not interfere with normal vessel operating activities.**
- **Wiring harnesses must not be supported by or otherwise be in contact with engine coolant or fuel lines.**

Throttle – Mechanical Engines

- **Mechanical fuel pump throttle lever must be against the idle stop when the hand lever(s) is in the idle position and against the wide open stop when the hand lever(s) is in the fuel throttle position (both forward and reverse.**

GENERAL INFORMATION

Cummins MerCruiser Diesel offers instrument panel and throttle options for customers seeking a pre-engineered solution. For those customers wanting to provide a custom solution, the following section will also describe the requirements for non-factory supplied controls, gauges, and alarms.

Due to the large number of unique controls, gauges, and alarm interfaces that require independent installation instructions, this document will only address general installation requirements relating to these components. For detailed instruction on how to install the controls, gauges, and accessories for your application, the appropriate Marine Application Bulletin (MAB), wiring diagram, and any instructions supplied with the kitted option should be consulted.

☎ **For assistance with obtaining the proper MABs for your application, contact your local Cummins Marine Certified Application Engineer.**

△ **If welding on the vessel or engine, the following must be performed to protect the engine: 1. Disconnect the battery positive and negative conductors from the battery 2. Turn off circuit breakers or remove fuses in all the power supplies to the engine and any engine associated electrical equipement, and 3. Disconnect and pull back the OEM interface connector from the engine control module and any other engine related electronic control modules.**

SERVICE ACCESSIBILITY

The following is a list of Controls, Gauges, and Accessories service points that should be accessible:

- Harness connection points
- Overcurrent protection devices
- Mechanical throttle adjustment points
- All wiring connection points
- All control modules

INSTALLATION DIRECTIONS

Controls, Gauges, and Alarms – Factory Supplied

Instrument panels and wiring must be installed according to Cummins installation instructions.

There must be no additional electrical devices connected to the instrument panels.

Instrument panels and associated wiring that are provided with the engine must be installed according to Cummins Inc. installation instructions. Installation instructions may be included with the kitted option or can be found in the appropriate Marine Application Bulletin (MAB). MABs can be obtained by logging onto http://marine.cummins.com or contacting your local Cummins Marine Certified Application Engineer.

In all installations, there must be no additional electrical devices connected to the instrument panels and associated wiring. Additional electrical loads on the instrument panel and wiring can adversely affect operation of the system.

The 2nd station panel must be used only with a main station panel and must be connected using the appropriate "Y" harness.

Main station and 2nd station panels in a dual-station installation must be of the same voltage.

Many applications require multiple instrument panel locations. This may be for vessels with two or more helm locations, or where an engine room panel is requested in addition to the helm station. When multiple stations are used, the 2nd station panel must be used only with a main station panel and must be connected using the appropriate "Y" harness. Main station and 2nd station panels are unique and must only be used at their intended location. In addition, the main station and 2nd station panels must be of the same voltage.

Note: *The use of 2nd station panels may require sensors to be changed on some mechanical engines. This is generally limited to the oil pressure and coolant temperature switches. If an engine is ordered as a single station, but applied with a second station, and vice versa, compatibility of the sensors should be checked by referencing the proper options for the intended configuration.*

Controls, Gauges, and Alarms – Customer Supplied

Each engine installation must include the following mandatory controls, gauges, and alarms: Start and stop switches and/or buttons, engine running hour indicator, tachometer, engine oil pressure, engine coolant temperature, and battery voltage.

Start and stop switches are required. The location of start switches is not critical; only that they be accessible to the operator. Stop switches are required at each station (local or operator location) for safety and must be readily accessible. Stop/start switches and a tachometer are recommended for each maneuvering station.

For those customers wanting to provide custom instrumentation, Table 14-1 provides a list of the gauges and alarm thresholds required for engine protection. Table 14-2 provides recommendations for optional gauges and alarm thresholds. Shutdown thresholds are provided in the tables, but are not required. If shutdowns are enabled, they must meet the minimum requirements as given in Table 14-1 and Table 14-2.

Note: *The term “Local” below refers to a location where an operator, other than the person piloting the vessel, can monitor engine status. An example is a manned engine space.*

Parameter	Displayed Location	Alarm	Alarm Threshold	Shutdown Threshold
Engine Run Time (Hour Meter)	Local or Operator Station	None	None	None
Engine Speed (RPM)	Operator Station	None	None	Not required; optionally set to the maximum speed limit value on the Engine Performance Curves and Data Sheet or set to the classification society requirement of 115% of genset rated speed or 120% of propulsion rated speed, with a persistence time of 1 second
Engine Lube Oil Pressure	Operator Station	Local & Operator Station	20 kPa (3 psi) less than the minimum low idle value on the General Engine Data Sheet, with a persistence time 5 seconds	Not required; optionally set to 55 KPa (8 psi) less than the minimum low idle value o the General Engine Data Sheet, with a persistence time of 15 seconds
Engine Coolant Temperature	Operator Station	Local & Operator Station	96° C (205° F), with a persistence time of 5 seconds	Not required; optionally set to 104° C (220°), with a persistence time 10 seconds
Battery Voltage	Local or Operator Station	None	Not required; optionally set to minimum battery voltage rating	None
Audible Alarm Test	Operator Station	Local & Operator Station	None	None
Visual Alarm Test	Operator Station	Local & Operator Station	None	None

