

400

Series

Perkins 400J-E Series

Models: IW IQ IR

APPLICATION & INSTALLATION MANUAL

403J-E17T
404J-E22T
404J-E22TA

Three and Four-cylinder diesel engines for agricultural, industrial, construction applications

Developed to meet EPA Tier 4 Final and EU Stage V off highway emissions legislation.

Note: Information in this manual is preliminary and is subject to change or withdrawal.

The information contained in this manual is confidential and proprietary to Perkins. It is intended for circulation only to Perkins employees, or to employees of OEMs intending to purchase and install Tier 4 Final/EU Stage V engines in their equipment. Distribution of this material must be limited to personnel whose duties require knowledge of such material and is intended exclusively for their information and training. Distribution of this material for other purposes is strictly prohibited.

A&I Manual Introduction

This manual has been compiled to explain mandatory requirements, provide information for designers, and provide information on the application and installation of the 400 Series engines into Industrial equipment, to meet U.S. Environmental Protection Agency ("EPA") Tier 4 Final regulatory requirements and European Union ("EU") Stage V non-road mobile machinery emissions legislation.

The information provided in this manual is correct at the time of issue. Continuing product developments and changing legal requirements will, however, continue to drive further changes in installation requirements and attention must be paid to ensure that the latest information is utilised, and valid data is obtained from the engine specification manual.

Serial number prefixes for the engines referenced in this manual are:

403J-E: IW.

404J-E: IQ.

This manual is not an exhaustive source of instruction or data and should only be used in conjunction with advice from your local application engineers, sales manager and or technical support representative.

The following media publications for the relevant engine type should also be used for further technical information

400J-E Series Electrical and Electronic A and I Manual.

Operator and maintenance manual (OMM).

System Operation Test and Adjust (SOTA).

Specifications (Specs).

Disassembly and Assembly (D&A).

Engine Specification Manual (ESM).

Customer Assembly Requirements Document (CAR).

Correct practices, procedures and safety precautions should always be followed.

Please note:

The information provided may be subject to change.

Perkins Engine Company Limited ("Perkins") has provided this information in good faith and are not liable for how this information is interpreted or applied.

Perkins is not responsible for failures resulting from attachments, systems, accessory items, and parts not sold nor approved by Perkins. Consult the applicable warranties for complete details of the Perkins warranty coverage.

The manufacturer and customer are reminded that it is their responsibility to ensure compliance with the requirements of the Health & Safety at Work Act 1974 and any other applicable legislation, both nationally and internationally, in relation to the engine installation applicable to the equipment concerned. In giving notice of approval in respect of the installation, Perkins do not assume such responsibilities on behalf of the manufacturer or customer and while engine installation approval and advice is an opinion given in good faith, the equipment manufacturer and customer remain responsible as detailed above and must act and insure accordingly.

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1.0 Introduction

1.1 How to use this manual

This manual has been structured so that each chapter corresponds to a different engine system.

The start of each chapter details the mandatory installation requirements relevant to that particular engine system. These mandatory requirements include emission related requirements and warranty related requirements.

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

‘Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.’

All mandatory requirement must be adhered to in order to ensure emission compliance and attain full engine warranty.

For full details of the structure of the complete manual please refer to the table of contents.

For details of electronic and electrical systems please refer to the 400J Series Electrical and Electronic Application and Installation Manual.

1.1.1 Terminology

The terminology used throughout this book is as follows:

AITP	Application and Installation Test Procedure
AT	Aftertreatment
ATAAC	Air to Air After-Cooled
BPV	Back Pressure Valve
CAR	Customer Assembly Requirements Document
CCB	Closed Crankcase Breather
CG	Centre of Gravity
CO ₂	Carbon Dioxide
CO	Carbon Monoxide
DCU	Dosing Control Unit
DEF	Diesel Exhaust Fluid
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EMAT	Engine Mounted Aftertreatment
ECM	Electronic Control Module
ESM	Engine Specification Manual
ELP	Electric Lift Pump
FIP	Fuel Injection Pump
HC	Hydrocarbon
H ₂ O	Water
ID	Identification
IGB	Installation Guideline Bulletin
MAF	Mass Air Flow
NO _x	Nitrogen Oxides – NO and NO ₂
OMM	Operation and Maintenance Manual
OEM	Original Equipment Manufacturer (Machine)
PETU	Pump Electronic Tank Unit
PEU	Pump Electronic Unit
PM	Particulate Matter
PRV	Pressure Relief Valve
RF	Radio Frequency
ROA	Rise Over ambient
S/N	Serial Number
SOF	Soluble Organic Fraction
SCR	Selective Catalytic Reduction
ULSD	Ultra Low Sulphur Diesel
WIF	Water in Fuel

1.2 Safety

The manufacturer and customer are reminded that it is their responsibility to ensure compliance with the requirements of the Health & Safety at Work Act 1974 and any other applicable legislation, both nationally and internationally, in relation to the engine installation applicable to the equipment concerned. In giving notice of approval in respect of the installation, The Engine manufacturer does not assume such responsibilities on behalf of the manufacturer or customer and while engine installation approval and advice is an opinion given in good faith, the equipment manufacturer and customer remain responsible as detailed above and must act and insure accordingly.

Most accidents that involve product operation, maintenance and repair are caused by failure to observe basic safety rules or precautions. An accident can often be avoided by recognizing potentially hazardous situations before an accident occurs. A person must be alert to potential hazards. This person should also have the necessary training, skills, and tools in order to perform these functions properly.

The information in this publication was based upon current information at the time of publication. Check for the most current information before you start any job. Distributors will have the most current information.

Improper operation, maintenance or repair of this product may be dangerous. Improper operation, maintenance or repair of this product may result in injury or death.

Do not operate or perform any maintenance or repair on this product until you have read and understood the operation, maintenance, and repair information.

The engine factory cannot anticipate every possible circumstance that might involve a potential hazard. The warnings in this publication and on the product, are not all inclusive. If a tool, a procedure, a work method, or an operating technique that is not specifically recommended by Perkins is used, you must be sure that it is safe for you and for other people. You must also be sure that the product will not be damaged and / or made unsafe by the procedures that are used.

1.2.1 Safety Warnings

The following warnings are appropriate to the engines referenced in this manual.

⚠ WARNING – Do not operate or work on this product unless you have read and understood the instructions and warnings in the relevant Operation and maintenance Manuals. Failure to follow the instructions or heed the warnings could result injury or death. Proper care is your responsibility.

Correct practices and procedures including safety and lifting information should be followed as outlined in the following appropriate service manuals.

- Operation and Maintenance Manual (OMM)
- System Operation Test and Adjust (SOTA)
- Specifications (Specs)
- Disassembly and Assembly (A&A).

1.2.2 California Proposition 65 Warning

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

⚠ WARNING - This product can expose you to chemicals including lead and lead compounds, which is known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to:

www.P65Warnings.ca.gov

Wash hands after handling components that may contain lead.

⚠ WARNING - This product can expose you to chemicals including ethylene glycol, which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to:

www.P65Warnings.ca.gov

Do not ingest this chemical. Wash hands after handling to avoid incidental ingestion.

1.3 Engine Installer Responsibility

The following information forms part of the Engine Manufacturer safety compliance documentation, as a supplier of partly completed machinery. Consideration of the safety requirements detailed below forms part of the technical construction file for the product and should be taken into consideration and addressed during installation of the product into the final machine, before placing on the market.

This is a generic document that covers all engine families and therefore some of the safety considerations may not be relevant to the technology of the engine selected.

The Engine Manufacturer recommends that a risk assessment and FMEA is conducted on all installations to consider all aspects of machine/installation and operational safety.

The manufacturer and customer are reminded that it is their responsibility to ensure compliance with the requirements of the Health & Safety at Work Act 1974 and any other applicable legislation, both nationally and internationally, in relation to the engine installation applicable to the equipment concerned. In giving notice of approval in respect of the installation, The engine manufacturer does not assume such responsibilities on behalf of the manufacturer or customer and while engine installation approval and advice is an opinion given in good faith, the equipment manufacturer and customer remain responsible as detailed above and must act and insure accordingly.

1.3.1 2006/42/EC - Machinery Safety Directive, Annex 1 and for GB, The Supply of Machinery (Safety) Regulations 2008 and other applicable Enactments

Fixed Guards:

The Engine Manufacturer takes into account various applicable standards when designing guarding, however it cannot foresee all possible installation scenarios and any residual risks remain the responsibility of the engine installer. Although the Engine manufacturer offers guarding on some products to prevent some access to the hazards at the front of the engine, the expectation is that the engine will be fully installed in an enclosure that meets local guarding requirements. Particular attention should be made to hot surfaces and moving parts, residual risks associated with catastrophic failure of the engine or turbocharger, explosion in the aftertreatment due to ether abuse and high-pressure fluid leaks.

1.3.2 EN1679-1: 2011 - Reciprocating internal combustion engines – Safety Part 1: Compression ignition engines

Safety requirements and / or measures

Starting Systems:

The engine installer is responsible for understanding the requirements and properly installing other parts of the starting system.

Normal Stopping:

For engines installed in machines the OEM is responsible for installation of the stopping system, normally by ignition switch or key.

Emergency Stopping - Manually controlled:

For engines installed in machines the OEM is responsible for installation of the emergency stopping system.

Emergency Stopping – Automatically controlled:

The engine installer is responsible for understanding the requirements and properly installing the automated emergency stopping controls.

Machine operation outside of defined gradient limits

For engines fitted with closed circuit breathers, engine installers should be aware that in the event of machine operation outside of defined gradient limits (e.g., Machine roll over) there is the potential for lubricating oil to overwhelm the breather system and for oil to be carried over into the induction system of the engine resulting in engine runaway.

Controls

The engine installer is responsible for understanding the requirements positioning of engine controls. If a secondary control panel is fitted the installer should consider placing the panel in a safe operating position, not close to the side of the engine. The secondary control panel must be installed so that it cannot override the primary control panel.

Throttle controls on off road mobile machines should have sufficient resistance to ensure that when the machine is moving over bumpy ground minor fluctuations in pressure applied to the throttle do not result in undesired changes in engine/machine speed.

A robust signal is required from the machine ECM to the Engine ECM to ensure engine control is not compromised.

Hand controls for the engaging and disengaging of driven equipment such as hydraulic pumps should be positioned so as not to be close to the side of the engine.

Ensure that strategies to automatically increase engine idle for aftertreatment regeneration etc. have safeguards to prevent machine movement during operation.

Monitoring devices:

It is the engine installer's responsibility to understand the requirements and ensure warning indicators are present for functions such as delayed engine shutdown and Diesel Exhaust Fluid (DEF) system purge etc. - The engine installer should understand the requirements and consider installing a warning light to advise operators and technicians when the DEF system is purging. Some engine health functions such as oil pressure monitoring can result in a derate where engine power can be reduced by up to 50%.

Guarding against mechanical hazards:

The Engine Manufacturer takes into account various applicable standards when designing guarding, however it cannot foresee all possible installation scenarios and any residual risks remain the responsibility of the engine installer. Although the Engine manufacturer offers guarding on some products to prevent some access to the hazards at the front of the engine, the expectation is that the engine will be fully installed in an enclosure that meets local guarding requirements. Particular attention should be made to hot surfaces and moving parts, residual risks associated with catastrophic failure of the engine or turbocharger, explosion in the aftertreatment due to ether abuse and high-pressure fluid leaks.

Guarding against hot surfaces:

Depending on the location of the hot surface & its temperature, the engine installer needs to decide if a hazard exists that should be guarded. For IOPUs, the engine installer should understand requirements and consider whether additional guarding is required to protect against hot surfaces including the aftertreatment. Consideration to fluid lines and components affected by heat should be given when mounting engine and aftertreatment. It is recommended that the engine installer gives consideration to the risk of burns from the exhaust system and mitigate the risk accordingly.

Handling:

When lifting or handling the engine or aftertreatment the engine installer should refer to the advice contained in the Operation and Maintenance Manual regarding safe practice.

Fire protection:

The engine Installer needs to understand the requirements for all fuel supply line routing. Drain ports are supplied as standard and if the installation impedes access to all drain ports, the engine installer is responsible for rerouting the service point.

Protection against explosion:

The engine installer is responsible for compliance with local regulations, directives, and certification where appropriate if an engine is known to be going into an explosive atmosphere(s). Due to the volatile nature of ether, the customer should ensure that ether supply lines are robust and securely clipped, and that they can operate at the intended system pressure to minimise the risk of leaks and the potential for explosion.

Pressure vessels

Engine components containing pressurised air or fluids are not considered pressure vessels. It is recommended that the engine installer understands requirements and considers the risk of escaping steam and hot or cold coolant from the radiator cap during its removal and take action to mitigate the risk.

Hoses, Pipes, and electric harnesses:

The risk of electrostatic discharge from fuel filter bowls and pipes should be considered as part of the Original Equipment Manufacturer or Cat Machine Group risk assessment conducted in support of machine manufacture.

As part of the machine risk assessment, the engine installer should understand requirements and consider whether guarding of the high-pressure fuel system is necessary, to protect the operator or bystanders from high pressure fluid penetration.

DEF pipes should not be positioned above other fluid pipes that could be damaged by leaking DEF, also consider of effects of DEF on other engine components due to potential corrosion.

Access to service points

It is recommended that the engine installer gives consideration to access of all service points on the engine during the installation process and takes action to mitigate the risk of injury to operators & maintenance technicians.

Noise:

The engine is not supplied with a silencer as it is considered partly completed machinery, the engine installer is responsible for ensuring that the completed machinery meets the noise regulations.

Exhaust emissions:

The engine is not supplied with an exhaust and is classed as "partly completed machinery" in the Machinery directive. The engine installer should understand requirements and is responsible for ensuring that the exhaust gases are directed away from the engine operator workstation. It is recommended that the engine installer gives consideration to the risk from inhaling exhaust fumes. If the engine is to be installed inside a building, take appropriate action to ensure the exhaust fumes are released outside and away from the operator workstation.

Drainage:

It is the responsibility of the installer to keep draining locations accessible, or to provide alternative means of draining if not possible.

Special requirements:

Some customer applications may require that the engine is designed to meet special requirements (e.g., health and safety regulations, hazardous environments, etc.) The party responsible for the installation of the engine must specify the special requirements to be met. Any new components or systems will be designed, validated, and documented individually.

**1.3.3 EN60204-1:2006+A1:2009 – Safety of machinery – Electrical equipment of machines
Part 1: General requirements****Electrical Supply****Electrical supply – AC supplies:**

All power is DC, except for certain engine installer wired components, e.g., Engine Block Heater. Engine Installer is responsible for meeting the above standard as well as any local requirement for wiring electrical supply to various components.

Electrical supply – Special supply systems:

No Special supplies are available. The engine installer is responsible for any specialised electrical supply.

Physical environment & operating conditions:**General:**

See normal operating conditions in respective clause.

Special requirements can be met if requested, for example cold weather packages, but this must be agreed in writing between the Engine Manufacturer and the purchaser.

Electromagnetic compatibility:

EMC testing is not applicable to engines, this is a requirement for the entire machine and must be completed by the end user before putting the machinery into use.

Contaminants:

The customer is responsible for external control.

Ionizing and non-ionizing radiation:

Engine installer responsibility

Vibration, shock, and bump:

The customer is responsible for external control.

Supply conductor terminations and devices for disconnection and switch off:

Supply conductor terminations on generator sets:

Engine installer responsibility.

Terminal for connection to the external protective earthing system:

It is the responsibility of the installer to connect engine to a grounding location on the machine, generating set or IOPU.

Supply disconnecting device:

Engine installer responsibility.

Protection against electric shock:

Protection against indirect contact:

Protection by electrical separation:

Engine installer responsibility.

Protection by automatic disconnect of supply:

Engine installer responsibility.

Protection of equipment:

Abnormal temperature protection:

Engine installer responsibility.

Earth fault / residual current protection:

Application specific, and the responsibility of the engine installer.

Protection against over voltages due to lightning and to switching surges:

Application specific, and the responsibility of the engine installer.

Equipotential bonding:

General:

Linking together of common earth connections. Engine installer controlled.

Protective bonding circuit:

Application specific, and engine installer responsibility.

Functional bonding:

Application specific, and engine installer responsibility.

Measures to limit the effects of high leakage current:

Application specific, and engine installer responsibility.

Control circuits and control functions:

Control functions:

Engine installer responsibility.

Protective interlocks:

Engine installer responsibility.

Control functions in the event of a failure:

Engine installer responsibility.

Operator interface and machine mounted control devices:**General:**

Engine installer responsibility.

Emergency stopping devices:**Types of emergency stop device:**

Engine only - Engine installer responsibility.

Colour of actuators:

Engine only - Engine installer responsibility.

Local operation of the supply disconnecting device to effect emergency stop:

Engine only - Engine installer responsibility.

Control gear: location mounting and enclosures:

Engine installer responsibility.

Wiring outside enclosures:**Interconnection of devices on machine:**

Engine installer responsibility.

Marking, warning signs, and referencing:**Functional identification:**

Engine installer responsibility.

Marking of equipment:

Engine installer responsibility.

Reference designations:

Engine installer responsibility.

Verification:**Verification of automatic disconnect of supply:****General:**

Responsibility of the engine installer for the completed machine.

Test methods in TN-systems:

Responsibility of the engine installer for the completed machine, the engines are DC only.

Application of the test methods for TN-systems:

Responsibility of the engine installer for the completed machine, the engines are DC only.

Retesting:

Engine installer controlled.

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2.0 Engine Selection and Application

2.1.1 Introduction

The purpose of the engine selection chapter is to provide guidance regarding the correct engine and aftertreatment system selection for the machine application.

2.2 Engine Selection and Application Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.

2.2.1 General

- The Installation design must allow for all service and maintenance procedures, including engine replacement, to be conducted safely in accordance with the guidelines published within the relevant service manual.
- The engine is supplied paired to the aftertreatment at the engine factory, so it is essential that the engine and aftertreatment are kept together.
 - Any deviance from this requires engine factory approval.

2.2.2 Ratings

- EM** The engine rating must be selected to have the necessary power and torque characteristics for the machine in which it is installed so that it can operate in all necessary environmental conditions.
- EM** The engine must be selected to comply with all the necessary legislation for the area in which the machine is to be sold and operated. Legislative compliance should be checked on the power curve.
- EM** An engine that has been certified for constant-speed operation must not be used in a variable speed application.
 - The engine must be correctly selected and applied in accordance with the industrial rating tier to which the engine has been developed. Rating classifications can be found listed in the ESM.
- EM** The engine must not be subjected to speeds in excess of 3700rpm (any customer supplied rotating equipment must be selected taking this into consideration).
- EM** The engine low idle must not be reset to a value lower than the default setting unless approval from the engine factory has been obtained.
- EM** In the installed condition, the engine must be able to achieve speeds greater than 1500rpm. The machine must not be allowed to constrain the engine speed in anyway such that speeds greater than 1500 rpm cannot be achieved.
- EM** In the installed condition, the engine must not be constrained to exclusively operate within a power range that has more stringent emissions limits than the (sub-) category the engine belongs to e.g., >560kW engine must not be permanently constrained to operate exclusively below this power.
- EM** The machine must be able to achieve the desired cold ambient capability with the configured elevated idle speed and machine parasitic load.
 - This must be tested in accordance with the relevant engine exhaust temp test procedure.
- EM** It is the OEM's responsibility to ensure that the machine marking/labelling should be consistent with the unconstrained certified engine speed and power.
- EM** The installed engine must be operated within the parameters defined in the 'Application concept Appraisal' as detailed in the relevant engine audit form.

2.2.3 Labels

- EM** The engine emission control information label must be in a location that is readily visible to the average person after all installation and assembly are complete.
- EM** If a duplicate emission control information label is supplied with the engine, then the duplicate label must be permanently attached to the equipment, even if the label supplied fitted to the engine is not obscured.
- EM** If a duplicate label is not supplied with the engine this must be requested from the Engine Factory.
- EM** In all cases the duplicate label must be secured to a part needed for normal operation and not normally requiring replacement.
 - A procedure must be in place to ensure these labels are fitted and positioned correctly.
 - The use of a duplicate emission label must meet the regulatory requirements set out in 40CFR 1068.105(c).
- EM** It is the responsibility of the equipment manufacturer to supply and permanently attach a separate label with the statement 'Ultra low sulphur fuel only' to the equipment near the fuel inlet in accordance with regulatory requirements 1039.135. This label is not supplied with the engine.
 - If the Ether warning label is supplied loose with the engine it must be placed in a permanent location that is clearly visible where Ether would be applied into the engine induction system.
- EM** If any of the engine labels are damaged or over sprayed after shipment of the engine it is the responsibility of the equipment manufacturer to replace these labels and fit them in accordance with the Engine Manufacturers' instruction.
- EM** For Installations where a factory provided oil filler cap is not used a visual aid, on or adjacent to the fill location is required to identify the correct oil specification for the engine and operating territory, information on the engines oil specification can be found in the operation and maintenance manual.

3.0 Mounting Systems

3.1 Introduction

For engines that require aftertreatment in the exhaust system as part of the engine emission solution, the mounting system is critical, not only to the engine, but to maintain compliance with emissions regulations.

The following points should be taken into consideration when designing the mounting system of the engine and its associated system components.

- To meet emissions requirements the integrity and durability of emission critical components must be maintained under all machine-operating conditions for the life of the engine.
- For 'off- engine aftertreatment' the key additional challenge is the requirement to ensure the relative displacement between engine and aftertreatment does not exceed application guidelines for the flexible installation connection kit. To do this it is important to understand and define the alignment and dynamic movement between the aftertreatment and the engine.
- For some engines additional consideration will need to be made for mounting of the engine ECM.
- In all cases it is recommended that you contact your mount suppliers in the early stages of the installation design process.

3.2 Mounting System Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

3.2.1 Engine Mounting

- The engine must only be mounted using the engine mounting pads provided.
- The engine must not be mounted in a location where the engine can be submerged in water during operation.
- EM** The engine mounting system must not be designed in isolation and must take into consideration the mounting of any after treatment that is required as part of the engine emissions solution.
- EM** For engines with remote mounted aftertreatment
 - The engine mounts must accurately control relative movement, between engine and after treatment, and ensure the gross deflection does not exceed the limits of the flexible installation connection kit for the life of the engine.
 - For further information refer to chapter 5 exhaust and aftertreatment systems.
- The static engine installation, from horizontal, must not exceed.
 - 2° LHS down, 15° RHS down for EMAT **OR** +/-15° side to side for Remote mounted Aftertreatment.
 - - 15° down at rear. Nose down installation not acceptable.
 - Any Installed angle must be taken into consideration when considering grade ability. Refer to chapter 9.0 Lubrication Systems for more information.
- EM** The engine must be mounted so that equipment frame deflections do not stress the engine castings and engine to aftertreatment connection beyond allowable limits and must protect the engine and engine to aftertreatment connection from excessive machine vibrations and shock loads.
 - The engine mounts must limit the engine movement from shock, inertia, or other forces so that the engine cannot make contact with chassis components.
 - The mounting system must adequately dampen 1st and 2nd order vibrations and not induce resonance throughout the normal operating speed range.
 - The mounting system must adequately dampen power train or machine induced dynamic loading e.g., track pass frequency, rock hammer and compactor frequency.
 - 4-cylinder engines must not be solidly mounted unless fitted with a balancer
 - Engine mounts must not be subjected to excessive heat that will cause deterioration of the material and may have a consequential effect on the control of engine movement. The material temperature limit is to be defined by the mount supplier.
 - Engine mounts must not be subjected to fluid contamination resulting from oil / coolant servicing that will cause deterioration of the material and may have a consequential effect on the control of engine movement. The material tolerance to fluids is to be defined by the mount supplier.
 - When using a 'saddle bracket mounted to the front side mounting holes and a single point front mount, the tolerances of the brackets must be sufficient to ensure that the bracket does not stress the block.
- EM** An engine factory supplied flywheel must be used for all installations
- EM** An engine factory supplied flywheel housing or backplate option must be used for all installations.
- EM** Customer supplied flywheel housings:
 - Require the use of the factory supplied backplate which incorporates the mounting bracket for the speed sensor.
 - Must be designed in accordance with the requirements detailed in section 3.3.7
- For DRY back ends only. It is necessary to have an air vent between the flywheel housing /transmission interface and atmosphere.
 - This is to allow air to transfer into and out of the flywheel housing, thus preventing the accumulation of water which may build up as a result of condensation and certain operating, temperature, and pressure conditions.

- All flywheel housing options are supplied with either a drain plug at the bottom of the housing, a plugged sensor port in the side of the housing or an inspection plate.
 - The drain hole or sensor port will allow sufficient ventilation if it is not sealed with a threaded insert.
 - As supplied, the inspection plate is not fully sealed and will provide sufficient ventilation.
- The engine and transmission must be mounted so that the engine structural limits are not exceeded.
 - The dynamic bending moment and shear forces at the RFOB and the reaction forces at the front mount and rear mounts, where applicable, must be calculated using the correct Engine Bending Moment Calculator Tool for the engine type selected. The calculated values must be within the maximum and average loading limits in the vertical and lateral planes as detailed in the ESM.
 - **The definition of Average Loading** is +/- g shock loading which occurs frequently; 1,000,000 events in engine life.
 - **The definition of Max loading** is +/- g peak shock loading, typically 95% of all shock loads should fall below this value; 10,000 events in engine life.
- The dynamic bending moment calculation tool does not take into account the resonance of the powertrain system. Resonance is of particular concern with cantilevered transmissions and pump sets. Care must be taken to ensure there is no resonance of the powertrain within the operating speed range of the machine. Refer to section 3.3.1 for more information on design and test requirements.

3.2.2 Aftertreatment Mounting

- Refer to [Chapter 5.0 Aftertreatment & Exhaust Systems](#) for details of mounting a remote aftertreatment system.

3.2.3 Mounting of Electronic Components

- Refer to [Chapter 11.0 Mounting of Electronic components](#).

3.3 Mounting System Design Considerations

Although the required mounting properties for a particular installation can be determined by purely theoretical methods, the practical selection of suitable flexible mountings to give these properties is an extremely specialised subject. This is particularly true if an optimised system is required which not only minimizes transmission of engine noise and vibration to the vehicle or machine structure, but also controls bodily vibration of the complete power unit and bolted-on driven equipment. Consideration must also be given to minimization of excitation to bolted-on auxiliary equipment e.g., filters, coolers, etc.

The problem to the installer lies in identifying; from mount manufacturers' published data, the required physical properties of the mounts, namely stiffness (in various directions) and damping characteristics and tolerances.

For this reason, **it is strongly recommended that intended mount suppliers should be consulted in the early stages of an installation design**, since they are best qualified and equipped to give specialist advice on the properties and application of their own products.

The information provided in this section is given as an aid to help guide this process. Additional relevant information can be found in the General Installation Manual.

3.3.1 General considerations

At all engine speeds, the mountings should isolate engine vibrations to the machine in order to maximise operator comfort, reduce noise and ensure durability of any ancillary components. For a successful installation, the mountings must be able to withstand, without excessive deflection, the static loadings due to the weight of the system being supported.

The mountings (and brackets) must be strong enough to withstand all dynamic loadings, which may be induced by the type of application.

The mountings should protect the engine from any stresses caused by distortion of the frame on which they are located.

If the line of action of engine imbalance force doesn't pass through the powertrain centre of gravity, then additional moments will be created.

On mobile and portable equipment, allowance should also be made for cornering, which can give high lateral horizontal loads, and for braking which can give up to 1g in the forward direction. Large static bending moments in the vertical plane at the cylinder block/flywheel housing interface should be avoided at all times, since these can lead to broken flywheel housings and damaged cylinder blocks. The magnitude of the bending moment is dependent upon the positions of the mountings and can be calculated by taking moments about the cylinder block/fly-wheel housing interface.

For an indication of static bending moment values that should not be exceeded for safe operation refer to the mandatory requirements section.

3.3.2 Driveline/transmission system resonance

In some applications, it will be necessary to check for driveline system resonance with nodes at the block/transmission system interface.

The bending limits at the interface still apply, but the resonance condition and bulk accelerations of the transmission system are not assumed to act simultaneously. If a resonance exists, that can be excited in the engines normal operating speed range, and the mode shape indicates a node at the transmission interface, the resonant bending moment/critical stresses have to be determined by measurement before the installation can be approved.

3.3.3 Cantilevered Transmissions

Where the Transmission/Pump Stack is cantilevered on the rear of the Flywheel Housing, care should be taken to ensure the design of the interface between the Engine or Flywheel Housing and Customer Transmission/Pump Stack is stiff enough to avoid any natural frequencies of the assembly being excited (resonance) by engine forcing throughout the engine operating speed range within the application.

Experience has shown that designs with the following features have a high risk of resonance:

- Adaptor Plates (between FWH and Transmission/Pump Stack) which are manufactured from Steel Plate without any strengthening detail.
- Relatively large distance between the CoG of Transmissions/Pump Stack and Adaptor Plate (when compared to the Flywheel Housing Length).
- High Ratio of Bolting Pitch Distance of Flywheel Housing to Adaptor Plate compared to Bolting Pitch Distance of Transmission/Pump Stack Mounting to Adaptor Plate.
- No additional brackets/beams to add stiffness across the FWH to Transmission assembly.

Where possible steps should be taken to remove these features from the design, or the design should be modified to reduce the risk i.e., by increasing the stiffness and moving the natural frequency above the highest significant forcing frequencies (4th order).

In all cases testing is recommended to ensure that the Flywheel Housing Adaptor Plate and Transmission/Pump Stack assembly is not forced into resonance. This must be conducted where designs exhibit the features considered to be a high resonance risk.

The use of Flexible or Solid Mounting Systems may be employed.

3.3.4 Flexible mounting systems

The General installation manual provides detailed design requirements and considerations for all types of flexible mounting system including:

- Different mounting configurations,
- Number of mounting points,
- Location of mounts and bending moments,
- Orientation of mounts including vertical and inclined,
- Different types of applications with mechanical gearboxes, Hystat, CVT and Torque Convertor transmissions.

It also provides a Method for designing optimised flexible mounting systems.

3.3.5 Solid mounting system design considerations

The General Installation Manual provides detailed design requirements and considerations for Solid Mounted systems including:

- Resonance.
- Alignment of engine and driven system.
- Shock loading for mobile applications.

3.3.6 Application Specific Considerations

The General Installation Manual provides detailed design requirements and considerations for Specific Applications such as:

- Light machines
- Forklift Trucks
- Combine Harvesters
- Other Mobile and Portable machines
- Stationary Equipment.

3.3.7 Customer Supplied flywheel housings.

Customer supplied housings require the use of the factory supplied backplate which incorporates the mounting bracket for the speed sensor as detailed in [Figure 3-1](#):

Customer housings must be designed to accommodate this bracket. The design must:

- Have a 36mm ϕ through hole
- Have a 48mm spot face
- Meet the tolerance and position detail in the relevant engine ESM.
- Allow for the assembly requirements detailed in the CAR
- Contact Applications for additional information.

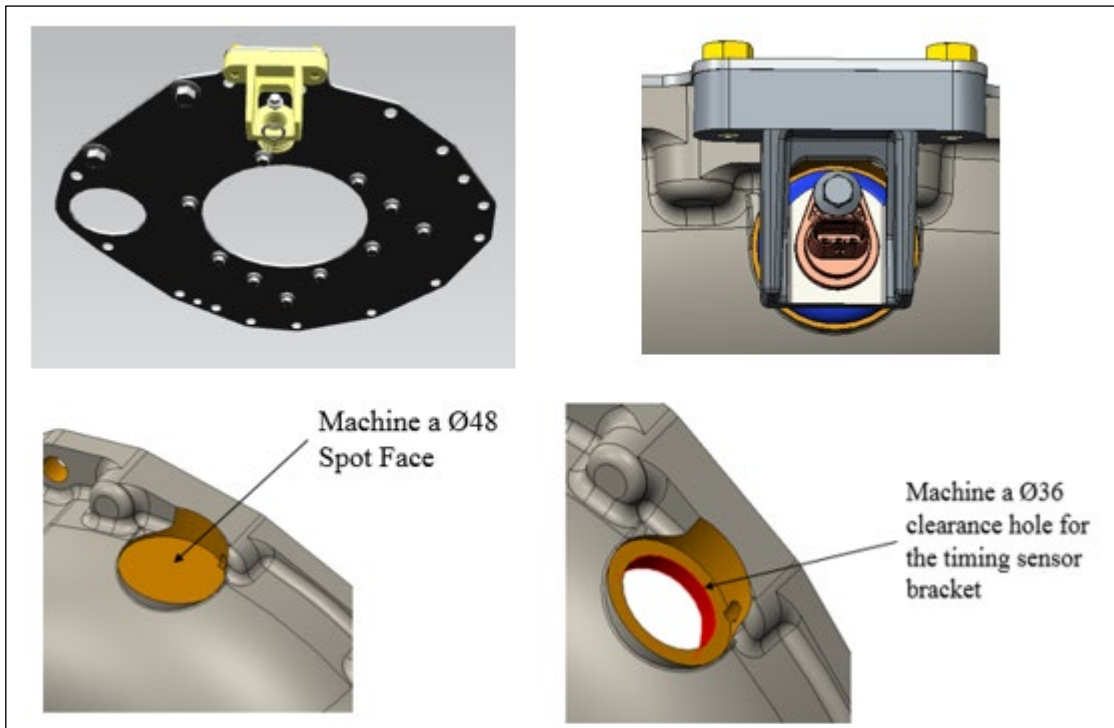


Figure 3-1- Backplate including speed sensor mounting

4.0 Induction System

4.1 Introduction

The induction system is one of the most important aspects of an engine installation as it can have a direct effect on engine output, fuel consumption, exhaust emissions and engine life.

It is, therefore, essential to ensure that the Induction system and any associated components are correctly specified and installed to provide a robust and durable system that ensures emissions compliance throughout the life of the product.

With this in mind, the installed induction system must be designed to supply clean, dry, and cool air to the engine, with a minimum of restriction. The system must be designed to withstand the shock loadings and working conditions that will be met in service and must provide reliable sealing and durability with a minimum of maintenance.

Air-to-Air Charge Cooling requirements are covered separately in the cooling system, Chapter [6.0](#).

4.2 Induction System Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

‘Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.’

4.2.1 Air cleaner

- The air cleaner must have adequate dust-holding capacity to achieve acceptable air cleaner life in representative field applications see Table 4.1 below.

Duty classification	Dust Holding Capacity (Tested to SAE J726b or ISO 5011)	Suitable Environments	Example Applications
Medium Duty	10g/cfm (353 g/m ³ m)	No significant dust concentrations	General Agricultural and construction equipment. Gensets in buildings. FLT in normal factory conditions, airport equipment.
Heavy Duty	25g/cfm (883 g/m ³ m)	Dirt/dusty environments	Rock crushers/screeners, mining equipment. Mobile equipment working in high dust concentrations.

Table 4-1 Air Cleaner Duty Classification.

- The air filter efficiency must be 99.5% with a particle size down to 80μ and be capable of 80% ingested moisture removal.
- The air filter must be suitable for the environment in which it is going to operate and must include a safety element. The use of a filters without a safety element requires applications approval.
- The air filter element must be serviceable without major component removal.
- EM** There must be a visible air cleaner restriction indicator. The set point must be the correct restriction for the rating and must take into account any restriction across the intake pipework.
- The air cleaner itself must not be subject to excessive heat that may result in its deterioration.
 - The temperature limit is to be defined by the air cleaner supplier.

4.2.2 Air inlet

- EM** The induction depression for clean and dirty filters must not exceed the maximum limits detailed in the relevant ESM.
 - These must be tested in accordance with the Air Inlet Restriction test procedure
- EM** The air inlet must be protected against the ingestion of water, foreign particles from dust or dirt and re-circulated hot air and exhaust gas.
- The intake air temperatures must comply with all the following conditions:
 - EM** The air inlet temperature sensor must be no more than 5°C above the local machine ambient temperature.
 - The turbo compressor inlet temperature must be no more than 5°C above the air inlet temperature sensor reading.
 - The turbo compressor inlet temperature should be no more than 10°C above the weather station ambient.
 - These must be measured in accordance with the relevant test procedure.
 - Refer to section [4.5.5.1](#) for temperature definitions and further information.
- The engine uses temperature offsets to establish a representative ambient temperature to use in fuelling calibrations and derate strategies. Therefore, it is imperative that the stated limits are complied with to avoid performance issues and unnecessary derates becoming active.

- For IOPU/EPak applications with puller fans this may require air to be ducted to the air filter from a colder region of the engine bay.
- For best performance it is recommended that the air is drawn from in front of the radiator. Compressor inlet depression limits will still apply in this case.

4.2.3 Air inlet Temperature Sensor

The air inlet temperature sensor and 'O' ring is supplied loose for fitment by the customer.

It is a passive sensor used to measure the air temperature entering the turbo, after the air cleaner.

EM The factory supplied sensor must be installed in the induction pipework upstream of the turbocharger.

