NEF SERIES

AUTOMOTIVE ENGINES
INTRODUCTION
We would like to thank you for buying an FPT product, and compliment you on your choice of engine. Before you carry out any operation involving the engine or its fittings, please read the contents of this manual carefully; compliance with the instructions provided in the manual is the best way to guarantee trouble-free, long term operation of the engine.

The contents of this manual refer to the standard configuration of the engine, and the illustrations are purely indicative. Some instructions are provided by giving the sequence of operations to be carried out in order to allow the engine and/or its fittings to perform in a certain way. In some cases they will be dependent on the configuration of the commands and the set-up of the machine on which the engine is installed; for any points that differ from the contents of this manual, please consult the instructions provided by the machine Manufacturer or a specific manual.

The information provided below was current at the date of publication. The Manufacturer reserves the right to make modifications at any time without prior notice, for technical or commercial reasons or to update the engines to comply with legal requirements in the various Countries. The Manufacturer declines all liability for any errors or omissions.

Please remember that the FPT Technical Service Network is available to offer you its experience and professional skills, wherever you may be.
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**GENERAL INFORMATION**

**GUARANTEE**
In order to ensure that your engine gives the best possible performance and to take advantage of the FPT warranty, you must follow the indications provided in this publication with great care; failure to do so may result in invalidation of the warranty.

**SPARE PARTS**
Always use Original FPT Spare parts. This is essential to keep the engine in original running order.
The use of non-original spare parts will not only invalidate the guarantee, but will mean that FPT will not be considered liable in any way during the whole working life of the engine.

**LIABILITY**
The Manufacturer will only be considered liable subject to performance of the control and maintenance operations indicated and described in this manual; to this effect, proof that these operations have been performed must be provided. Any special maintenance operations that may be necessary must be carried out by qualified technicians from Workshops in the FPT Network, using the instruments and equipment provided for the purpose.

**SAFETY**
The following information is intended to encourage caution when using the engine, so as to avoid damage to persons or property as a result of improper or incorrect behaviour.

- The engines must only be used for the purposes indicated by the Manufacturer.
- Any tampering, modification and use of non-original spare parts may compromise proper operation and safe use of the engine; **never, under any circumstances** make modifications to the wiring and to the units equipping the engine, or connect them to other power systems.
- Pay particular attention to moving parts of the engine, to high temperature components and to circuits containing pressurised fluids; its electrical equipment houses electrical currents and voltage.
- The exhaust fumes produced by the engine are bad for your health.
- The engine must be handled using suitable lifting tackle, making use of the U-bolts provided on the engine for that purpose.
- The engine must not be started up and used until the machine in which it installed has satisfied all necessary safety requirements, or until the machine has been guaranteed to comply with local laws and regulations.
- The operations required to guarantee the best possible use and preservation of the engine must only be carried out by persons of proven experience, equipment with tools considered suitable by FPT.

For the purpose of safety, further recommendations are given in the CONTROLS AND MAINTENANCE chapter.
SAFETY WARNING SYMBOLS
You will find these symbols on the following pages; follow the instructions to which they refer, for your own safety and that of your engine.

**Risk of injury:** failure to comply with these instructions can result in the risk of serious injury.

**Risk of serious damage to the engine:** the partial or total non-observance of these instructions could cause serious damage to the engine and may nullify the warranty.

**General risk:** combines the risks of both the signs described above.

**Safeguarding the environment:** indicates the correct behaviour so that vehicle use is as environmentally friendly as possible.
ENGINE TECHNICAL DATA

The technical code and serial number are indicated on a plate, which is located on different parts of the engine, according to the model: flywheel casing, tappet cover, other.