Table 14-1: Specifications for Required Controls, Gauges, and Alarms

Parameter	Alarm Threshold	Shutdown Threshold
Low Engine Lube Oil Pressure	Not required; optionally set to 228 kPa (33 psi) at 1200 RPM	Not required, optionally set to 193 kPa (28 psi) at 1200 RPM
High Lube Oil Temperature	Not required; optionally set to 121° C (250° F)	None
Fuel Supply Restriction	Not required; optionally set to +5 in. Hg above the Dirty Filter limit on the General Engine Data Sheet	None
Exhaust Gas Temperature	Not required; optionally set to 100° C (180° F) above the maximum value on the Engine Performance Curves and Data Sheet	None
Crankcase Pressure	Not required; optionally set to 8 in. H_2O above the highest pressure observed during full throttle, maximum load operation	None
Low Coolant Pressure	Not required; optionally set to 28 kPa (4 psi), with a persistence time of 5 seconds	None
Low Coolant Level	Not required; optionally set to the low expansion tank level	None
Boost Pressure	None	None

Table 14-2: Recommended Specifications for Optional Controls, Gauges, and Alarms

The following are supporting requirement statements for the tables above:

! **Fault indicators must be located at the operator location.**

Fault indicators must, at a minimum, be located at the operators location.

! **All audible and visual alarms must have test and acknowledge/reset capability.**

Alarm test and acknowledge/reset capability is necessary to allow the operator to verify proper operation and silence fault conditions.

! **The engine oil pressure alarm must be set to activate at 20 kPa (3 psi) below the minimum idle value specified in the Engine General Data Sheet, with a persistence time of 5 seconds.**

Engine oil pressure alarms supplied by the customer must be set to activate at 20 kPa (3 psi) below the minimum idle value specified in the Engine General Data Sheet. The alarm condition cannot persist for more than 5 seconds before the audible/visual fault indication is activated.

! **The engine coolant temperature alarm must be set to activate at 96° C (205° F), with a persistence time of 5 seconds.**

Engine coolant temperature alarms supplied by the customer must be set to activate at 96° C (205° F). The alarm condition cannot persist for more than 5 seconds before the audible/visual fault indication is activated.

For non-electronic engines, the tachometer must be driven by a magnetic pickup installed in the flywheel housing and properly calibrated, depending on the number of ring gear teeth.

Non-electronic engines require that the tachometer is driven by a magnetic pickup installed in the flywheel housing. Cummins Inc. does supply a magnetic pickup standard on all non-electronic engines. Typically they are dual output with one of the outputs driving the intake air heater system, if equipped, and the other for the tachometer. A Cummins Inc. supplied tachometer should be received pre-calibrated for the engine. When installing a customer supplied tachometer, it must be calibrated, depending on the number of ring gear teeth. See Table 14-3 for engine model ring gear teeth. Follow the tachometer manufacturer's instructions for calibration. Driving a tachometer by using the alternator "R" terminal is not approved.

Engine Model	Number of Ring Gear Teeth
6B	159
6C	127

Table 14-3: Ring Gear Teeth

For electronic engines, tachometers must be driven by the ECM, not the Alternator "R" terminal.

Electronic engines by design require a speed signal input to operate. Speed sensors, usually located at the crankshaft and camshaft gear, provide the signal to the ECM. The ECM processes the signal to maintain operation and also sends it to the instrument panel/display over the data link. For electronic engines, tachometers must be driven in this manner by the ECM. Driving a tachometer by using the alternator "R" terminal is not approved for electronic engines.

Wiring harnesses and hoses must be secured to the vessel where the harness will not be subjected to physical damage or high temperatures, and will not interfere with normal vessel operating activities.

Wiring harness and hoses must be secured to the vessel where the harness will not be subjected to physical damage or high temperatures, and will not interfere with normal vessel operating activities. The Electrical System and Starting System should be referenced on proper installation of harnesses. Installation of hoses should follow the same guidelines as harnesses.

Wiring harnesses must not be supported by or otherwise be in contact with engine coolant or fuel lines.

Wiring harnesses must not be supported by or otherwise be in contact with engine coolant or fuel lines. Good installation practices dictate that a possible source of ignition (wiring harnesses) is not in contact with a possible fuel source (diesel fuel and coolant).

Throttle – Mechanical Engines

Mechanical fuel pump throttle lever must be against the idle stop when the hand lever(s) is in the idle position and against the wide open stop when hand lever(s) is in the fuel throttle position (both forward and reverse).

Mechanical engine(s) use a mechanical link such as a cable from the throttle hand lever to fuel pump to control engine speed. The throttle hand lever and/or cable must be adjusted to meet the following: The fuel pump throttle lever must be against the idle stop when the hand lever(s) is in the idle position and against the wide open stop when the hand lever(s) is in the fuel throttle position. For installations with dual function controls (both shift and throttle integrated into on lever) the above must be met in both the forward and reverse positions (see Figure 15-1)

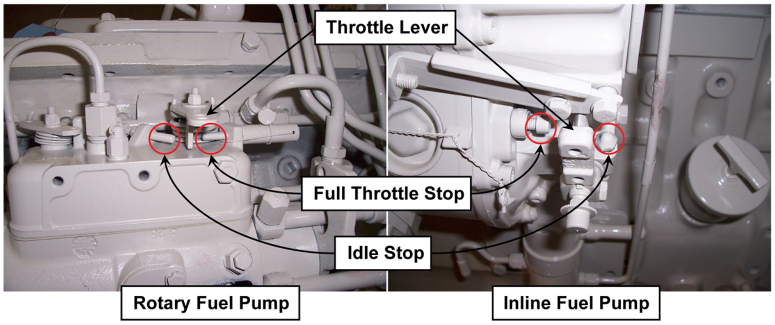


Figure 15-1: Examples of Fuel Pump Throttle Stops

CAUTION: Do not adjust the wide open throttle stop on the fuel pump. The wide open throttle stop is tamper proof. Attempted adjustments will void the fuel pump manufacturer warranty and may cause engine damage. The idle stop may be adjusted only to achieve the proper idle speed as indicated on the Performance Curves and Data Sheet.