- The sensor:
 - Should be installed between the air filter and the turbocharger.
 - If this is not possible, then engineering approval is required for any alternative location.
 - Must be in continuous air flow.
 - Must not be exposed to debris.
 - Must not be exposed to radiated heat.
 - Must NOT be downstream of the CCB connection as the tip could be fouled and an incorrect temperature measured. Refer to [Figure 4-1](#) below.
 - The sensor requires an 'O' ring seal and M18x1.5 port to seal the interface.
 - The maximum permissible tightening torque for this sensor is 20+/-3 NM.
- EM** The air inlet temperature sensor must not be exposed to temperatures in excess of 125°C.
- The sensor must be connected in accordance with the requirements in the Electronic Application and Installation manual.

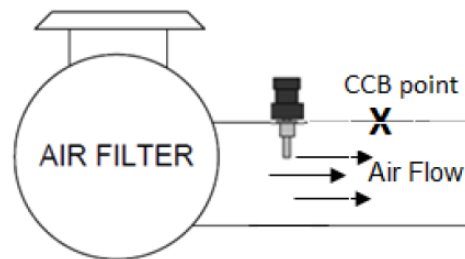


Figure 4-1 Air inlet temperature sensor location

4.2.4 Induction pipework (pre- engine inlet)

- Use of the factory supplied air inlet pipe is mandatory. Removal of this pipe is prohibited.
- The induction system hose material must be of adequate specification to withstand service/working conditions. It is recommended that hoses are specified to meet the requirements listed below, however temperatures will vary with application and it is therefore necessary to test each application to ensure the specification selected is sufficient:
 - Maximum working temperature: $\geq 140^{\circ}\text{C}$.
 - Minimum working temperature: -40°C .
 - Maximum working pressure: 10kPa.
 - Minimum working pressure -8kPa .
 - Resistant to fuel oil and lubricating oil on the external surface.
 - Cleanliness level as defined in [Figure 4-2 - Induction system cleanliness](#).

Perkins Component Cleanliness Standard For induction system components							
This specification defines cleanliness levels applicable to finished engine components and assemblies. All cleanliness standards are based on flushing the specified area with solvent filtering the flushed solvent onto a membrane filter patch, measuring particle dimensions with a microscope and measuring total particle mass with an analytical balance. The specified cleanliness must be met at the time of assembly							
Particle to be measured for size are metallic, rust (either free or loosely attached), slag, sand, and other abrasives. If particles are fragile and break up with gentle probing (gentle probing will not tear a membrane filter patch), only the remaining s							
Largest Particle Allowed, in microns (A)			Maximum No. Particles allowed per given particle length, in Microns (a)		Maximum mass allowed		Abrasives (Oxides) >40uM (C)
X	Y	Z	#	X	mg/m ²	mg	Allowed
1200	1200	200	4	500-1200	230	16	
			# = maximum number of particles				

Figure 4-2 - Induction system cleanliness

- The integrity of the pipework must not be disturbed for routine maintenance procedures.
- All pipework must have beaded ends when connecting flexible hose.
- The internal bore of any metallic intake pipe must be corrosion resistant.
- Hoses using separate internal reinforcement are not permitted. Reinforcement must be either external or fully integrated into the structure of the hose.
- The air cleaner to turbo inlet pipe must be supported so it doesn't induce any stress on the turbo inlet.
- The turbo inlet pipe must:
 - Have a diameter, throughout its length, greater or equal to the diameter of the turbo inlet connection
 - Have a minimum centre-line bend radius of 1.5D
 - Complex turbo induction pipes with changes in cross sectional shape (i.e., square to round), with restricted sections or with complex compound angles require applications approval to ensure laminar flow into the turbo. Refer to section 4.5.3.
- The turbo compressor outlet to charge air cooler inlet hose must meet the requirements detailed in the cooling system.

4.2.5 Pre-cleaners

- Pre-cleaners or dust evacuator valves must be matched to airflow of the engine.
- Evacuator valves must be installed vertically.

4.2.6 Exhaust Assisted Evacuation

- EM** The use of exhaust assisted pre-filter evacuation systems is acceptable.
- EM** The exhaust /scavenge pipe must be connected into the exhaust pipe work after any aftertreatment canisters to prevent fouling.
- EM** A check valve must be incorporated into the scavenge line to prevent reverse flow during all conditions.
- EM** Provision will need to be made to exclude the scavenge line from the system during in use (Portable emissions measuring system PEMS) testing.

4.2.7 Air intake Shutdown Valve

- The use of an air intake shutdown valve is acceptable for an emergency stop use only.
- The intake throttle must not be used as an emergency shutdown device.
- The valve should be installed in accordance with the requirements detailed in section 4.5.7 and details provided in the electronic A&I Manual.
- Refer to section 1.3.2 Emergency stopping in the Engine installer's responsibility section.

4.3 Induction System Overview

4.3.1 Air System Circuit

- The air system circuit for a 404J-E22TA Engine is shown in Figure 4-3 below.

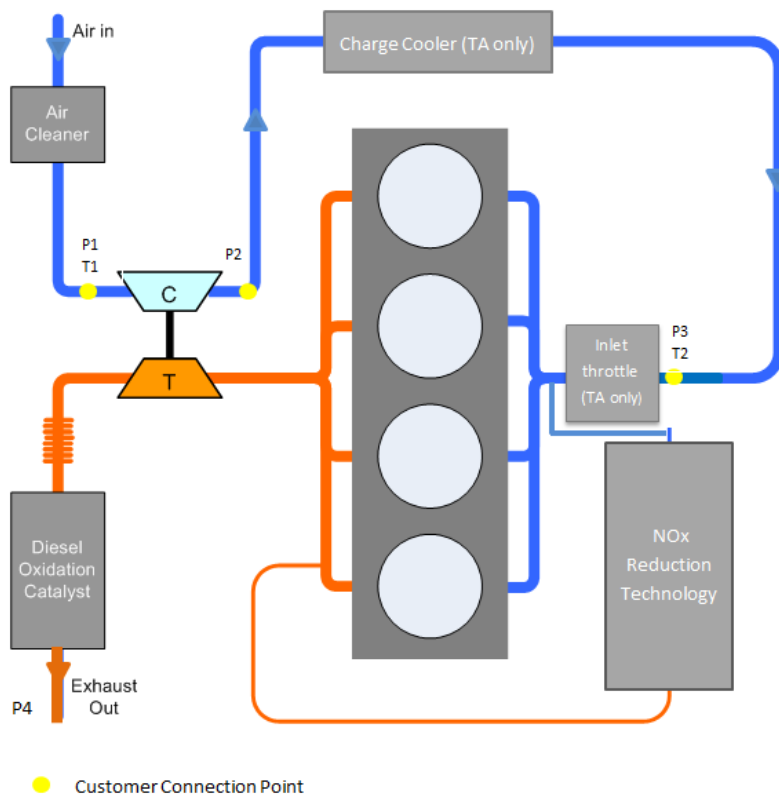


Figure 4-3 - Air System Circuit 404J-E22TA

- The customer is responsible for connecting the air cleaner to the turbo air inlet connection, (SV option), connecting the turbo compressor outlet to the charge air cooler and the charge air cooler to the inlet throttle connection (SB option). For straight turbocharged engines that don't need a charge air cooler, the connection between the turbo compressor outlet and inlet throttle is supplied factory fitted. All other air system pipework indicated on the circuit diagram is supplied connected.
- Induction system components covered in this chapter include the engine intake manifold connection and all the components prior to the turbocharger. The charge air cooling circuit is covered separately in the cooling system chapter section [6.3](#) and the components after the turbocharger are dealt with in the exhaust system chapter [5.0](#)

4.4 Induction System Components

4.4.1 Turbo -air inlet connection

Both 3- and 4-cylinder engines must have an air inlet connection (SV option) selected from the option offering. This provides a horizontal or vertical connection supplied fitted to the turbocharger inlet as shown in Figure 4-4.

- The Engine Factory supplied components within the crankcase breather system must not be modified, tampered, or disturbed in any way from the supplied condition. If this is a requirement contact your Application Engineer.
- Changing the factory supplied breather system on the engine i.e., from closed to open or from open to closed requires that the engine certification is checked to ensure the engine legislative status is maintained and that the engine software is modified accordingly.
- Operation of the breather system below -25°C requires additional precautions to be taken to ensure the breather gas does not freeze. This requires Engine Factory Approval and additional validation work.
- In certain circumstances for example where the cold air flow across the breather assembly is in excess of 1.5m/s, where there is low residual load or extended idle etc., the use of insulation or a heated breather maybe required at a higher ambient temperature than -25°C . This is application dependant, and a risk assessment must be carried out as well as testing.

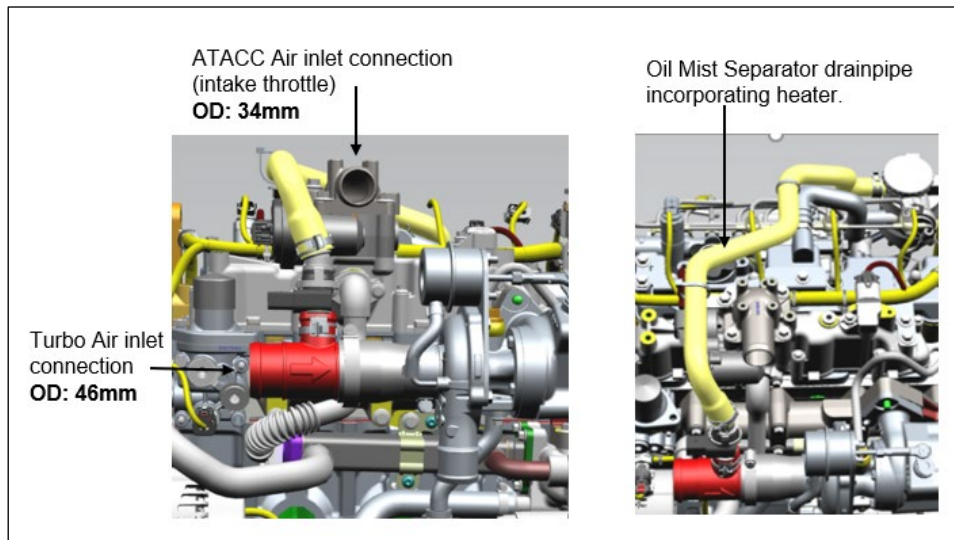


Figure 4-4 – Turbo air inlet and ATACC inlet connection

4.4.2 Inlet Throttle

All engines use an inlet throttle on the engine intake manifold as shown in Figure 4-4 above. This throttle is a thermal management device used to ensure effective operation of the DOC at all engine operating conditions. The throttle assembly also incorporates the customer connection for cooled air into the intake manifold from the charge air cooler.

4.5 Induction System Design Considerations

4.5.1 General Recommendations

- The use of a single stage filter with a safety element is recommended.
- It is recommended that the intake pipe work must be kept as short and straight as possible to reduce induction restriction.
- The diameter of the pipe work should not be less than the diameter of the turbo inlet connection.
- The number of joints within the system should be minimised and the reliability of seals ensured to maintain the integrity of the induction system under all operational conditions.
- The use of constant torque clamps is recommended.
- The air cleaner and pipe work should be shielded from heat sources that may excessively increase the induction air temperature.
- It is recommended that the air cleaner inlet is located so that the air temperature is kept as close to ambient as possible.
- It is recommended that the air cleaner is isolated from excessive engine or machine vibration.
- Relative motion between engine and cleaner must be catered for with the use of flexible fittings if required and pipe work adequately supported to ensure no stress is induced on the turbocharger inlet.

4.5.2 Induction Restriction

The induction system restriction, measured at the turbocharger inlet, is the total restriction due to:

- Air filter restriction
- Resistance to air flow due to pipe friction
- Air velocity effects.

If the restriction is excessive then the engine will not receive sufficient air for complete combustion to occur. This may result in a loss of power, increased DPF soot loading rate (DPF engines), risk of visible smoke (non DPF engines), poor fuel consumption and other issues that may impact emissions.

The maximum induction depression must be measured during installation audit testing and is a requirement for installation sign-off. This must be tested in accordance with the relevant engine test procedure.

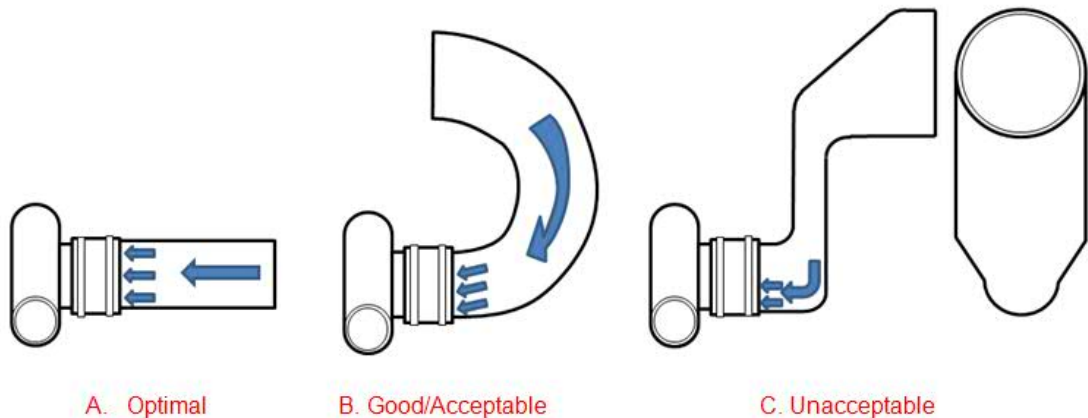
4.5.3 Induction system pipework and clamps

Careful attention must be given to the pipework and associated fittings used within the induction system in order to minimise restriction and ensure reliable sealing will be maintained under the operating conditions which will be found in service.

To minimise the restriction incurred in the system, pipework should have a large diameter bore and be as short as possible. The number of bends should be kept to a minimum with bends that cause the least amount of restriction utilized.

Turbocharger performance can be heavily impacted by poorly directed air flow into the compressor inlet which may lead to reduced engine performance. Ensuring laminar flow into the turbo eliminates the risk of surge and unstable operation.

Typical examples of optimal and poor turbo inlet pipe designs are provided below:



- A. Optimal:** Straight section of pipe of length equal to 2x Diameter of compressor inlet or greater.
- B. Good/Acceptable:** Large sweeping bend ideally with a larger diameter reducing down to the turbo
- C. Unacceptable:** Very tight radius bends especially close to the turbo. High level of change to cross sectional shape further compromising laminar air flow

Packaging limitations usually limit the use of an optimal arrangement and more commonly installations utilise a variation on design B.

Pipework must be designed to meet the mandatory requirements in section 4.2.4

Complex turbo induction pipes with changes in cross sectional shape (i.e., square to round), with restricted sections or with complex compound angles require applications approval to ensure laminar flow into the turbocharger.

Relative motion between engine and cleaner must be catered for with the use of flexible fittings if required and pipe work adequately supported to ensure no stress is induced on the turbocharger inlet. Material, temperature, and further design requirements can be found in the mandatory requirements.

4.5.3.1 The effect of elbows and entrance diameters on induction restriction

Detailed information of the effect of elbow diameters on induction restriction can be found in the General Installation Manual.

4.5.4 Air Inlet Location

The position of the air filter inlet, or of the inlet to the air filter extension if fitted, should be such that air is drawn from an area:

- Of the lowest possible dust concentration.
- Shielded from water ingress including spray and cleaning processes. Water will cause filter damage or plugging and possible engine and intake system corrosion.
- At a temperature, as close as possible to the prevailing ambient temperature. Additionally, care should be taken to minimise the possibility of exhaust fumes being drawn into the induction system, since this will result in a reduction in element life and increased air inlet temperatures.

Industrial Applications

In general, in enclosed applications, air should be drawn from outside the engine enclosure, in order to avoid excessive intake temperatures. Exceptions to this are certain applications using pusher-type cooling fans, where, depending on enclosure ventilation arrangements, air temperature in the enclosure may be relatively low close to the ventilation inlets. Care should be taken, however, to avoid local high temperature areas close to the exhaust system.

Agricultural Applications

Many arrangements are used where chaff or similar contaminants are likely to be encountered. In such cases a pre-screener should be fitted to prevent ingress into the main filter.

4.5.5 Air Inlet Temperature

4.5.5.1 Induction Temperature Definitions

- **Weather station temperature:**
The temperature that would be measured by a static weather station in a given region.
- **Local Ambient temperature:**
Air temperature into air inlet ducting.
For installations that are permitted to draw air from an under-hood location then the ambient temperature shall be the air temperature immediately outside the hood.
- **Intake air temperature:**
The temperature measured at the intake air temperature sensor.

4.5.5.2 Induction Temperature Recommendations

- It is always advisable to keep the air temperature entering the engine as close as possible to the local ambient temperature. High intake air temperature means less dense air entering the engine, which may result in increased smoke, less power, increased fuel consumption, overheating and charge cooler performance issues.
- To encourage good machine design, help machine performance and avoid hot air recirculation there is also a requirement to keep the engine air inlet temperature less than 10 degrees rise over the weather station ambient. It is recognised, however, that for certain machines like a Backhoe Loader and Hydraulic Excavator, this is not always possible. In certain modes of operation these machines create and operate within their own temperature bubble causing an increased local machine ambient temperature.
- In all cases care should be taken to ensure that the correct temperature is used in machine design to maintain the required machine performance and capability under all operating conditions.

4.5.5.3 Induction Temperature Measurements

Figure 4-5 below shows the allowed temperature rises above ambient within the induction system. Temperature measurements must be taken to ensure compliance with the mandatory requirements in section 4.2.2 in accordance with the defined test procedure.

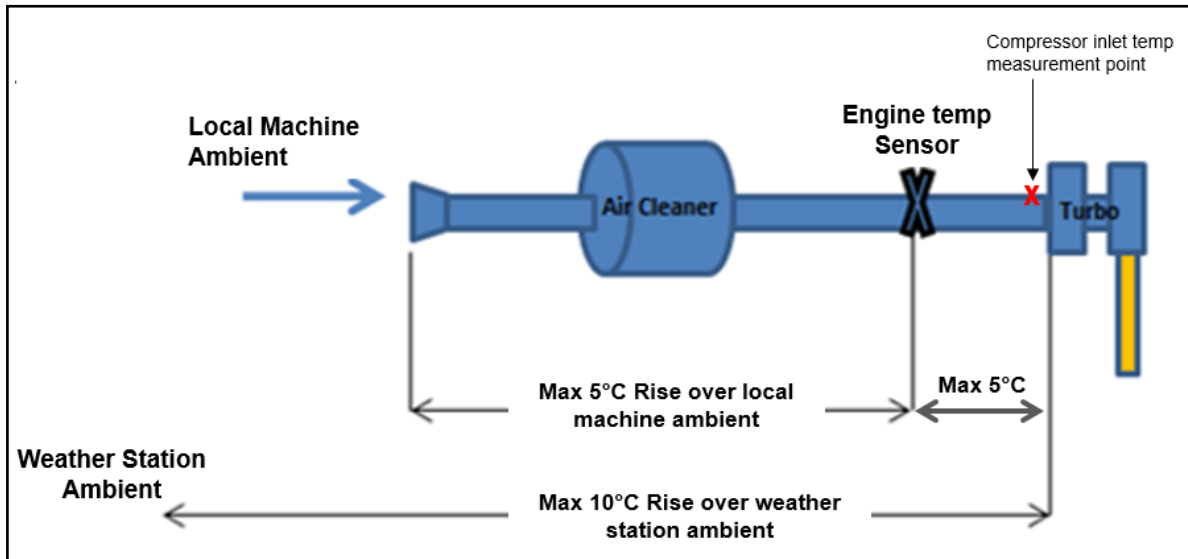


Figure 4-5- Induction System Temperatures

4.5.6 Air Cleaner Mounting

The air cleaner must be mounted so that the element can be easily accessed with minimal disruption to other components. Thus, reducing the risk of damage and contamination of the filter during replacement.

The mounting brackets should be approved by the air cleaner manufacturer and must ensure that there is no deformation of the sealing surfaces.

As air cleaners are sensitive to vibration, they may require isolation to ensure the durability of both the brackets and the filter elements.

4.5.7 Air Intake Shutdown Valve

The use of an air intake shutdown valve is acceptable for use in an emergency situation and not a part of normal operating duty cycle.

The recommended installation of an air intake valve also incorporates the use of pressure release (dump) valve and is summarised below:

The air intake valve is installed after the charge air cooler and cuts off the air immediately. A pressure release (dump) valve is also used and installed after the turbocharger. This prevents excessive pressure building up which may lead to surge issues and problems caused by excessive loading on the turbocharger compressor blades.

The air intake shutdown valve can be installed in the induction pipework before the turbocharger however, the loss of pressure on the intake side of the compressor may result in an internal oil leakage at the turbo bearing and although this is not likely to cause damage to the turbocharger itself there is a risk that the leakage of oil may be drawn into the charge air circuit contaminating the cooler and reducing its overall efficiency. The amount of oil leaked will depend on pressure delta, angular tilt, oil temp, oil pressure, turbocharger speed and time spent at that condition. For infrequent, emergency use only, the risk may be considered as acceptable.

Installing the air shutoff valve after the turbocharger before the air charge cooler, however, is not acceptable as the build-up of pressure in the turbo compressor will cause surge events and high compressor blade loading, which if activated under high load conditions is likely to result in compressor blade failure.

5.0 Aftertreatment & Exhaust Systems

5.1 Introduction

To attain the relevant emissions standards, it is necessary for aftertreatment to be incorporated within the exhaust system of some engines. This aftertreatment is required to enable the engine to produce its published rated power, fuel consumption and conform to the new emissions standards.

This chapter outlines the mandatory requirements and design considerations for exhaust systems and components, including aftertreatment modules where relevant.

5.1.1 Safety

Warning: Improper operation, maintenance, or repair of this product may result in injury. Do not operate or perform any maintenance or repair on this product until you have read and understood the operation, maintenance, and repair information.

Burn and fire hazards are possible. Failure to properly connect the Aftertreatment, manage the regeneration gas temperature, adequately route exhaust gases, and remove debris around hot components significantly increases risk and may result in personal injury. High component skin temperatures also increase the risk on personal safety and care should be made to protect or advise the operator where necessary.

5.2 Aftertreatment and Exhaust Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

5.2.1 General Exhaust System Mandatory Requirements

- It is not permitted to use exhaust brakes on any engine model.
- EM** The customer tailpipe:
 - Must be designed to prevent water and dirt ingress into the aftertreatment and engine.
 - Must be matched to suit the engine or aftertreatment outlet connection. This is detailed in [Table 5-3](#) section [5.5.3.3](#).
 - Must not exceed the bending moment limit at the aftertreatment outlet connection in [Table 5-2](#) section [5.4.2](#).
 - Refer to section [5.4.2.2](#) for calculation process.
- EM** The exhaust system backpressure must be within the limits published within the relevant ESM. Refer to section [5.4.1](#) for more information.
 - All testing must be conducted in accordance with the defined test procedure
- The Exhaust system component temperature limits must be adhered to:
 - Refer to Appendix D 'UHT and DEF test Acceptance Criteria and UHT Gauge map' in the relevant engine test procedure document for component temperature limits.
 - Component temperatures must be tested in accordance with the relevant engine test procedure.

5.2.2 General Aftertreatment Mandatory Requirements

- EM** The engine must be installed and operated with the aftertreatment that has been matched to the engine to ensure emissions compliance.
- EM** All joints used between the engine and aftertreatment must be industry standard, leak tight and must be durable for:
 - 8000 hours for engines >37kW.
 - 5000 hours for engines <37kW.
- EM** Under no circumstances is it acceptable to modify, tamper or customise the aftertreatment assembly, aftertreatment components or engine to after treatment interconnecting pipework as supplied from the Engine Factory.
 - The aftertreatment and aftertreatment mounting brackets must not be re-orientated from the supplied position.
 - It is not permitted for the aftertreatment canister restraining clamps (to the mounting frame) to be loosened to re-orient the canister.
- EM** The use of thermal insulation (for example thermal lagging or wrapping):
 - Must not be used on any engine or engine system component, including the aftertreatment, without factory approval.
 - Should be used on the aftertreatment interconnecting pipework for remote aftertreatment, to minimise heat loss.
 - Must not come into contact with or restrict the movement of any flexible (bellows) connection.
 - Refer to section [5.5.3.7](#) for guidance on insulation design.
- EM** Welding components onto the aftertreatment canisters is prohibited.

- EM** Mounting components, including the tailpipe support structures, to the aftertreatment or aftertreatment brackets is prohibited.
- EM** The aftertreatment is not qualified as a spark arrestor. If this is an application requirement then it is recommended to work directly with the applicable bodies (i.e., U.S. Department of Agriculture, Forest Service) to ensure all the necessary requirements are met.
- Painting of any aftertreatment component is prohibited.
- EM** If a Muffler, Dust Ejector or Spark Arrestor is required, it must be connected after the outlet from the aftertreatment can.

5.2.3 Cleanliness Requirements

- EM** The internal surfaces of all engine exhaust system pipework from the engine to the aftertreatment outlet must adhere to the cleanliness requirements detailed in [Table 5-1](#) below:
 - This is needed to prevent poisoning of the aftertreatment and requires the pipework to be clean and free of the additives used within the production process.
 - The cleanliness must be maintained through the customer assembly process.

Internal Specification reference	Type of surface the cleanliness requirement applies to	Largest Particle size allowed in any direction (μm)	Max mass of contaminants allowed per square meter of tube's fluid-wetted area. (mg/m^2)
1E0318E	Internal	1200	230

Table 5-1 Engine to aftertreatment pipe work Cleanliness

5.2.4 Remote Aftertreatment Requirements

5.2.4.1 Aftertreatment mounting

- EM** The aftertreatment must not be mounted on the engine or the engine system except when supplied as an installed option from the engine factory.
- EM** The aftertreatment canister must be mounted to a structure that will provide sufficient rigidity to support its mass and be capable of withstanding the maximum loading during a worst-case work cycle (including shock loading) for that application.
- The aftertreatment must not be mounted close to fluid lines or flammable components.
- EM** The aftertreatment's lowest natural frequency should be above 60Hz and the canister vibration must be within the component PSD curve - refer to the relevant engine test procedure for the PSD limit and test requirement details. In order to achieve this:
 - It is recommended that the aftertreatment canister is solidly mounted to the machine chassis.
 - For 'Harsh' applications that are subject to high vibration during operation; including Rock Crushers, Tracked Type Tractors and Pavers ISO mounting maybe required.
- EM** If the engine utilises off engine aftertreatment and both the engine and aftertreatment are solidly mounted this must be approved by Engineering and extensive validation work will be required. Please contact your Application Engineer for further information.
- EM** The aftertreatment is flow-directional and must be installed the correct way around; Refer to [Figure 5-7](#) for more detail.
 - Pipe with Marmon flange – Inlet, Engine side.
 - Plain pipe – Outlet, Exhaust side.

- The aftertreatment must be hard mounted to the machine chassis using the mounting bracket supplied refer to [Figure 5-1](#) below.
 - All 4x M10 mounting holes must be used.
 The mounting surface must be flat with a tolerance 0.5mm.

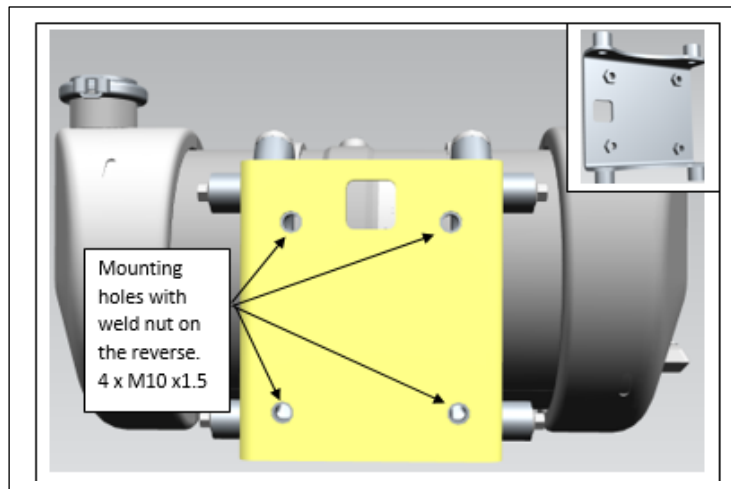


Figure 5-1- Remote Aftertreatment mounting bracket

- The aftertreatment must be mounted within the tilt angle capabilities specified in [Figure 5-2](#) and [Figure 5-3](#) below:

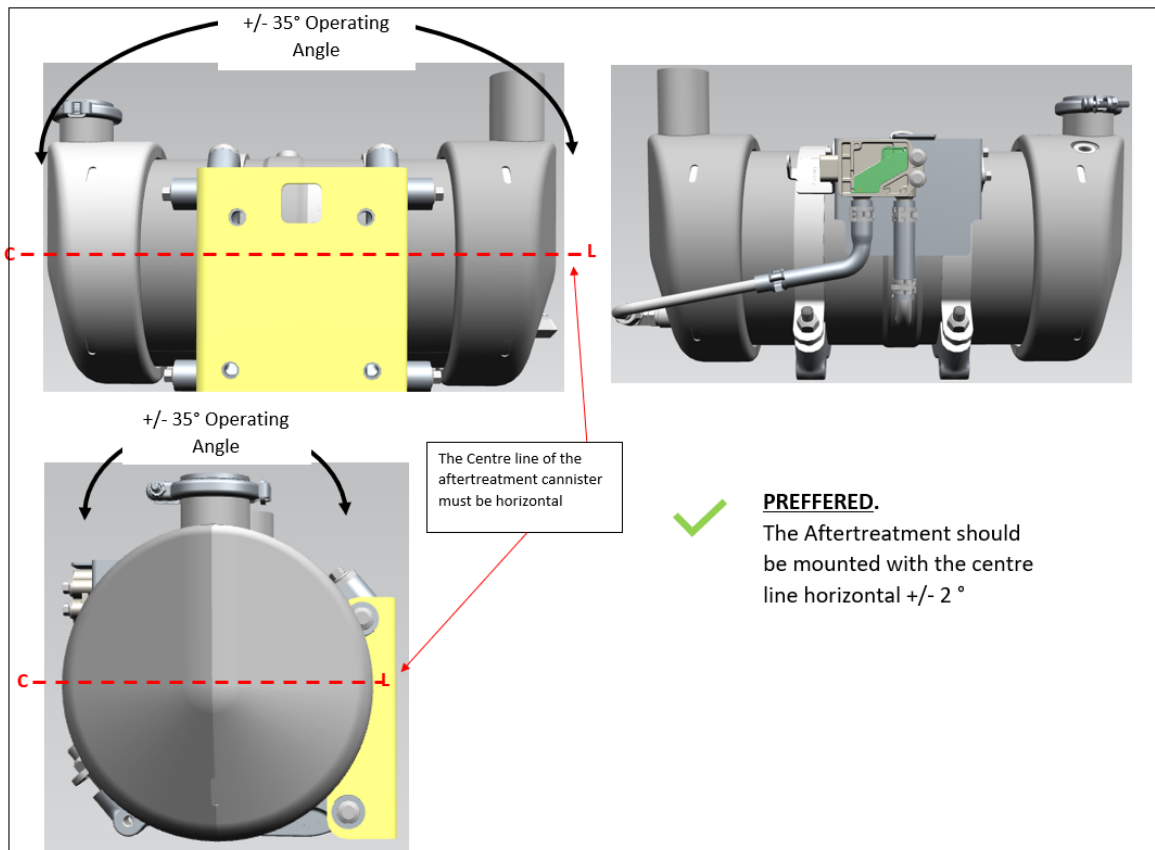


Figure 5-2 -Preferred Aftertreatment mounting orientation

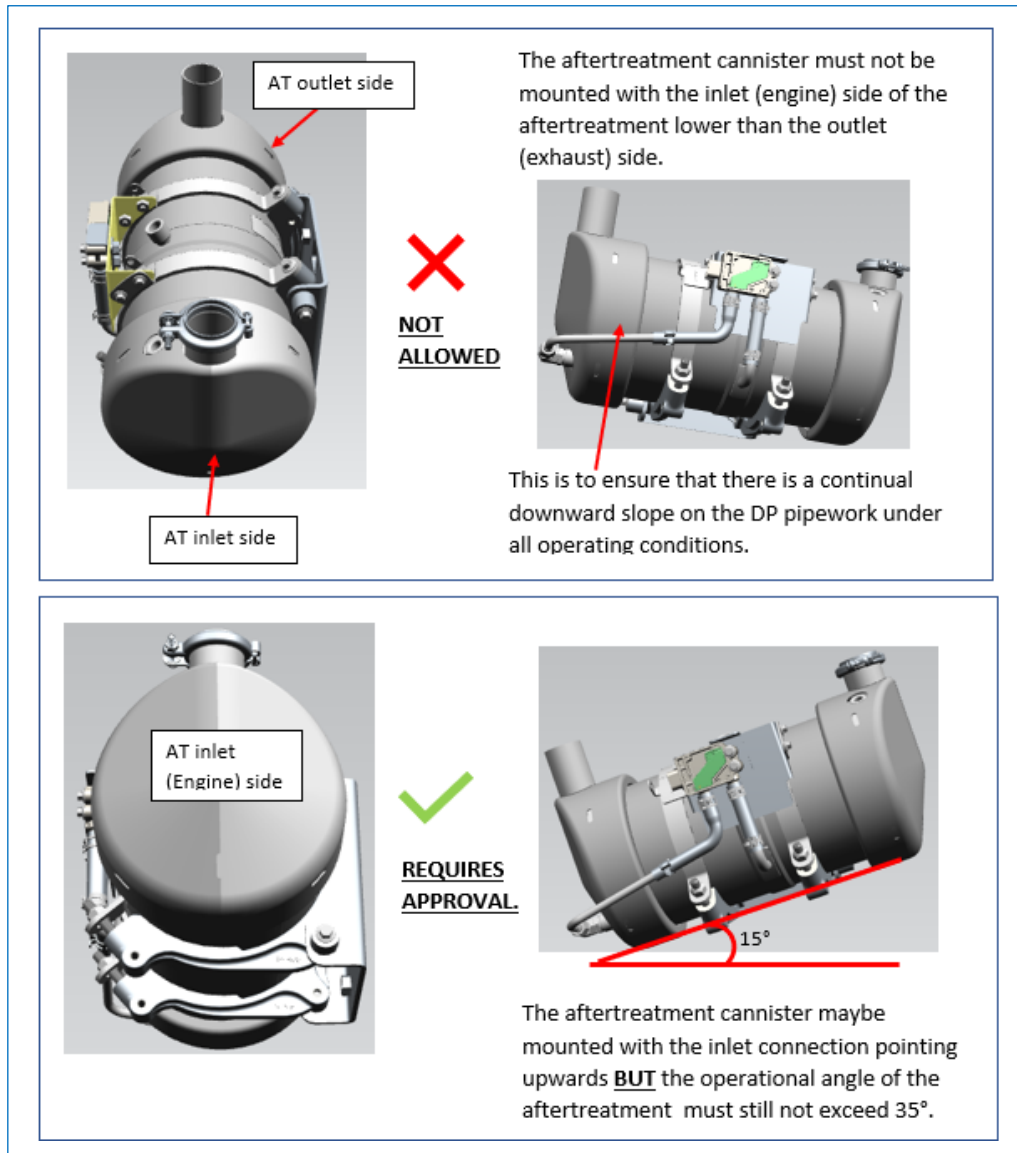


Figure 5-3-Alternative aftertreatment mounting orientation

5.2.4.2 Engine to Aftertreatment interconnecting pipework

- A factory supplied turbo outlet adapter (SD option) must be selected from the engine offering for all remote mounted aftertreatments.
- EM** A factory supplied flexible installation kit should be used between the engine and the aftertreatment inlet connection.
 - The use of a customer supplied flexpipe between the engine and aftertreatment inlet connection requires Engine Factory Approval.
- EM** The factory supplied flexible exhaust Installation kit must be assembled following the correct procedure detailed in the customer assembly requirements (CAR) document.
- EM** The Flexible Exhaust Installation kit assembly supplied with the engine requires the installation to be designed to meet the following design constraints:
 - Thermal Expansion and Dynamic movement (combined).
 - Axial = +/- 11mm.
 - Lateral = +/-11mm.
 - Maximum capabilities of adjustable elements:
 - Fore/Aft = +/- 15mm, per slip joint (x3).
 - These capabilities do not take into consideration any engine or aftertreatment tolerances, these must be combined with installation tolerances to ensure the above are not exceeded.
- EM** The capability of the system must be verified using the bellows displacement calculator. This can be provided by your Application Engineer.
'No part of the pipework from the turbo outlet adapter to aftertreatment should be bracketed back to the engine, either before or after the flexible section.
- EM** Any customer fitted pipe must be adequately supported after the flexible section.
 - It is recommended that it is supported from the same rigid structure that the aftertreatment is mounted to.
 - Seek Applications Engineer advice for any concerns relating to supporting brackets.
- The exhaust system must be designed to meet the following geometric constraints: -
 - It must be matched to suit the aftertreatment outlet connection*. This is detailed in Table 5-3 section 5.5.3.3.
 - Wall thickness (typical) 1.5 mm.
 - Material Spec 304 SS.
 - Constant diameter, smooth internal bore, no sharp edges, or weld splatter.
 - The pipework insulation must be 60mm clear of the slip joint.
 - The cleanliness must meet the requirements detailed in Table 5-1 section 5.2.3.