<table>
<thead>
<tr>
<th>Code</th>
<th>N45 ENT 6 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine family</td>
<td>F4</td>
</tr>
<tr>
<td>Cycle</td>
<td>4-stroke diesel</td>
</tr>
<tr>
<td>Number and arrangement of cylinders</td>
<td>4, in line</td>
</tr>
<tr>
<td>Bore x stroke</td>
<td>104 x 132 mm</td>
</tr>
<tr>
<td>Total displacement</td>
<td>4,485 cm³</td>
</tr>
<tr>
<td>Air system</td>
<td>Turbocharged with intercooler</td>
</tr>
<tr>
<td>Injection type</td>
<td>Direct - high pressure pump supply and common rail system</td>
</tr>
<tr>
<td>Engine direction of rotation</td>
<td>Anticlockwise (seen from flywheel side)</td>
</tr>
<tr>
<td>Dry weight</td>
<td>~ 400</td>
</tr>
</tbody>
</table>

Electrical system | 24 V |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternator</td>
<td>90 A</td>
</tr>
<tr>
<td>Starter electric motor</td>
<td>4 kW</td>
</tr>
</tbody>
</table>

Accumulator's
- capacity
  - Max. 110 Ah - min. 44 Ah
- discharge current (EN 50342)
  - Max. 765 A - min. 357 A

The technical data for the electrical system and the relative maintenance checks are not the responsibility of FPT (Engine Supplier) but of the customer.

Performance (*)

<table>
<thead>
<tr>
<th>N45 ENT 6 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>F4AFE411A*C005</td>
</tr>
<tr>
<td>118 kW (158 hp) @ 2,500 rpm</td>
</tr>
<tr>
<td>580 Nm (59.14 Kgm) @ 1,250 rpm</td>
</tr>
<tr>
<td>F4AFE411C*C026</td>
</tr>
<tr>
<td>152 kW (204 hp) @ 2,500 rpm</td>
</tr>
<tr>
<td>750 Nm (76.47 Kgm) @ 1,250 rpm</td>
</tr>
</tbody>
</table>

(*) Flywheel net performance compliant with ISO 3046-1 standard.
Testing conditions: T 25°C; atmospheric pressure 100 kPa; relative humidity 30%.

It is severely prohibited, under penalty of cancellation of the warranty and of the responsibilities of FPT, to change the characteristics indicated above.

**F4AFE411A*C005 - F4AFE411C*C026**


**F4AFE411A*C005 - F4AFE411C*C026**

SIGNS
Certain warning signs are affixed to the engine by the Manufacturer, and their meanings are indicated below.

NOTE: The signs with an exclamation mark on them underline a potential danger.

Lifting point (engine only).

Fuel Cap (on the fuel tank, if there is one).

Oil Cap.

Oil dipstick.

Danger of burning: Expulsion of hot water under pressure.

Danger of burning: Presence of high temperature parts.

Danger of fire: Fuel present.

Danger of impact or catching on moving parts: Presence of fans, pulleys, belts or the like.
### USE

#### PRELIMINARY CHECKS

Before each engine start-up:

- Check and refill technical fluids level if necessary (fuel, engine oil and coolant).
- Make sure that the air aspiration filter is not clogged or obstructed. If the engine is equipped with an electrical blockage sensor, an alarm will be displayed on start-up by means of the indicator light on the instrument panel.
- Make sure that the start batteries are efficient and relative clamps are correctly connected.

**NOTE:** The current document refers only to the engine configuration and does not contain any explanation related to the components installed on the vehicle. Refer to the corresponding documentation of the manufacturer for any information about those components.

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### STARTING AND STOPPING THE ENGINE

The start-up and shut-down operations described below are applicable if is available on-board a key switch that is peculiar to automotive application; if the Manufacturer of the vehicle or machine has fitted a customized instrument panel, these operations may vary according to the various choices made during manufacturing. In these cases, follow the start-up/shut-down sequences and use the instrument panel description provided in the specific documentation.

#### Starting the engine

1. Insert the key into the switch and turn it to the right to position RUN. Once the indicator lights have been tested, check the plausibility of the indications on the dashboard.
2. Turn the key to position START and release it once the engine has started, without accelerating.
3. In the event that the efficiency indicators such as the “Accumulator recharge” or “Oil pressure” are available on the on-board equipment, check that the operation status is appropriate. If the preheating system is enabled, the relevant indicator will turn on again to indicate that the post-heating phase is in progress; the duration of this function is proportional to the temperature value.
4. If the engine does not start, after releasing the key it will only be possible to turn it back to the start position after first returning the switch to the rest position.