Note: *For information regarding electronic throttles, refer to the Electronic Controls System section of this manual.*

Automatic Fire Extinguishing Systems

Automatic fire extinguishing systems require that the engine(s) and ventilation system are shut down immediately when the system is discharged into the engine space. The reasons for immediate shutdown are:

- The fire is not be fueled by the continuation of the engine systems (fuel, lubrication oil, electrical) and/or air from the ventilation blowers.
- The extinguishing agent is not removed or depleted from the engine compartment due to the engine air intakes or ventilation blowers.

Automatic fire extinguishing systems typically provide a control box that is wired in series with the keyswitch and ventilation blower circuits. The control box has relays that open the circuits when the system is activated to facilitate shutdown. Correct integration of these systems into the engine wiring is critical. Incorrect integration can cause delayed shutdown, no shutdown, and/or engine damage. Follow the automatic fire extinguishing system manufacturer's instructions how to install the system. Below describes where these systems should be connected to the engine.

Electronic engines are equipped with a 2 pin keyswitch jumper breakout connection at the helm station keyswitch harness and/or at the engine. If given a choice of locations, the location closest to the automatic fire extinguishing control box should be used to limit voltage drop due to long wire runs.

Mechanical engines require the keyswitch wire (purple) from the helm to be cut and the automatic fire extinguishing control box connected in series with the keyswitch circuit. Installation at either the main or second station is acceptable. Marine quality wire connections with strain relief should be used when attaching the keyswitch circuit to the control box. Additional keyswitch circuit length may be needed to facilitate installation. If so, it should be kept at a minimum to limit the potential of voltage drop.

Lubrication System

Summary of Requirements

All Applications

- ! **The lubricating oil used in the engine must meet the specifications listed in the Operation and Maintenance Manual.**
- ! **Unmarked oil dipsticks must be engraved (not stamped or notched) with the high and low levels when the vessel is in the water and at its normal trim.**
- ! **The primary lubricating oil filter that is supplied by Cummins Inc. with every engine must be used.**
- ! **Non-Cummins Inc. supplied hoses and fittings connected to the engine or marine gear must comply with SAE J1942/J1527.**
- ! **All joints, components, and connections must be leak free.**
- ! **Fittings and threaded connections must be free from Teflon tape or wrap style thread sealants.**
- ! **All hoses must be adequately protected from chafing and clipped to appropriate pieces of the engine/vessel structure such that there is no overhanging load on connections.**
- ! **Hoses must be routed away from excessively hot components, or a fire sleeve around the hose must be used.**
- ! **Flexible line must be installed between the engine and vessel plumbing to allow for relative motion.**

General Information

The lubrication system must supply a continuous supply of clean oil to the engine and marine gear at a controlled temperature. Cummins Inc. typically provides this system complete, integrated into the engine package, and requiring no installation other than filling the engine with oil and marking the dipstick if necessary. However, the customer may elect to install a marine gear or remote mount a filter to the vessel structure, requiring routing of hoses and connections to be made. The following provides the installation requirements for the lubrication system.

Definition of Lubrication Oil Filter Types

Full Flow Filter – Contains a single element filter media that provides adequate filtration and low restriction. All the flow from the oil pump passes through the filter before providing lubrication to the engine.

Bypass Filter – Contains a single element with a very fine (low micron) filter media that collects very small particles. Restriction through the filter is relatively high. Only a small portion of the total oil flow is directed to the bypass filter so that adequate oil flow is maintained to the engine.

Combination Filter – Contains both the filter media of the full flow and bypass filter in one unit. It requires a bypass hose from the filter head to the oil pan.

Venturi Combination Filter – Same as the combination filter, but the filter and head design is such that it doesn't require a bypass hose.

Service Accessibility

The following is a list of Lubrication System service points that should be accessible:

- Engine oil fill and dipstick
- Engine oil filter(s)
- Engine oil drain
- Marine gear oil fill and dipstick
- Marine gear oil filter(s)
- Marine gear oil drain

Installation Directions

All Applications

The lubricating oil used in the engine must meet the specifications listed in the Operation and Maintenance Manual.

CAUTION: Failure to use the proper oil may result in engine damage or dramatically reduced maintenance intervals.

Consult the Operation and Maintenance manual for proper lubricating oil specifications for your engine.

The lubricating oil used in the engine must meet the specifications listed in the Operation and Maintenance Manual. Listed in Section V of the Operation and Maintenance Manual is information for selecting the proper oil, including acceptable API performance classifications and viscosity versus ambient operating temperatures.

For operation below -18° C (0° F), an oil pan immersion heater and/or coolant (block) heater is recommended to maintain oil temperature and viscosity in an acceptable range for easier cranking and to prevent oil starvation at startup (see Figure 15-1).

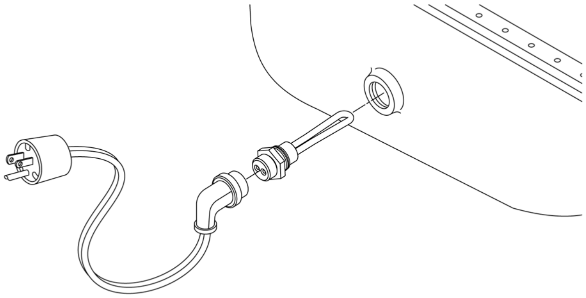


Figure 15-1

Unmarked oil dipsticks must be engraved (not stamped or notched) with the high and low levels when the vessel is in the water and at its normal trim.

CAUTION: Dipsticks must be marked by engraving. Stamping or notching will weaken the dipstick, causing it to break.