** All standard supplied tubes may not meet this specification and must be checked to ensure this requirement is adhered to.*

- There must be no cold spots (due to fan blasts etc...) along the length of the engine to aftertreatment pipework.
- The bending moment at the turbocharger outlet and the aftertreatment inlet must be kept to a minimum and must not exceed the values in Table 5-2 section 5.4.2.
 - To reduce loading on the turbocharger outlet the pipe between the turbo adapter and bellows should be kept as short as possible.
- The maximum temperature drop recorded between the turbo outlet and the aftertreatment inlet must be less than the maximum permissible value for the operating speed and engine fuelling.
 - This must be measured in accordance with the relevant engine exhaust temp test procedure.
- In order to meet this temperature requirement, the pipe:
 - Should be insulated but the insulation must not come into contact with the flexible bellows connection – Refer to section 5.5.3.7 for insulation recommendations.
 - Should be as short as possible. It is recommended that the length should be within:
 - 0.7m.
 - Lengths in excess of these recommended values may require additional insulation and validation.

5.2.5 Aftertreatment Sensors

- The installation requirements for aftertreatment sensors can be found detailed in Chapter 11 section [11.3](#).

5.2.6 Maintenance and In Use Testing Mandatory Requirements

- EM** Where the addition of a sample pipe to the exit of the exhaust stack does not provide a suitable non-diluted sample for in use testing (e.g., due to excessive backpressure, or use of air entrainment into the exhaust for cooling) adequate provision must be made in the design to enable emission-sampling equipment to be used successfully.
- EM** The aftertreatment is not serviceable. Only the aftertreatment temperature sensors can be replaced.

5.3 Aftertreatment System Overview

5.3.1 Engine Platform Technologies

Figure 5-4 below shows the aftertreatment technology for each engine platform and power band. These technologies have been selected as the optimal combination to meet emissions standards. The following section provides details of the aftertreatment arrangements.

		403J-E17T	404J-E22T	404J-E22TA
EU Stage V	Displacement	1.7L	2.2L	2.2L
	Cylinders	3	4	4
	Maximum power	36 kW	45 kW	55 kW
	Maximum torque	166 Nm	222 Nm	270 Nm
	Rated speed	2800 rpm	2800 rpm	2800 rpm
	Aspiration	Turbo	Turbo	Turbo After-cooled
	Fuel system	High Pressure Common Rail		
	Emissions Technology	EGR, DOC,DPF		
	Thermal Management	Intake Throttle, Injection timing		

Figure 5-4 - Platform Technologies

5.3.2 Aftertreatment Arrangements

DOC and DPF aftertreatment is required on all 400J-E engines with EPA Tier 4 Final and EU Stage V emissions certification. This is offered in both engine mounted aftertreatment and remote mounted variants.

5.3.2.1 System layouts/ Aftertreatment arrangements

Figure 5-5 below shows a generic layout of the exhaust system.

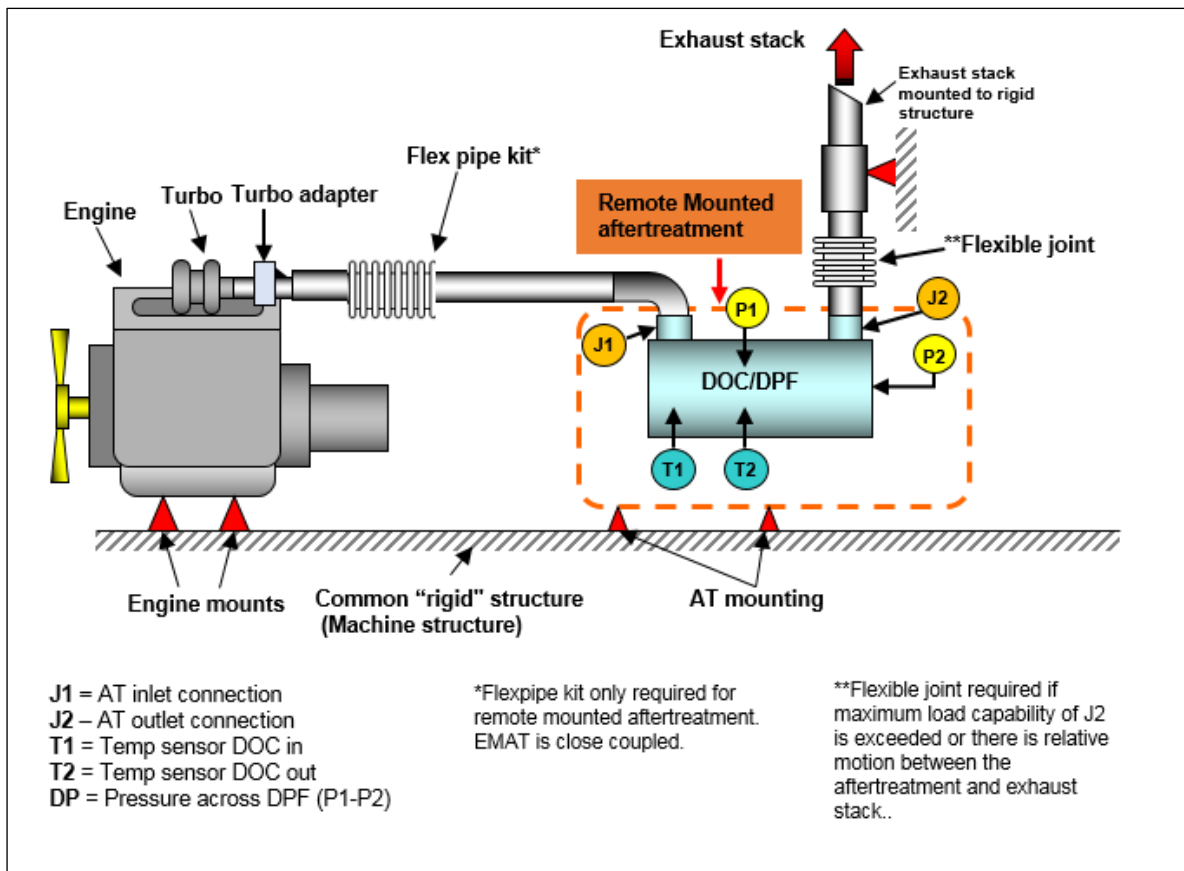


Figure 5-5- Aftertreatment Schematic

5.3.2.2 System Hardware Overview

The aftertreatment used on these engines is a single DOC/DPF cannister. It can be supplied engine mounted, transversely on the flywheel housing and close coupled to the engine as shown in Figure 5-6 or loose for remote mounting to the machine chassis using a flexible connection.

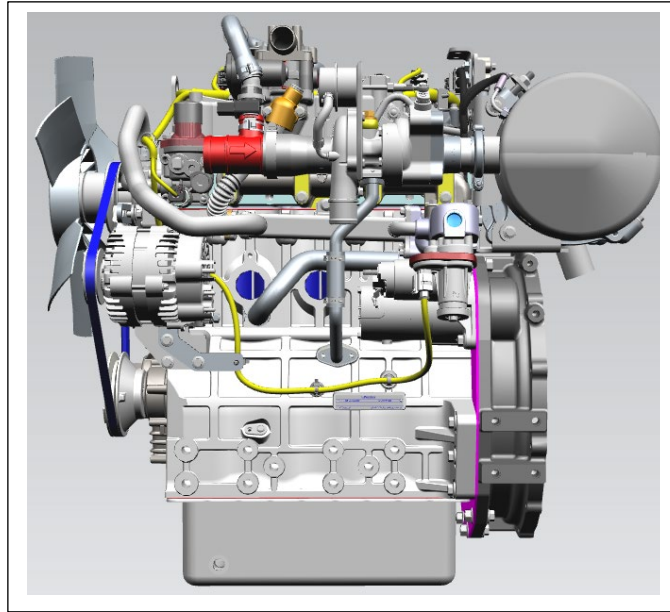


Figure 5-6- Engine Mounted aftertreatment (EMAT)

The aftertreatment, DOC/DPF cannister, is fit for life with a dual temperature sensor at the DOC inlet and outlet. These sensors are supplied fitted for EMAT and supplied loose for remote mounted aftertreatment.

The DPF delta pressure lines and the controller are supplied mounted to the DOC/DPF cannister for both EMAT and remote aftertreatment. For EMAT this is on the near side under the aftertreatment mounting bracket for remote aftertreatment it is on the opposite side of the aftertreatment mounting bracket.

The remote aftertreatment cannister is shown in Figure 5-7 below.

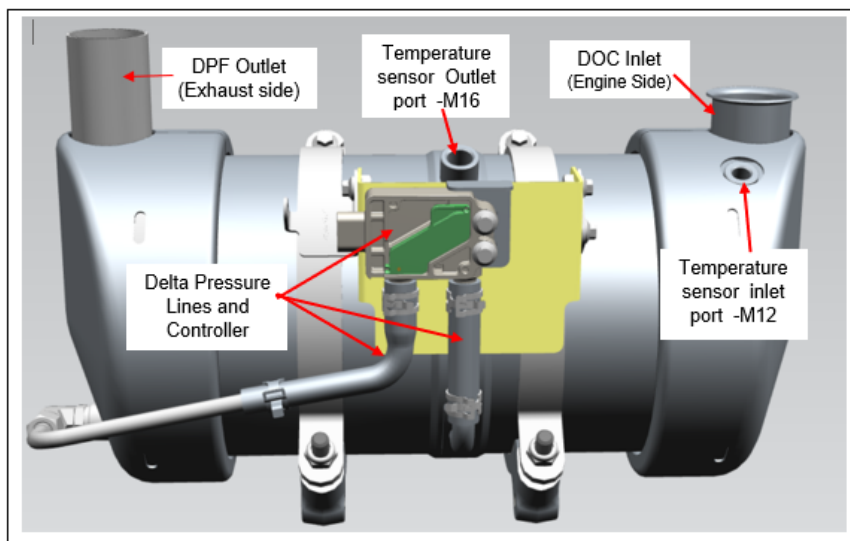


Figure 5-7- Remote aftertreatment cannister

5.4 Aftertreatment and Exhaust Operational Parameters

5.4.1 Backpressure Requirements

Refer to Mandatory Installation Requirements section 5.2.1 and section 5.2.4

The exhaust backpressure must be measured for both 3 and 4-cylinder engines.

As all engines include a DPF in the aftertreatment, the maximum pressure (back pressure) of the exhaust system is achieved when the aftertreatment is fully loaded with ash, this is known as the 'end of life' (EOL) condition.

A 'New' exhaust system must be designed and tested to be within the maximum and minimum 'start of life' (SOL) limits, which take into account the additional restriction as the DPF becomes loaded with soot. The minimum SOL condition is normally easily met by the exhaust system components supplied with the engine, however in some cases it is not, and it is necessary to meet a minimum back pressure as well as maximum.

The location of the exhaust backpressure measurement is dependent on whether the engine has engine mounted aftertreatment or if it is supplied loose for customer fitment on the machine chassis. For EMAT the backpressure should be measured at the DPF outlet to ensure an accurate measurement and prevent the need to disturb the close coupled engine to aftertreatment connection. For remote mounted aftertreatment, however, the exhaust back pressure must be measured at the turbo outlet.

The back-pressure limits depend on engine type and or rating and care should be taken to ensure the correct values are used. This information is detailed in the relevant engine ESM.

Note the value published on the power curve should not be used for this purpose.

All testing must be conducted in accordance with the defined test procedure.

5.4.2 Joint Loading

5.4.2.1 Joint Loading Limits

Refer to mandatory installation requirements section 5.2.2 and section 5.2.4.

Table 5-2 below shows details of the maximum allowable static and dynamic load on the Turbocharger and aftertreatment inlet and outlet connections. This must not be exceeded under any operating condition.

Engine	Exhaust Component	Aftertreatment		Static BM Limit (Nm)	Dynamic BM Limit (Nm)
		EMAT	Remote		
403J-E17T,	Turbo outlet		x	0.24	24
404J-E22T,	DOC/DPF inlet		x		
404J-E22TA	DOC/DPF outlet	x	x		

Table 5-2-Exhaust Component Load Limits

5.4.2.2 Aftertreatment Joint Loading

All pipe work connected to the inlet and outlet should be carefully designed, assembled, and adequately supported in order to minimise the joint load, prevent induced stress, and avoid vibration and resonance.

In order to establish whether the joint loading is acceptable for a particular installation, the step-by-step method, detailed below should be followed.

Step 1.

Calculate static load acting on the joint using the following formula:

$$\text{Static Bending Moment} = m \times g \times L$$

'm' = Total mass of the unsupported pipe including any sensors, sensor bosses etc

'g' = Acceleration due to gravity (9.8m/Sec²)

'L' = Total length of the unsupported pipe from the Aftertreatment outlet (including the engagement length with the ball/slip joint) to the centre of gravity of the pipe. Refer to worked examples below to calculate total length.

- If Static Bending Moment \leq Value specified in Table 5-2 - The design is acceptable and is approved.
- If Static Bending Moment $>$ Value specified in Table 5-2 - The Dynamic Bending Moment must be calculated -proceed to step 2.

Step 2.

Operate the machine on a regular work cycle and take acceleration measurements at the centre of gravity of pipe.

Calculate dynamic load using the following formula:

$$M = m \times a \times L$$

M= Dynamic load in Newton-Meter, Nm

'm' = Total mass of unsupported pipe (including any sensors, sensor bosses etc. that are supported by the joint) in Kilogram, Kg.

'a' = Peak Acceleration (not RMS) at the centre of gravity of the unsupported supported pipe in m/s². *Ensure Frequency limits from up to 200Hz are covered.*

L = Total length of the unsupported pipe from the aftertreatment outlet (including the engagement length with the ball/slip joint) to the centre of gravity of the pipe in metres, m. Please see examples in section 2 to calculate Total length.

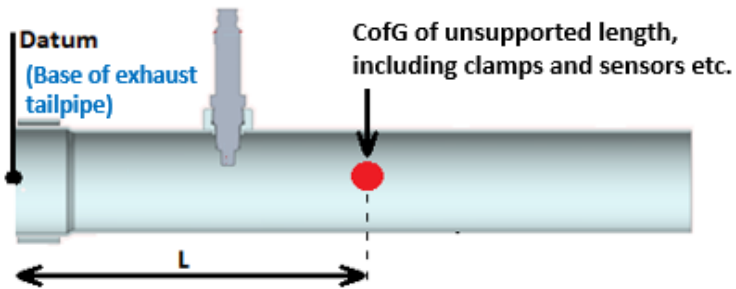
- If Dynamic Load is \leq 24Nm – The design is acceptable and is approved.
- If Dynamic Load is $>$ 24Nm – The design is not acceptable and must be re-designed - proceed to step 3.

STEP 3: Redesign Exhaust Stack Connection.

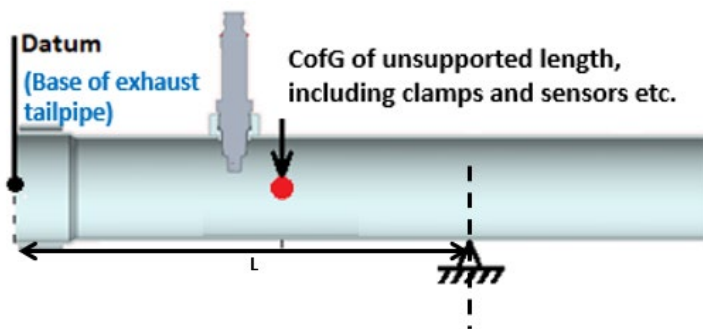
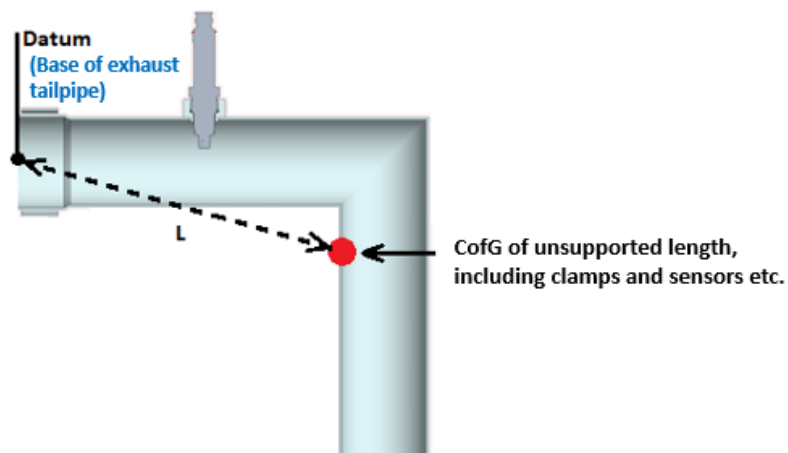
If a redesign of the exhaust stack is necessary, then the following points should be considered:

- The use of shorter or lighter pipes.
- Supporting pipes using brackets. Use sufficiently stiff brackets to avoid system resonances. Brackets should be durable enough to meet machine durability life requirements. Ensure Brackets are supported by the machine chassis or other significant machine mounting structure and not the Engine or aftertreatment.
- A flexible bellows section and supporting brackets can be used to decouple tail pipe resonances from the aftertreatment. Support brackets are recommended on the machine side of the flex pipe. The mass of the bellows section should be taken into account to calculate any static or dynamic loading as above.

Any re-design must be re-evaluated to ensure the design is robust and the limits are met.

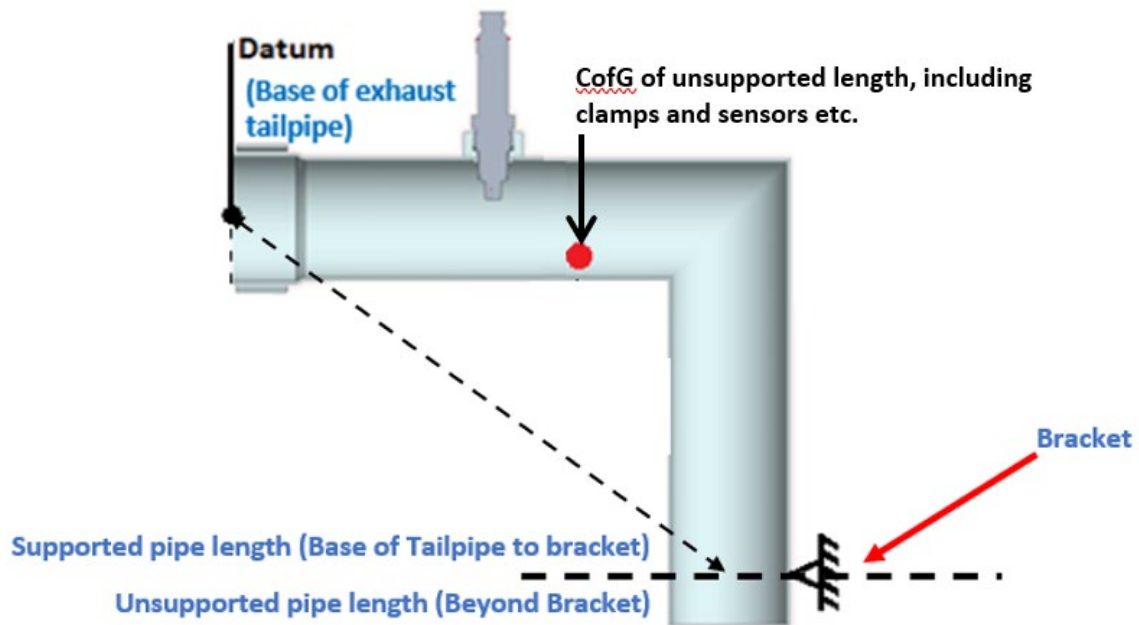
Worked examples:**Case 1: Straight pipe, unsupported.**

'L' = Total length from CEM outlet to the c of g of unsupported pipe.

Case 2: Straight pipe supported**Case 3: Bent Pipe unsupported**

$$L = \sqrt{(x)^2 + (y)^2 + (z)^2}$$

Where X, Y & Z are the distance of the c of g of the unsupported pipe from the aftertreatment outlet in each of the three planes.

Case 4: Bent Pipe Supported

$$L = \sqrt{(x)^2 + (y)^2 + (z)^2}$$

Where X, Y & Z are the distance of the c of g of the unsupported pipe from the aftertreatment outlet in each of the three planes.

5.4.3 Temperature Requirements

Refer to Mandatory Installation Requirement section [5.2.4.2](#)

Retention of exhaust temperature and reducing the heat lost from the turbo outlet to the aftertreatment inlet connection is vital to ensure effective and timely aftertreatment regeneration. Insufficient temperature can lead to reduced passive regen, increasing the need and frequency of active regeneration, which if required too often can initiate engine protection strategies.

The use of insulation is discussed in section [5.5.3.7](#).

5.4.3.1 Engine Mounted Aftertreatment (EMAT)

For EMAT the aftertreatment design has been fully validated taking into consideration a maximum air temperature and flow across it. It is, therefore, not mandated to measure the temperature drop at the aftertreatment inlet. If the installation design however provides a significant continual path of cool air flow across the aftertreatment or allows cool air to be blasted onto the aftertreatment then a temperature test will be required to ensure the minimum temperatures are maintained.

5.4.3.2 Remote Aftertreatment

For installations with remote mounted aftertreatment the temperature differential between the engine and the aftertreatment must be measured for ALL installations. This is a mandatory requirement as the temperature loss is significantly affected by the engine to aftertreatment connection, use of insulation and the air flow across it, as well as operation of the machine.

The testing must be conducted in accordance with the relevant engine exhaust temp test procedure and must not exceed the maximum allowable temperature drop under the given load/fuelling and speed conditions.

5.4.4 Vibration Requirements

All vibration limits are now contained within the relevant test procedure document.

The requirement to measure vibration is dependent on the engine type, aftertreatment configuration, EMAT or remote, the type of machine, installation itself and machine operation. Further advise and recommendations can also be found in the test procedure document.

5.5 Aftertreatment and Exhaust System Design Considerations

With the inclusion of aftertreatment into the engine system, emissions will no longer be regulated at the engine exhaust outlet but will be regulated at the aftertreatment outlet. This means that the aftertreatment unit itself and the connecting parts from the engine to the aftertreatment are now considered to be “emission critical components” under the legislative (EPA /EU) regulations, and must consequently, be very carefully designed and controlled to ensure the emissions regulations are adhered to throughout the life of the product.

Compliance with regulations governing emissions related components is imperative. In order to comply with these requirements, there are a number of key elements that must be considered when designing the exhaust system. These are detailed in the sections below:

5.5.1 Engine Mounted Aftertreatment

An on engine mounted aftertreatment is available as part of the option offering. This is a fully validated approved solution and should be used for all machines where the installation allows.

The EMAT should not be modified in any way from the supplied condition, this includes the mounting or welding any components to the aftertreatment or aftertreatment brackets, which is prohibited.

5.5.2 Remote Mounted Aftertreatment.

5.5.2.1 Mounting Requirements

The engine and aftertreatment should be considered as a system and the installation of these should not be designed in isolation. Please refer to mounting Chapter [3.0](#) for further engine mounting system requirements and considerations.

The aftertreatment is supplied fitted with a mounting bracket that is suitable to be either hard mounted directly on the machine chassis or onto a secondary support structure. The aftertreatment is designed to withstand the same G-Load limits as the engine. When considering a suitable mounting structure and location the following points must be taken into consideration:

- The structure must provide sufficient rigidity and be stiff enough to support the aftertreatment mass.
 - The structure should be a minimum of 10mm thick.
 - The mass of the aftertreatment can be found in the ESM.
- The mounting surface should have slotted or oversized holes to ensure alignment and allow for design and assembly tolerances.
- The bolts used must be to a minimum grade of 8.8.
- Any brackets, bolted joints, mounts, welds, or other structural elements supporting the aftertreatment must be able to withstand all mechanical loads seen during operation (including thermal growth) or shipping. Each of these elements may have different load limits, and the limits may depend on the direction of loading or number of load cycles expected during the product's lifetime.
- Any structural elements must provide acceptable strength and durability over the entire temperature range expected to be experienced in the application.
- Removing the mounting bracket provided and/or welding an alternative mounting bracket to the aftertreatment is not permitted; this could lead to failure of the unit and possible emissions non-compliance.
- The orientation of the inlets and outlets must not be adjusted during the installation process.

The aftertreatment assembly should be mounted in a location that:

- Allows air circulation around the can
- Avoids debris build up and damage from foreign objects
- Has the identity plate clearly visible, and
- Is easy to access, without major component removal, for any service and maintenance requirements. This is product dependant, and it is recommended that reference is made

to the Operation and Maintenance Manual (OMM) for the specific engine model when considering these requirements.

5.5.3 Engine to Aftertreatment inter-connecting pipework

The pipework between the engine and aftertreatment components must adhere to the requirements detailed in sections [5.2.4.2](#).

In order to provide a robust and durable connection between the aftertreatment and the engine a flexible connection is required in order to accommodate:

- Dynamic movement for Worst Case Engine Operation/Duty Cycle:
 - From Engine-on-Engine Mounts and aftertreatment on chassis or support structure. To include Start/Stop and Shock Loading.
- Thermal Expansion:
 - From Turbo or BPV to aftertreatment.
 - Vibration.
 - From Engine.
 - From Chassis.
- Misalignment.
- Tolerance Stack up (static).
 - between Engine and aftertreatment Interfaces.

5.5.3.1 Flexible Installation Kit

A flexible exhaust installation kit is available as part of the engine offering and should be selected as part of the engine specification. These options have been specifically designed and tested to provide a robust and durable connection between the engine and aftertreatment, provided the mandatory installation requirements are adhered to, reference section [5.2.4.2](#).

The flexible installation kit allows the use of a customer supplied pipe as part of the design. Figure 5-8 shows the customer pipe in the preferred location with the bellows connected directly onto the turbo adapter, thus reducing the load on the turbo, and minimising the overall length of the engine to aftertreatment connection by the use of a single customer pipe.

Figure 5-9 shows an alternative setup which provides additional flexibility to the design by allowing a customer pipe straight onto the turbo adapter instead of the bellows. This design is more complex, with more joints and puts additional load onto the turbo. It is also likely to have an increased overall length as it requires the use of two customer pipes. It is for these reasons that this design is not preferred and if required, care must be taken to ensure that all mandatory requirements are adhered to.

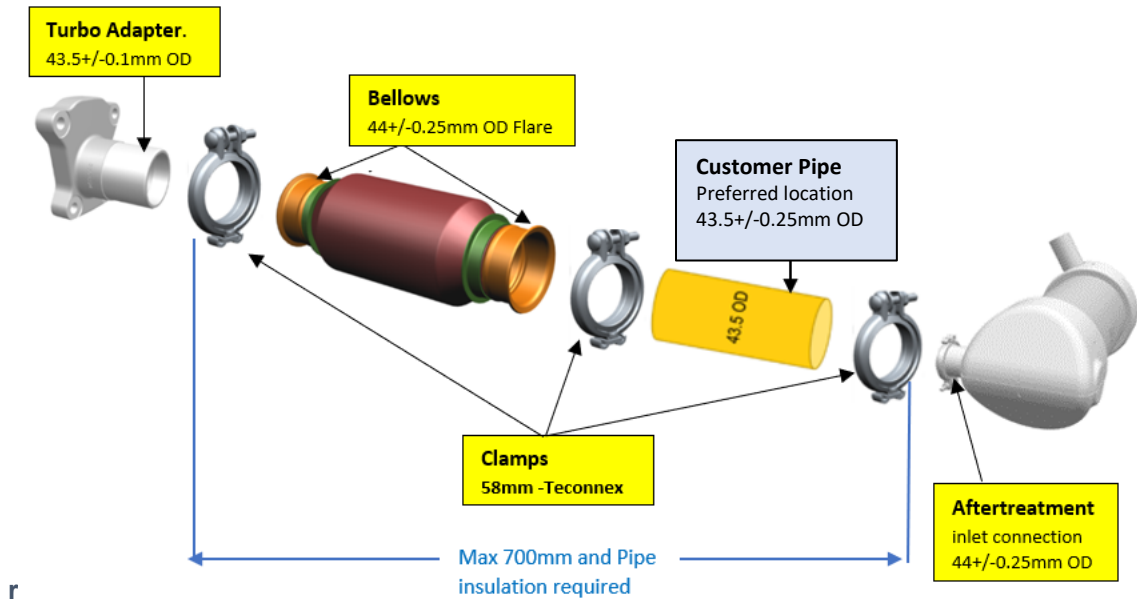


Figure 5-8 - Flexpipe Kit with preferred customer pipe location

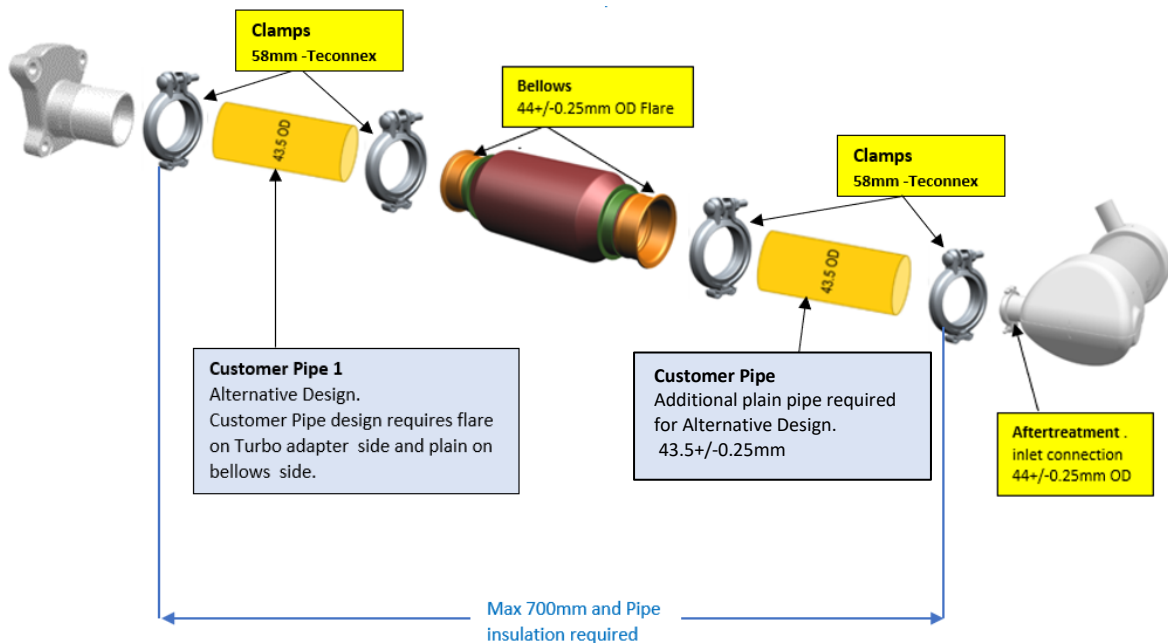


Figure 5-9 Flexpipe kit with alternative customer pipe location

5.5.3.2 Tolerance Stack Up

It is essential to ensure that the exhaust components and corresponding pipework are designed and positioned so that the limitations of the flexible exhaust Installation kit are not exceeded. In order to do this it is recommended that the system is designed around the capability of these components and the adjustable elements of the assembly, orientated to allow for any misalignment.

To ensure these requirements are adhered to the amount of static misalignment, due to tolerance stack up, between the engine and aftertreatment interfaces must be calculated. The sources of static misalignment are listed below, with appropriate values where available.

- Engine mounting pad to engine exhaust outlet in X, Y, Z refer to ESM for values.
- Aftertreatment mounting pad to aftertreatment inlet connection – refer to ESM for Value
- Engine mounting pad to chassis mounting point (including flexible engine mount) - customer assessment required.
- Chassis mounting point to Aftertreatment mounting point - customer assessment required
- Customer supplied pipe work - customer assessment required.

5.5.3.3 Pipe Size

Table 5-3 details the inlet and outlet connection sizes for the supplied aftertreatment system components. The customer supplied mating connections must be designed to match these connections.

It is imperative that the diameter and minimum length requirements are adhered to, in order to ensure that both the leak rate and pressure drop limits of the exhaust system meet legislative requirements.

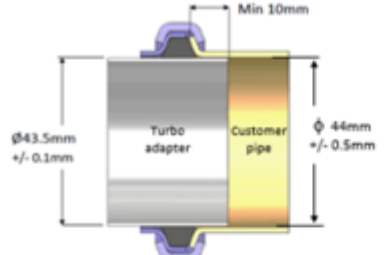
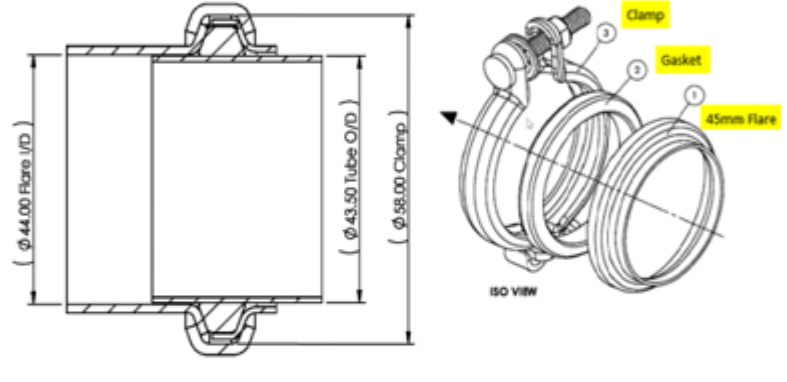
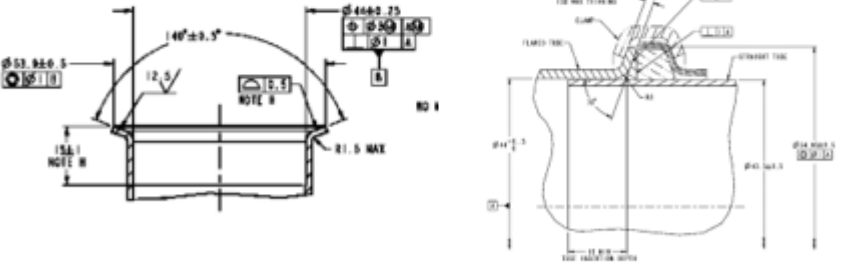
Engine	Exhaust Component	Engine Side Connection	Required customer connection type and size	
403J-E17T, 404J-E22T, 404J-E22TA	Turbo outlet adapter (SD034)	43.5 +/- 0.25mm OD straight connection	Suitable for direct connection of Flexpipe (bellows). Or swaged up tube with flared end 44+/-0.25mm ID Min 1.5 wall thickness and 10mm insertion.	
	Flexpipe – SU012 Bellows	44+/-0.25mm ID Teconnex flared connection	Plain pipe 43.5+/-0.25mm OD	
	Clamp	58mm Teconnex Clamp	On Assembly all components in slip joint must be assembled in correct sequence shown. This clamp has a graphite gasket and provides a leak free seal. It is fit for life but must be replaced once disturbed after the engine has run.	
	DOC/DPF inlet	44 +/- 0.25mm ID	Plain pipe of swaged down 43.5mm +/- 0.25mm OD. Min 10mm insertion SS304.	
	DOC/DPF Outlet	Slip Join 47+/-0.5mm OD	Plain pipe 48+/-0.5mm ID 35-45mm insertion. (connection for venturi also acceptable)	

Table 5-3-Exhaust Component Connection Sizes

5.5.3.4 Pipe Length

The pipe length should be as short as possible, not only to reduce the joint loading and potential resonance on the engine and aftertreatment connections but to ensure a high temperature is maintained at the DOC/DPF inlet. Details of the requirement for this can be found in the following sections [5.2.4.2](#) and [5.4.3](#).

In order to meet this temperature requirement, it is recommended that the total length of the connection between the turbo adapter outlet and the aftertreatment inlet is no more than 0.7metres.

The pipe should be thermally wrapped (lag) to retain the heat along its length and help maintain the required aftertreatment inlet temperatures- refer to section [5.4.3](#).

5.5.3.5 Pipe Material

The material selection is an important part of ensuring that the system will continue to perform over the life of the application.

- For the pipe supplied by the customer, between the turbo adapter and bellows and/or the bellows and aftertreatment inlet, the material of this pipe must be 304 or 321stainless steel. This is required to match the flexible installation kit material and ensure a leak tight connection is maintained under all thermal conditions.

5.5.3.6 Exhaust flex pipe capability calculator

The Applications flex pipe calculator should be used to determine if the installation satisfies the required flex pipe capability. This calculator must be used with the aftertreatment Mounts Decision Tree to determine aftertreatment vibration acceptability. The flex pipe calculator is available from your Application Engineer.