#### Stopping the engine

Before stopping the engine it is recommended to keep it running at idle and unloaded for a few minutes; this will allow a uniform decrease of temperature and avoid harmful thermal shocks.
Shutting down the engine:
- Turn the key switch to position REST.

Restarting the engine:
1. Return the key switch from the position REST to position RUN only after a few minutes.
2. Turn the key to position START and release it once the engine has started, without accelerating.
3. Proceed as described previously.

Starting the engine at low temperatures
The electrical device - managed by the Electronic Control Unit controlling the engine - for the preheating of the inducted air is used to assist the starting of the engine at low temperatures. In the event that the starting of the engine is not requested anymore after the key has been turned on the position RUN, the device will be disabled while the relevant indicator light is blinking. Proceed to the next starting repeating the sequence beginning with the key on the position REST.

EDC indicator light - Electronic Diesel Control
In the event that, after the starting phase, the EDC indicator light is on, contact the Technical Service Network asking for instructions. The anomaly state - detected by the electronic unit managing the engine - may allow the vehicle to reach the Technical Service Centre (for more information see the ENGINE MALFUNCTIONS section).

CAUTION!

In the event of momentary stoppage of the engine, check for any alarm signals. Do not restart the engine until the cause of the problem has been removed or proper operating conditions have been restored.
FOR PROPER USE OF THE ENGINE

- Do not leave the key turned to the START position, when the engine has been started.
- It is not efficient to leave the engine running at idle while waiting for it to reach the proper working temperature; it is preferable that, after approximately one minute from start-up, the engine load should be increased gradually.
- Do not leave the engine running at minimum speed for a longtime as this does not guarantee a smooth engine operation.
- The engine speed must be increased and decreased gradually, to allow a proper operation of all engine components.
- The running speed and power values must comply with the specifications of the technical and commercial documentation.

During use, check that:
- The engine coolant temperature does not reach the alarm threshold.
- The oil pressure remains within normal values.

Pay attention to the board panel instrument readings and indications.

SPECIAL WARNINGS

Coolant circuit

When the engine is running, regularly check that the engine coolant temperature does not reach the alarm threshold. In case the temperature detected is excessive, disconnect the load and stop the engine to check the cooling circuit status.

Pay attention to the board panel instrument readings and indications.

CAUTION!

When the engine is hot, pressure builds up in the cooling circuits which may eject hot liquid violently, resulting in a risk of burns. Open the filler cap of the coolant tank only when the engine is cold.

If the temperature is considered too high, reduce speed and stop to check the state of the cooling system circuits.
Check the following:
- the tension of the auxiliary member drive belt;
- the thermostatic valve’s efficiency;
- the conditions of the heat exchanger (to be cleaned if necessary).
**Lubrication circuit**

Regularly check that the oil pressure keeps within normal values. In case the value detected is too low, check the oil level and refill if necessary following the instructions reported in the CONTROLS AND MAINTENANCE section.

If the condition persists, contact the Service Centre.

**Fuel circuit**

Avoid using the engine with small reserve of fuel in the fuel tank. Thus the vapour condensation is encouraged and makes the engine more likely to suck up dirt or air, resulting in engine stoppage.

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**CAUTION!**

While refuelling, always pay attention to ensure that no solid or liquid pollutants enter the fuel tank; remember that smoking and live flames are prohibited during refuelling.

**CAUTION!**

Never loose the high pressure fuel circuit connectors in any way.

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**Air intake and exhaust gas circuits**

Inspect the cleanliness of the air intake circuit on a regular basis. The maintenance intervals indicated in this manual vary according to the conditions in which the engine is operated.

In particular dusty environments it is necessary to carry out maintenance within more frequent intervals than indicated in the CONTROLS AND MAINTENANCE chapter.

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**CAUTION!**

Visually check that the exhaust circuit is not obstructed or damaged to prevent noxious and harmful fumes inside the ducts.