Depending on the oil pan and oil dipstick options specified, the oil dipstick may be unmarked. Unmarked oil dipsticks must be engraved with the high and low levels when the vessel is in the water and at its normal trim (see Figure 15-2).

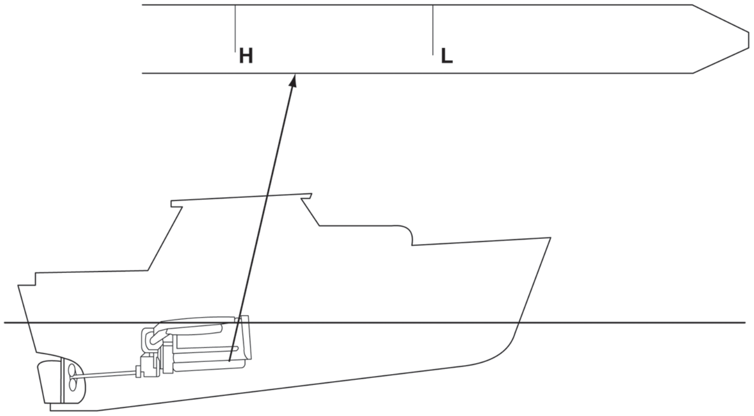


Figure 15-2

The dipstick must be marked by engraving (see Figure 15-3). Stamping or notching oil dipsticks is not approved because these methods can weaken the dipstick causing it to break.

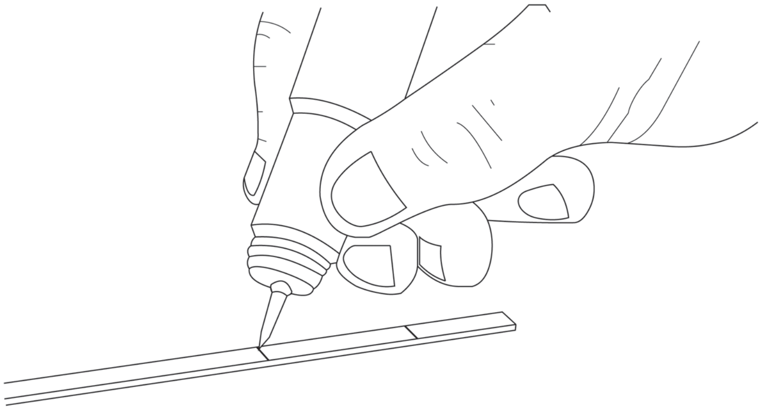


Figure 15-3

To correctly mark the oil dipstick, the following procedure should be followed:

1. Open oil drain plug to ensure the oil pan is empty, then close.
2. Fill engine with the Low Oil Pan capacity listed in the General Engine Data Sheet.
3. Allow oil to drain to oil pan (at least 5 minutes)
4. With the vessel waterborne and at its normal trim, verify low oil level on dipstick and engrave.
5. Add oil to reach High Oil Pan capacity.
6. Allow oil to drain to oil pan (at least 5 minutes).
7. Verify high oil level on dipstick and engrave.
8. Operate engine and add oil if necessary to bring level up to the high mark.

CAUTION: Do not crank or operate the engine during the process of marking the dipsticks, except when specified. Engine damage may result.

Some engines may be equipped with center sump oil pans and centrally located, pre-marked oil dipsticks. Because of the symmetrical geometry of the oil pan and location of the dipsticks, the oil level will not change depending on fore and aft trim angles. Fill these engines with the High Oil Pan capacity, operate, and then verify the oil level on the dipstick.

The primary lubricating oil filter that is supplied by Cummins with every engine must be used.

All engine models will have a full flow or combination filter, filter head assembly, and associated plumbing that is specifically designed for proper operation. The lubricating oil filter assembly that is supplied by Cummins must be used. Use of a non-Cummins Inc. supplied lubricating oil filter assembly is not approved and may cause failure due to oil starvation, low oil pressure, high oil pressure, and/or inadequate filtering.

Multiple engine mounted filter locations may be available for some engine models to facilitate easier service. The engine installation drawing specifies the filter location and space required for element serviceability.

Depending on engine model and options selected, a bypass filter may be included. Bypass filters are normally engine mounted. All Cummins bypass filters are spin-on types and must be mounted vertically (see Figure 15-4). If a bypass filter is to be remote mounted, the locations for the supply and return can be found on the engine installation drawing. Bypass filters have considerable weight and sturdy brackets are required to support it. A location should be selected where it can be easily serviced and where neither the filter nor the connecting lines are subject to damage.

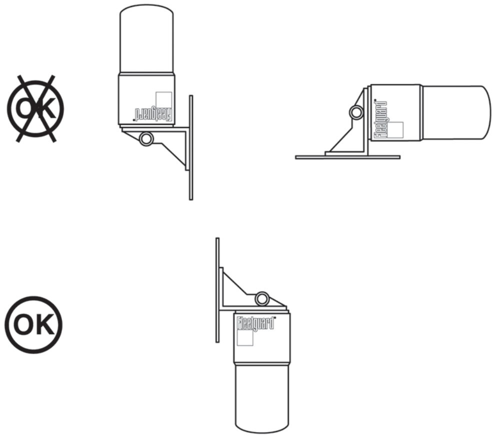


Figure 15-4

Non-Cummins Inc. supplied hoses and fittings connected to the engine or marine gear must comply with SAE J1942/J1527.

All lubrication hoses must meet the flame resistance, burst pressure limits and other requirements of SAE J1942/J1527. The following gives further guidance on selection of hoses and fittings:

Proper lube oil and fuel hose selection and installation are essential for meeting engine operational criteria and establishing a safe environment for the vessel and crew. Marine societies and the United States Coast Guard (USCG) have strict requirements for the application of marine nonmetallic flexible hoses. This section will define the requirements for hose selection and provide guidance for fabrication, installation, and routing of marine lube oil and fuel hoses not supplied by Cummins Marine. H (hydraulic systems), VW (vital and nonvital fresh and salt water), and NVW (nonvital water and pneumatic) hoses will not be discussed in this document.