The installer-designed engine and aftertreatment installed system must satisfy two criteria to ensure acceptable flex pipe durability:

- Radial Capability.
- Axial Capability.

The flex pipe calculator requires several inputs including the following: -

Engine

- Installed mass of the engine and all loads cantilevered off the flywheel housing.
- Installed centre of gravity for the engine and all loads cantilevered off the flywheel housing.
- Number of engine mounts.
- G-load.
- Engine mount positions.
- Engine mount stiffness.

Aftertreatment

- Mass.
- Centre of gravity.
- Number of CEM mounts.
- G-load.
- Aftertreatment mount positions.
- Aftertreatment mount stiffness.

The calculator uses this information to determine radial and axial movement at the flex pipe. Based on this movement the calculator will designate the radial and axial flex pipe capability as acceptable or unacceptable. All installations must achieve flex pipe radial and axial acceptability.

5.5.3.7 Pipework Thermal Insulation

Insulation is required on the engine to aftertreatment pipe work in order to reduce temperature loss and meet the temperature requirements detailed in mandatory requirements section [5.2.4.2](#) and section [5.4.3](#).

The appropriate level of insulation will depend on a number of factors which must be considered during the machine design:

- Length of pipes (within the A&I guidelines)
- Airflow over the pipes and aftertreatment
- Number of bends in pipework
- Significant time spent operating in cold conditions
- A reasonable allowance should be added for losses around clamps, bellows, sensors etc.

The installation should cover the entire exhaust installation except for the bellows section and sufficient clearance should be allowed for the slip joints.

The following insulation specification could be used:

- E-Glass or ECR:
 - Nominal Thickness 12mm
 - Area Density 2.25Kg/m²
 - Peak temperature 600°C.
- Thermal conductivity:

MEAN TEMPERATURE °C	200	400	600
W/mK	0.060	0.104	0.172

- Thermal resistance -0.23m²K/W @200°C
- Insulation to be enclosed in a dimpled foil 0.3mm thick 309 stainless steel material and directly fixed to the tube.

A significant amount of heat is lost around the clamps, bellows, and any sensors causing less favourable results when insulation is used that is restricted for use across the pipework only.

The use of a blanket style of insulation is not recommended. Care must be taken to ensure that it is fitted correctly as it can easily be positioned incorrectly or omitted after service. The assembly of the insulation blanket should be repeatable, producing the same insulation capability every time avoiding cold spots on the pipe surface.

5.5.4 Noise attenuation

Please refer to section [13.0](#) Noise Control, for further information.

The use of a silencer within the exhaust system is application specific. Should a silencer be required it must meet the backpressure limits and be fitted after the Aftertreatment. However, due to the good noise attenuation properties of the DPF substrate, in some applications the DPF can replace the silencer without any additional provisions for noise attenuation.

5.5.5 Exhaust pipe outlets

- The exhaust pipe outlet must be adequately supported in order to minimise the joint load, prevent induced stress, and avoid vibration and resonance. The design must:
 - Not exceed the maximum dynamic joint load of the DPF outlet connection. Refer to section [5.4.2.1](#).
 - Must have a nominal internal diameter to match the aftertreatment outlet connection. Refer to [Table 5-3](#).
- Exhaust outlets must be provided with an appropriate means of preventing water ingress. This can be accomplished by several methods, but these can impose restrictions that can significantly increase the backpressure so careful consideration must be taken during selection.

- The use of a rain cap, exhaust flaps, slots within the exhaust pipe or angled outlets are commonly used methods.
- It is most important to select the direction of the tail pipe exit so that the exhaust gas:
 - Is not drawn into any dry element air cleaner, subsequently rapidly clogging the element, and reducing service life.
 - Is not drawn back through the radiator by a puller fan installation. This is likely, where exhaust exit, and radiator entry are both on top of the machine.
 - Is directed away from the sight lines of the machine operator.
- Consideration should also be given to the noise regulations or requirements that must be met (i.e., bystander, operator, etc.) as some advantage may be gained by directing the outlet away from microphones or observers.
- The exhaust pipe can accumulate a considerable amount of condensed moisture, especially when the pipe is long. To avoid internal corrosion, a condensate trap with an open drain can be provided at the lowest point in the system.
- The exhaust pipe should avoid touching or passing close to the air cleaner, fuel and lubricating oil filters, fuel tank or piping, injection or lift pumps, radiator, or sump and also, alternator, starter motor wiring or any electronic components. If this is unavoidable then suitable heat shields should be employed.

5.5.5.1 For 4-cylinder engine mounted aftertreatment:

When designing the exhaust pipe for on engine mounted aftertreatment care must be taken to ensure that the exhaust pipework avoids 4th order resonant speeds. In addition, it:

- Must not induce any resonant conditions in the exhaust system
- Must not exceed the maximum dynamic joint load in section [5.4.2.1](#).
 - In order to achieve this limit, the pipework must be kept as short as possible and should not exceed 700mm (including engagement length) TBD.
 - If this length is exceeded, then the dynamic load must be calculated using the calculation method described in section [5.4.2.2](#) or a verification test must be conducted to validate the system.

5.5.6 Spark Arrestors

The aftertreatment is not qualified as a spark arrester. If this is an application requirement then it is recommended to work directly with the applicable bodies (i.e., U.S. Department of Agriculture, Forest Service) to ensure all the necessary requirements are met.

The DPF cannot, as a component, be USFS (US Forestry Service) certified as a spark arrester because USFS certification using their current draft standard has requirements in addition to spark arresting.

5.5.7 Thermal Management

Please refer to the Chapter [7.0](#) Thermal Management for detail of the component temperature limits and suggested methods to reduce and control temperatures within the engine bay.

The addition of aftertreatment on EU Stage V and EPA Tier IV Final engines and muffler, if fitted, will increase Underhood temperatures due to radiated heat. Ways to dissipate this heat and improve airflow across the engine and aftertreatment will be necessary particularly over sensitive electronic components.

5.5.8 Design Considerations for Electrical Components

Please refer to Chapter [11.0](#) Mounting of Electronic Components for more information and the Electrical and Electronic Application and Installation Manual for details of the control systems, harnessing and connection of the aftertreatment.

All aftertreatment contains electronics and subsequent wiring harness connections.

5.5.9 Service and Maintenance

Refer to mandatory requirements [5.2.6](#).

Please refer to OMM for detailed service requirements.

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6.0 Cooling Systems

6.1 Introduction

All internal combustion engines produce heat as a by-product of combustion and friction.

Within the engine the exhaust gas recirculation, cylinder block and cylinder head are all water-cooled, and the lubricating oil temperature is maintained within acceptable limits through the use of a water cooled, engine mounted cooler.

The use of after-treatment, auxiliary emissions control strategies and turbo charging to increase boost temperatures and pressures all add additional heat load into the system.

It is essential to manage both the heat to coolant and the induction air temperature to maintain engine life, performance, durability, and emissions compliance for the life of the engine. The integration between engine and machine is critical.

In all cases a system must be designed to maintain engine temperatures within the specified limits under the most extreme conditions of ambient and operation that the machine will encounter.

This chapter outlines the mandatory requirements and design considerations for engine cooling and charge air cooling systems.

6.2 Cooling System Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

- ***'Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'***

6.2.1 General Requirements

- The system must have a pressure cap that maintains system pressure within the range of 0.90 to 1.1bar.
- The total allowable external restriction across the cooling system (engine water outlet to water pump inlet) is dependent on the engine operating speed and the water pump drive ratio. The limits when operating the machine at the standard rated engine speed can be found in the radiator cooling flow rate table in the cooling system technical data section of the relevant engine ESM.
 - If the rated engine speed is reduced, then the maximum allowable cooling system restriction limits will also reduce. Please contact applications for further information.
- The engine must be run on a 50:50 water/ethylene glycol (antifreeze) mix.
- Coolant should only be taken from the engine using the approved connections in the authorised locations (cab heater and compressor).

6.2.2 Coolant Temperature

- For all applications
 - The maximum top tank temperature must not exceed 112°C.
 - Coolant temperature must be tested in accordance with the defined Test Procedure.

6.2.3 Coolant pressure

- The water pump inlet pressure must be maintained at or above the threshold shown on the graph in Figure 6-1:
 - For example, 1.6 bar (absolute) @107°C water pump inlet temp (approximately equal to 112°C top hose temperature depending on radiator performance).

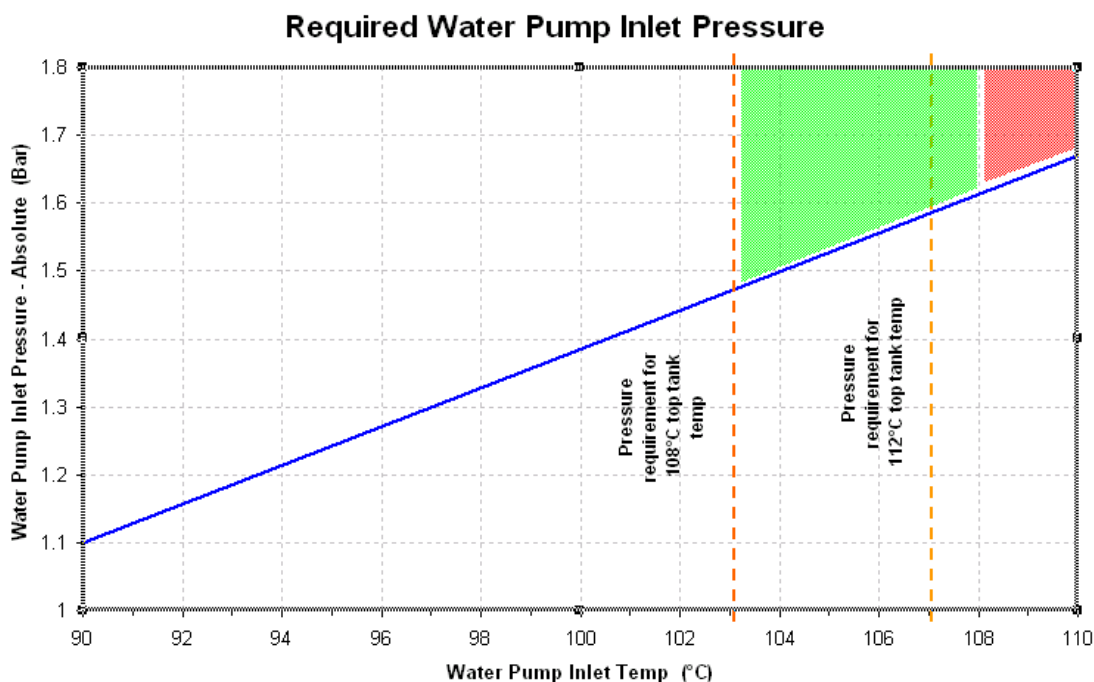


Figure 6-1 -Water pump inlet pressure

6.2.4 Hot Shutdown Mandatory Requirements

- The total accumulative discharge on repeated hot shutdown must not exceed 10% of the total system volume.
- The water pump inlet pressure must be maintained above the threshold (ref Fig 6.1) for 4 successive hot shutdowns.
- All tests must be conducted in accordance with the relevant Test Procedure.

6.2.5 Coolant Recovery Systems

- Coolant recovery systems are non-preferred and require approval for use. If a coolant recovery system is employed the following criteria must be adhered to:
- The recovery bottle must be designed so that:
 - The minimum cold level provides sufficient volume to ensure the suction pipe does not come uncovered under all tilt conditions.
 - There is a minimum of 10% of the coolant system volume between the minimum cold level and the maximum cold level.
 - There is a minimum of 8% expansion volume above the maximum cold level.
- The system must successfully pass the fill and hot shutdown tests in accordance with the relevant engine test procedure.
- The recovery bottle should be positioned above the bottom of the radiator.
- The recovery bottle should be as close to the radiator pressure cap as possible but within a maximum of 0.5m.
- The return hose from the recovery bottle must be a short single length of hose. It must not include any joints and must terminate at the bottom of the recovery bottle below the fluid level under all tilt conditions.
- The vacuum valve in the pressure cap must operate with a small pressure differential of 5kPa or less.
- There must be a clear and visible indication and service instruction for coolant fill and level checking.
- It is mandatory that a coolant level switch or visible indication of coolant level is employed on the radiator:
 - It is recommended that the Engine ECM input and associated configuration settings are used for diagnostic purposes.

6.2.6 Integrated radiator top tank with pressure cap and no separate auxiliary header (shunt) tank

- These systems are non-preferred and require Engine Factory Approval:
 - They add significant risk to cooling system de-aeration and water pump inlet pressure.
 - They require significant additional testing to ensure the venting characteristics are acceptable.
- The radiator top tank must be sized in accordance with the requirements for an auxiliary header tank - expansion volume space, max, min fill level, Refer to section [6.2.7](#).
- These systems must only be used when:
 - The tank is the highest point in the cooling system.
 - The bottom of the tank is higher than the engine water outlet connection.
- A baffle plate must be incorporated into the top tank design.
- A quiescent area must be provided for deaeration.
- It is mandatory that a coolant level sensor or visible indication of coolant level is employed on the radiator:
 - It is recommended that the Engine ECM input and associated configuration settings are used for diagnostic purposes.

6.2.7 Auxiliary Header (Shunt) Tank and Radiator Top Tank design

- An Auxiliary Header (Shunt) tank is the preferred cooling system design. Any system not utilising a shunt tank system must be Engine Factory approved and will require additional testing to ensure the venting characteristics are acceptable.
- The tank volume should be a minimum of 16% and a maximum of 20% of the total system volume.
- The coolant expansion volume must be no less than 8% of the total cooling system volume
- The coolant level must be clearly visible on the side of the tank or a coolant level sensor with appropriate indicator must be used.
- The header/shunt tank should be the highest point in the system. If this is not possible then this point should be vented separately.
- The pressure cap must be located in an area where air/gas is present under all tilt conditions.
- There must be sufficient volume in the shunt tank to ensure that the fill/shunt line is submerged in coolant at all machine-operating conditions including slew or gradients.

6.2.8 Filling

- The cooling system must fill at a rate of between 5l/min.
 - In order to achieve this the fill line:
 - Must have a minimum internal diameter of 25mm.
 - Must continuously run downhill and contain no dips or sags that may hinder venting.
 - A system incapable of filling at a rate of at least 5l/min demonstrates a likelihood of trapped air in the customer or engine cooling system.
 - A complete fill on level ground must be achieved.
 - The system must not be allowed to false fill. The fill must be continuous with no air locks resulting in a static coolant level.
- To facilitate engine warm up and reduce the risk of cavitation, the fill line:
 - Must not be connected directly into the radiator.
 - Should be connected as close to the water pump inlet as possible.

6.2.9 Venting

- Flow through all vent lines should not exceed 5% of total systems flow
 - This is to prevent bypassing the radiator, compromising engine warm up and promoting the separation of air from the coolant in the quiescent area of the shunt tank.
- Vent lines from the cooling system should be restricted to a maximum internal diameter of 6mm. A minimum of 3mm is required to minimise the risk of blockage.
- Vent lines must not include dips or sags and must continuously run upwards.
- For shunt tank arrangements:
 - The radiator must be vented.
 - The highest point/s in the system must be vented.
- In some complex installations one or more additional vent lines from the engine or machine cooling system may be required (refer to section 6.6.1).
 - The internal diameter of the vent line must be restricted to between 3 and 6mm.
 - Testing of air separation capability will be required. Consult your Applications Engineer.
- Each vent line must terminate in its own separate connection in the expansion volume. This must be above the normal coolant level under all tilt conditions.
- Where teeing of vent lines cannot be avoided:
 - The 'Tee' should be as close to the expansion tank as possible.
 - Care must be taken to ensure that the restriction at the header shunt tank is not greater than that at the radiator connection.
 - Specific approval and testing must be conducted to ensure reverse flow is prevented under thermostat open and closed operation.

6.2.10 Coolant Hoses

- Coolant hose material specification SAE J20R4
- Reinforced hose must be used to minimise expansion when system is pressurised
- Hoses using internal reinforcement are not permitted. Reinforcement must be either external or fully integrated into the structure of the hose.
- All hose connections should have a means of preventing the hose from slipping this can either be by a hose bead or hose barb in conjunction with a clip.
 - Recommended internal standard 1E4386 or SAEJ962 (Formed tube end for hose connections)

6.2.11 Cab Heaters

- Coolant for the cab heater must only be taken from the designated coolant ports refer to section [6.5.1](#) Figure 6-3 for details.
- If customer supplied connectors are used, then the maximum internal diameter of the connector or hose must be restricted to 10mm.
- It is recommended that the flow of coolant to the cab heater circuit is switched off when not in use in order to provide increased cooling flow and improve efficiency to the radiator cooling circuit. This may also provide fuel efficiency benefits.

6.2.12 Fans

- Where engine factory supplied fans are being used, the minimum clearance to the front and rear edges of the fan blades is 25mm; However, it is recommended to have a clearance of at least one projected blade width to obtain optimum noise and airflow performance.
- Customer supplied fan and fan drive arrangements must be assessed for acceptability refer to chapter [12.0](#) Driven equipment, fan, and fan drive arrangement section for further information.

6.3 Charge Cooling System (ATAAC) Mandatory Requirements

6.3.1 System Limitations

- EM** The maximum pressure drop across the charge air cooler and pipe work must be between 5 and 10kPa at full load rated speed (FLRS). Measured from turbo compressor outlet to the throttle valve inlet.
- EM** The charge cooler outlet temperature must be between 40°C and 50°C in a 25°C ambient. In ambient temperatures above or below 25°C the minimum charge cooler outlet temperature must not be below 15°C rise over ambient (ROA) and the maximum must not exceed 25°C ROA.
- These temperatures must be measured at the engine air inlet connection with the engine at full load rated speed (FLRS) and must be tested in accordance with the relevant test procedure.
 - If FLRS is not be achieved during machine operation and the machine has a fixed fan, then the maximum temperature limit for the rating at the maximum attainable speed can be found in the ESM.
 - By exception, some ratings (i.e., 45kW and 50kW) have a different maximum charge air cooler outlet temperature limit which can be used provided the application does not use a demand fan. In these cases, the limit, not to be exceeded, is specified as the 'Manifold Charge Air Temperature' and can be found on page 2 of the relevant engine rating curve.
- EM** If a variable speed or demand fan option is selected, then the fan must be full speed/flow at the following conditions:
- Charge air cooler outlet temperature: 50°C.
 - Maximum permitted engine coolant outlet temperature 112°C
 - Simple viscous fans using a bi-metallic strip to control fan speed require Engine Factory Approval.

6.3.2 Pipe work

- The Turbo to ATAAC pipe work and associated hoses must be designed to operate in the operating temperature and pressure conditions detailed in Table 6-1 below.

Engine Type	Max Working Temp (°C)	Max Working Pressure (kPa)
404J-E22TA	200	225

Table 6-1 - ATAAC pipework specification requirements

- Hoses should be designed to meet a minimum temperature in line with the minimum ambient temperature for the machine specification as sold.
- For applications with high under bonnet temperatures it may be necessary to ensure that the maximum temperature limit of the charge air hose is not exceeded.
- Hoses must be capable of withstanding a negative pressure of 5kPa to prevent collapse.
- The Hose material:
 - Must be Silicon rubber with a liner for oil resistance.
 - Must be resistant to oil both externally and internally and must not allow oil condensation penetration through the hose wall. They must withstand 130°C Oil immersion on the inside and not weep oil to the exterior.
- Hoses using internal reinforcement are not permitted. Reinforcement must be either external or fully integrated into the structure of the hose.
- All pipe work and hoses must the cleanliness specification detailed in Figure 6-2 below:

Cleanliness Level (Internal reference)	Largest Particle Allowed, In Microns (a)			Maximum No. Particles Allowed Per Given Particle Length, In Microns		Maximum Mass Allowed		Abrasives (Oxides) >40 μM
	X	Y	Z	#	X	mg/m^2	mg	>40 μM
1E2500B	1200	1200	200	4	500-1200	230	16	Allowed

Figure 6-2 - ATAAC pipework cleanliness requirement

- The internal bore of the intake pipe must be corrosion resistant.
- Pipe sealing surfaces must be smooth and free of defects.
- All pipe work should include full 360° hose beads to SAE J1231, internal standard J9.6
- The hose should have an interference fit to the pipe to which it is fitted (ref SAE J1697).
- Constant torque retention clamps must be used.
- All pipe work must allow relative motion between the cooler core and engine, allow for thermal expansion and contraction and be capable of withstanding flow and pressure pulsations.
- All pipe work must be adequately supported so that no stress is induced on the compressor outlet connection.

6.4 Cooling System Overview

6.4.1 Engine Cooling Circuit

The basic components of an engine cooling system are the coolant, water pump, engine oil cooler, thermostat, radiator fan and the radiator/s.

In operation, the water pump pushes coolant through the engine oil cooler and into the cylinder block. The coolant then flows through the cylinder block and into the cylinder head where it flows to the hot areas of the cylinder head. After flowing through the cylinder head the coolant goes into the thermostat housing. When the engine is cold, the thermostat is closed, and the coolant bypasses the radiator and circulates only around the engine. As the temperature increases the thermostat opens and the coolant flow to the radiator increases along with the pressure in the header tank until the thermostat is fully open.

The thermostat maintains the correct engine temperature. The amount it opens and the percent of coolant flow to the radiator depends on the load on the engine, and the outside air temperature.

The fan pushes or pulls air through the radiator and around the tubes that extend from the top to the bottom of the radiator. When the hot coolant goes through the tubes in the radiator, the flow of air around the tubes lowers the temperature of the coolant. The coolant then flows back through the water pump.

Coolant expands as it is heated. Expansion tanks are used to contain the increased volume and provide header pressure through the use of an air space.

A pressurised cooling system allows the coolant to circulate at a higher temperature without boiling and heat to be transferred more rapidly due to the greater coolant and air temperature difference, effectively reducing the size of the required radiator core.

External coolant lines are supplied on the engine to cool both the EGR cooler and oil cooler. Ports are also available on the thermostat housing and top of the water pump for the cab heater supply and return. The coolant flow in auxiliary circuits normally bypasses the thermostat and radiator and flows whenever the engine is running unless controlled by flow valves in the auxiliary circuits.

6.4.2 Lubricating Oil Temperatures

The engine oil temperature is directly related to coolant temperature through the use of a water-cooled engine mounted oil cooler. It is also related to engine compartment temperature and airflow across the sump. The correct oil temperature is essential to maintain a protective film on the bearing surfaces and ensure the engine's integrity.

For further information please refer to the lubrication systems chapter [9.0](#).

6.4.3 ATAAC System

Some 4-cylinder Stage V engines are turbo charged and charge air-cooled. The purpose of an Air-to-Air After cooler arrangement is to improve fuel consumption, and to lower emissions (NOx) to meet government regulations.

The success of this cooling system arrangement is dependent on the level of reduction in compressor outlet temperatures and maintaining the boost pressure in the system.

Failure to meet the engine air inlet connection and/or system pressure restriction limits will result in emissions non-compliance and the installation cannot be approved by the applications engineering team.

It is necessary to reduce the temperature of the charge air under the most severe operating conditions to a temperature relatively close to ambient air (normally in the range of 25°C to 30°C above ambient). It is therefore essential that the supply of cooling air to the charge cooler is as close to ambient air temperatures as possible.

6.5 Cooling System Components

This section covers information on specific 400J-E series cooling system components and ancillary components requiring a coolant feed.

The use of ancillary components that are engine cooled must be approved by the Applications team. For IOPU Installations it will also be necessary to establish the effect on the cooling system ambient clearance. Testing should be conducted in accordance with the relevant test procedure.

6.5.1 Cab heaters

It is essential that only the cab heater ports and connections identified and supplied with the engine are used. This is to ensure sufficient pressure differential across the engine to provide the necessary flow requirements. It also ensures that the engine coolant flow is not adversely affected, which could lead to long-term engine damage.

Cab heaters must be selected to ensure that they can sustain the maximum coolant pressure without deformation or failure.

Cab heater hoses should be to hose specification SAE J20R3 and not exceed the maximum internal diameters specified in section [6.2.11](#).

The cab heater connections, sizes and locations are detailed in Figure 6-3 below. This shows two potential ports that can be used for the cab heater suppl. Care must be taken however, to ensure sufficient clearance is provided to the air intake connection, which is a mandatory part of the air intake system design.

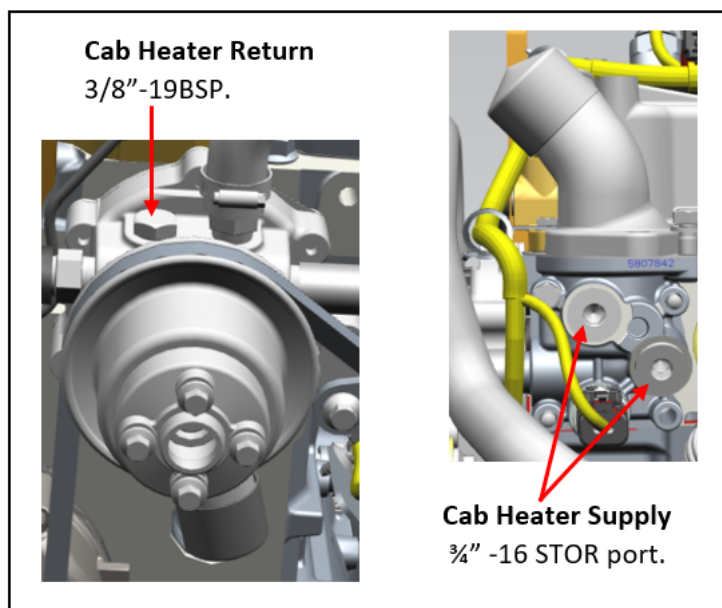


Figure 6-3 - Coolant ports for Cab Heater

For machines with cab heaters, heat loss from the coolant through the cab heater in cold climates can have a detrimental effect on coolant warm up time at low idle. Machines with parasitic loads of < 0.3 l/hr fuel delivery may need further assessment of the cab heater sizing or coolant flow rate.

6.5.2 Coolant level sensors

The engine supports the use of an electronic coolant level sensor. Although this is not part of the product offering. Please refer to the Electrical and Electronic Application and Installation Manual for further information.

6.5.3 Compressors

The coolant supply for airbrake compressors must be taken off the cab heater ports or alternatively connected into the cab heater hoses.

6.5.4 Fuel coolers

Fuel coolers are frequently required to lower the fuel temperature to within the limits of the engine low-pressure fuel system and material limits of the composite fuel tanks, connections, and lines.

Please refer to chapter [8.0](#) and the relevant engine ESM for more details.

The fuel cooler is an additional core that must be considered in the layout of the cooling cores.

6.6 Cooling System Design Considerations

Best practice and detailed system and component design information can be found in the General Installation manual.

6.6.1 Coolant Filling, venting and De aeration

A well-designed cooling system will vent during fill, allow continuous deaeration of the coolant during operation and maintain a net positive suction head at the water pump inlet.

Filling

It is of primary importance that the system should be designed to ensure that complete filling of the engine; radiator and associated pipe work can be carried out without air being trapped at any point in the system.

Trapped air may result in localised boiling, damage to the water pump seal, reduced water pump flow and in severe cases complete loss of coolant flow. Expansion of the air at working temperature can also result in excessive coolant loss.

Auxiliary circuits (e.g., cab heaters) should be designed to fill during routine filling of the total cooling system. This is helped by ensuring sufficient pressure differential across the circuit (supply to return line) and avoiding undulations and excessively long pipe runs.

Care should be taken to ensure that the engine/machine is level when filling the engine.

De-Aeration

In addition to a satisfactory fill the system must incorporate features within the design, which will permit continuous de-aeration, i.e., removal of entrained air, from the coolant while running. A poor performing system will often have to go through one or more start-up and shutdown cycles to purge enough air from the coolant to achieve acceptable coolant flow.

High mounted cab heaters or other system components are frequently problematic from both a fill and deaeration perspective. It is essential that the system must be capable of deaerating quickly and completely during machine operation. If this is not possible then it may be necessary to provide a vent valve or plug at the highest point. The system should be designed not to need this valve, as there is no guarantee that this valve will be used in service.

In complex Installations or applications that have a liquid-to-liquid cooler in the bottom hose or in applications that spend long periods with low flow through the external cooling system (thermostat not fully open) an additional vent line from the cylinder head may be required.

These more complex cooling systems with additional heat sources or compromised flow systems may mean that the 1:1 assumption used to extrapolate cooling temperatures to the maximum ambient condition may no longer be appropriate and additional testing and analysis maybe required.

Causes of Aeration

Aeration of the coolant may take place for the following reasons:

- Possibility of local boiling, and high metal temperatures.
- Excessive coolant loss on hot shut down.
- Rapid break-down of the water pump seal leading to poor performance and increased leakage
- Deterioration in water pump performance, resulting in a reduction in flow rate and an adverse effect on cooling. In severe cases, a complete breakdown in coolant flow may occur.

Effects of Aeration

Aeration of the coolant is likely to result in the following:

- Possibility of local boiling, and high metal temperatures.
- Excessive coolant loss on hot shut down.
- Rapid break-down of the water pump seal leading to poor performance and increased leakage.
- Deterioration in water pump performance, resulting in a reduction in flow rate and an adverse effect on cooling. In severe cases, a complete breakdown in coolant flow may occur.

Various methods can be employed to provide system deaeration; the preferred method is to use an auxiliary header tank. This system along with some of the more commonly used alternatives is detailed further in the general installation manual.

7.0 Under Hood Thermal Management

7.1 Introduction

The addition of aftertreatment components to engine exhaust systems can both add radiated heat and restrict airflow within the engine compartment. This drives the need for increased focus on thermal management systems and strategies which have become a necessity to control the additional temperatures and protect sensitive electronic components.

For separate air systems (engine compartment separate from the cooling package), higher temperatures will melt the components and/or reduce the effective life of the components. For integrated systems, (where the engine and aftertreatment are in the same compartment), besides the component failure issues, higher under hood temperature may also increase the temperature of the air entering the cooling cores, affecting the air-to-core (ATC) rise.

Table 7.1 indicates the temperature capabilities for the engine and supplied components. You should aim not to exceed these general limits. Some local temperature limits will however be lower or higher and are defined in Appendix D 'UHT and DEF test Acceptance Criteria and UHT Gauge map' in the relevant engine test procedure document.

Under-bonnet Temperatures			
Ambient Temp in Engine bay (°C)	Engine state	Percentage of engine life	Max time at Max Ambient temp
120	Stopped, but must be startable (heat soak)	2	20mins
105	Running	13	3 hours
85	Running	85	Indefinite

Table 7-1 Under bonnet temperatures

7.2 Thermal Management Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

‘Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.’

7.2.1 General

- Adequate cooling for all engine components must be provided within the enclosure design to ensure they do not exceed their maximum temperature limit for all conditions or exceed the maximum intermittent temperature limit in worst case operating conditions (hot shut down).
 - The component temperature limits are detailed in Appendix D 'UHT and DEF test Acceptance Criteria and UHT Gauge map' in the relevant engine test procedure document.
- Where extremely high local temperatures are measured additional cooling, methods must be used to control the component temperatures.
- The use of thermal insulation (for example thermal lagging or wrapping):
 - Is not permitted on any engine component including: the exhaust manifold, turbocharger and EGR pipework.
 - EM** Is not permitted on the flexible section (bellows) of the engine to aftertreatment connection.
 - Refer to section 7.4.6 Reducing heat transfer - Lagging and wrapping.

7.3 Thermal Management Overview

Before under-hood temperature concerns can be addressed the mechanisms of under-hood heat transfer must be understood. The fundamental modes of heat transfer are conduction, convection and radiation and the temperature of the engine compartment air, or any component involves a balance of these modes.

Many of the areas of concern for under-hood temperature involve components that are not directly attached to the engine and the relevant modes of heat transfer are convection and radiation. Either or both these modes may be important depending on the magnitude of the airflow through the compartment and the magnitude of the temperatures of the hot components that act as heat sources.

Radiation is proportional to the difference of the temperatures to the fourth power, so temperatures above ~300°C become an important source of radiation in typical ambient conditions.

Forced convection is roughly proportional to the air velocity and the temperature difference to the first power, so engine compartments with flow velocities above 3 m/s will have significant convective heat transfer. Free or natural convection can have an impact when velocities are significantly lower and the temperature difference between the air and the surface is high, but typically radiation becomes the dominant mode of heat transfer in these situations.

A significant new source of heat radiation and/or conduction in Stage V installations is the aftertreatment. The regeneration process is the cause for the high temperatures seen from this emission critical component and cannot be avoided.

The most appropriate method for mitigating high under hood temperatures should be used, there is no one fixes all solution, it is application/installation specific. The method best used is dependent on the available packaging space, cooling fan system being used and the positioning of sensitive or hot components etc.

7.4 Thermal Management Design Considerations

7.4.1 Airflow Requirements

Airflow requirements are sensitive and dependant on the machine design and component layout. The key to meeting the temperature requirements is to encourage even airflow around the engine compartment; with the aim of this being to eliminate dead zones and hot spots.

Increasing the fans airflow will not always provide the solution, as unless the airflow across the critical components is significantly increased it is an inefficient use of power.

If the layout is poor, the air may be going directly in and out of the engine compartment through the shortest route, bypassing the sensitive components completely.

Theoretical modelling is a good tool to fully understand the airflow and heat transfer characteristics of the installation. It is understood that this is not a tool that is commonly available, and, in all cases, there is no substitute for development test work.

To ensure that the temperature of all the critical components is maintained within limits, it is suggested that a minimum airflow of 9m³/min is achieved across them.

7.4.2 Location of heat sources

The careful positioning of the more extreme heat sources, such as the after-treatment module and exhaust pipe routing, is a first step towards meeting the temperature limits of critical engine and aftertreatment components.

These items should not be positioned, if possible, close to the critical components. Ideally the heat sources should be downstream of the airflow from the main fan to avoid additional convection of heat over the engine.

When the positioning of hot items cannot be further improved alternative actions must be taken to meet the temperature limits for the critical components. Suggestions for these are detailed in the rest of this chapter.

7.4.3 Thermal Survey

A thermal survey of a 400 series Stage V engine with a flywheel housing mounted DOC/DPF has been conducted in order to provide give an indication of the surface temperatures across the aftertreatment during worst-case engine running conditions.

The test was conducted in a test cell environment with an ambient temperature of 29°C and no forced convection.

The results achieved are applicable to the 404J-EE22T, 22TA and 17T engines. They do not take into account changes in ambient temperatures or ambient air flow conditions and the results are, therefore, only applicable for the stated ambient temperature and air flow conditions.

Figure 7-1 shows the maximum temperatures achieved across the aftertreatment cannister.

The temperatures are provided as a guideline for safe design of the vehicle and proper precaution should be taken to ensure that the aftertreatment device is properly shielded and not mounted close to surrounding components that may be damaged by heat.

Installing a module in an enclosure without airflow will not be possible due to the temperature limitation of the control systems components.