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**ATS system**

This system is used to maintain the nitrogen oxide (NO\textsubscript{x}) emissions in the exhaust within the limits required by standards, transforming the nitrogen oxide into inert compounds: nitrogen (N\textsubscript{2}) and water vapour (H\textsubscript{2}O). Periodically clean the filters at the intervals indicated in the CONTROLS AND MAINTENANCE chapter.
**Electric starter system**

Check periodically the cleanliness and efficiency of the batteries, particularly during winter, as indicated in the CONTROLS AND MAINTENANCE chapter. Top up if necessary. In the event of battery replacement, observe the characteristics contained in the ENGINE TECHNICAL DATA section.

Contact a specialised workshop and check battery and recharging system efficiency if the voltmeter indicates a voltage below 11 V (for 12 V rated systems), or 22 V (for 24 V rated systems).

The batteries contain an acid solution that will burn the skin and corrode clothing; when checking them, always wear protective clothing, gloves and goggles, do not smoke or use live flames in the vicinity, and make sure that the room they are housed in is adequately ventilated.

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**RUN-IN**

Thanks to modern engine design technology, no particular run-in procedure is required. However, for the first 50 hours, it is not recommended to operate the engine at high power for long periods. To guarantee high performance during the engine life cycle, during the first 50 hours of use it has been prescribed to:

- keep the engine at average speed during the first minutes after engine start without using the power take-off components in order to reach optimal operating condition.
- do not run the engine at maximum power for a continuous period of 2 hours.
- do not exceed 1,900 rpm.
- let the engine rest every 30 minutes by momentarily lifting the accelerator pedal.
- do not idle the engine for long periods.
CONTROLS AND MAINTENANCE

MAINTENANCE PERSONNEL
The engine control and maintenance operations described in the following chapter require training, experience and compliance with current safety regulations. For this reason, the following operations must be carried out by special technicians.

- **Checks during the period of use**: by workshop technicians or the engine user if necessary.
- **Periodic maintenance**: by qualified personnel using suitable equipment and adequate means of protection.
- **Special maintenance**: by qualified personnel from Authorised Service Centres who have detailed technical information and specific equipment.

The most qualified Assistance Centres are those which make up the FPT Technical Assistance Network.

ACCIDENT PREVENTION
- Always wear heavy-duty footwear and overalls.
- Never wear loose, flapping garments, rings, bracelets and/or necklaces close to engines or moving parts.
- Always wear protective gloves and goggles when:
  - filling up batteries with acid solution
  - check cleanliness of battery clamps and terminals
  - refilling with inhibitors or antifreeze
  - replacing or topping up lubricant (hot engine oil may cause burns and scalds. Only carry out these operations when the oil has dropped to a temperature of below 50°C).
- While working in the engine compartment, pay particular attention on movements, to avoid contact with moving parts and high temperature components.
- Wear safety goggles while using compressed air jets. Maximum air pressure used to clean is 200 kPa (2 bar, 30 psi, 2 kg/cm²).
- Wear a protective helmet when working in an area were there are suspended loads or systems installed at/above head-height.
- Use protective hand creams.
- Replace wet overalls immediately.
- Always keep the engine clean removing oil, fuel and coolant stains.
- Store cloths in flame-proof containers.
- Do not leave external objects on the engine.
- Use suitable, safe containers for used oil.
- Once the repair activities are completed, take the necessary steps to stop engine air suction in case of uncontrolled increase in engine speed after start-up.

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Do not carry out maintenance operations when the electric power supply is turned on: always check to ensure that the appliances are properly earthed. During diagnosis and maintenance operations, make sure that your hands and feet are dry, and whenever possible use insulating stands.
## REFILLING

<table>
<thead>
<tr>
<th>Parts to be supplied</th>
<th>N45 ENT 6 W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>litres (kg)</td>
</tr>
<tr>
<td>Cooling circuit (1)</td>
<td>8</td>
</tr>
<tr>
<td>Lubrication circuit (2)</td>
<td></td>
</tr>
<tr>
<td>total capacity (3)</td>
<td>13.5 (12.2)</td>
</tr>
<tr>
<td>Periodic replacement</td>
<td></td>
</tr>
<tr>
<td>Oil sump at minimum level</td>
<td>9 (8.1)</td>
</tr>
<tr>
<td>Oil sump at maximum level</td>
<td>12 (10.8)</td>
</tr>
<tr>
<td>Fuel tank (4)</td>
<td>Defined by vehicle</td>
</tr>
<tr>
<td>Urea tank (5)</td>
<td>Defined by vehicle</td>
</tr>
<tr>
<td>Power steering oil (6)</td>
<td>-</td>
</tr>
</tbody>
</table>

(1) The quantities indicated only relate to the engine in its standard configuration. Use a 50% mixture of water and PARAFLU HT even during the summer months. As an alternative to PARAFLU HT, use another product that complies with FPI9.COOL002 or CNH MAT 3624 or SAE J1034 specifications.