A number of factors must be considered when choosing the correct hose in order to meet the requirements of the application and achieve the maximum life of the hose assembly. A systematic review of each application based on these factors should be made prior to selecting the hose that best meets the requirements. The following are some factors for consideration:

- Pressure: The system pressure should be determined. A hose should be selected having a maximum operating pressure which is equal to or greater than the system pressure. Pressure surges which exceed the system pressure should also be considered. Hoses used on marine engines, which are approved by Marine Classification Societies, must have a maximum operating pressure at least 1.5 times the system pressure.

- Temperature: Consideration must be given to the operating temperature of the fluid transmitted through the hose. The temperature of the fluid must not exceed the temperature limitation of the hose.
- Fluid Compatibility: The hose selected must be compatible with the fluid being used. This includes the hose material, the fittings, and cover (when used).
- Flow Requirements (Size): the size of the hose and fittings must be chosen to allow adequate flow and keep pressure losses to a minimum. Supplier catalogs provide charts for recommended velocities and flows.
- Environment: Consideration must be given to the environment in which the hoses will operate. Environmental conditions such as ultraviolet light, ozone, salt water, chemicals, and air pollutants can damage the hose and shorten its life.
- Mechanical Loads: Excessive flexing, twist, kinking, tensile or side loads, bend radius, and vibration are all external forces which can reduce hose life. Fitting types and hose routings must be selected to avoid these problems. Bend radius must not be less than the minimum provided in the supplier catalog.
- Space Availability: The amount of space should be considered for ease of assembly, serviceability, and to accommodate allowable bend radius.
- Dual Seat Fittings: If the choice is made to use conical seat type fittings, they should be of the dual seat variety. Dual seat fittings are available in either JIC 37.5 degree or SAE 45 degree varieties

Effective August 28, 1991, the Society of Automotive Engineers (SAE) replaced the USCG as the listing agency for Marine Nonmetallic Flexible Hose Assemblies. The SAE has established specific requirements for hose and/or hose assemblies in systems on board commercial vessels inspected and certificated by the USCG. Consult SAE J1942-1 for a listing of all qualified hoses arranged by manufacturer. An example of the listing is shown in Table 15-1.

Hose Number	Application Code	Hose ID	MAWP (PSI)	Fittings	Fire Sleeve
E704	H	4-Jan	3000	HF,EA,CH	------
G104	HF	4-Jan	3000	GL,EC	------
Y904	F	16-Mar	300	BC,BN	14372
N256-2	VW	2	400	H-620	------
N-1401-12	NVW	4-Mar	50	H-132	------

Table 15-1. Sample Hose Listing

For the purposes of this document, discussion will be limited to Qualified Marine Lube Oil and Fuel Hoses. All SAE hoses are coded to differentiate the intended application. For example, HF coded hoses are acceptable for all services, including lube oil and fuel. HF hoses are constructed of piles or braids of steel wire, with or without textile reinforcement. F coded hoses are acceptable for lube oil and fuel systems and are constructed the same as HF hoses. Fuel hoses used on marine engines must meet the requirements in SAE J1527. A description of the qualification tests for all Marine hoses can be found in SAE J1942, Hose and Hose Assemblies for Marine Applications.

Marine hoses must be identified by the manufacturer in accordance with the Code of Federal Regulations (CFR) CFR 33 part 183.54 and contain, as a minimum, the manufacturer's name and part number, maximum operating pressure, and hose size. In addition, as an option to expedite USCG inspection, hoses may be marked with a propeller symbol followed by the application code. All hoses are subject to review by the USCG and classification society surveyors, and therefore must not be painted.

Hoses and hose fittings used must be compatible and should be a product of the same manufacturer. Fittings must conform to SAE J1475. Applicable fittings are listed in SAE J1942-1. Push-on fittings, quick connect couplings, and fittings with a single worm-gear clamp or a single band around the hose are unacceptable.

The use of nonmetallic flexible hoses should be kept to a minimum. Ideally, hoses should only be used where movement occurs between the two connections. To comply with USCG requirements CFR 46 part 50.60-25 (4) states "Nonmetallic flexible hose may be used in lube oil, fuel oil, and fluid power systems, only where flexibility is required and in lengths not exceeding 30 inches". Proper installation techniques must be observed to ensure hoses are securely fastened to prevent chafing, and stress on the hose and connections. Also, the hose must not be routed near excessively hot components. If such routing cannot be avoided, a fire sleeve around the hose should be used. All joints and connections must be checked for leaks using a suitable leak check fluid.

All joints, components, and connections must be leak free.

Fittings and threaded connections must be free from Teflon tape or wrap style thread sealants.

All joints, components, piping, and connections used in the lubrication system must be leak free. Robust methods for joining components should be used to make sure leaks do not develop over time. A suitable pipe sealant compatible with engine and marine gear oil should be used on threaded connections. Teflon® tape and other wrap style thread sealants must not be used, because of the risk of the material entering the system.

Cummins recommends the use of a dual seat JIC 37.5/SAE 45 conical or o-ring face seal fittings wherever possible. These fittings provide a robust connection that facilitates easy and repeated removal and reinstallation. Fittings that are hydraulically crimped to the hose ends are necessary due to the operating pressures.

All hoses must be adequately protected from chafing and clipped to appropriate pieces of the engine/vessel structure such that there is no overhanging load on connections.

Hoses must be routed away from excessively hot components, or a fire sleeve around the hose must be used.