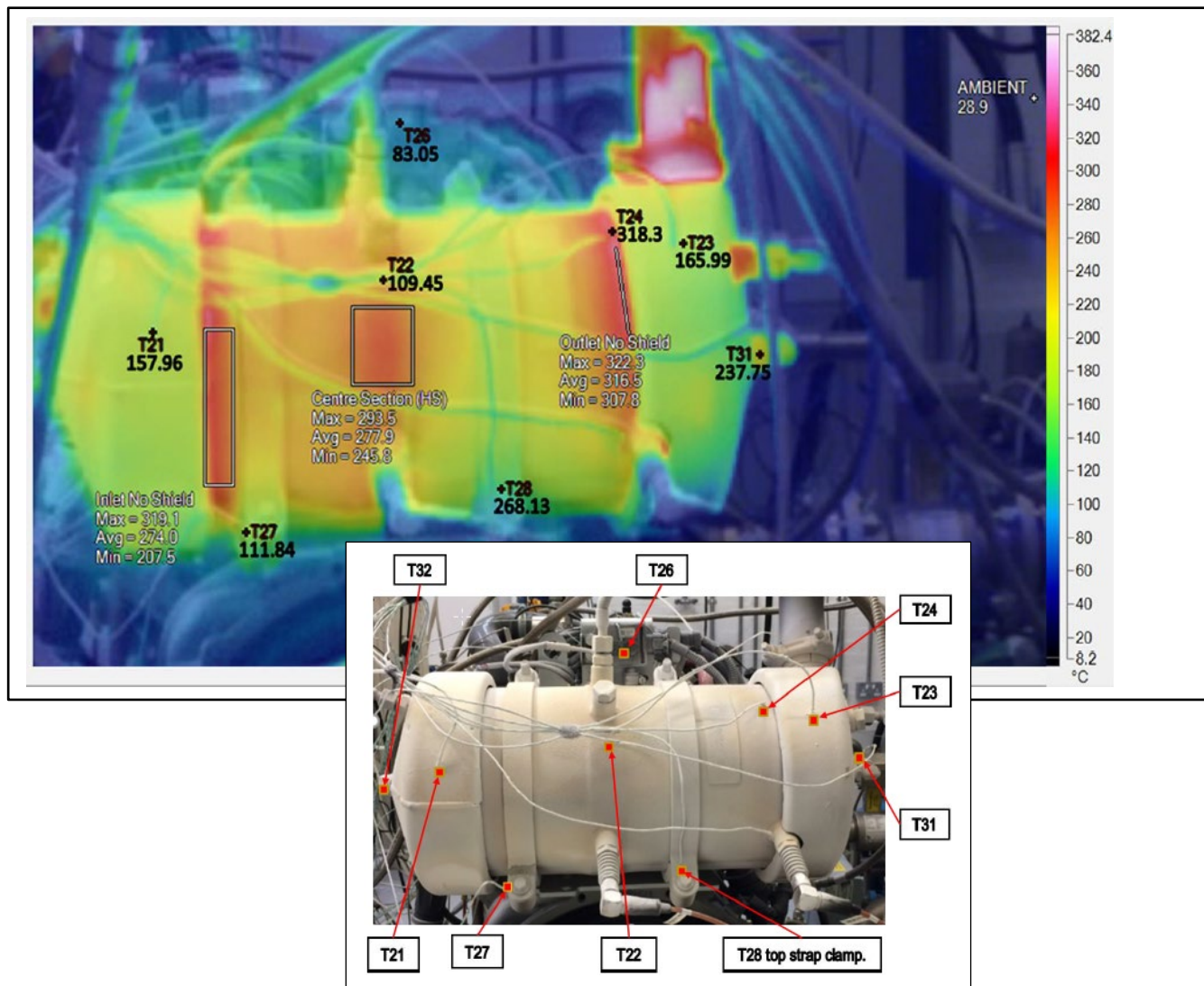


Figure 7-1 -400J Aftertreatment Thermal Survey

7.4.4 Lowering risk of debris build up

In harsh environments debris can quickly build up on engine components if the operator does not regularly inspect and clear debris from inside the engine compartment. This build-up of debris (chaff, straw, dirt, dust etc) may lead to engine components either:

- Overheating, causing temporary or permanent damage, as the debris acts to insulate the component as well as limiting the cold airflow over its surface. This is mainly a concern for engine electronics.
- In the worst case causing a fire as the debris reaches a temperature high enough to cause it to combust (i.e., chaff on exhaust manifolds). This is a concern for hot engine components, such as the CEM, Turbo and manifold etc.

To combat this, the following installation design considerations should be taken into account:

- Fine grills in front of all air inlet features on the enclosure design. The mesh should be a compromise between being so fine as to become clogged on a frequent basis and so large that it does not do a sufficient job of reducing build up on engine components. If this outer mesh becomes blocked it will be more visible to the operator, this is preferable to debris build up in unseen areas of the engine compartment.
- When designing protective shields for engine components consider the effect on the likelihood of debris build up. If the shields are poorly designed they can capture debris that would otherwise pass through the engine compartment, in a manner that increases the temperature of the component being protected.

In all cases the operator's maintenance manual should request that debris build up is cleared from the engine compartment on a regular basis.

7.4.5 Increasing airflow

Additional fans – electric

- Where aftertreatment or engine components are separated from the engine compartment additional electric fans can be used to increase airflow.
- They can also be used to force cool air to, or extract hot air from, components sitting in "dead zones" of the engine compartment, where there is limited natural or forced airflow from the existing fan configuration.
- This may require additional air intakes or vents on the exterior of the engine enclosure.
- Ducting of cooler air.
- Metallic or polymer (convolute) ducting can be used to take cool air directly to critical components.
- The air can be ducted from the ambient air outside or from a cooler area of the engine compartment (with or without the assistance of an electric fan).
- This method is particularly useful for applications where the at-risk component is tightly packaged and in very close proximity to hot components.
- Often this approach requires the component to have ducting built into its design to ensure the cool air hits the critical parts of its assembly (i.e., alternator rear cover ducting).

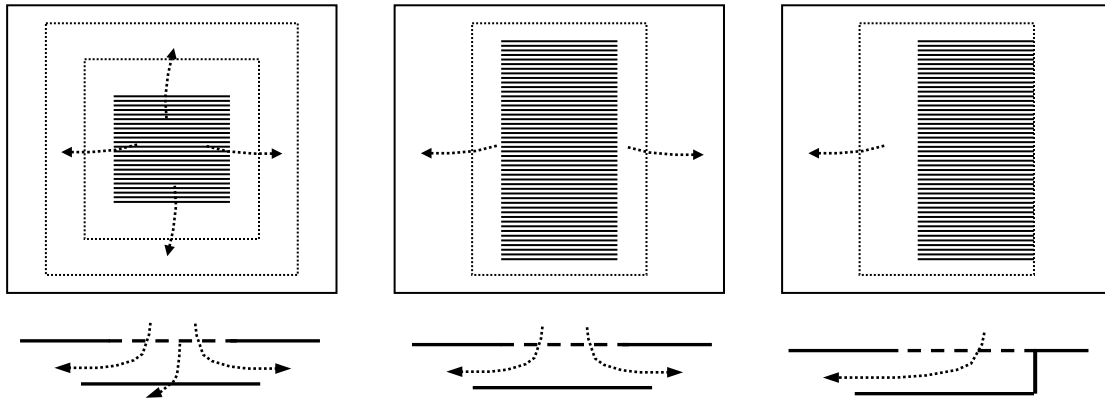
Increasing Under-hood volume

- Increasing the under-hood volume can have a positive effect on the amount of airflow through the engine compartment.
- Creating clear routes for air to flow around the engine is vital to ensure that areas of static air are minimised where localised hot spots may occur.

Perforations in sheet metal/enclosure walls

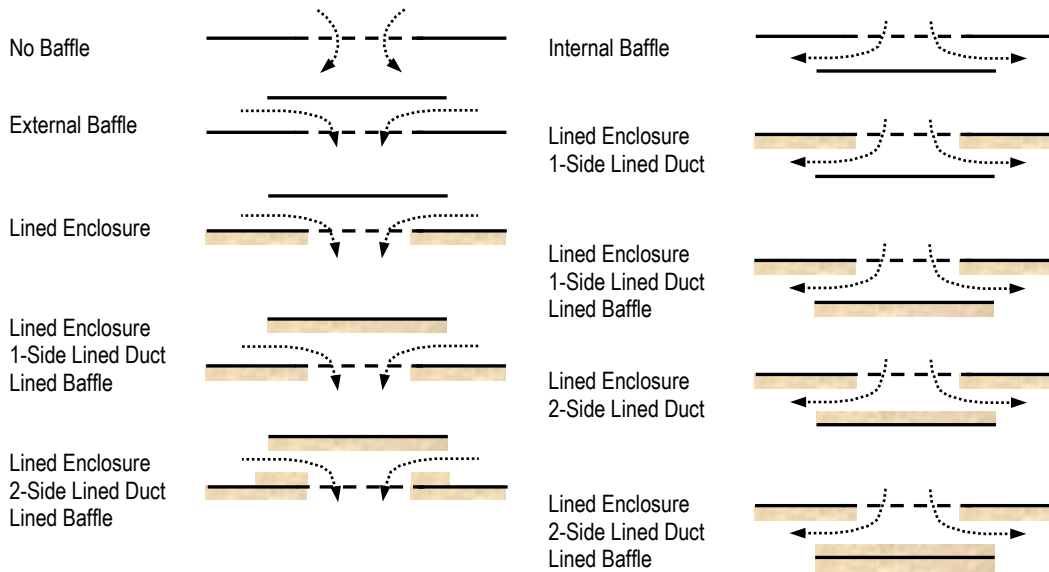
- A range of baffle/perforation designs can be used to help increase the airflow to the engine.
- The additional open area allows the opportunity for increased airflow. The same openings will allow additional sound to escape.

The size and shape of the perforations should be selected with safety and plugging/debris ingestion considered.



External Baffle Noise Treatments

Internal Baffle Noise Treatments



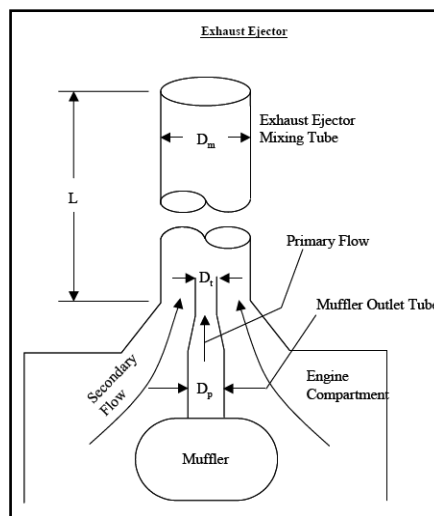
Exhaust ejectors (sealed engine compartments only)

These can also be known as exhaust venturi systems. They work on the principle of the pressure differential between the exhaust flow and the pressure in the engine compartment drawing warm air out and mixing with the exhaust gases.

This approach requires understanding of the pressure levels within the engine compartment and drives the need for good quality control over sealing, ducting or sheet metal perforations.

If the pressure within the engine compartment is too low, it can lead to the exhaust gasses being drawn back into the engine compartment. This can occur at low engine speeds as the exhaust flow levels drop meaning the compartment pressure can drop lower than the exhaust flow (particularly if additional fans are being used).

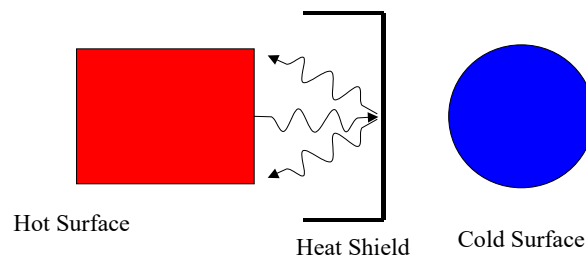
To balance the pressures requires careful design and testing to optimise the system performance. Critical design parameters include the diameter of the stack, the height of the stack and the insertion of the muffler outlet pipe into the ejector stack.



7.4.6 Reducing heat transfer

Heat Shielding

- Heat shields work by reflecting the heat back towards the source component.
- The surface that faces the hot component must have a low emissive value (reflective surface).
- Heat shields are generally thin, externally metallic, components composed of one or more layers.
- They are typically mounted with an air gap to the component being shielded.
- They can be mounted either on the source of the heat or the component which has become the sink.
- Care should be taken not to exceed the hot components maximum temperature limit as the heat reflected back increases its temperature further.



Lagging/Wrapping

Modifications made to the engine in the course of installing or using lagging could result in the EU type approval being invalidated for that engine.

Wrapping of the after treatment is not recommended as the insulation can cause local hot spots that may exceed the material temperature limits. However, it is understood that, in some installations, insulation of the Aftertreatment will be necessary when heat shield is not a satisfactory solution. When insulation is used it is necessary to confirm that the material temperature limits are not exceeded. Also, that the temperature limits of components close to the aftertreatment are not exceeded in areas where it is not practical to completely insulate, for example around sensor connections. Additional temperature measurements will be required to allow an installation sign-off.

Wrapping of the engine to aftertreatment interconnecting pipework may also be required in certain circumstances but this must not under any circumstances come into contact with the bellows section as this would lead to reduced movement capability. Further detail on the requirements for lagging of the engine to aftertreatment pipework can be found in section [5.5.3.7](#).

In general:

- Wraps are generally thicker than heat shields and work to minimise the amount of heat that can be radiated from a components surface.
- The wrap is normally made from a material with low thermal conductivity and must have sufficient thickness to achieve the temperature reduction required.
- A construction with a low emissivity internal surface can help reduce heat transferred into the wrap.
- They can only be used on the heat source component.
- It should be ensured that the wrap will not increase the source components temperature above its limit.

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8.0 Fuel Systems

The fuel system is a critical engine system and plays a vital role in delivering not only engine performance, but also compliance with emission regulations.

In order for a diesel engine to function correctly it must be supplied with an adequate supply of fuel. The fuel must meet the recommended specification and be free from air, water, and solid matter. The fuel system must be installed correctly and must adhere to installation instructions, cleanliness standards and be subject to regular maintenance following correct practices and procedures.

8.1 Introduction

8.1.1 Fuel System Safety Requirements

- Correct practices and procedures should be followed as outlined in the following appropriate service manuals:
 - Operator and maintenance manual (OMM)
 - System Operation Test and Adjust (SOTA)
 - Specifications (Specs)
 - Disassembly and Assembly (D&A).
- Due to the high pressures generated by the Common Rail Fuel system the following safety requirements MUST be adhered to when working on the engine.
 - After the engine has stopped the fuel pressure must be dissipated from the high-pressure (HP) fuel lines before any service or repair is performed on the fuel system. To do this please follow the service guidelines detailed in the OMM.
 - Contact with high-pressure fuel may cause fluid penetration and burn hazards. High Pressure fuel spray will cause a fire hazard.
 - Inspection of the fuel lines, hoses, filters, and system components should be undertaken to check for wear and deterioration and to ensure there are no foul conditions. Correct fitment of clamps and heat shield should also be ensured.
- Care must also be taken to ensure the fuel return to tank line does not become blocked or restricted in anyway and the tube assemblies for the low-pressure fuel system are correctly installed. Failure to heed this warning can lead to premature failures, product damage, personal injury, or death.
- Failure to follow the correct inspection, maintenance and service instructions may cause personal injury or death.

8.2 Fuel System Mandatory Installation Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

8.2.1 General Requirements

- No electrically powered engine cranking is allowable without both the ECM powered up and the HP fuel pump electrically connected. However manually turning the engine over by hand, where the engine speed can never exceed 15 rev/min, is acceptable. Refer to the Electrical and Electronic A&I manual for further information.
- The engine must be equipped and operated with the filters supplied with the engine.
- Under no circumstances is it acceptable to modify the fuel system components or replace/customise sections of the fuel system that were supplied with the engine (as delivered).
- It is not acceptable to disturb or alter the fuel system lines, mounts, clips, or common rail assembly.
- The use of fast fill requires engine factory approval.
- It is not permitted to prime the fuel system by utilising compressed air.

8.2.2 Cleanliness

- The fuel entering the tank and the supply prior to the water separator must meet cleanliness requirements detailed in the Standard ISO 4406: 1999 level 18/16/13. Engine specific requirements are in the OMM or the Perkins Diesel Engines Fluids Guide M0113102.
- Fuel lines and components from the fuel tank to the primary filter /water separator must meet internal cleanliness requirements 1E2500C, detailed in [Figure 8-1](#).
- Fuel lines and components installed between the primary filter /water separator and main engine (secondary) filter must meet the cleanliness specification 1E2500A detailed in [Figure 8-1](#).
- When the Main (secondary) engine fuel filter is supplied connected to the FIP by the engine factory it is not permitted to disturb any components after the main engine fuel filter.
- When the Main (secondary) engine fuel filter is NOT supplied connected to the FIP by the engine factory then the following requirements must be adhered to:
 - Components after the main (secondary) fuel filter must meet cleanliness standard 1E2500G detailed in [Figure 8-2](#).
 - Controls and procedures must be in place to ensure this.
- Fuel lines and components used for the return to tank must meet internal cleanliness requirements 1E2500C, detailed in [Figure 8-1](#).
- All metal components must be deburred to internal standard 1E0009 section 7 onwards or an equivalent external standard.
- Where applicable, the fuel filter caps, fuel line caps and fuel pump caps must only be removed just prior to fitment of the fuel line.

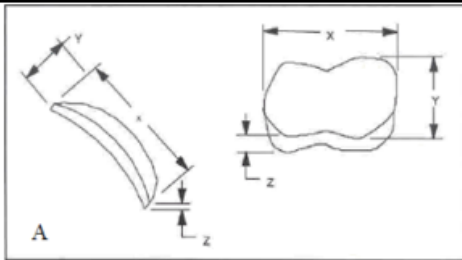
Fuel System Component Cleanliness Standard									
This specification defines cleanliness levels applicable to finished engine components and assemblies. All cleanliness standards are based on flushing the specified area with solvent filtering the flushed solvent onto a membrane filter patch, measuring particle dimensions with a microscope and measuring total particle mass with an analytical balance. The specified cleanliness must be met at the time of assembly Particle to be measured for size are metallic, rust (either free or loosely attached), slag, sand, and other abrasives. If particles are fragile and break up with gentle probing (gentle probing will not tear a membrane filter patch), only the remaining solid pieces are to be measured for specification performance.									
Largest Particle Allowed, in microns (A)					Maximum No. Particles allowed per given particle length, In Microns (a)		Maximum mass allowed (B)		Abrasive (Oxide) restricted (B)
		X	Y	Z	#	X	mg/m ²	mg	> 40µm
1E2500A	Pre Secondary Filter	1200	500	150	4	500-1200	170	10	Allowed (C)
1E2500C	Tank to Primary Filter	2000	2000	200	4	1000-2000	535	-	Allowed
 <p>(C) For fuel system components only, No more than 10 abrasives greater than 40 microns in size per cleanliness patch # = Number of particles</p>									

Figure 8-1 -Fuel Component cleanliness before Main Engine filter

Fuel System Component Cleanliness Standard - Common Rail						
This specification defines cleanliness levels applicable to finished engine components and assemblies. All cleanliness standards are based on flushing the specified area with solvent filtering the flushed solvent onto a membrane filter patch, measuring particle dimensions with a microscope and measuring total particle mass with an analytical balance. The specified cleanliness must be met at the time of assembly Particle to be measured for size are metallic, rust (either free or loosely attached), slag, sand, and other abrasives. If particles are fragile and break up with gentle probing (gentle probing will not tear a membrane filter patch), only the remaining solid pieces are to be measured for specification performance.						
Max Allowable contamination per fluid-wetted area (mg/m ²)	Max Allowable absolute mass (mg)	Max Allowable particle number against particle size				Abrasives (Oxides) > 100µm
		Particle Size (µm)				
		100-200	201-300	301-400	>401	
55	2	50	10	2	0	Not Allowed
Maximum allowable residual magnetic flux density: 1 gauss Audit filter patch: 5µm Micropore Fibre particles counted in mass only						

Figure 8-2 - Fuel Component Cleanliness after Main Engine filter

8.2.3 Fuel Specification

- Engine specific fuel requirements are in the OMM or the Perkins Diesel Engines Fluids Guide M0113102.

8.2.4 Pressure and Temperature limits

- Please refer to Table 8-2 for the process limits of the fuel system.

8.2.5 Fuel Tank requirements

- The fuel tank must meet cleanliness standard 1E2500C detailed in [Figure 8-1](#).
- The fuel tank must be vented, and the vent filtered to a maximum filtration level between 4 and 10 microns depending on efficiency i.e.
 - 10 microns - 99% efficient.
 - 4 microns – 84% efficient.
- The vent must be serviceable, and an appropriate maintenance instruction included in the machine manual.
- A serviceable large particle filter must be used within the tank filler neck to ensure the fuel in the tank meets the required cleanliness specification specified in the OMM.
 - The use of non-serviceable fuel tank inlet filter (filler neck) is not permitted.
 - The use of any type of filter on the fuel supply/pick up line is not permitted including any mesh, gauze, strainer, or any device that may become blocked.
 - Refer to [Figure 8-3](#) below.
- The fuel tank must be designed so the fuel pick-up and return meet the requirements detailed in section [8.2.6](#).
- The tank material must be able capable of withstanding the maximum temperature requirements, withstand the fuel types required for use and must not contain any materials listed within [Table 8-1 - Prohibited materials](#).

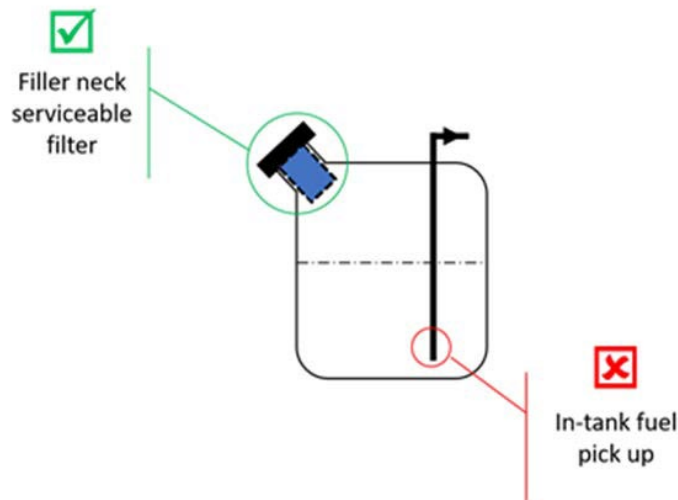


Figure 8-3 - Fuel Tank Filtration

8.2.6 Fuel Line Requirements

- Customer supplied fuel lines must adhere to SAE J30 R9/DIN 73379 (inclusive of a Fluro elastomer liner) or better or must meet internal standard 1E4340B. This should be discussed with the fuel line supplier to ensure that the hose material:
 - Is capable of meeting the fuel and under hood temperatures,
 - Is durable within its operating environment,
 - Is robust to electrostatics and
 - Is compatible with all fuel specifications to prevent injector deposits.
- Fuel lines must be adequately supported as short and direct as possible with no dips, sags, or kinks. They should be kept away from heat sources and be clear of all fouls with other components.
- Shut off valves must not be used in either the supply or return line. If employed an electrical interlock must be employed to prevent the engine cranking with the valves closed. Cranking/running with the supply/return valve(s) closed will cause damage to the electric fuel pump or common rail pump.

8.2.6.1 Fuel supply line

- The fuel supply line must be a minimum of 150mm away from the fuel return line or lines, at their point of termination inside the fuel tank.

- This is to prevent the hot return fuel being sucked straight back into the engine through the supply line.
- The fuel supply line must not become uncovered under any operating conditions (machine pitching/slewing, gradeability etc.)
- The use of any type of filter on the fuel supply/pick up line is not permitted including any mesh, gauze, strainer, or any device that may become blocked.
- All fuel supply lines prior to the ELP must have a minimum id of 8mm.

8.2.6.2 Fuel Return line

- This engine requires two fuel return lines. The main engine fuel return line returning fuel from the injector, fuel pump and common rail and an additional return line from the transfer pump regulator/PRV.
- The return lines must terminate below the minimum fuel level within the fuel tank and must not be directed towards the supply line.
 - This is to prevent jetting (aeration of the fuel)
 - This is also to prevent drain down of the fuel system when the engine is not running.
- It is recommended that the main and regulator fuel return lines are not joined. If this is a requirement then:
 - The backpressure in the regulator return line must not exceed the limit in Table 8-2 - Fuel System Limits Table 8-2.
 - The join must be after the fuel cooler.
- If the fuel supply tank is above the fuel filters, then a non-return or isolation valve with an electrical interlock should be fitted in main return line after the fuel cooler to prevent fuel system drain back.
- A non-return valve may be fitted in the RTT line provided the limits in Table 8-2 are not exceeded.
- The fuel-return line from engine to fuel cooler must be capable of withstanding a maximum temperature of 145°C.
- It is recommended that the fuel return lines have a minimum diameter of 8mm.

8.2.7 Fuel Filter Requirements

- Only Engine Factory supplied filters may be used within the fuel supply system.

8.2.7.1 Primary (Pre-filter)

Two primary filter options are available from the option offering, one with a WIF switch and serviceable filter element and the other without a WIF switch which does not have a serviceable element. The installation requirements of these filters are detailed below:

- The factory supplied primary fuel filter with serviceable water separator must be installed prior to the ELP.
- The filter must be installed and assembled the correct way around to ensure correct flow through the filter head, as shown by the arrow on top of the filter head.
- The primary filter must:
 - Not be mounted on engine.
 - Be mounted and assembled the correct way around to ensure correct flow through the filter.
 - Be mounted in a location that is isolated from excessive vibration to prevent the emulsification of water in fuel.
 - Not be subject to G loading in excess of 10g vertical low cycle acceleration
 - Be located in a position that is clearly visible and allows sufficient access for servicing safely without damage to other components.
 - Be mounted vertically within a tolerance of +/-5° to prevent air entrapment.
 - Not have the filter head as the highest point in the fuel system. If this is a necessary, then priming and aeration checks must be conducted.
 - Not be mounted directly above hot surfaces or electrical components.
- The primary filter without WIF must be mounted using:
 - A single M8 bolt - Refer to [Figure 8-5](#) section [8.4.1](#).

- The primary filter with WIF must be mounted using:
 - The 2 slotted holes - Refer to [Figure 8-6](#) section [8.4.2](#).
 - M8 x 1.25 flange head bolts
 - grade 8.8.
 - length 110mm
 - Torque 22+/-2Nm.
- The primary filter with WIF switch requires:
 - A minimum of 50mm clearance for element removal.
 - The WIF switch to be connected in accordance with the requirements in the Electronic Application and Installation manual.

8.2.7.2 Secondary (main engine) Filter

For the 4-cylinder engine - The main engine fuel filter is supplied engine mounted as standard, but a remote mounted filter is available as an option. For the 3-cylinder engine - There is no in engine mounted option and the main fuel filter is remote mounted. Mounting of remote mounted fuel filters is the responsibility of the customer and the following requirements must be adhered to:

- Remote mounted filters are supplied fitted to a temporary transit bracket. This bracket
 - Must be discarded before engine installation.
 - Must not be used to mount the fuel filter in the installed condition.
- The integrity of the filter assembly must be maintained. It is not permitted to disturb or replace any of the supplied hoses or hose connections.
- The secondary filter supply fuel line must meet material standard specified in section Fuel Line Requirements [8.2.6](#).
- The secondary filter fuel supply line must have an internal bore no less than 8mm
- The secondary filter must:
 - Be mounted using the 2 slotted holes on the filter head -and 2xM10 bolts – Refer to [Figure 8-8](#) section [8.4.4](#).
 - Not be mounted on engine, except when supplied as an installed option from the engine factory.
 - Be mounted in a location that is isolated from excessive vibration.
 - Not be subject to G loading in excess of 10g vertical low cycle acceleration
 - Be located in a position that is clearly visible and allows sufficient access for servicing safely without damage to other components.
 - Be in a location that is clearly visible and allows sufficient access for servicing safely without damage to other components.
 - Be mounted vertically within a tolerance of +/-5° to prevent air entrapment.
 - Not have the filter head as the highest point in the fuel system. If this is a necessary, then priming and aeration checks must be conducted.
 - Not be mounted directly above hot surfaces or electrical components
- The pressure at the FIP inlet must be measured on all remote secondary Filter Installations and must be within the limits specified in Table 8-2.

8.2.8 Electric Lift Pump (ELP)

- The factory supplied ELP must be installed in the fuel line between the primary filter and the main engine (secondary) fuel filter.
- The pump can be mounted in any orientation, but the pump outlet should face upwards and be no lower than the inlet
 - It is recommended that it is mounted at 45 degrees to the vertical.
- The ELP must not be mounted on the engine.
- The ELP must be mounted:
 - Using the 2 mounting holes provided on the pump Refer to Figure 8-7.
 - So that it is isolated from excessive vibration. Vibration exposure must not exceed 5 to 800Hz: 10g peak in any direction.
 - So that it is clearly visible and allow sufficient access for servicing safely without damage to other components.
 - So that the pump body is earthed.
- To aid priming performance the ELP should be mounted as close to the fuel tank as possible and below the minimum level of fuel.
- The ambient temperature surrounding the ELP must not exceed 93°C
- The ELP inlet restriction must not exceed the limit in Table 8-2.
 - This must be measured at the ELP inlet in accordance with the relevant test procedure.
 - To help meet this restriction limit the height between the ELP and the minimum fuel level should not exceed 0.8m.
- The ELP must not:
 - Be used without the supplied primary filter.
 - Be operated without a fuel supply.
 - Operate submerged in water or any other fluid. Direct jet washing is prohibited
- Installation Torque 13.5-20Nm (10-15ft-lbs).
 - When installing fittings, hold the inlet and outlet Hex with a second wrench isolate the torque.

8.2.9 Prohibited Materials

- Table 8-1 contains a list of prohibited materials that must not be used within the fuel system.
- These should be taken into consideration when selecting and designing any fuel system components such as the fuel tank or fuel cooler. Particular care should be taken with the application of any plating and /or coatings that are used.
- Use of these materials may contaminate the fuel leading to coking of the injector nozzle

Prohibited Material	Symbol
Lead	Pb
Sodium	Na
Calcium	Ca
Zinc or Zinc Plating	Zn
Copper	Cu

Table 8-1 - Prohibited materials

- The use of the following Zinc plates is acceptable for FUEL CONNECTORS ONLY.
 - Zinc Phosphate: ASTM 117,
 - D609 Zinc Chromate/ Trivalent plates: ASTM 4042.

These materials along with chemical compounds may also be present in fuel and certain fuel additives, e.g., corrosion inhibitors, the presence of which can cause Internal Diesel Injector Deposits (IDID). These deposits may affect the proper functioning of the fuel injectors.

In order to prevent this, fuel additives that have measurable levels of any of the following listed substances should not be used:

- Acids e.g., Dimmer and Fatty (Oleic, Stearic and Linoleic); including DDS (Diamino Diphenyl Sulfone)
- Alkali metals e.g., Sodium, Calcium, Potassium, etc; including compounds, e.g., sodium chloride, sodium hydroxide, sodium nitrate, etc
- Carboxylates
- Organic amides

If in doubt, please consult your Application Engineer for further guidance

8.3 Fuel system Overview

8.3.1 Fuel System Schematic

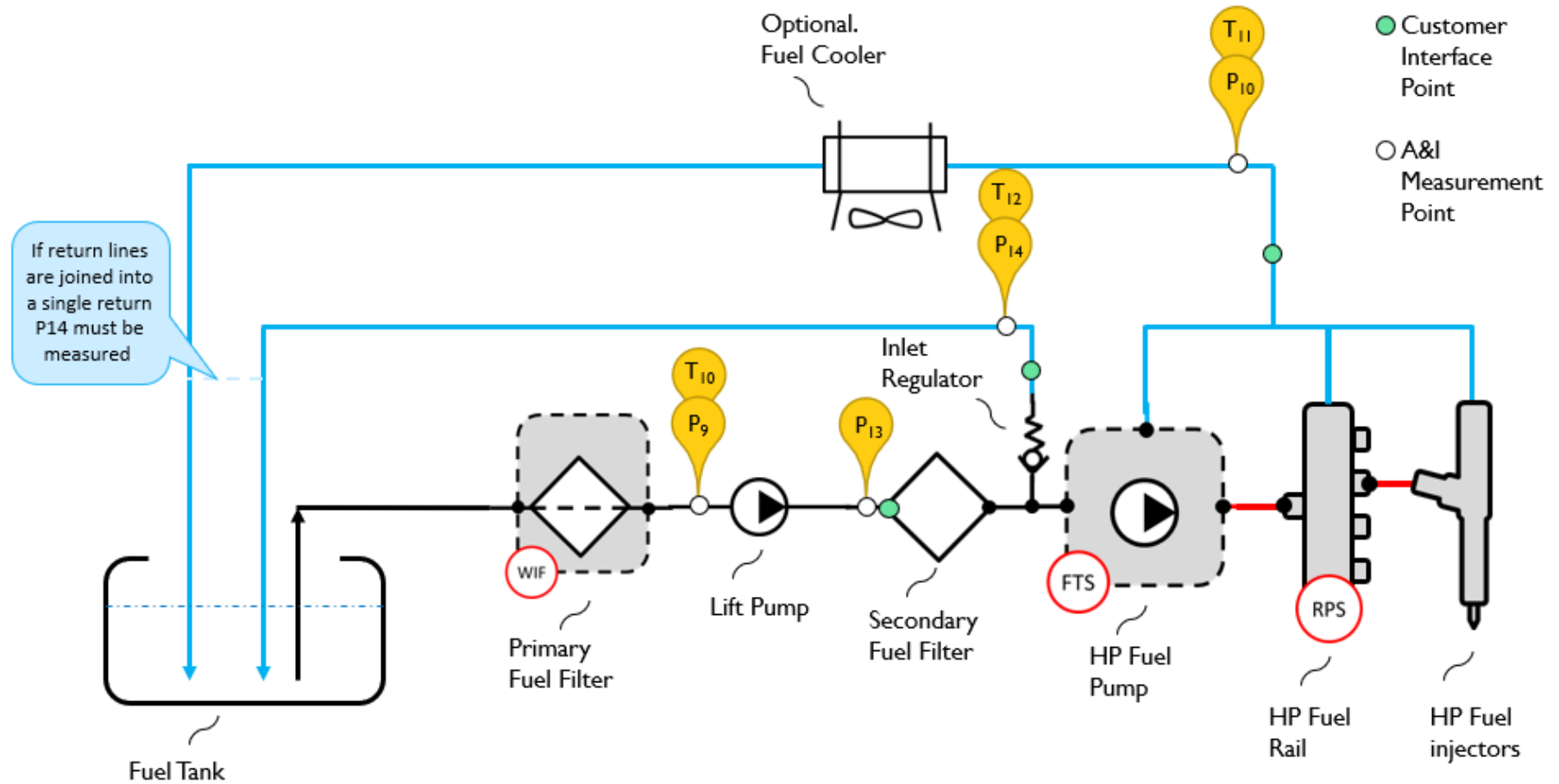


Figure 8-4- Fuel System Schematic

The required pressure and temperature measurement points are shown on the fuel system schematic above. The limitations and requirements for these are detailed in below:

8.3.2 Fuel System Limits

Component	Channel	Min	Max	Measurement Condition/Position	Comments
Transfer Pump Inlet	P9	-11kPa	+10kPa	Engine off, ELP on, Min Fuel*	Pass/Fail
	T10		70°C		Guideline Required to meet T12
FIP inlet	T12		75°C	FLRS, min fuel* Measured at LP Regulator (secondary) return	Pass/Fail
Secondary Filter Inlet	P13**	30kPa	70kPa	Low idle, min fuel*	Pass/Fail
Main Return to Tank	T11		145°C	Measured at LP Regulator (secondary) return	Pass/Fail
	P10	0kPa	20kPa	FLRS, Min fuel*	Pass/Fail
LP Regulator (Secondary) return connection	P14	0kPa	10kPa	Engine off, ELP on, Min Fuel*	Pass/Fail

Table 8-2 - Fuel System Limits

* *If the fuel tank is above the fuel inlet connection then the pressure at the Max fuel level must be measured.

**P13 needs to be measured to ensure the pressure into the HP pump is within specification. The limit depends on the pressure in the TP regulator return line (P3) as this pressure effects the operation of the TP inlet regulator, which controls the HP inlet pressure.

In order to meet the maximum fuel inlet temperature at HP pump T12 it may be necessary to install a fuel cooler in the return leak-offline from injectors and pump.

For fuel cooler sizing:

- The maximum fuel temperature leak off return - 145 °C.
- The fuel return flow is expected to be between 0.8 and 1.2 l/min

8.3.3 Fuel Specifications

Please refer to mandatory Installation requirements for details of fuel specifications, quality, and cleanliness requirements.

8.3.4 Ultra-low sulphur diesel (ULSD)

ULSD is required in all diesel applications using a diesel particulate filter (DPF and DOC). The fuel must adhere to the specification detailed in the OMM. High sulphur levels will rapidly damage the DPF and DOC, likely resulting in the need to replace the aftertreatment unit. Damage to the DPF and/or DOC may impact emissions.

For cleaning and replacement of the DPF please contact your service dealer.

8.3.5 Biodiesel

Bio-diesel fuel may be used as long as it adheres to the specification and requirements detailed in the OMM.

Bio-diesel use is limited by percentage bio-fuel dilution by volume and the use of an appropriate approved additive is normally required. Higher concentrations than those approved will affect performance, durability, and warranty conditions.

As biofuel is chemically more reactive than the mineral oil used in diesel fuel, it is imperative to consider the effects of this fuel on all components that it may come into contact with.

Advice should be sought from the Applications department if the use of biodiesel is required.

8.3.6 Temperature & Viscosity

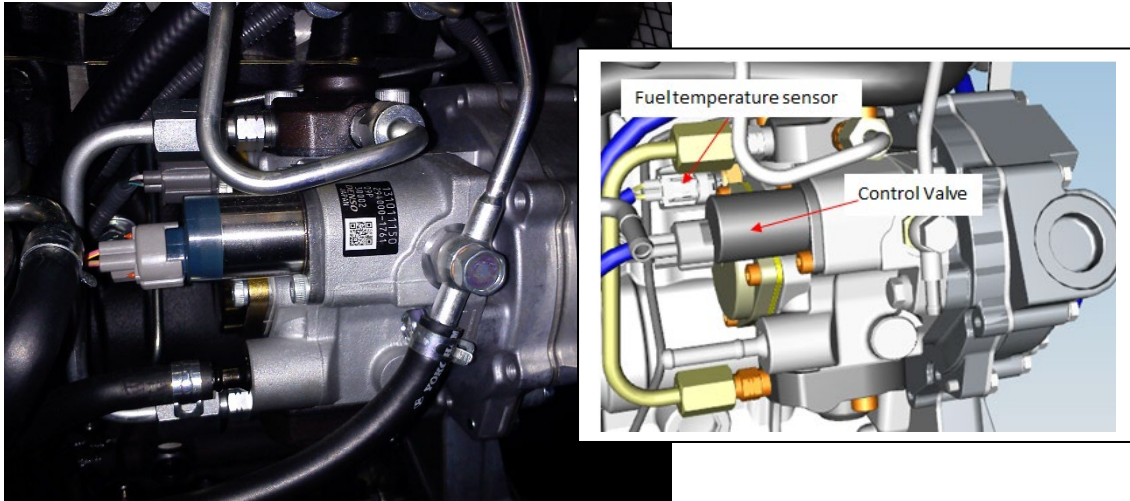
The 400J-E series engine measures the fuel temperature in the fuel pump and provided the temperature does not exceed the maximum fuel temperature limit, makes the necessary compensations to maintain performance.