(2) Only use lubricants which meet the international standards API CJ-4 / ACEA E9-E6. Recommended oil is SAE 10W-40 or 5W-30 meeting FPI9.LUBR001 or CNH MAT 3521. The oil used is considered to be acceptable until a quantity equalling 0.15% of fuel consumption is reached.

(3) The quantities indicated relate to the first refill only and are relative to the engine, oil sump and filter filling.

(4) Not supplied by FPT. Use STANDARD fuel compliant to the EN 590. Instructions connected to the fuel tank capacity are the responsibility of the FITTER since these are subject to changes depending on the various vehicle configurations.

(5) Only use AdBlue®/DEF in accordance with ISO 22241 specification.

(6) It is recommended the use of Tutela GI/A or product complying with the ATF DEXRON IID standard.
Coolant refilling
For the initial engine start-up and in the cases in which the refilling of the cooling circuit is required with a considerable quantity of coolant, proceed as follows:
- Refill the engine and the exchanger until the exchanger is completely filled.
- With the coolant filler plug open, start the engine and let it idle for approx. 1 minute. This helps to completely bleed the air contained in the cooling circuit.
- Stop the engine and then top up with coolant if necessary.

Refuelling
Use only diesel oil in accordance with EN 590 standard normally commercially available. Fuel additives are not recommended. Use of additives can limit the guarantee performance offered for the vehicle.

CAUTION!
When the engine is hot, pressure builds up in the cooling circuits which may eject hot liquid violently, resulting in a risk of burns. Open the filler cap of the coolant tank only if necessary and only when the engine is cold.

CAUTION!
The failure to observe the aforesaid procedure does not guarantee the presence of the correct quantity of coolant in the engine.

Low temperature diesel
At low temperatures the degree of fluidity of the diesel can become low due to the separation of the paraffin resulting in the filters becoming clogged. EN590 specifications distinguish different classes of diesel fuel, identifying the characteristics of those best suited to low temperatures. It is entirely up to the Oil companies to comply with these regulations, which foresee that fuels suited to the climatic and geographic conditions of the various Countries be distributed.
**INTERVALS**

The intervals indicated below take into account the factors of use, typical of various types of engine, always observe scrupulously the prescriptions in order to preserve the best engine efficiency.

<table>
<thead>
<tr>
<th>Checks</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual inspection of engine</td>
<td>50 hours</td>
</tr>
<tr>
<td>Check engine lubricant oil level</td>
<td>Daily</td>
</tr>
<tr>
<td>Check engine coolant level</td>
<td>Daily</td>
</tr>
<tr>
<td>Drain water from the fuel pre-filter (*)</td>
<td>150 hours (1)</td>
</tr>
<tr>
<td>Check/top up electrolyte level in batteries (*)</td>
<td>Defined by vehicle</td>
</tr>
<tr>
<td>Check auxiliary members' belt condition</td>
<td>600 hours</td>
</tr>
<tr>
<td>Check the condition of the exhaust duct(s)</td>
<td>6 months</td>
</tr>
<tr>
<td>Check coolant density</td>
<td>1 year</td>
</tr>
<tr>
<td>Engine EDC system check-up by diagnostic tool</td>
<td>Only in case of anomaly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Periodic maintenance</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change engine lubricant oil</td>
<td>600 hours (2) (3)</td>
</tr>
</tbody>
</table>

(*) Not supplied by FPT.

(**) Early air filter clogging is usually due to environmental conditions. For this reason, the filter should be changed if clogging is signalled by the related sensor, regardless of the prescriptions that shall be observed if no specific indications have been provided.