Proper installation techniques must be observed to make sure oil lines are securely fastened and routed to protect them from damage due to vibration, excessive load, heat, and chafing.

Hoses should be installed without twists or kinks and all bends should be larger than the minimum bend radius given by the hose manufacturer (see Figure 15-5).

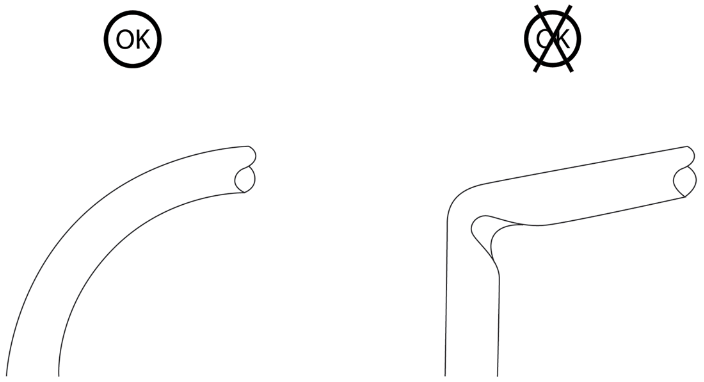


Figure 15-5

Oil lines should be supported along their length and secured at regular intervals using chafe protected clips (see Figure 15-6). Electrical wire ties are not designed to secure oil plumbing and are not recommended. When installing hoses, provide enough slack in the hoses to allow for changes in the lengths when the hose is pressurized. Hose can shrink up to 4 percent of its length when under pressure.

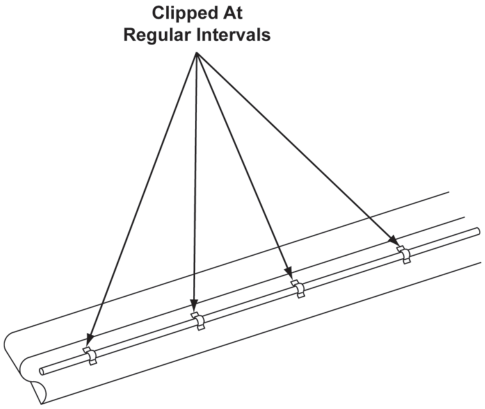


Figure 15-6

Routing of oil lines away from heat sources, such as exhaust plumbing, is done primarily for safety reasons. In the event that a leak develops, oil must not impinge on any hot surfaces. If the routing can not avoid hot surfaces, adequate insulating sleeves must be used. For agency classed vessels, fittings/flanges/connections on fuel and oil lines shall be screened or otherwise suitably protected to avoid spray or leakage onto hot surfaces or machinery intakes. The Safety of Life at Sea (SOLAS) requirements regarding fuel lines and fuel fittings are described in detail in MAB 5.00.00 - 07/14/2003, SOLAS Fire Prevention Requirements.

! **Flexible line must be installed between the engine and vessel plumbing to allow for relative motion.**

All oil line connections from the vessel to the engine or any components that may have relative motion must have a flexible section (see Figure 15-7). Engine vibration, thermal growth, and flexure of the vessel when pitching and rolling in heavy seas may cause a rigid line to fail. If hose is used for the flexible section, it must meet the requirements set forth in the document. Cummins recommends the hose is installed with a sweeping bend to provide the best isolation of movement and protect the hose from tensile and compressive loads.

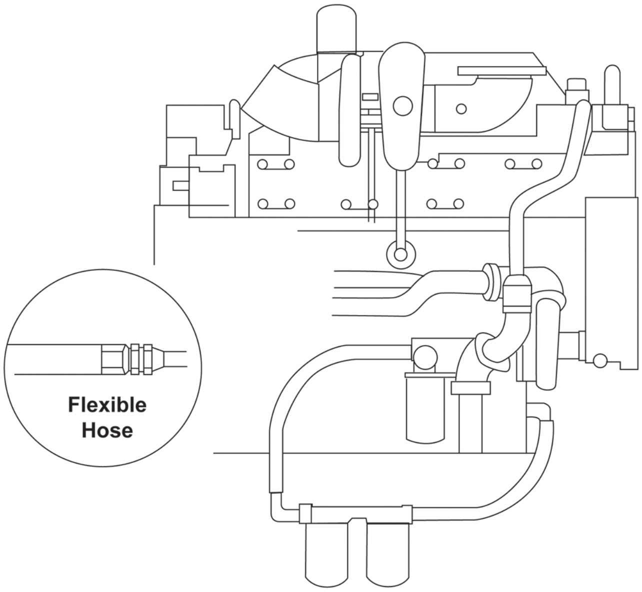


Figure 15-7

Sea Trials

Summary of Requirements

All Applications

- ! **Sea trial tests must be completed according to the procedures specified within this document for all new engine installations and following major engine repairs.**
- ! **All readings requiring manual measurements must be recorded at three speeds: Full throttle, cruise (200 rpm below rated), and peak torque rpm.**
- ! **All readings that can be electronically measured with INSITE™ electronic service tool must be recorded along the propeller curve (idle to full throttle) with adequate dwell time at every 200 rpm increment.**
- ! **Sea trial measurements must be above the minimum value and below the maximum value listed in the Engine General Data Sheet and the Engine Performance Curves and Data Sheet.**
- ! **Engines must achieve or exceed rated speed at full throttle under any steady state operating condition; except engines in variable displacement vessels, which must achieve not less than 100 rpm below rated speed at full throttle during a dead push or bollard pull.**

General Information

Sea trial performance and acceptance testing is the culmination of the time and effort put forth into the installation. While performing a sea trial, accurate and complete collection of sea trial data is necessary to validate whether the installation is correct or if changes are required. A full set of accurate data will also provide a useful baseline to reference for subsequent production builds as well as for troubleshooting service related issues.