High fuel inlet temperatures can be avoided by careful routing of the fuel lines, ensuring that they do not run, in close proximity to any heat source, and ensuring there is good air flow across the lines within the engine and machine enclosure. If the fuel temperature is high, then it may be necessary to use a fuel cooler.

8.3.7 High Pressure Fuel System

The HP fuel system consists of a gear driven fuel pump, run at half engine speed and a high-pressure common rail. A control valve within the fuel pump controls the fuel pressure in the rail depending on the speed and load of the engine. The ECM then controls the beginning of injection and duration for each cylinder.

A fuel temperature sensor measures the temperature of the fuel in the pump to allow the necessary compensations to be made to maintain performance.



8.3.8 Low Pressure Fuel System

The LP pressure fuel system consists of a pre-filter/water separator, electric lift pump (ELP) then a single main engine fuel filter.

Priming of the low-pressure fuel system is achieved via energizing the ELP during service. This can be achieved via ignition key operation (refer to OMM). Please note that the ELP should not be energized for longer than 2 minutes without a fuel supply otherwise ELP damage may result. Nor should it be energized when the fuel supply is shut off; there is a mandatory requirement for an electrical interlock on any shut off valves in the supply or return lines.

The system is self-venting, and therefore you must not loosen the LP or HP pump, rail or injector pipes during priming of the system.

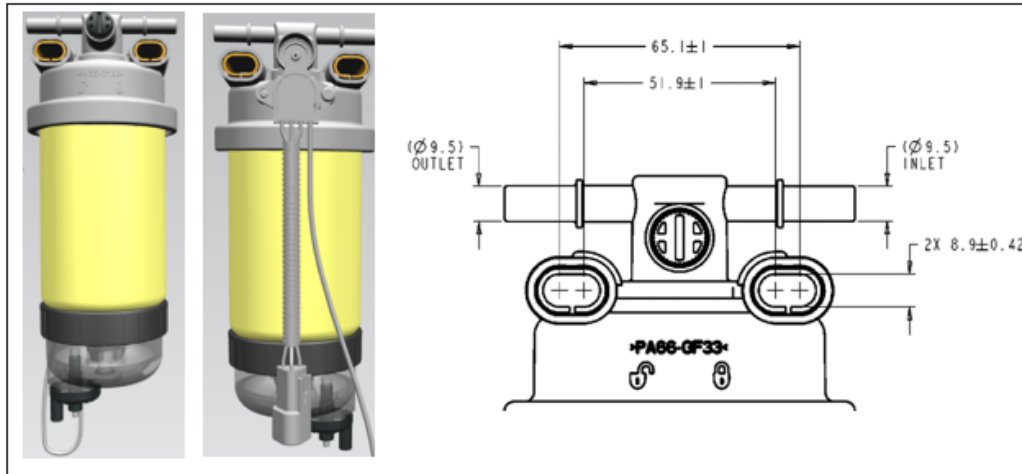
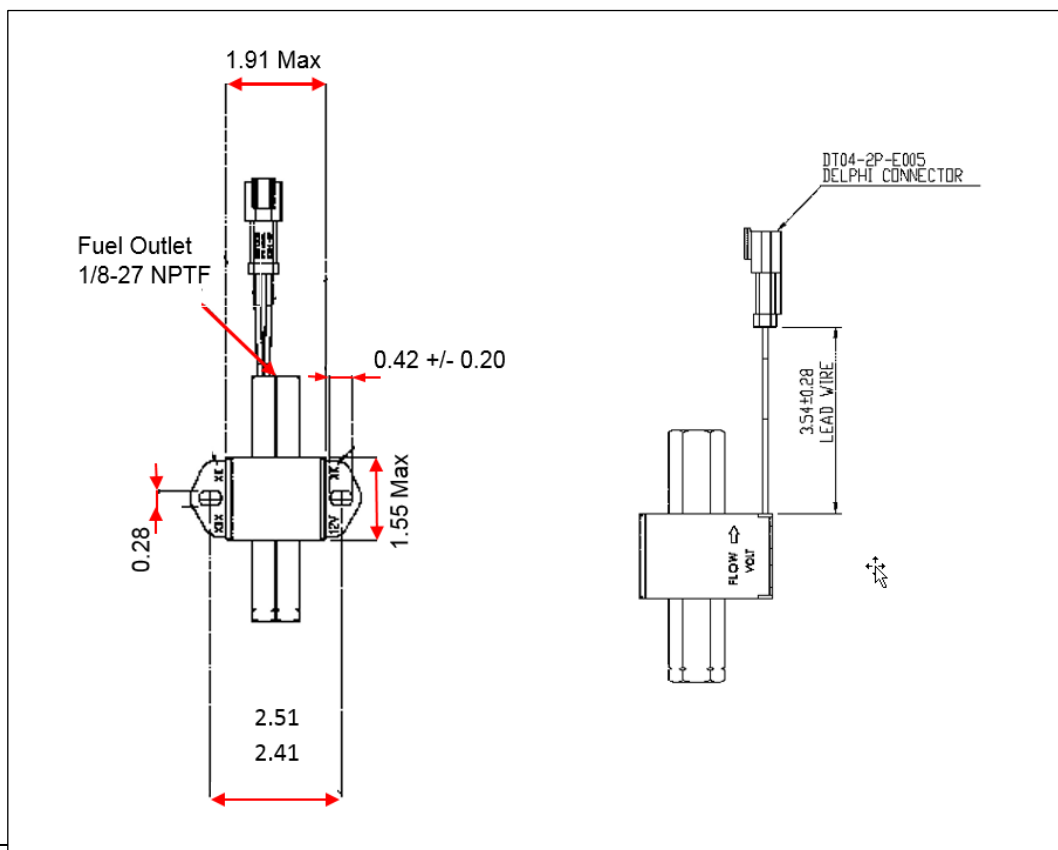


Figure 8-6 Pre-filter/water separator with WIF sensor

8.4.3 Electric lift pump (ELP)

Reference should be made to the Mandatory Installation Requirements in section 8.2 .

The electric lift pump is a solid-state pump with a reciprocating plunger and is self-priming. It supplied as a loose component for customer fitment, off engine. The pump should be mounted using the 2 slotted mounting holes detailed in Figure 8-7 below: It can be mounted in any orientation, but the pump outlet should face upwards and be no lower than the inlet. It is recommended that it is mounted at 45 degrees to the vertical. For details of the required electrical connections and requirements please refer to the Electrical and Electronic A&I manual.



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Figure 8-7 - Electric Lift Pump**8.4.4 Main Engine Fuel Filter**

Reference should be made to the Mandatory Installation Requirements in section 8.2.7.2.

The main engine fuel filter provides 4 μ m filtration with 99% efficiency and provides additional water separation capacity.

All 4-cylinder engines have the main engine fuel filter supplied mounted to the engine, as standard but a remote mounted filter is available for selection from the option offering.

On the 3-cylinder engine, however, there is no on-engine mounted option and the main engine fuel filter must always be mounted remote from the engine.

The remote filter:

- Is shipped mounted to the engine on a temporary transit bracket, which must be removed and discarded before fitment to the machine chassis. The bracket is not suitable to be used to mount the filter permanently in the installation.
- Is supplied with the clean side of the filter already connected to the FIP with a standard length of fuel hose which is coiled up and attached loosely to the temporary transit bracket. The hose should be uncoiled but remain connected during installation of the filter onto the machine chassis. This means that the integrity of all connections clean side of the filter is maintained, which is critical as this filter is the last serviceable filter before the fuel enters the high-pressure pump, fuel rail and injectors.

Details of the customer connection points; the inlet and secondary fuel return connection are shown in Figure 8-8 below.

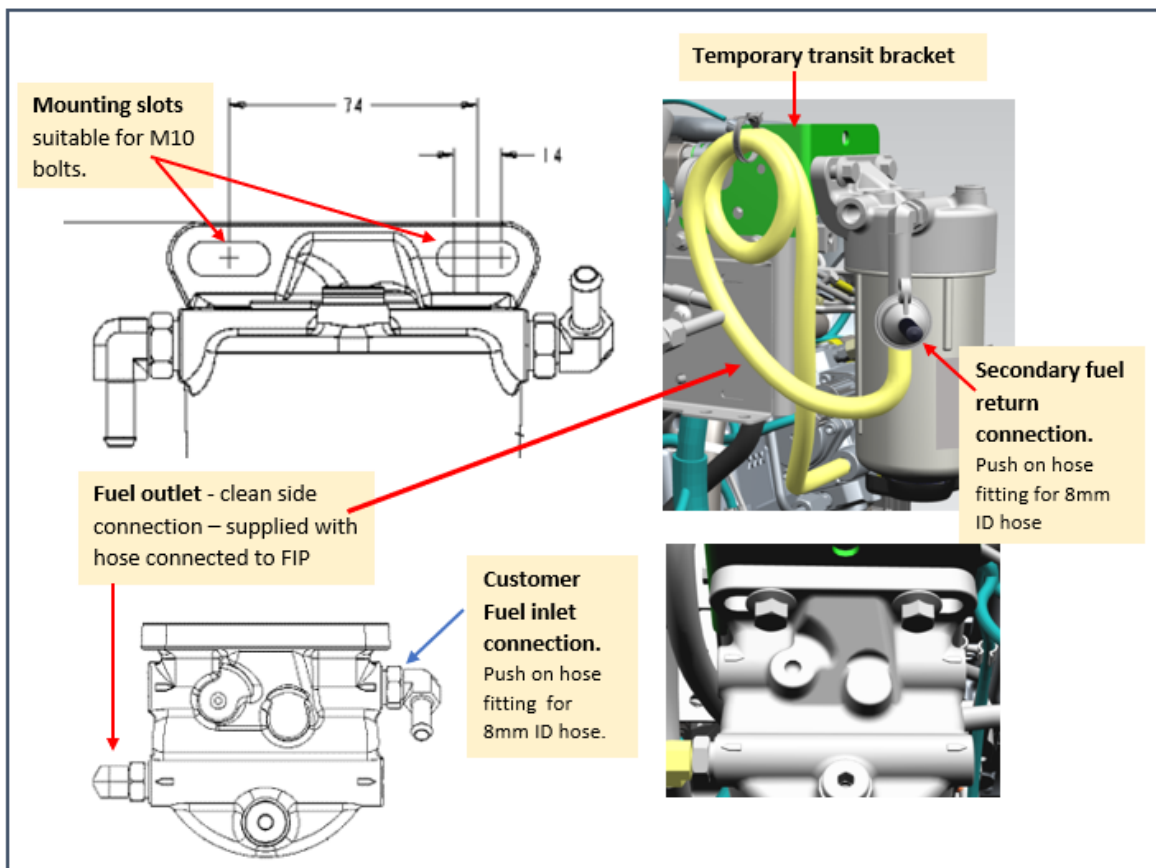


Figure 8-8-Main Engine Fuel Filter

8.4.5 Main return to Tank

The main fuel return to tank connection is situated on the side of the FIP and is suitable for an 8mm ID push on hose as shown in Figure 8-9 below.

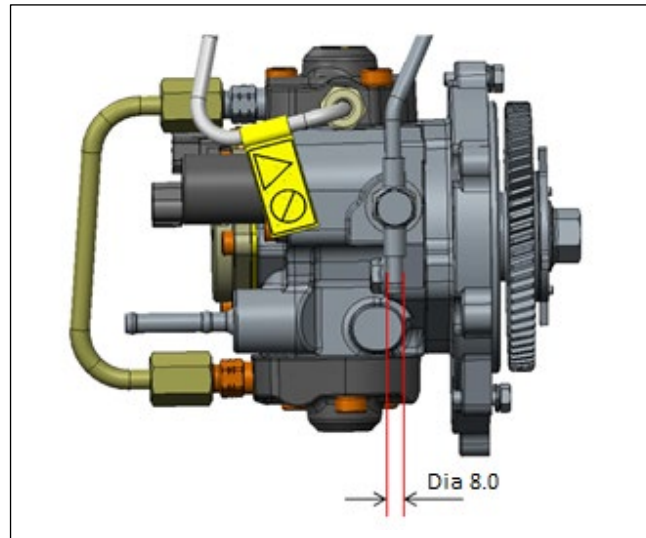


Figure 8-9- Main Engine return to tank connection

8.4.6 Secondary Return to tank line

A secondary fuel return line is required from the pressure relief valve outlet in the fuel line between the secondary filter and the FIP. This connection is found on the side of the Main fuel filter as shown in [Figure 8-8](#) in Section [8.4.4](#).

For the pressure relief valve to function correctly the pressure in the secondary return line must be kept to a minimum and must under no circumstance exceed the limit in [Table 8-2](#), Section [8.3.2](#). This means it may be necessary to have the secondary return line discharge directly into the fuel tank and not be joined to the main engine return to tank line.

8.5 Fuel System Design Considerations

8.5.1 Fuel System Lines and Connectors

The customer is responsible for fitment of the following fuel lines:

- Tank to Water Separator
- Water separator to ELP
- ELP to Main engine filter
- Main return to tank (including fuel cooler, if required)
- Secondary (PRV) return to tank.

Most customer fuel system connections supplied on the 400 series engine are suitable for push on hoses secured by hose/jubilee clips.

Table 8-3 below provides detail of the customer fuel connections and sizes.

Customer connection	Size	Ref Section 8.4
Pre filter /Water Separator inlet/outlet (No WIF)	For 8mm ID Hose	Figure 8-5
Pre filter Water Separator inlet/outlet with WIF)	9.49 OD dia. male quick fit - requires female.	Figure 8-6
ELP inlet/outlet	1/8 -27NPTF	Figure 8-7
Main engine fuel filter inlet	For 8mm ID Hose	Figure 8-8
Main Return to tank	For 8mm ID hose	Figure 8-9
Secondary fuel return to tank	For 8mm ID Hose	Figure 8-8

Table 8-3 - Customer Fuel connections

8.5.2 Fuel system pipework

- All fuel lines should be designed to be as short and direct as possible with no dips, sags, or kinks. They should be kept away from heat sources and be clear of all fouls with other components.
- Pipework must be to the material specifications outlined in this document. It is recommended that all fuel supply lines have a minimum internal diameter of 8mm.
- Fuel lines should be clipped and adequately supported within 100mm of the screen and ELP interfaces.
- The use of shut off valves must not be used in either the supply or return line unless an electrical interlock is employed. This is to prevent the engine cranking with the valves closed. It should be noted that cranking/running with the supply/return valve(s) closed can cause electric fuel pump or engine damage.
- The fuel return lines must terminate below the minimum fuel level within the fuel tank. This is to prevent jetting (aeration of the fuel) and prevent drain down of the fuel system when the engine is not running.

8.5.3 ELP and water separator

- A fuel pre-filter is supplied as part of the water separator. The water separator must be fitted prior to the ELP to maintain the performance of the pump, without which, the performance may degrade, and premature failure may occur.

- All connections to and from the water separator and ELP must be clean, tight and leak free.
- The water separator must be mounted to a rigid flat surface that is not subject to vibration
- The ELP must be adequately supported to prevent any vibration or transmission through the fuel lines, which may cause consequential damage.
- The ELP and water separator should be in a location that is easily accessible for service. Areas that are exposed to collision, operator or service damage should be avoided as well as positions that are close to any source of heat. They should be placed in a location with good airflow to ensure that the temperature under all conditions remains below the maximum component temperature and fuel temperature limit reference 8.2.8 and Table 8-2.
- To prevent damage to the ELP then there must also be a continuous, uninterrupted fuel supply to the pump to prevent premature failure of the pump or motor.

8.5.4 Fuel Tank Design and Installation

The fuel tank must be located to ensure that the maximum fuel pressure head, fuel supply and fuel return restrictions are not exceeded.

The tank must be designed to include the following features:

- Expansion space
- Sediment space (required to prevent suction screen plugging)
- Drainage
- *Tank vent and filter – see mandatory requirements
- Serviceable large particle filter, within tank filler neck.

Tank Baffling should be considered, particularly where machines can experience extreme or frequent changes in gradient. It is essential to ensure that under all achievable gradient conditions that there is sufficient fuel level to cover the fuel supply line; this is to prevent unnecessary machine stoppages or reduced ELP pressure/flow and hence engine performance. Min tank volume of 5% or more.

Care should be taken not to exceed the maximum high-pressure pump inlet pressure specified in the ESM when applying fast fill procedures during machine assembly; adequate venting during filling should control this.

*The tank vent must be serviceable and sized to achieve a 500-hour service interval, taking into consideration the environment where the machine is operating, particularly if high levels of air borne debris are likely.

Material Specifications

The fuel tank material should be matched to the calculated return to tank fuel temperatures as stated in the mandatory requirements. This should include the fuel temperatures seen in all operating conditions and under all tank fuel levels.

The tank should not contain any of those materials on the prohibited materials list see Table 8-1.

If the use of biofuels is likely then care should be taken that the material selected is resistant to the solvent effects and their associated degradation, which may adversely affect some tank paints and surface coatings. The tank should not be translucent, as light can cause photo-degradation of biofuels.

8.5.5 Fuel Cooling

In order to meet the maximum fuel inlet temperature then it may be necessary to employ a fuel cooler in the main engine return line.

- The expected fuel temperature in the fuel return line is 92°C with a maximum of 145°C.
- The flow is approximately 0.8 l/min.

8.5.6 Serviceability

All filters and screens must be in locations, which are easily accessible for service with sufficient space allowed for filter removal and access to the water drain. Consideration should be made for the addition of a hose on the water drain which may be required to help capture the water when draining.

Care must be taken to ensure that filters are not placed directly above any rotating electrics or hot surfaces which would be at risk from any fuel leaks and spillages during normal operating practices.

In addition to the fuel filters the fuel tank vent location must also be accessible for service and the filter media easily removed and replaced as part of a routine maintenance schedule for the machine.

9.0 Lubrication Systems

9.1 Introduction

It is important to ensure that the lubrication system is compatible with the particular application and operating conditions to which the engine will be subjected.

Factors that should be taken into consideration include:

- Lubricating oil specifications
- Lubricating oil temperatures
- Oil sump capacity and gradeability (tilt)
- Pressure losses in any external systems
- Protection from dirt contamination
- Reference should also be made to Chapter 6 Cooling Systems, in relation to lubricating oil cooling.

9.2 Lubrication System Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

9.2.1 General Requirements

- The correct oil must be used as specified in the OMM.
- The engine must be operated with a factory supplied oil filter and oil cooler.
- The maximum operating temperature of the oil must not exceed 125°C continuous and 135°C intermittent:
 - This must be measured in accordance with the appropriate engine test procedure.
 - Intermittent is defined as when the maximum sustained temperature is limited to 10% of the total machine operation or no more than 1 hour in every continuous operating period.
- The maximum gradeability (tilt) of the machine must be within the capability of the selected oil pan.
 - This must include the installed engine angle plus the maximum machine tilt in operation.
- Care must be taken to ensure that the machine design minimises build-up of debris around the sump to help improve heat rejection.
- The maximum oil change interval and oil specification is specified in the OMM. In certain circumstances the engine oil change period may be reduced i.e., for machines that operate with a high average load factor or that operate in severe conditions e.g., heavy dust or elevated operating temperatures. This requires engineering approval.
- A minimum of 15mm clearance is required for removal and servicing of the oil filter canister.
- Sufficient clearance must be provided for access and removal of the sump oil drain plug or valve.
- For Installations where a factory provided oil filler cap is not used a visual aid, on or adjacent to the fill location is required to identify the correct oil specification for the engine and operating territory, information on the engines oil specification can be found in the operation and maintenance manual.

9.2.2 Remote Filter Installation Requirements

Where possible an engine mounted oil filter should always be used. A remote oil filter option, is however, available for selection from the standard option offering for installations where it is necessary, and an engine mounted filter is not accessible. This remote mounted option contains a

kit of parts including an adapter, filter head and connector. If a remote oil filter is required, then the following requirements must be adhered to:

- All remote oil filter installations must be approved by Applications Engineering.
- The remote mounted option (JC004) must be selected from the option offering and all parts provided, used in the design of the remote system.
- An Engine Factory supplied filter element must be used.

- The remote oil filter must be mounted:
 - Off engine.
 - In a location that is:
 - Easily accessible
 - Not subject to excessive vibration *
 - Not in close to any heat source.
 - Not mounted directly above hot or electrical components.
 - The top of the filter head must be:
 - Horizontal.
 - No lower than the maximum oil level in the sump.
 - No higher than the top of the cylinder head.

- The remote filter kit is not supplied with any hoses. Customer supplied feed and return hoses must:
 - Be a suitable material to meet requirements detailed in internal standard 1E0716
 - High temperature, medium pressure wire braid reinforced hose similar to SAE J517 100R1 Type "AT" and BS EN 853-1SN
 - Oil resistant synthetic rubber inner tube with one ply of braided wire reinforcement, and an oil and weather resistant synthetic rubber outer cover.
 - Continuous operating temperature -40 to 135 °C.
 - Be 12.7mm (½") OD.
 - A constant diameter is required, changes in diameter are not acceptable.
 - Have a maximum length of 0.75m each (total length 1.5m).
 - One single piece of hose must be used for each supply and return line. Joints or fittings within each hose length are not acceptable.
 - Be adequately supported to prevent stress on end fittings or abrasion
 - Not be routed in close to any heat source.
 - Be clear of any foul conditions under all operating and service conditions.
 - Meet the following cleanliness requirements:
 - Maximum particle weight: 6mg/m length.
 - Maximum particle size: non rubber particle – 125microns, rubber – 600microns.
 - Port Specifications – Filter Base: Recommend ½ - 14 BSP to ISO 1179 – 1
 - Port Specifications - Adapter Assembly: Recommend ISO 1179 – 1, type E fittings

- The delta pressure across the remote oil system must not exceed the maximum limit
 - This must be tested in accordance with the relevant engine remote oil test procedure. This document also contains acceptance criteria.

- The maximum time to prime the turbocharger must not be exceeded. This is a mandatory test requirement if:
 - Any part of the remote oil filter kit or Engine factory filter is not used or modified in any way or the mandatory requirements in section 9.2.2 are not adhered to.
 - This must be tested in accordance with the relevant engine remote oil test procedure. This document also contains acceptance criteria.

- Refer to section [9.5.2](#) for design considerations for remote oil filter systems.

9.2.3 Customer Components requiring oil feed

- It is not permitted for the engine oil to be used to lubricate ancillary components.
- Customer supplied ancillary components requiring engine oil feed require Engine Factory Approval.

9.3 Lubrication System Overview

The lubrication system includes a gear driven oil pump, pressure relief valve, engine oil filter, oil cooler, oil pan, suction tube and strainer, oil level gauge and oil switch.

The oil pan and oil level gauge are customer selectable options. All the other components are standard non selectable components.

Oil from the oil pan travels through the strainer and suction pipe to the oil pump where it is pumped to the filter and cooler before reaching the main oil gallery and cylinder head. From here it is directed through oil passages to feed all the required engine components.

9.3.1 Lubrication System Operating Parameters

9.3.1.1 Oil temperature

The maximum operating temperature of the oil must not to exceed 125°C continuous and 135°C. Intermittent *(measured at filter head).

Intermittent is defined as when the maximum sustained temperature is limited to 10% of the total machine operation or no more than 1 hour in every continuous operating period.

9.3.2 Approved Oils

It is important to use only lubricating oil that conforms to an approved specification to suit a particular engine type. The engine ESM gives approved oil specifications. Information is also given on viscosity ranges recommended for operation within various ambient temperature ranges.

9.4 Lubrication System Components

9.4.1 Lubricating Oil Filters

- The engines are supplied with full flow lubricating oil filters as standard.
- These filters are designed specifically for use on diesel engines to adequately handle the flow, temperature and pressure involved, and provide the required filtration capacity.
- It is not recommended that any filter type other than that supplied with the engine should be used.

9.4.2 Lubricating Oil Cooler

- All engines are fitted with an engine mounted oil filter and coolant cooled oil cooler between the oil filter and block as shown in [Figure 9-1](#) below.

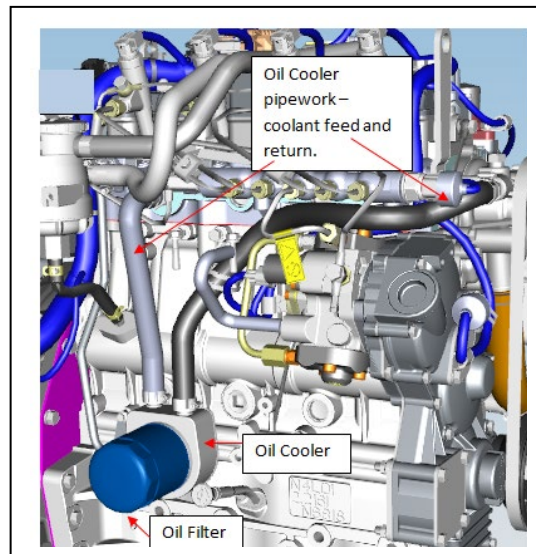


Figure 9-1 Oil Filter and Cooler

- A remote mounted filter can be selected as an option from the engine offering.

9.4.3 Sump Eco drain valve

An Eco drain valve can be selected as part of the engine offering and is supplied fitted to the sump in the horizontal drain position.

9.5 Lubrication System Design Consideration

9.5.1 Oil Temperature

Working within the maximum oil temperature limits specified in the mandatory requirements helps to:

- Protect bearings, oil seals and all wearing surfaces of the engine, as well as avoiding excessively high oil consumption.
- Control Viscosity.
- Ensure that oil condition is managed satisfactorily up to the specified oil change periods.

The engine oil temperature is directly related to coolant temperature through the use of a water-cooled engine mounted oil cooler. In order to help maintain oil temperature, within the mandatory limits, the Installation should be designed to provide good airflow across the engine; particularly around the sump (Oil Pan) area where hot air can stagnate.

In order to maintain the oil temperature within the maximum limits an oil cooler is fitted on all engines. Refer to section [9.3.1](#) operational parameters

9.5.2 Remote Oil Filters

In applications where none of the standard engine mounted oil filter positions are accessible in the installation, a remote mounted filter system may be considered the only alternative. This is non-preferred as it increases the complexity of the system and not only adds the risk of leakage and contamination but adds additional risk to key engine components requiring oil feed such as the turbo charger. Utilising a factory supplied remote filter kit reduces this risk and provides a partially validated system within the installation constraints of the kit itself. This must adhere to the installation requirements detailed in section [9.2.2](#).

Any remote system must be designed to be robust, reliable, and fully validated and tested for all machine operating conditions thus helping to prevent issues in the field which could lead to consequential component failures.

In addition to the mandatory requirements the following additional considerations for a remote mounted oil filter system should also be taken into consideration:

- Ensure that the system does not present any leakage risks:
 - Pressure tight, screw connections should be used for lubricating oil pipes.
 - Fully swaged fittings to be used. Push on hoses with screw clamps are not suitable and will not be approved.
- When arranging the pipework, enough flexibility should be allowed to accommodate any relative movement of components, but it is important that the pipe is positioned to prevent abrasion during any operating condition.
- Additional clamping may be used on all pipes except on the braided part of those pipes with external metal braiding.
- Minimize hose lengths to reduce incremental system capacity.
 - Ensure that the increased oil circuit volume does not impact priming of the turbo charger. Oil starvation to the turbo will lead to bearing damage and very quickly result in complete turbo failure.
- Avoid using pipe fittings with high-pressure drops. i.e., right-angled connectors or those with restricted internal bore diameters.
- Use the correct oil filter adaptor and filter to ensure a low, acceptable restriction.
- The size of the remote filter delivery and return pipes should be 1" or 25mm internal diameter.
- The remote oil filter must be installed the correct way around and procedures in place to endure the correct direction of flow.
- The remote filter should be mounted on a stiff solid structure independent of the engine. This is required to minimize vibration. The vibration should be monitored by a touch test and if thought to be excessive a full vibration test must be conducted.

- The remote filter should be positioned to minimize system drain back after a hot shutdown.
- Serviceability must be taken into consideration when positioning the filter:
 - There must be clear access to the filter.
 - Positioning the filter height above the engine oil take off point can offer a cleaner filter change operation. Testing by the customer is recommended.
- Care must be taken to ensure correct assembly of the remote oil filter in production, adhering to the required cleanliness specifications.

Thorough validation of the remote oil filter system is required for all remote all filter systems. The minimum test required is:

- A Delta Pressure test – required on all systems using the Engine Factory supplied remote oil filter kit.
- Cold ambient testing to measure the maximum time to prime the turbocharger – this is recommended for all remote filter systems but is a mandatory requirement if:
 - The remote oil filter kit is not used or is modified in any way.
 - A non- Engine Factory supplied oil filter is used.
 - Any of the remote oil filter mandatory requirements are not adhered to.
- All tests must be conducted in accordance with the relevant engine test procedure.

Time to prime the turbocharger with lubricating oil will vary; not only with the system design and oil volume within the system, but it is also very sensitive to ambient temperature, oil viscosity and machine operation. The worst-case condition for time to prime is starting the engine under cold conditions (10 degrees and below) when the oil is more viscous. The condition is further exacerbated when the engine is started following a previous hot shutdown where the lower oil viscosity allows a more complete system drain down. It is, therefore, very important to use the correct viscosity oil for the ambient temperature especially below -10 °C where the effects of low ambient temperature and oil viscosity have the greatest impact.

9.5.3 Serviceability

- To achieve satisfactory engine service life, it is essential to adhere to the oil and filter cartridge change periods recommended in the OMM.
- To facilitate oil changes and filter cartridge removal, it is essential for these and the dipstick to be positioned in a readily accessible position and to be protected from possible damage.
- Whenever possible it should not be necessary to remove the engine in order to remove the oil sump (Oil Pan).
- It should be recognised that the oil cooler can hold significant quantities of oil, which may not be fully drained and changed in the course of routine engine oil changes.

10.0 Crankcase Ventilation Systems

10.1 Introduction

From Tier IV regulations onwards, all crankcase emissions are required to be included in the total system emission values. It is, therefore, essential; to ensure that the crankcase ventilation system and any of its associated components are correctly installed to provide a robust and durable system that ensures compliance throughout the life of the product.

The correct Installation of the crankcase ventilation system is mandatory to enable installation approval.

10.2 Crankcase Ventilation System Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

10.2.1 General Requirements

- EM** Recirculation of the breather gas is mandatory for engines supplied as CCV.
- EM** Under no circumstance may any of the Engine factory supplied components within the engines breather system be modified, tampered, or disturbed in any way:
 - Changes to the factory supplied breather system components may affect the emissions compliance of the engine, any changes to the as shipped configuration must be agreed be risk assessed and approved by the engine factory.
- EM** The use of the factory supplied turbo compressor air inlet pipe is Mandatory as this forms part of the certified breather system.
 - Removing or replacing this supplied connection is prohibited.
- EM** The standard factory fitted crankcase ventilation system is expected to operate down to -25°C.
- EM** An engine factory approved cold climate protection kit must be used to operate in temperatures from -25°C to -32°C.
- EM** In certain circumstances i.e., high air flow across the breather hose, low residual load, extended idle etc., this cold climate kit maybe required at higher temperatures. This is application dependant and can be assessed by measurement of the gas temperature.
- EM** Temperature of all ventilated gases, between engine and intake connection should be kept above 10°C (under all operating ambient temperatures).
- EM** The closed crankcase breather system must be protected from exposure to any direct blasts of cold air.
 - This is a particular concern where remote cooling fans are utilised.
- EM** The crankcase ventilation systems component operating temperature limits must not be exceeded.
 - Refer to Appendix D 'UHT and DEF test Acceptance Criteria and UHT Gauge map' in the relevant engine test procedure document for component temperature limits.
 - Component temperatures must be tested in accordance with the relevant engine test procedure.
- EM** The crankcase breather hose must be clear of any interference or constriction to ensure the free flow of gas.

10.3 Crankcase ventilation System Overview

Crankcase emissions result from combustion by-products and/or exhaust fumes escaping around the piston rings, turbo chargers, valve stem seals and auxiliary driven equipment into the crankcase. These escaping fumes are commonly called blow-by. The overall volume of blow-by varies due to cylinder pressure, piston ring pressure and component wear.

Elements found in blow-by can include wear particles, oil, fuel, gas, and air. The specific composition of the elements varies due to fuel type, engine type, engine speed, load, and maintenance history. Typically, blow-by is made up of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO₂) and nitrogen oxides (NOX).

Regulatory requirements drive the need to manage these emissions.

Both 4- and 3-cylinder Stage V, EPA Tier 4 Final engines are supplied with a low pressure integrated closed circuit breather system.

For engines supplied with CCV the crankcase gas is routed through an external pipe from the engine top cover to the oil mist separator (OMS). This uses a serviceable filter element to separate the oil vapor from the blow-by gases. The condensed vapour is returned back to the block via the breather filter drain valve. The gas exiting the filter is directed into the low-pressure side of the turbo charger through an external pipe from the top cover to the turbocharger air inlet hose as shown in Fig 10.1 below. A breather heater is also incorporated into this hose to prevent any freezing in low ambient conditions – refer to Chapter [14.0](#) for more detail.

This gas is then ingested the turbocharger, passing through the charge air cooler then entering the engine again through the intake manifold.

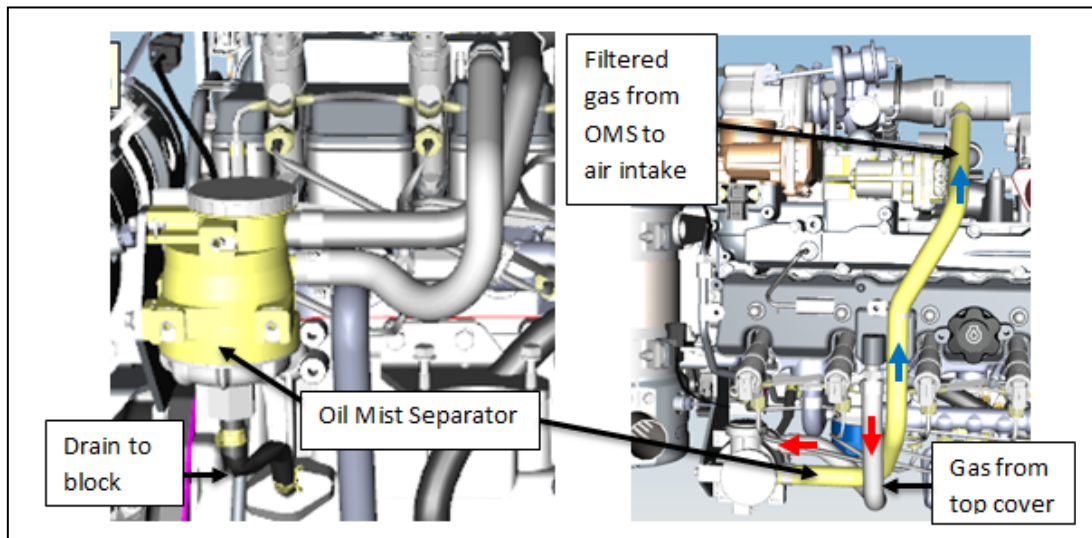


Figure 10-1- Closed Crankcase Breather System

10.4 Crankcase ventilation System Components

10.4.1 Oil Mist Separator (OMS)

The oil mist separator uses a serviceable filter element to separate the oil vapor from the blow-by gases. The oil mist separator includes a pressure relief valve to prevent excessive crankcase pressure build-up, which can lead to the damage of oil seals resulting in engine oil leaks.

The OMS is mounted high on the rear upper RHS of the engine on a bracket located directly off the aftertreatment mounting bracket. If a remote aftertreatment is selected, then the OMS is still in the same location but mounted from a different mounting bracket so the position may vary slightly. Figure 10-1 shows the location of this filter.

The OMS filter must be serviced at predefined service intervals in accordance with the requirements detailed in the OMM.

10.5 Crankcase Ventilation Design Considerations

10.5.1 Operation in cold ambient conditions

Refer to Mandatory Requirements section [10.2](#).

Crankcase ventilation gases contain a large quantity of water vapour. This water can freeze in cold ambient conditions and block or damage parts of the crankcase ventilation system. The extent of vulnerability is highly dependent on the application.

In order to prevent this from happening a heated breather is supplied fitted to the engine and must be used in applications that operate in ambient conditions of -25°C or below. In certain circumstances i.e., high air flow across the breather hose, low residual load, extended idle etc., this heater maybe required at slightly higher temperatures. Applications with a pusher (blower) fan are particularly vulnerable. This must be assessed by testing and advise sought from engineering.

Figure 10-2 shows the heated breather which is incorporated into the external breather pipe and includes an electrical connector which must be wired in accordance with the requirements in the Electrical and Electronic A&I Manual.

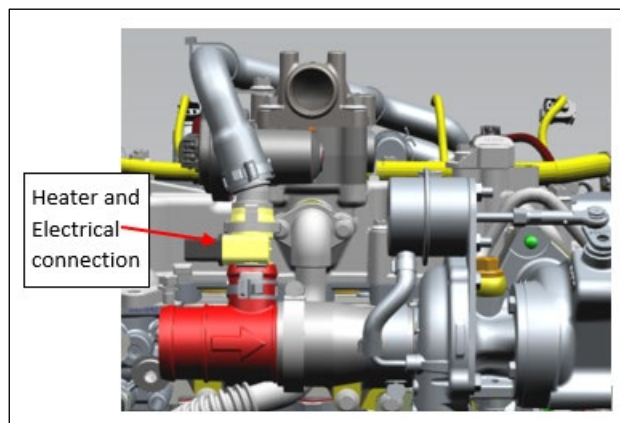


Figure 10-2- Heated Breather

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11.0 Mounting of Electronic Components

11.1 Introduction

This chapter includes the Mandatory requirements for installation of the Electronic components that are supplied loose with the engine. This includes the ECM and electronic sensors related to the aftertreatment system. Electronic connection of all these parts is covered in detail in the relevant engine Electronic Application and Installation Manual.

11.2 ECM Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

These engines use an **A6:E10** ECM which is supplied loose with the engine. Mounting of the ECM is the customer's responsibility and must follow the installation requirements detailed below.

11.2.1 ECM General

- The ECM must not be painted.
- The ECM must not be submersed. The pressure compensation valve and integral barometric sensor will not operate correctly if submersed in fluids.

11.2.2 ECM Mounting

- The ECM must NOT be mounted to the engine or any engine mounted component.
- The ECM must be mounted in a location:
 - That is protected from exposure to fluids and debris.
 - to prevent foreign object damage and clogging of the air-cooling fins and connector mechanisms.
 - If necessary, measures must be taken to prevent fluids channeling towards the ECM through conduit or wiring.
 - That is protected from exposure to chemicals.
 - In an area where there is a free flow of cooling air and not stagnant hot air.
 - That provides sufficient clearance to allow connection and removal of the connectors.
- The ECM must be mounted so that:
 - It does not touch other machine or engine components under any operating conditions.
 - It does not exceed the component vibration profile. Refer to Appendix G 'Vibration acceptance Criteria and Gauge Map' in the relevant engine test procedure document:
 - To achieve this, the ECM may be hard mounted to the machine chassis, however the design should allow for the provision of ISO mounts; should vibration testing indicate this is a requirement.
 - Vibration testing must be conducted on all ECM's and must be in accordance with the appropriate test procedure.
 - It does not exceed the specified component temperature limits in [Table 11-1](#) below.

ECM Type	Measurement Location	Temp Limits ($^{\circ}\text{C}$)	
		Hard (Chasis Mount)	ISO Mount
A6-E10	ECM surface (case)		-40 to 100
	ECM ambient (50mm from surface)	-40 to 105	-40 to 75
	ECM Mounting surface	-40 to 70	

Table 11-1- ECM Temperature Limits

- This limit is specified as an ECM surface temperature, an ambient air temperature limit and a mounting surface temperature limit, as the ECM's mounting feet are used as a heat sink to help dissipate heat. These limits dependent on how the ECM is mounted.
- Temperature testing must be conducted on all ECM's and must be in accordance with the appropriate test procedure.
- The ECM must be mounted using all 4 fixing points.
 - Using M6 flat shouldered stainless-steel bolts (not countersunk).
 - Tightened to a torque between 9 - 12Nm.
- To ensure the ECM case is not twisted, which will damage the internal circuit board:
 - All 4 mounting holes must be in the same plane and flat within a maximum 1mm tolerance.
 - Each mounting point must be flat within a maximum 0.5mm tolerance.
 - Each mounting point must sit on a boss with a minimum diameter of 20mm.
 - Mounting the ECM to a flat surface is acceptable provided the flatness tolerance is met.
 - Refer to Figure 11-1 below:

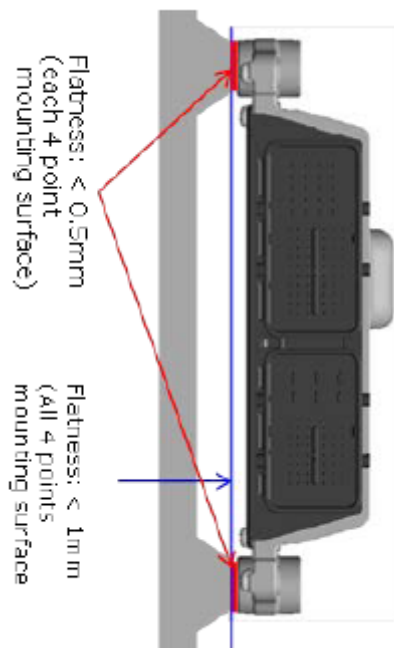


Figure 11-1 -ECM Mounting

11.2.3 ECM Orientation

- The mounting orientation of the ECM must not allow water ingress or water collection on the ECM surface, harness, or sensor.
 - To ensure this, the ECM must meet the orientation requirements detailed in Figure 11-2 for the X-Y plane.

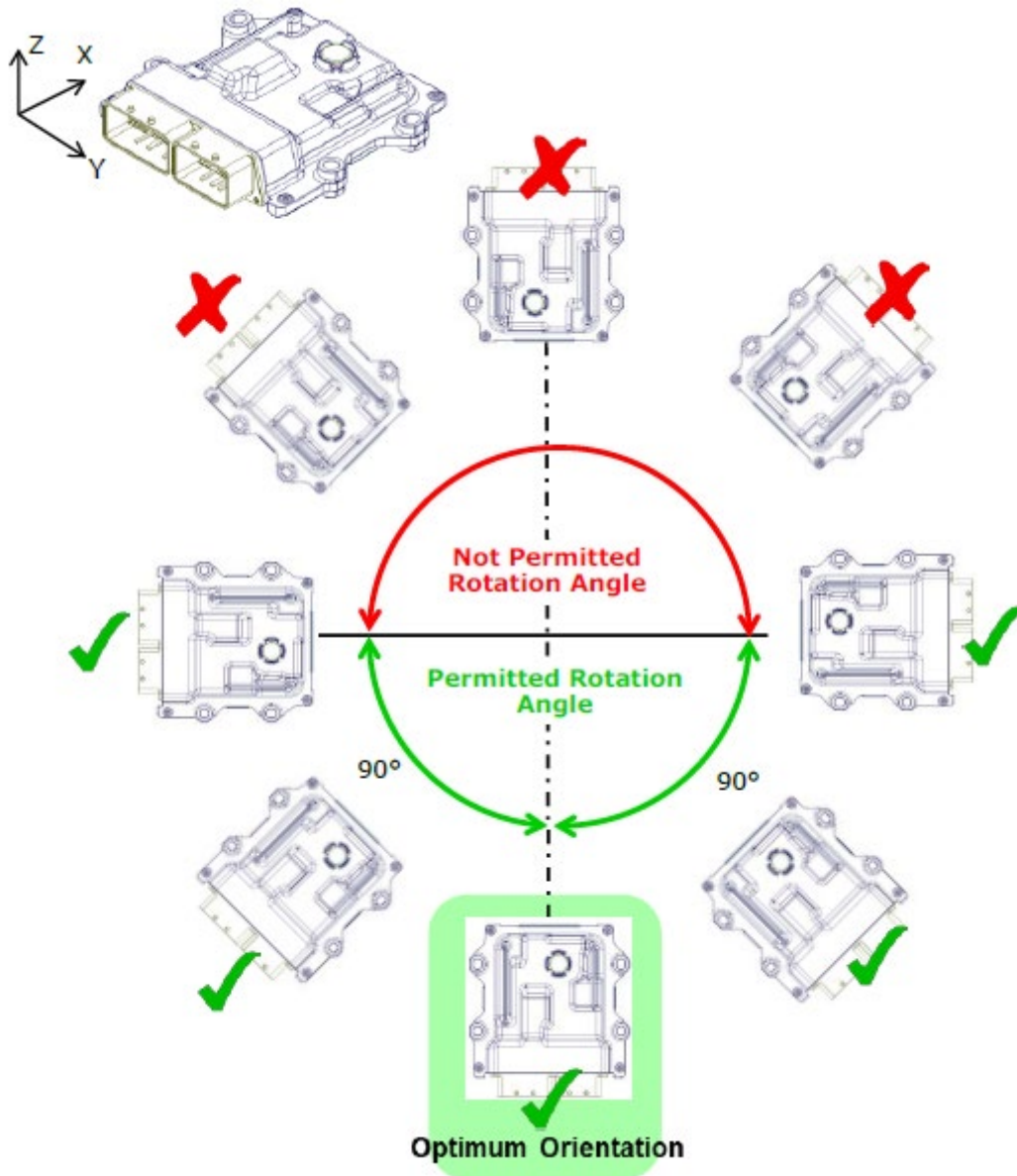


Figure 11-2- ECM Orientation XY Plane

- To ensure this, the ECM must meet the orientation requirements detailed in Figure 11-3 for the X-Z plane.

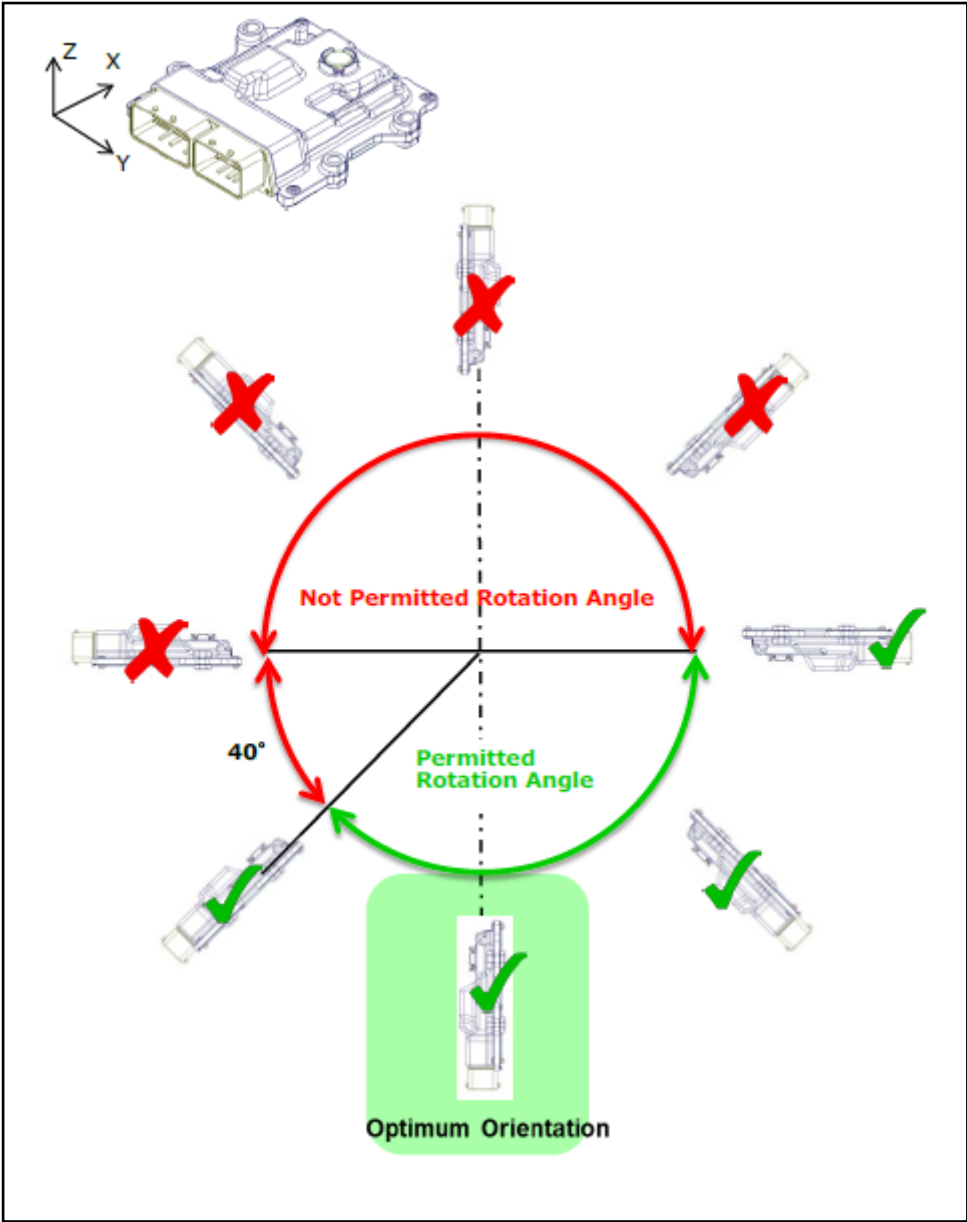


Figure 11-3- ECM Orientation in the XZ Plane

11.2.4 ECM Wiring

- The ECM wiring harness must always point down to prevent water from collecting at the ECM connector.
- Acceptable and unacceptable wiring harness locations are shown in Figure 11-4 below:

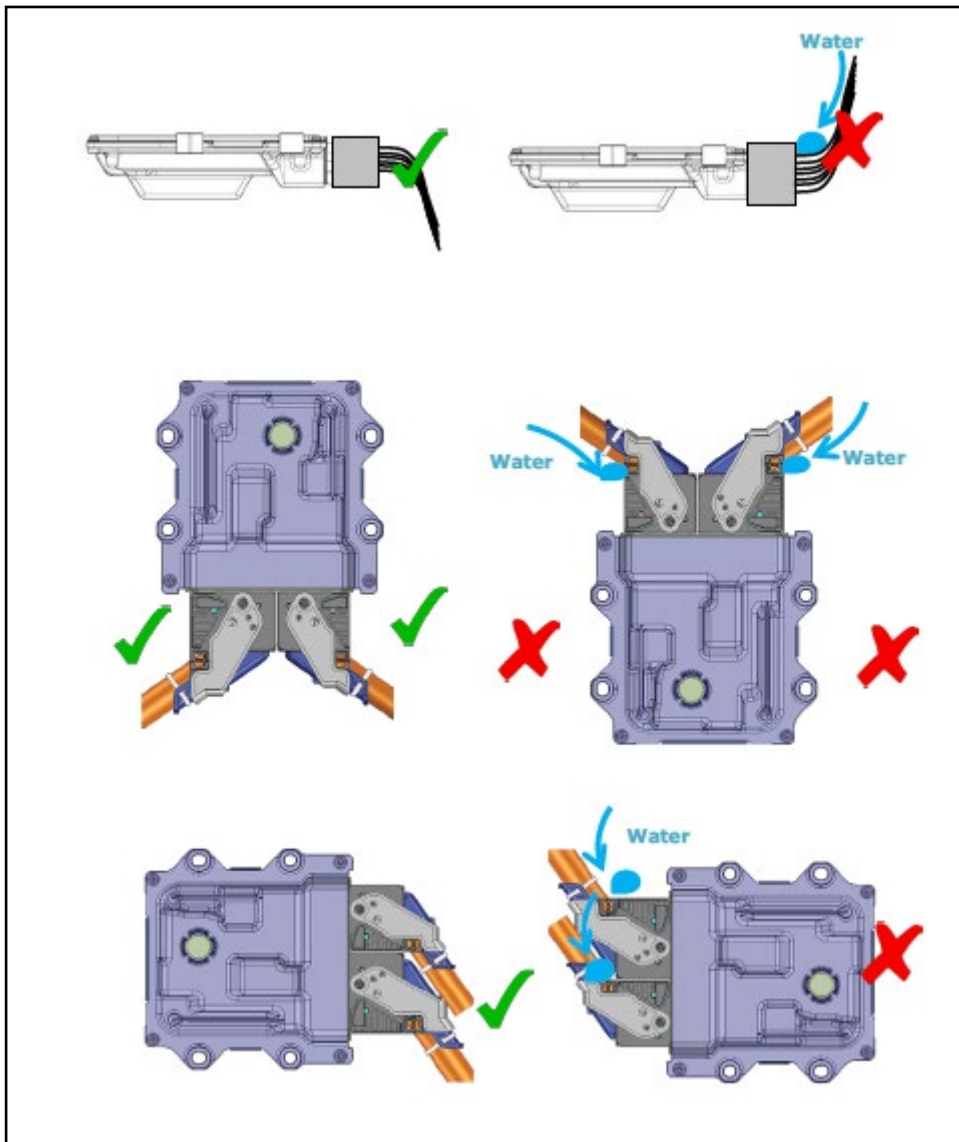


Figure 11-4- ECM Wiring Harness Direction

- Strain relief must be applied to the ECM harness to ensure durability of the connectors:
 - The first strain relief point must be a maximum of 200mm away from the edge of the ECM connector and must be fixed to the same structure as the ECM, to ensure the ECM and connector are subject to the same vibration inputs.
 - The next strain relief point must be 300-400mm away from the first.
 - Refer to Figure 11-5 - Harness Strain Relief.

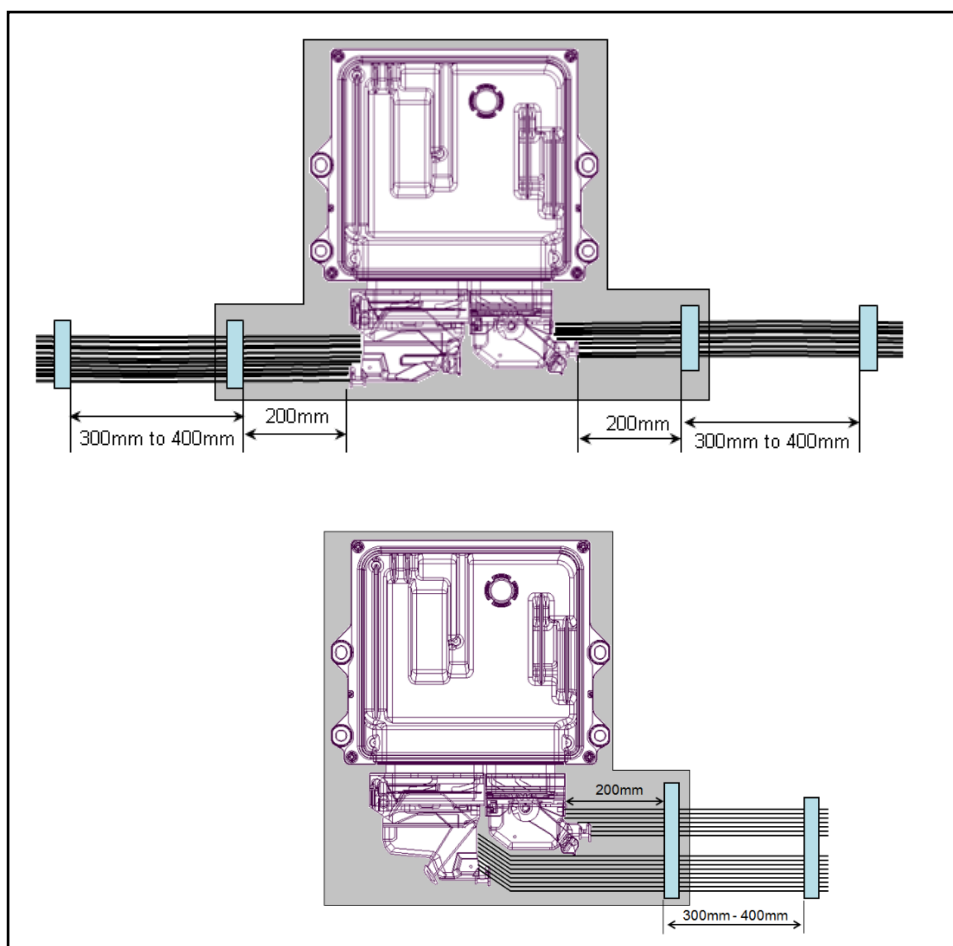


Figure 11-5 - Harness Strain Relief

11.3 Aftertreatment Sensors Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

11.3.1 Aftertreatment Temperature Sensors

The aftertreatment temperature sensors are supplied fitted for engine mounted aftertreatment and supplied loose for customer fitment, with remote aftertreatment.

11.3.1.1 General temperature sensor requirements

- For EMAT the temperature sensors and control module are supplied fitted and must not be moved from their supplied position.
- The sensors must be wired in accordance with the wiring requirements detailed in the Electronic Application and Installation manual.
- Painting of the sensor and sensor control module is prohibited.

11.3.1.2 Loose temperature sensor requirements (remote aftertreatment only):

- The temperature sensors must be fitted within the correct port in the aftertreatment body. Refer to the Exhaust and Aftertreatment Chapter 5 [Figure 5-7](#) section [5.3.2.2](#).
- High temperature nickel free anti-seize paste must be applied to both sides of the threaded joint before installation. Anti-seize paste that reacts and seizes with chemicals in the exhaust gas are not permitted.
 - The recommended product that meets REACH compliance is Molyslip Ferroslip.
- The thread torque for the sensors are:
 - DOC inlet sensor - 35+/- 7Nm. DOC outlet sensor - 45 +/-5Nm.
 - Installation detail can be found in the Customer Assembly Requirements document (CAR).
- The temperature sensor central control module should be:
 - Mounted to the breather bracket as shown in [Figure 11-6](#).
 - Mounting in an alternative location requires approval and will require vibration testing.
 - Secured with a cable tie with a width between 8-10mm (0.3-0.4") as shown in [Figure 11-7](#).
 - Have the connector horizontal or pointing downwards to reduce moisture or debris ingress to meet the requirements in [Figure 11-8](#).
 - Have a temperature within -55° to 120°C.

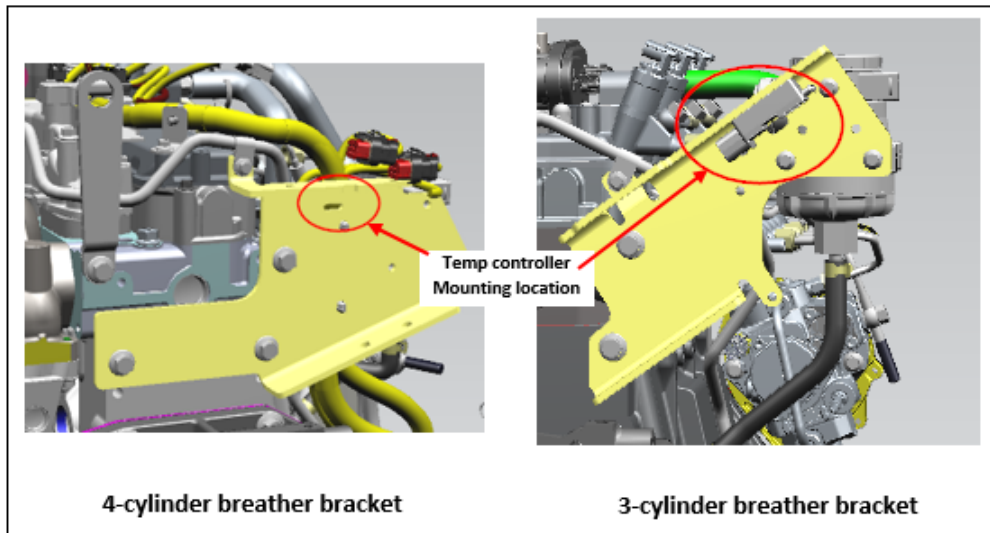


Figure 11-6 – Temperature sensor control module mounting location.

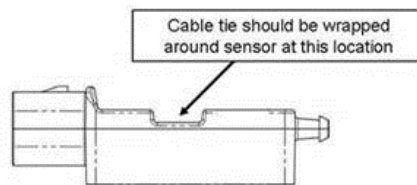


Figure 11-7 - Temp Sensor ECU Mounting

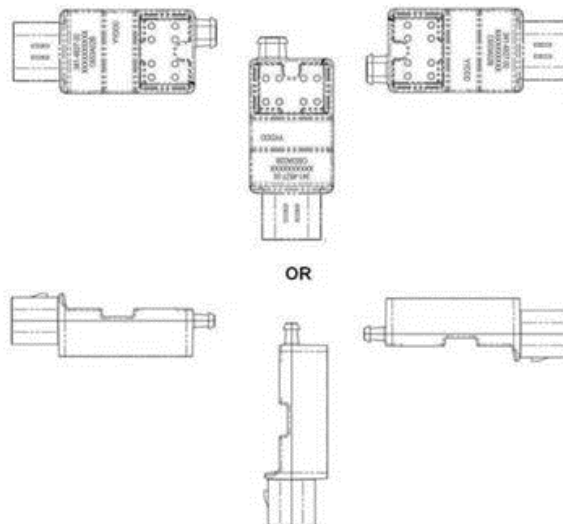


Figure 11-8-Temp sensor ECU Orientation

11.3.2 Delta P sensors

The Delta P sensors are supplied mounted on the Aftertreatment cannister for both engine and remote mounted aftertreatment.

- The Delta P sensor assembly must not be moved or modified in any way from the supplied position.
- The ambient temperature of the Delta Pressure sensor must be within -40° to 140°C, avoiding locations that are susceptible to freezing during engine operation.
- The sensor connector must not exceed 125°C.
- The sensor must not be exposed to vibrations in excess of the component vibration profile. Refer to Appendix G Vibration Acceptance Criteria and Gauge Map' in the relevant engine test procedure.
- The sensor must be wired in accordance with the wiring requirements detailed in the Electronic Application and Installation manual.

11.4 Electronic Component Design Considerations

If isolation of the ECM is found to be necessary in order to meet the vibration limits (Refer to Appendix G 'Vibration acceptance Criteria and Gauge Map' in the relevant engine test procedure) then the guidelines in the following sections should be considered in order to achieve a successful design.

11.4.1 ECM Isolator Mounting Plate

- In order to design an acceptable mounting solution, the ECM must be hard mounted to a metallic mounting plate which is then iso-mounted to the machine body/chassis. The purpose of this plate is to provide a stiff flat mounting surface that provides sufficient surface area to adequately dissipate the heat generated from the ECM. The mounting feet are used to transfer heat from the ECM to the chassis and therefore must not be isolated from the mounting material.
- The design of the ECM mounting plate must:
 - Be metal - zinc electroplated or similar
 - Meet the flatness required detailed in [Figure 11-1](#).
 - Allow adequate dissipation of heat in order to achieve a maximum ambient temperature around the mounts detailed in [Table 11-1](#).
 - Have a thermal conductivity > 52.0 W/mK (i.e., mild steel).
 - Have a 2D surface area > 286 cm² around the ECM mounting points.
 - Have a thickness > 5mm.
 - Have a surface finish that is not painted and is zinc electroplated or similar.
 - Incorporate strain relief / support of electrical connection cables.
- The ECM fasteners must not be used for secondary retention of pipe or wire clips.
- The mounting plate must be iso-mounted to a stiff rigid structure that is not subject to high vibration levels. It should be mounted in a firm location on the machine body or chassis avoiding flimsy panels which might vibrate.
- The plate should be iso-mounted to the machine body/chassis using a 3-point mount arrangement. The mounts should be equally spaced round the centre of mass of the system.
 - For details of isolation mount design refer to section 11.4.2 and 11.4.3 below:
- An earth strap will not be required to the ECM mounting plate as the main earth connections to through the ECU main connector are used for all ECU grounding. It is, however, recommended that the ECM case is connected to chassis ground by the fixing points.

11.4.2 ECM Isolation Mounts

- In order to protect the electronic components within the ECM it is recommended that the isolated ECM mounting system (ECM, ECM mounting plate, harness, and fixings) should start to isolate vibration at frequencies of 100 Hz and above.
 - This assumes that there is no significant vibration present on the machine mounting structure below 100Hz.
 - Targeting 100Hz offers a significant reduction to the vibration input to the ECM using a relatively stiff mount that should also offer suitable durability performance, assuming an adequate rubber profile is selected for the environment. 1.7.1 below shows an example of this in practice. It does however use an isolation frequency around 80Hz but does show the theory being applied.
 - [Figure 11-9](#) shows the effect of using a similar mount which targets an isolation frequency around 80Hz.
- The selected mounts must be resistant to oil, fuel, and coolant.

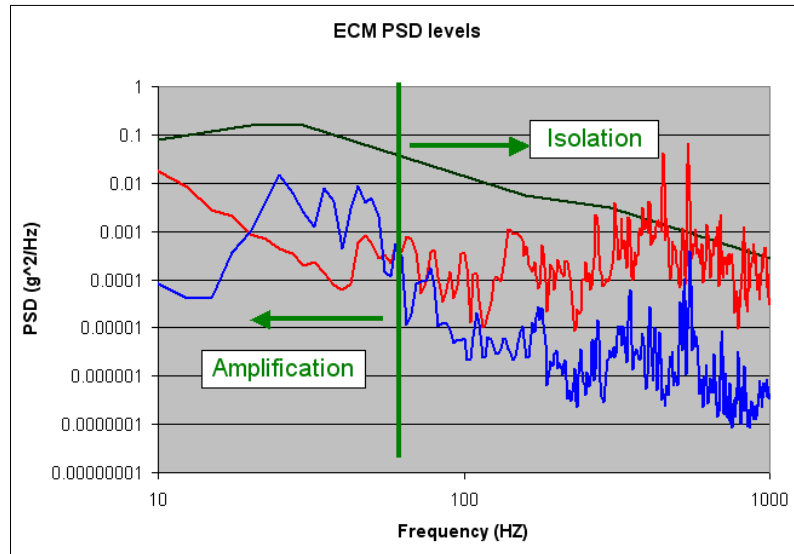


Figure 11-9 Example of resultant effect of isolation

11.4.3 Isolation Mount Type

- It is recommended that a simple 'sandwich' style mount is used as shown in Figure 11-10
 - The use of double ended mounts like this gives the flexibility to attach the mounts using nuts or a tapped hole.

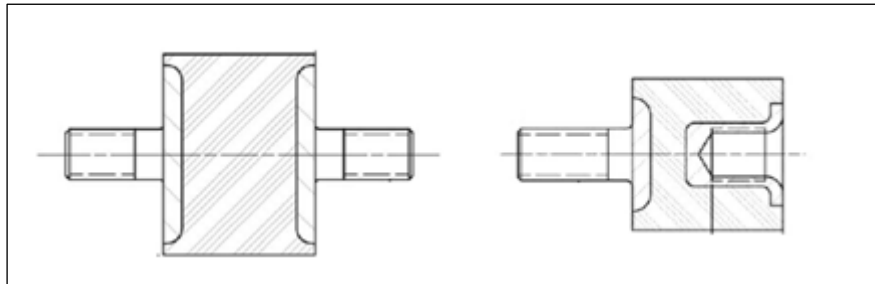


Figure 11-10 Recommended Isolation Mounts

- The precise specification of the isolators will be dependent upon the mass of the mounting plate, the type of mount used, the orientation of the mount, the number of mounts used and the input force direction. As a result, it is recommended that you contact your mount suppliers in the early stages of the installation design process.
- If the ECM and bracket is circa 2Kg, mounts of a similar specification detailed below have been found to be in the correct region on some applications. Softer and harder mounts either side should also be considered. The specifications below should only be used as a rough guideline only.
- Figure 11-11 below shows an example of an acceptable ECM mounting system. The features of this system meet the recommended requirements and are summarised below:

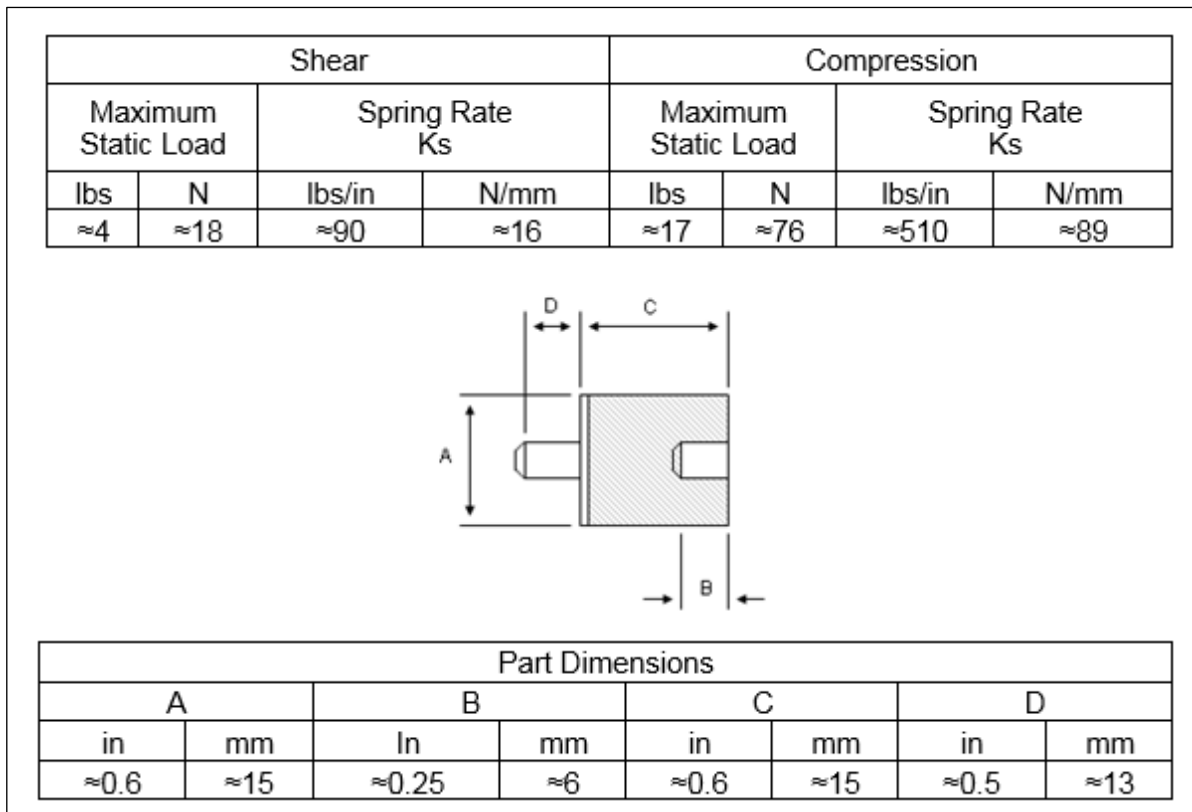


Figure 11-11 - Isolation mount dimensions

11.4.4 Remote aftertreatment sensor locations

For remote aftertreatment the temperature sensor and controller are supplied loose for customer fitment. These sensors must be installed in accordance with the mandatory requirements detailed in section [11.3.1](#).

The correct location of the sensors in the aftertreatment cannisters is shown in the Exhaust and Aftertreatment Chapter 5 Figure 5-7 section [5.3.2.2](#).

The temperature sensors are Poke Yoke, with different size bosses to ensure the correct sensor is installed in the correct location.

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12.0 Driven Equipment

12.1 Introduction

The standard front-end belt drive arrangement consists of a single-vee belt to drive the water pump/fan drive and alternator. The tension of the belt is manually controlled by the alternator tensioning arm. There is also a 5 rib multi-vee belt available from the option offering which is also tensioned by the alternator and requires the selection of the correct crank and fan drive options with compatible pulleys.

Additional belt driven accessories can be driven using a secondary pulley off the crank pulley which can be selected from the standard offering in the ESM.

An SAE A drive is available on the rear of the timing case as a selectable option. Refer to the ESM for options and compatibilities.

12.2 Driven Equipment Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

12.2.1 FEAD (Front End Accessory Drive)

12.2.1.1 General

- The minimum distance of any component from the inside or outside face of the belt must not be less than +/-5% of the unsupported span length and no less than 6mm from the edge of the belt.
- Painting - Any over-spraying operation that is conducted must adhere to strict masking guidelines and procedures, which must be controlled and repeatable. Please contact your application engineer for further information.
- The front of the engine must be accessible to meet servicing requirements. Refer to OMM for servicing information

12.2.1.2 Standard configured front-end arrangements

For standard configured front-end arrangements where the belts and all driven components are supplied fitted. For 400 series engines this includes the supply of the Fan and Fan extension.

- The supplied arrangement must not be modified and should be serviced regularly in accordance with the OMM.
- For customer supplied fans, fan hubs, alternators, belts, and air conditioning units the requirements detailed in section 12.2.1.3 and Q below must be adhered to.