The installation review form, depending on the application, will include a sea trial sheet with fields relating to the vessel pertinent data, test conditions, and necessary engine parameters to be recorded.

Service Accessibility

The following is a list of Sea Trial service points that should be accessible:

- Diagnostic connector for electronic engines
- Intake air restriction test port
- Exhaust system test port
- Intake manifold pressure test port (mechanical engines only)
- Sea water pump inlet restriction and discharge pressure test ports (heat exchanger cooled)
- Coolant inlet and outlet test ports (keel cooled)
- Fuel inlet and return restriction test ports
- Starter and battery wiring connectors

Installation Directions

All Applications

! **Sea trial tests must be completed according to the procedures specified within this document for all new engine installations and following major engine repairs.**

Table 16-1 shows the need to perform sea trials, depending on installation type. Where procedures are given for performing sea trial tests within the Installation Directions document or any other Cummins document, they must be followed.

Installation Type	Sea Trial
New Vessel	Yes – Complete sea trail
Repeat Build for Volume Production (no design changes)	Recommended – Partial sea trail to confirm operating parameters are within limits at full throttle and rated speed
Modifications for Existing Vessel Design (including volume production)	Partial – Any system affected by change(s)
Repower of an Existing Vessel	Yes – Complete sea trial
Major Engine Repair, Engine Rebuild, Like Repower, or Power Update	Yes – Complete sea trial
Troubleshooting of Engine or Vessel Performance	Partial – Depending on needs
Regular Audits of Production Vessels	Recommended – Complete sea trial

Table Sea Trials Need Versus Installation Type

! **All readings that can be electronically measured with INSITE™ electronic service tool must be recorded along the propeller curve (idle to full throttle) with adequate dwell time at every 200 rpm increment to capture steady state operation.**

The installation review document, depending on the application, will include a sea trial form with fields relating to the vessel pertinent data, test conditions, and necessary engine parameter to be recorded. All applicable fields must be filled out accurately.

Test instruments such as gauges, thermocouples, multimeters, etc. used to record manual measurements should be calibrated and certified to be within their manufactured accuracy. In general, to obtain an accurate measurement, the resolution of the test instrument should be one tenth of the attribute trying to be measured. For example, if the reading requires a measurement of one tenth of a unit (0.1), the test instrument should be accurate to one hundredth of the unit (0.01).

All readings that require manual measurements, such as fuel restriction, exhaust restriction, and sea water inlet restriction must be recorded at three speeds. The three engine speeds are idle, peak torque, and full throttle. However, CMD encourages that testing be performed at every 200 rpm. The peak torque can be found on the Engine Performance Curves and Data Sheet. Mechanical engines will require all readings to be taken manually.

When testing electronic engines, most readings can be obtained by using INSITE™ electronic service tool. All readings that can be electronically measured with INSITE™ electronic service tool must be recorded along the entire propeller curve from idle to full throttle in a continuous log. At every 200 rpm increment, adequate dwell time must be taken to allow the engine parameters to stabilize. Cummins recommends using either stabilization of: 1. Exhaust gas temperature or 2. Vessel speed to conclude that steady state operation has been achieved.

! **Sea trial measurements must be above the minimum and below the maximum value listed in the Engine General Data Sheet and the Engine Performance Curves and Data Sheet.**

Sea trial measurements must be above the minimum and below the maximum value listed in the Engine General Data Sheet and the Engine Performance Curves and Data Sheet. Measurements that fall outside the minimum and maximum values must be identified for cause and corrected before the vessel is placed into service. Failure to ensure all parameters are within their allowable range may impact engine performance, reliability, and/or durability.

! **Engines must achieve or exceed rated speed at full throttle under any steady state operating condition; except engines in variable displacement vessels, which must achieve not less than 100 rpm below rated speed at full throttle during a dead push or bollard pull.**

△ **CAUTION: If full throttle engine rpm is below the Engine Rated rpm, the propellers will have to be changed to prevent loss of performance and possible engine damage.**

Engines must achieve or exceed rated speed at full throttle under any steady state operating condition. Conditions when testing a new vessel are usually ideal. New vessels have clean hulls, the displacement is light, and the environmental conditions are typically very good. To make sure that the vessel will continue to meet this requirement after it is placed into service, the builder must take into account the inevitable increase of displacement, increase in hull resistance between cleanings, and extreme environmental conditions. This is usually achieved through a combination of testing the vessel loaded to approximate a heavy condition and/or under-propping so that the engine(s) achieve rated speed at less than 100% load. It is the responsibility of the boat manufacturer or the selling dealer to equip the vessel with the correct propellers to meet this requirement.

The exception to the above is installation of engines in variable displacement vessels. In these installations the engines must achieve not less that 100 rpm below rated speed at full throttle during a dead push or bollard pull. Examples of variable displacement vessels are push boats, tugs, anchor handling, and deep/mid-water fishing trawlers.

Propping Electronic Engines

With the introduction of electronic control systems, the load demand on an engine is readily displayed and should be used to determine the appropriate propping of the vessel. An electronically controlled engine is able to determine the load placed upon it by using the inputs of engine speed and fueling required to achieve that engine speed. The load reading is displayed as the percentage of load placed on the engine compared to the full load capability of the engine at any given speed. For example, if an engine can produce 200 HP at 2000 rpm and there is a 100 HP draw upon it at 2000 rpm, it would be at 50 percent load. If the same engine can produce 300 HP at 3000 rpm and there is a 270 HP at 3000 rpm draw on it, the load would be 90 percent.