12.2.1.3 Customer supplied front end arrangements

For customer supplied front end arrangements including belts and or belt driven accessories the customer is responsible for the design and durability of the FEAD and supplied components. As the engine water pump is also belt driven then additional precautions must be taken to ensure the durability and performance of this component is not affected and Engine Factory approval is required Approval in this case does not, however, imply or assume responsibility for this arrangement. The responsibility for which, will remain solely with the customer.

For customer supplied front end arrangements the following additional requirements must be adhered to:

- A drive analysis must be conducted on all customer supplied front end arrangements and have Engine Factory approval.
- The maximum simultaneous power absorption from the main drive belt must not exceed the maximum capability of the front-end drive arrangement, detailed in Figure 12-1 below.

- Calculations must include the power for the alternator and fan but should not include the water pump power as this has already been taken into consideration.
- This is applicable to both the single vee and Multi vee 5 rib belt drive.

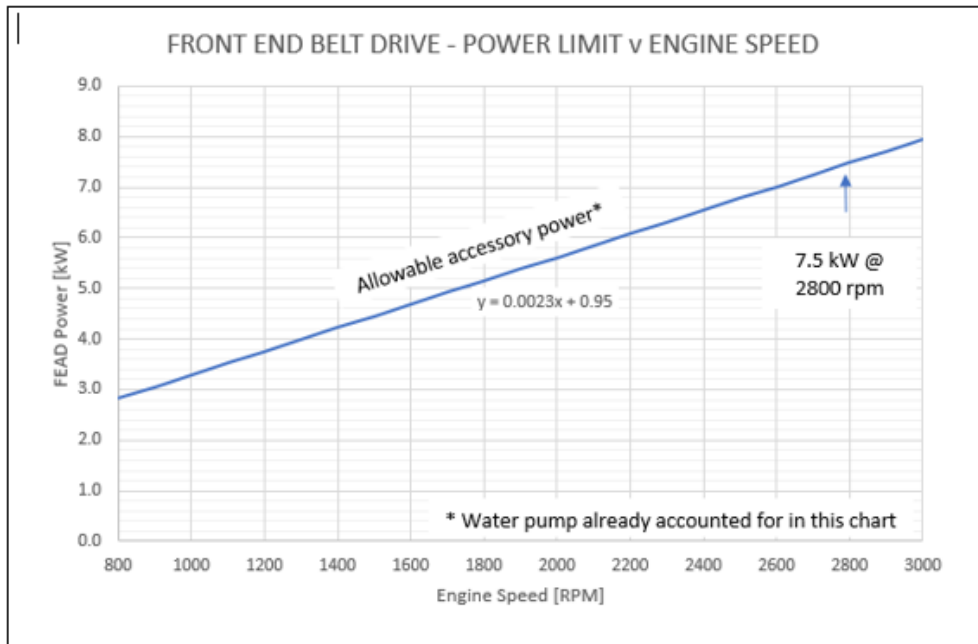


Figure 12-1-- FEAD Belt Power Absorption Curve

- The main drive belt (Single vee or 5-rib Multi vee ,option dependant) must only drive the water pump/fan pulley and the alternator. Additional belt driven accessories must not be driven from this drive belt.
- The water pump/fan hub must not be used to drive additional belt driven accessories.
- For engine factory supplied alternators, the maximum alternator hub load must not exceed the component limits. Please contact your applications engineer for further information.
- If a customer supplied alternator is used, then:
 - A full FEAD analysis must be conducted and be Engine Factory Approved.
 - The alternator mounting must include provision to tension the belt.
- The use of a customer supplied belt will require a full FEAD analysis to be conducted and approved.
- Misalignment - The maximum entry angle of the belt to the pulley must not exceed 0.5°. (Alignment of components must be within acceptable limits to prevent excessive wear). This includes consideration of crank end float service limits.
- Any additional belt driven equipment (i.e. air conditioning compressor) must be driven off the crankshaft using a secondary pulley fitted to the crank. This additional pulley can be selected from the standard options offering.
- Engine driven accessories must be mounted so:
 - The maximum front crankshaft overhung load must not exceed that shown on the polar moment diagram in the relevant ESM.
 - That its natural frequency is outside of that of the critical engine frequencies.
- The maximum crank hub side load must not exceed that which is shown on the polar moment diagram in the ESM.

12.2.1.4 Customer supplied Fans

- Please refer to Chapter [6.0](#) – cooling systems for mandatory requirements for Engine Factory supplied fans.
- Customer supplied fans, fan extensions or fan clutch arrangements require the water pump/fan drive load and bearing life to be assessed using the method detailed below:
 - The total mass of the fan and clutch assembly and the distance of its centre of gravity from the front face of the water pump pulley must fall within the green area shown on the chart in Figure 12-2.
 - If applications fall into the red area on the chart, then additional engineering assessment is recommended to establish acceptability.
 - This chart is applicable for engine speeds and all drive belt arrangements.
 - It is recommended that all complex fan drive arrangements should be fully assessed by engineering.

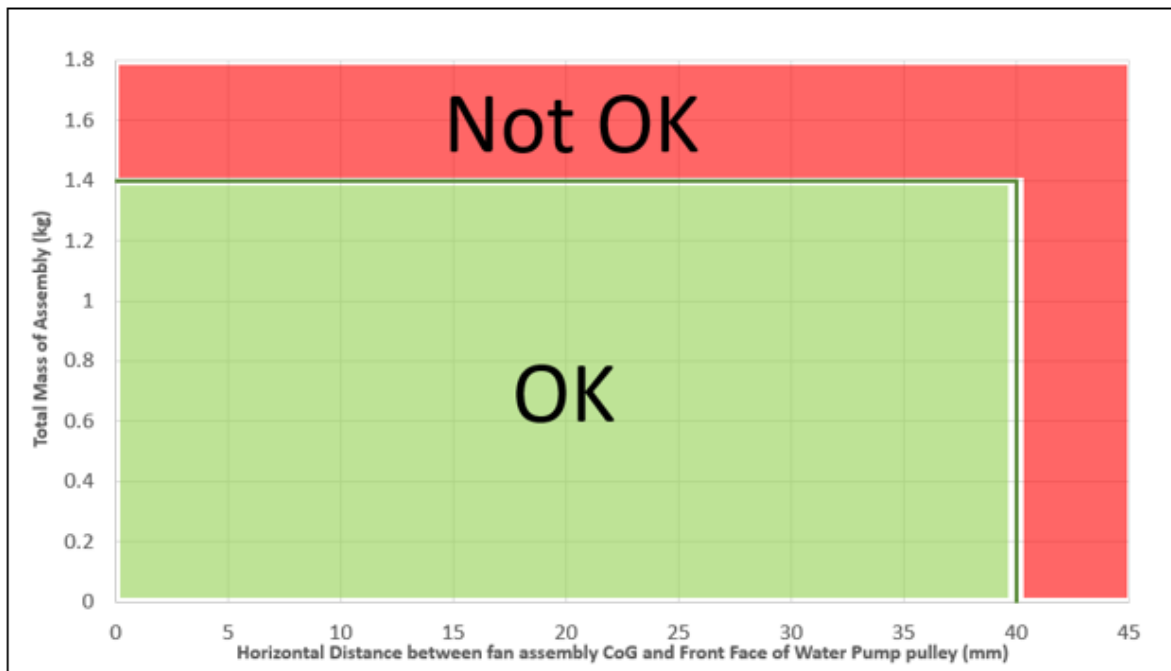


Figure 12-2- Fan Drive/Water pump load acceptability chart

- Customer supplied fan spacers should not exceed the max spacer length supplied from the factory for the relevant engine type.
- The use of all viscous fan arrangements will require additional analysis, testing and approval.
- The natural frequency of the fan drive system must be above the following limits :
 - 103Hz @2200rpm
 - 112Hz @2400rpm
 - 117Hz @2500rpm and
 - 131Hz @2800 rpm.
- The maximum simultaneous power absorption from the main drive belt must not exceed the limits specified in [12.2.1.3](#).
- Where a fan is not driven off the fan drive/water pump then a plate or spacer must be fitted to the front. This is supplied a part of the engine options offering.
- Crank mounted fans require Engine Factory approval.

12.2.2 Mandatory Installation Requirements PTO (power take off)

12.2.2.1 Gear driven (timing case) PTO

- The maximum static bending moment exerted on the timing case from auxiliary pumps and associated lines must not exceed 3Nm.
 - Where the unsupported mass exceeds the limit, it is recommended that an adequate support bracket is fitted.
 - Any bending moment in excess of this limit requires Engine Factory approval.
- The maximum torque taken off the PTO drive must not exceed the maximum limit for the duty cycle using the drive option as specified in the relevant ESM.
 - A maximum instantaneous 10% overshoot is allowed, at the point of the load being applied (not continuous).
 - For hydraulic pumps the maximum rate of pressure rise must be less than 4000bar/sec.
- Additional PTO installation, test and approval requirements must be adhered to, refer to your Application Engineer for more information.
- Any customer supplied PTO gear requires Engine Factory approval.

12.2.2.2 Rear Crankshaft PTO

Attaching large/heavy unsupported transmission components to the engine's flywheel increases the loads on the engine's crankshaft and bearings. There is a limit to the amount of mass and bending moment the crankshaft can support:

- Any rear crankshaft overhung loading must have Engine Factory approval.
- Any gear or belt driven load taken off the rear of the crank must not exceed the limits specified on the polar moment diagram in the relevant ESM.
- Any unsupported mass bolted to the crank palm (inclusive of flywheel and transmission components) must not exceed the maximum limits specified in the ESM.
- The maximum permissible rear crankshaft thrust loads must not exceed those specified in the relevant ESM.
 - This accounts for movement in both the forward and reverse direction.
- Any driven equipment taken from the rear of the crank must be within the maximum inertia limit specified in the ESM.

12.2.2.3 Front Crankshaft PTO

It is possible to take power from the front crankshaft pulley via belts, chains, etc. This type of PTO generates a bending moment on the front of the crankshaft. Excessive bending moments can cause issues excessive stresses on the crankshaft.

- Any customer PTO (axial or belt driven) from the front of the crank is not permissible from the standard crankshaft pulley. Customers must select a secondary crankshaft pulley from the option offering if this is a requirement.
- The max torque that can be taken from the secondary crank pulley must not be exceeded and is specified in the relevant ESM.
- The maximum front crankshaft overhung load must not exceed that shown on the polar moment diagram in the relevant ESM.
- The total inertia of any driven equipment taken from the front of the crank must be within the maximum inertia limit specified in the ESM.
- Engine driven accessories must be mounted so that their natural frequency is outside of that of the critical engine frequencies.
- Crank mounted fans are not approved.

12.3 Driven Equipment System Overview

FEAD Belt

There are two different main drive belts in the option offering for this engine. They are both stretchy belts, but one has a single vee and is capable of driving the smaller 85-amp alternator, fan and water pump and the other is a 5-rib Multi vee, which must be used for the larger 120amp alternator, water pump and fan. The Multi vee belt can also be used to drive the smaller alternator which has the advantage that a smaller bend radius can be achieved, and a smaller alternator pulley can be used. This means the alternator can be driven faster and a higher power output can be attained at a lower engine speed.

Accessories

Accessories such as compressors, steering pumps, etc, can be driven from various PTO positions on the engine. These positions will vary, depending on engine type, but generally accessories can be:

- Mounted on the engine, and belt driven from a PTO groove on the crankshaft pulley.
- Mounted on the back of the timing case/flywheel housing, and gear driven from the timing gears.
- Mounted on the engine frame and driven axially through a coupling from the front of the crankshaft.
- Driven directly off other equipment, e.g. from a gear driven compressor.
- Customer supplied accessories driven from the primary belt drive is not allowed on this engine.

The amount of power available from a crank driven PTO belt depends on the distance of the PTO pulley from the face of the cylinder block, and the direction of the resultant loads acting on the pulley. It will also depend on the pulley material and the type of drive from the crankshaft. Various crank pulleys are available, and some accept a 'bolt-on' PTO pulley.

12.3.1 Driven Equipment System Components

There are no driven equipment accessories offered as part of the engine option offering for this engine type.

12.4 Driven Equipment Design Considerations

It is recommended a standard configured and approved front-end arrangement be selected. If a customer specific FEAD is to be utilised analysis of the front-end drive is required to ensure that the engine components are not excessively loaded, and their durability reduced.

To aid design of any front-end arrangements the following recommendations are considered to be good practice and should be considered as a guide to help meet the requirements for approval.

The standard engine components (adaptors, pulleys, dampers, etc) must not be removed or modified without approval from the applications engineering team. A change of front-end pulley in some cases may introduce a torsional vibration problem (ref 12.4.2 Torsional Vibration). Any PTO auxiliary pulley manufactured by customers must be approved by the applications engineering team. The inertia of the customer pulley is very important as excessive inertia can cause torsional vibration issues. See the ESM for guidance on maximum permissible inertia.

12.4.1 Crankshaft Side Loadings

The allowable side loadings on the crankshaft depend on the engine type, operating speed and the machine application, please refer to the relevant ESM for these limits.

The engine can usually accept a greater side loading below the crankshaft than above. Where this is the case the belt drive should be arranged, if possible;

So that the driven equipment is below the crankshaft centre line

Where two or more belt drives are required and can be arranged in opposite directions this is

preferable to help balance the loadings.

12.4.2 Torsional Vibration

The diesel engine, plus its driven equipment (driven from either front or rear) is made up of rotating masses connected by a series of shafts. This forms a torsional mass-elastic system, which will vibrate at its own natural frequency when acted upon by an exciting torque.

A resonant condition will occur when the frequency of the exciting torque is equal to the natural frequency of the system, or one of its harmonics. This condition will result in high vibratory stress, which can lead to damage of the crankshaft or any driven shafting. It is therefore necessary to ensure that the characteristics of the total system i.e. engine and driven machinery (including front end P.T.O. if fitted) are such that excessive torsional vibration stresses will not occur.

The size and position of the P.T.O. pulley or coupling are important because of their effects on torsional vibration characteristics of the system. Crankshaft pulley loosening can result if these characteristics are not tuned to match the operating conditions of the installation.

The necessary tuning can be achieved by changing the inertia or stiffness of the system, by altering the rubber mix of a flexible coupling, or by using a special damper on the crankshaft pulley. As a general guide, all axially driven inertia should be as low as possible in order to minimise the effects of vibratory torque. Driven equipment that introduces damping into the system (e.g. hydraulic pumps) will have a beneficial effect on the torsional vibration characteristics. The use of a flexible coupling in the system will have a similar beneficial effect, and coupling manufacturers are usually able to give guidance in this respect.

12.4.3 Belts and Pulleys

The correct tension must be applied to any P.T.O. belt driving arrangement, as insufficient installation tension can cause belt slippage at high powers and high speeds, reducing belt life etc. With a P.T.O. drive from the crankshaft, excessive belt tension will result in higher side loadings than necessary, which could result in crankshaft failure.

The supplier of the fan belt/PTO belt will be able to supply the calculated belt tension, which can then be used to determine if crankshaft side loads are within the engine's limitations.

It is recommended that necessary guarding or safety provision is made to prevent human intervention to all exposed front-end drives or other rotating components. It is the responsibility of the OEM to ensure that the relevant directive and or legislation, dependant on application and operating territory is adhered to.

If a FEAD guard is deployed, then care must be taken that the design of this guard does not prevent airflow as that could result in overheating, and that it does not allow the build-up of excessive dust, dirt or water that may affect the durability of the belt.

Any customer designed/supplied pulleys should be made from aluminium or steel.

To help ensure satisfactory belt life the following should be taken into consideration:

- Standard available belt drive arrangements have been designed to withstand a continuous temperature of 85 °C.
- As a rough guide, for every 17 °C increase in ambient temperature the belt life will be reduced by 50%.
- Belt alignment also has a direct effect on the life of the belt. Misalignment can lead to a significant reduction in the belt life leading to premature failure. This must be taken into consideration when designing mounting pads for auxiliary components and during manufacture.
- Care should be taken to ensure that the minimum bend radius of the belt is not exceeded. This can be done by limiting the minimum pulley diameter.
Care should be taken to prevent the contamination of pulley grooves during storage, manufacture and operation. Problems are commonly caused by corrosion during storage and ineffective masking during over-spraying.

12.4.4 Timing Case PTO Recommendations

It is recommended that a support be provided for pumps and compressors driven from the rear - end gears to minimise the bending moment on the flywheel housing/PTO adapters and minimise misalignment of the PTO drive gear.

12.4.5 Hydraulic Pump Drive Recommendations

A wide variety of hydraulic pumps are available, with a range of flange and drive shaft connection types; commonly SAE-A or B flanges with splined or tapered shafts.

These pumps are customer supplied and fitted. It is necessary to select the correct adaptor and mating gear to suit the engine timing case and gears; please refer to the mandatory requirements.

All PTO drives must be installed and approved in accordance with the requirements detailed in the relevant installation guideline bulletin.

12.4.6 Air Compressors

Detailed below are some of the requirements and recommendations for air the installation of compressors. Where the air compressor is customer supplied, the supplier recommendations should be followed.

Engine Factory supplied Air Conditioning (AC) compressor Recommendations

A high/low pressure switch is required at the discharge side of the compressor.

This is to ensure the compressor shuts off prior to high discharge pressure relief and prevent running the compressor in low temperature conditions that do not or would not allow proper circulation of refrigerant.

The oil circulation rate in the system at low idle should be at or slightly above 3.3%.

The suction side pressure switch is typically at 5 PSIG and is there to give indication there is not enough suction pressure for proper continuous operation. If they have a system to detect low refrigerant charge would be a plus.

The compressor should be properly balanced with the cab or heat load for reliability and durability reasons. This includes examining machine operation and compressor speeds to match the heat loads.

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13.0 Noise Control

13.1 Introduction

There are no legislative noise requirements directed at the engine itself. Despite this, we recognise that it is a significant contributor to overall machine noise and as such have developed the engine to the lowest practical noise level within economic and technological constraints.

Noise reduction features are incorporated into the design of every engine and are part of the standard offering. Features designed into the engine itself include good control over piston dynamics, an optimised fuel system and good control of clearances within the gear train.

13.2 Noise Control Mandatory Requirements

There are no legislative noise requirements directed at the engine itself.

13.3 Noise Control Design Considerations

Reference should be made to the General Installation Manual for a detailed Introduction to noise, including in depth design considerations. This manual includes information on:

- The Definition of Noise (Sound Pressure and Sound Power)
- Measurement of Noise
- Calculation Methods (addition and subtraction of decibels)
- Legislation and marketing impacts
- Composition of machine Noise
- Identification of Noise Sources
- Nature of Engine Noise
- Noise Reduction Techniques including absorption, damping, stiffness, Isolation and separation
- Detail on Exhaust, Induction, Cooling, Cab and Other Sources of Noise.

It also Provides a good Noise Reduction Check List.

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14.0 Cold Weather Operation

14.1 Introduction

Diesel engines are more demanding than spark ignition engines when starting at low ambient temperatures because ignition of the fuel relies on the compression of the air.

Satisfactory starting is the ability of the engine to fire and pick up speed without damage or abuse to the engine, starting equipment or driven machinery. In order to achieve a satisfactory cold start and operate under cold weather conditions the engine and machine must be specified with the correct equipment suitable for the engine type and intended machine operation. This equipment must be correctly operated and maintained and the correct fuel and oil must be used.

Particular care must be taken in selecting and installing the relevant equipment, and the necessary information must be provided for the machine operator.

The following chapter details the mandatory requirements and aspects that need to be taken into consideration when operating a machine in low ambient conditions. It has been written to complement but not change the other installation requirements and recommendations within this manual. Further details can be found in chapter 11 of this manual, the Electrical and Electronic Application and Installation Manual, the Starting and Charging document, the relevant engine specification manual (ESM) and also in the OMM.

14.2 Cold Weather Operation Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of nonroad equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

14.2.1 General

- In order to achieve satisfactory cold start performance:
 - The engine must be operated with the correct fuel and oil for the machine operating temperature (ref OMM)
 - The engine must be equipped and operated with the necessary cold start aids for the machine operating temperature.
- To achieve satisfactory starting with either Engine Factory or OEM supplied rotating electrics and glow plugs fitted as standard, the following conditions must be achieved at the lowest ambient temperature that the machine is expected to operate:
 - Minimum cranking speed over TDC > 60rpm.
 - The minimum mean cranking speed must be > 100 rpm.
- Cold start testing should be conducted on all machines.
- Where fitted, glow plugs must be connected to improve starting, run up and smoke characteristics.
- For temperatures of -25°C or below the breather gas must be protected from freezing refer to chapter 10.0 Crankcase Ventilation Systems.
- The use of Ether is not permitted.

14.3 Cold Start Components

14.3.1 Auxiliary cold start aids

Starting aids are required for the engine to start satisfactorily below a certain ambient temperature. Unaided starting limits are given in the E.S.M and it can be seen that the limiting minimum ambient temperature varies according to engine specification; electric starting equipment and the engine lubricating oil viscosity.

Both 3 and 4-cylinder engines are supplied with glow-plugs as a standard factory fit. Other starting aids can be used in addition to this for more extreme operating ambient conditions.

14.3.2 Glow Plugs

The glow plug is a device, which protrudes into the combustion chamber of each cylinder, and, when activated, has a high temperature that ignites the fuel/air mixture. Precise tip protrusion is required to enable the sprayed fuel to be properly ignited during cranking, without causing a significant drop of combustion efficiency during engine running. As glow plugs enable the engine to start instantaneously, no other starting aid is necessary down to minus-25°C and below. Due to their high current draw a suitable relay must be used to actuate glow plugs. Activation of the glow-plugs is controlled by the ECM, which monitors the coolant and air inlet temperature and decides whether the glow plugs are required. The exact control strategy for glow plug control can be found in the Electrical and Electronic Applications and Installation manual.

14.3.3 Heated Breather

Refer to Chapter [10.0 Crankcase Breathing](#).

A heated breather is supplied to the closed crankcase breather hose as standard, for operation in cold ambient temperatures from -25° to -32°. If operation is required below -32° then a cold weather service kit will be required to provide additional protection such as insulation to the breather hose.

14.3.4 Block heaters

Block /Jacket Water Heaters are electrical heaters that maintain the jacket water at a temperature high enough to allow easy starting of the engine. Heaters pre-condition engines for quick starting and minimize the high wear of rough combustion, by maintaining the coolant temperature during shutdown periods. Heaters thermostatically control jacket water temperature near 30°C to 50°C to promote fast starts. Higher temperatures accelerate aging of gaskets and rubber material.

When using a block heater, it is essential that the unit selected is compatible with the engine. Due to tight internal clearances in the water jacket care must be taken to ensure that the element does not touch the internal walls of the casting, cause damage to the bore and result in sub sequential leaks.

For the 4-cylinder engine the block heater can be fitted in:

- The middle D plug ports on the LHS of the engine block.
 - Care must be taken that the heater does not foul on the internal walls
- The block drain on the RHS of engine.

For the 3-cylinder engine the block heater can be fitted in:

- The block drain on the RHS of engine ONLY
- The D plug ports on the LHS of the engine is not suitable due to accessibility with the EGR cooler hose.

Detail of the different block heater types and the ports are shown in Figure 14-1 and Figure 14-2.

There is no block heater in the engine offering and no specific supplier recommendations can be made. Please follow up with your Applications Engineer for recommendations on components.

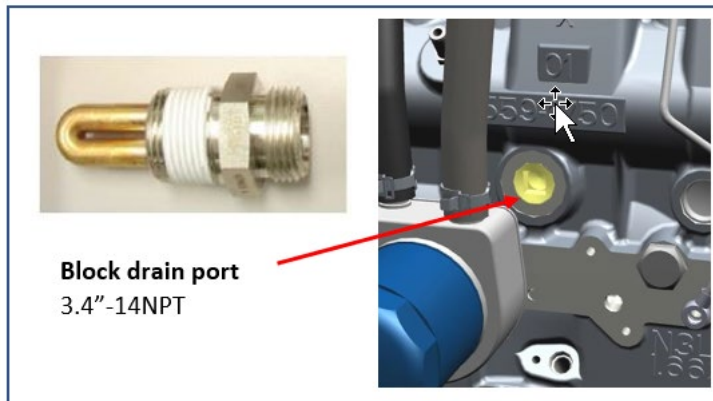


Figure 14-1 - Block Heater - Block Drain Port

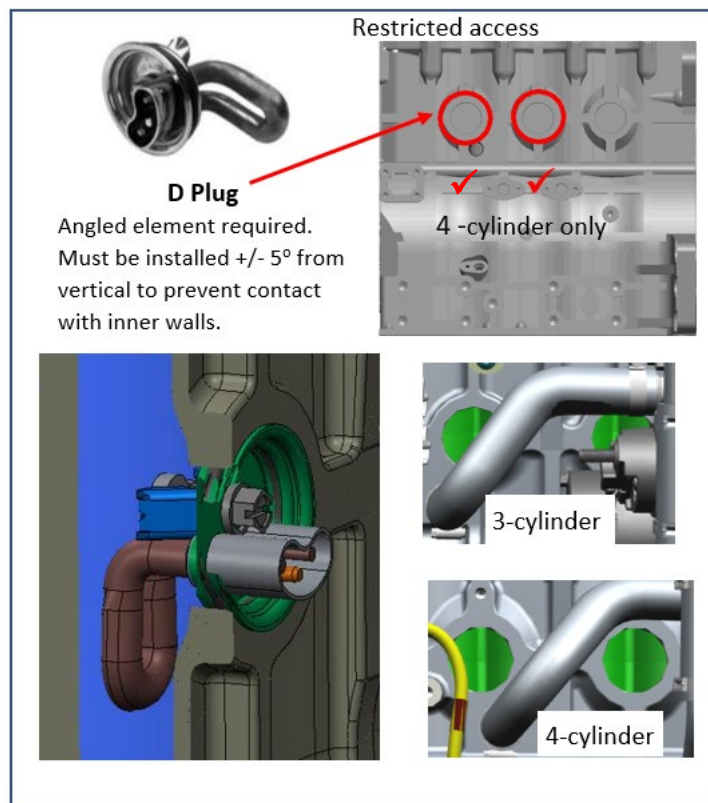


Figure 14-2 - Block Heater – Typical Examples

14.3.5 Elevated Idle

For all applications wishing to operate at low idle for long periods of time at an ambient below - 25°C a thermal management process is required to elevate the exhaust temperature and allow correct operation of the aftertreatment system. This is done by elevating the low idle setting to a fixed speed at level 1 then increasing the idle again at level 2, if required.

The configured elevated idle speed must be tested and validated to ensure sufficient temperature can be generated with the machine parasitic load at the lowest desired machine cold ambient. This must be tested in accordance with the relevant engine exhaust temp test procedure.

For further information and details of the wiring, operation and control of this feature refer to the Electrical and Electronic Application and Installation Manual.

14.4 Cold Start Design Considerations

The General Installation Manual contains detailed information on the use of Machines in cold weather and the appropriate precautions and design considerations that need to be made as a consequence. This includes information on:

- Cold Starting Requirements
- Starting Equipment
- Starting Aids
- Installation Requirements
- Extremely Low Temperatures and
- Testing requirements.

Other appropriate information containing relevant information on this subject include:

- The ESM
- The Electronic Application and Installation Manual
- Starting and Charging Manual and
- The OMM for appropriate fluids.

15.0 Production and Manufacturing

15.1 Introduction

The purpose of the Production and Manufacturing chapter is to provide awareness, at the machine design stage, of some of the considerations that need to be made and adhered to when installing these engines in the production facility.

Additional Production and Manufacturing requirements can be found detailed in the CAR (Customer Assembly requirement) document. Please contact your Application or Product Support representative for more information.

15.2 Production and Manufacturing Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

- EM** The Engine must be assembled in accordance with the requirements detailed in the Customer Assembly Requirements document (CAR).
- EM** The correct fluids must be used in the engine refer to the relevant engine OMM for details.
- EM** At no point within the production process should the engine, aftertreatment and electrical connectors exceed the maximum temperature limits of the individual components detailed in Appendix D 'UHT and DEF test Acceptance Criteria and UHT Gauge map' in the relevant engine test procedure document.
- EM** For remote mounted aftertreatment the flexible exhaust Installation kit must be assembled following the correct procedure detailed in the Customer Assembly Requirements (CAR) document.
- EM** It is not permitted to modify, tamper or affix anything to the supplied emissions critical components during the manufacturing or assembly process.
 - The ELP should be not be electrically connected until the machine has been filled with fuel this is to prevent the ELP from being operated dry.
- EM** If electrostatic paint spraying is used the engine must be specially prepared. Refer to the Electronic Application and Installation Manual.
- EM** Painting of the aftertreatment, flexible installation kit and any associated electronic components is prohibited.
- EM** If any over spraying of the engine is required, then the engine must be correctly masked please contact your Application Engineer for further information.
 - Masking requirements include the waste gate and the oil mist separator (to prevent blocking of vent holes).

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16.0 Installation and Audit Testing

16.1 Introduction

Application and Installation Test Procedures are available for all engine ranges. The test procedure document details the specific tests required for each engine type, a recommended order of test, the test method, instrumentation required, gauge maps where necessary and sign off criteria. Some of the sign off criteria is rating specific and this information is therefore held within the ESM.

16.2 Installation and Audit Testing Mandatory Requirements

All Emission Related Installation Instructions are highlighted by the **EM** symbol.

'Failing to follow these instructions when installing a certified engine in a piece of non-road equipment violates federal law (40 CFR 1068.105(b)), subject to fines or other penalties as described in the Clean Air Act.'

- Application audit testing must be conducted on all engine installations in accordance with the Application Engineering Policy.
- Testing must be conducted in accordance with the latest test procedure document.

16.3 Application and Installation Test Procedures (AITP)

16.3.1 Test Procedure Purposes

AITP 01 - Air Inlet Restriction Test

- To establish (with a clean air filter element) that the certified restriction of the air system at turbo inlet is not exceeded at a full load rated speed (or maximum load that the machine is capable of applying).

AITP 02 - Charge Cooler Restriction Test

- To establish that the customer air charge cooler and associated pipe work do not exceed the certified limit at a full load rated speed (or maximum load that the machine is capable of applying).

AITP 03 - Charge Cooler Efficiency Test

- To establish that the customer air charge cooler and cooling fan have sufficient capacity to reduce the temperature of the charge air to the certified limit and ambient at a full load rated speed (or maximum load that the machine is capable of applying).

AITP 04 - Jacket Water Cooling Test

- To establish that the customers jacket water cooler and cooling fan has sufficient capacity to limit the temperature of the jacket water to the Top Tank limit at a maximum ambient of 48°C (Worldwide clearance) The test cycle used to establish this must reflect the worst case for the specific machine.
- To establish that the oil temperature at the main gallery does not exceed the limit at a maximum ambient of 48°C (Worldwide clearance). The test cycle used to establish this must reflect the worst case for the specific machine and may be a different cycle to point 1 above.

AITP 05 - Cooling Fill Rate Test

- To establish that the cooling system can be filled at a minimum, continuous, rate of 5 L/Min.
- To establish that the cooling system vents air satisfactorily.

AITP 06 - De-aeration and Hot Shut down Test

- To establish that the cooling system is capable of withstanding repeated hot shut downs without expelling excessive amounts of coolant.
- To establish that the cooling system vents air satisfactorily.
- To establish that under hood temperatures during repeated hot shutdowns will not cause component failures due to excessive heat.

AITP 07 - Exhaust Back Pressure Test

- To establish that the customers exhaust system and associated pipe work do not exceed the certified back pressure limit at a full load rated speed (or maximum load that the machine is capable of applying).
- To establish that the parasitic load of the machine is sufficient to enable passive regeneration.

AITP 08 - Starter Circuit Resistance Test

- To establish that the customers starter motor wiring does not exceed the starter motor manufacturers resistance limit.

AITP 09 - Installed Cold Start Test

- To establish that the machine starts and runs up in line with the Product Objectives (Engine Manufacturer and Customer agreed Objectives).

AITP 10 - Auxiliary Regen Device Test

NOT APPLICABLE FOR THIS ENGINE RANGE

AITP 11a Low Pressure Fuel System Pressure tests

- To establish that the customers low-pressure fuel system does not exceed the Engine inlet restriction limit(s).
- To establish that the customers low-pressure fuel system does not exceed the Engine return pressure limit.

AITP 11b Low Pressure Fuel System Temperature tests

- To establish that the fuel inlet temperature(s) does not exceed the limit for the Fuel pump.

AITP 12- Air in let Temperature Offset Test

NOT APPLICABLE FOR THIS ENGINE RANGE

AITP 13- Under Hood Thermal Test

- To ensure that critical and sensitive engine and aftertreatment components are not subject to excessive temperatures during worse case machine operation and hot shutdown conditions, which may lead to deterioration in the performance, life and premature component failure.

AITP 14- Remote Oil Filter Test

Dependent on Application

- To establish the acceptability of a customer installed remote oil filter.

AITP 15- Front PTO load Demand Test

Dependent on Application.

AITP 16- DEF Temperature Test

NOT APPLICABLE FOR THIS ENGINE RANGE.

AITP 17- Vibration Test

To Ensure that critical DEF, aftertreatment system components and Engine ECM are not subject to excessive vibration levels during machine operation, which may lead to premature component failure.

AITP 19(A/B) – Exhaust temperature drop test

To ensure that the maximum permissible temperature drop between the engine and aftertreatment is not exceeded during any machine operating cycle and, to ensure that the selected elevated idle speed generates sufficient temperature at the aftertreatment inlet, in the lowest required cold ambient operating condition for the machine.

AITP 21 Alternator Load Balance

Electrical Test Refer to Electrical and Electronic Test Procedure Document.

AITP 22-ECM Circuit Resistance Test

Electrical Test Refer to Electrical and Electronic Test Procedure Document.

AITP 23 Engine Circuit and Injector Resistance Test

Electrical Test Refer to Electrical and Electronic Test Procedure Document.

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17.0 Record of Amendment

Version	Description	Section	Date
Prod issue 2	Updated air cleaner efficiency mandatory	<u>4.2.1</u>	Feb 21
Prod issue 2	Charge air outlet temperature mandatory changed to include a ROA for the min temperatures above and below 25degrees ambient. New bullet included for ratings with higher maximum temperature and bullet added for machines that can't reach FLRS point.	<u>6.3.1</u>	Feb 21
Prod issue 2	Removed ATAAC pipe burst and temp limit.	<u>6.3.2</u>	Feb 21
Prod issue 2	Updated Hose spec requirements for remote oil filter.	<u>9.2.2</u>	Feb 21
Issue 03	Changed Front Cover contents and added Back Cover.	n/a	Sept 21
Issue 03	Changed Issue number to have "E" in front for English issue number.	n/a	Sept 21
Issue 03	Added "and for GB ..." text to heading.	<u>1.3.1</u>	Sept 21
Issue 03	Added requirement that engine must never be submerged.	<u>3.2.1</u>	Sept 21
Issue 03	Removed Table 6.1 from section 6.2.1 and referred to ESM	<u>6.2.1</u>	Sept 21
Issue 03	Changed 6mm dia. to 8mm in Figure.	<u>8.4.5</u>	Sept 21
Issue 03	Updated X-refs in this Section.	<u>8.4.6</u>	Sept 21
Issue 03	Change text to state that the breather heater is supplied fitted and is not an option.	<u>10.5.1</u>	Sept 21
Issue 03	Added sentence for mounting flatness tolerance.	<u>11.2.2</u>	Sept 21
Issue 03	Earth strap guidance modified	<u>11.4.1</u>	Sept 21
Issue 04	Changed all references to Electric Transfer Pump (ETP) to Electric Lift Pump (ELP)	<u>n/a</u>	Feb 22
Issue 04	Changed reference from SEBU6251 standard to Perkins Diesel Engines Fluids Guide M0113102.	<u>8.2.2</u>	Feb 22
Issue 04	Changed reference from SEBU6251 standard to Perkins Diesel Engines Fluids Guide M0113102.	<u>8.2.3</u>	Feb 22
05	Added paragraph stating that for a remote oil fill system the oil specification for the engine must be clearly visible near the oil supply.	<u>2.2.3</u>	Apr 22
05	Added paragraph stating that for a remote oil fill system the oil specification for the engine must be clearly visible near the oil supply.	<u>9.2.1</u>	Apr 22
06	Amendments to Crankcase ventilation General requirements	<u>10.2.1</u>	Feb 23
06	Additional wording included for CCV	<u>10.3</u>	Feb 23
06	Section 4.4.1, wording added to for OCV/CCV requirements	<u>4.4.1</u>	Feb 23
06	Add thread sizes to remote oil filter section	<u>9.2.2</u>	Feb 23
07	Adjusted wording in "Cold Start Components – Block Heaters"	<u>14.3.4</u>	Feb 23
07	Adjusted "Fuel System Limits" table on limits matching to other manuals	<u>8.3.2</u>	Feb 23
07	Amended Customer Supplied Pipe Tolerances to +/- .25	<u>5.5.3</u>	Apr 23
08	Amended Fuel System Limits Table	<u>8.3.2</u>	May 23

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