During transient conditions such as hard acceleration, the engine can be at or near 100 percent load demand at less than rated speed. However, once 100% load is reached at steady state conditions, the engine will no longer be able to increase speed. Therefore, if an engine reaches a steady state 100 percent load before rated speed is achieved, it is over-propped. Conversely, if an engine is able to exceed rated speed, the load percentage will indicate less than 100 percent load at rated speed. The degree of under-propping will determine at what speed above rated speed 100% load is achieved.

Electronic engines have an isochronous governor which limits the maximum speed to a range typically between 50-75 rpm above rated speed. Once an engine reaches the governor, it will no longer advance in speed or power. Therefore, if a vessel is sufficiently under-propped so that an engine does not reach 100 percent load before the governor, the engine will be limited from producing all its available power. In some applications, it may be necessary to prop the vessel so that the engines are hitting the governor and not at 100 percent load at full throttle. Typically this applies to production vessels, where the first hull has been loaded to a heavy displacement, tested to comply with reaching rated speed, and then unloaded to conclude what subsequent sister vessels should be propped to when tested light. The resulting prop demand at a light condition may enter the range where the engine speed is limited at the governor and load is less than 100 percent.

Note: *CMD electronic engines are designed to produce constant power between rated speed and the governor speed.*

It is Cummins Inc. recommendation that the ideal propping point is to achieve 100 percent load at the governor speed. Typically this will yield a load of 92-95 percent at the rated speed. This maximizes performance, efficiency, and durability of the engine.

Figure 16-1 provides a sample engine performance curve for an electronic engine overlaid with propeller demand curves that graphically depict the above.

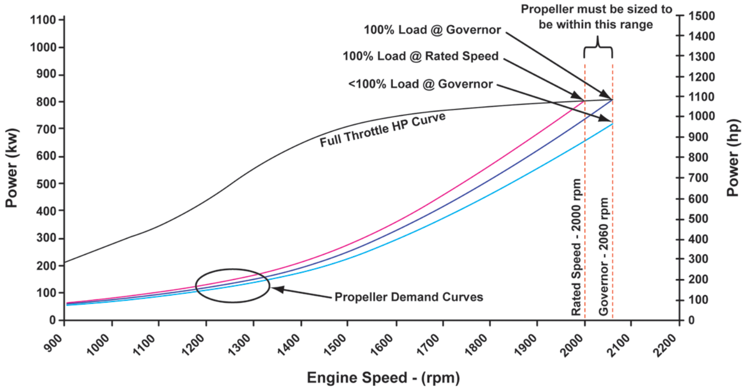


Figure 16-1

Propping Mechanical Engines

Mechanical engines, due to the nature of the mechanical, non-isochronous governors, must be propped solely on the attainable engine speed at full throttle, steady state conditions. Unlike electronic engines governors which have a precise, predetermined, and consistent governor set point; mechanical engines progressively limit fueling to limit engine speed (known as the high speed governor break point).

The high speed governor break point is defined as the speed at which the governor begins to reduce torque below the rated power value, when operating at full throttle. The difference in engine speed between the governor break point and the maximum no-load operating speed (also known as high idle) is called droop.

When propping a mechanical engine, the full throttle engine speed must be above the rated speed of the engine and should be below the point where the governor break point begins. Propping beyond the governor break point will result in a linear and progressive reduction in available engine power output as speed is increased to high idle. The governor break point on mechanical CMD engine is typically 100 to 125 rpm above the rated speed. Once an engine reaches the governor break point, it will advance in speed, but power will be reduced. Therefore, if a vessel is sufficiently under-propped so that an engine does not reach 100 percent load before the governor break point, the engine will be limited from producing all its available power. In some applications, it may be necessary to prop the vessel so that the engines are operating beyond the governor break point and not at 100 percent load at full throttle. Typically this applies to production vessels, where the first hull has been loaded to a heavy displacement, tested to comply with reaching rated speed, and then unloaded to conclude what subsequent sister vessels should be propped to when tested light. The resulting prop demand at a light condition may enter the range where the engine speed exceeds the governor break point and load is less than 100 percent.

Note: *CMD mechanical engines are designed to produce near constant power, increasing slightly from rated speed to the governor break point.*

It is Cummins recommendation that the ideal propping point is to achieve 75 to 100 rpm over rated speed. This maximizes performance, efficiency, and durability of the engine.

Figure 16-2 provides a sample engine performance curve for a mechanical engine overlaid with propeller demand curves that graphically depict the above.

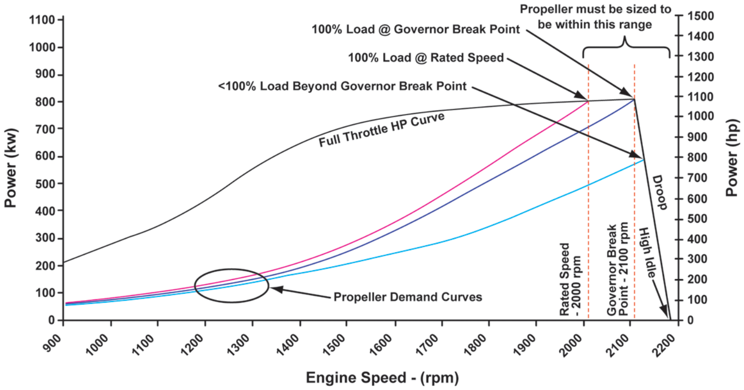

Propeller must be sized to be within this range
100% Load @ Governor Break Point
100% Load @ Rated Speed
<100% Load Beyond Governor Break Point
Full Throttle HP Curve
Droop
High Idle
Rated Speed - 2000 rpm
Governor Break Point - 2100 rpm
Propeller Demand Curves
Power (kw)
1100
1000
900
800
700
600
500
400
300
200
100
0
Power (hp)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
Engine Speed - (rpm)

Figure 16-2