<table>
<thead>
<tr>
<th>Periodic maintenance</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change oil filter</td>
<td>600 hours (2) (3)</td>
</tr>
<tr>
<td>Change fuel filter</td>
<td>600 hours (1) (4)</td>
</tr>
<tr>
<td>Change fuel pre-filter (*)</td>
<td>600 hours (1)</td>
</tr>
<tr>
<td>Change blow-by filter</td>
<td>1.200 hours</td>
</tr>
<tr>
<td>Change air filter and clean housing (*) (**)</td>
<td>1.200 hours</td>
</tr>
<tr>
<td>Clean the air filter (*)</td>
<td>600 hours</td>
</tr>
<tr>
<td>Change engine coolant</td>
<td>2 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extraordinary maintenance</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbocharger visual inspection</td>
<td>1.200 hours</td>
</tr>
<tr>
<td>Adjustment of valve/rocker arm clearance</td>
<td>2.400 hours</td>
</tr>
<tr>
<td>Change auxiliary members' belt</td>
<td>2.400 hours</td>
</tr>
</tbody>
</table>
(1) Maximum period relative to the use of high quality fuel, (specification ASTM D975 or EN 590); this is reduced based on fuel contamination and the alarm signals due to filter clogging and/or the presence of water in the prefilter. The filter clogging signal does not indicate the filter must be replaced. If the signal of water present in the prefilter does not turn off after it was drained, the filter must be replaced.

(2) Perform every year even if the specified operating hour interval is not reached.

(3) Frequency applicable for lubricants which meet the international standards API CJ-4 / ACEA E9-E6 as specified in the REFILLING section.

(4) Only use filters with the following specifications:
   - degree of filtering < 12 μm
   - filtering efficiency 99.5% (β > 200).

(5) Perform every two years even if the specified operating hour interval is not reached.

(*) for application working in dusty environment only.
### ATS System Extraordinary Maintenance

<table>
<thead>
<tr>
<th>Service</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service regeneration</td>
<td>150 hours (*)</td>
</tr>
<tr>
<td>AdBlue change in the urea tank</td>
<td>6 months</td>
</tr>
<tr>
<td>DPF filter replacement</td>
<td>Once clogging signals require the substitution</td>
</tr>
</tbody>
</table>

(**) To be performed every six months even if the specified operating hours interval has not been reached.

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**ATS System Filter Location**

1. Dosing valve filter (36 μm)  
2. Dosing module  
3. Supply module main-filter  
4. Supply module backflow-filter (100 μm)  
5. Supply module pre-filter (100 or 70* μm)  
6. Tank breather filter (5/10* μm)  
7. AdBlue tank  
8. Tank neck filter (300 or 100* μm)  
9. Supply module inlet-filter (100 μm)  
10. Supply module  

* for application working in dusty environment only.
REQUIREMENTS

- Do not disconnect the batteries with the engine running.
- Do not carry out arc welding operations in the vicinity of the engine without first removing electrical cables.
- After each maintenance operation involving disconnection of the battery/batteries, make sure that the terminals have been properly locked onto the poles.
- Do not use battery chargers to start the engine.
- Disconnect the on-board network battery/batteries when recharging.
- Do not paint the appliances, components and electrical connectors equipping the engine.
- Disconnect the battery/batteries before any electrical operations.
- Contact the Manufacturer before installing electronic equipment on board (two-way radios and the like).

CHECKS TO BE MADE DURING THE PERIOD OF USE – HOW TO PROCEED

Visual inspection of engine

Before starting, it is recommended to carry out a series of simple checks that can significantly help avoid problems, also of a series nature, while the engine is operating. These checks are usually performed by the vehicle operators and drivers.

- Check the levels and check for any leaks from the fuel, cooling and lubrication circuits.
- Inform maintenance personnel if any problems are found; top up if necessary.

After starting the engine and with the engine operating, perform the following checks and controls:

- Check for any leaks from the fuel, cooling and lubrication circuits.
- Make sure there is no unusual noise or beating during operation.
- Use the vehicle instruments to check the foreseen pressure, temperature values, etc.
- Visually check the smoke (colour of the exhaust gas).
- Visually check the level of the coolant in the expansion tank.

⚠️ Do not execute any operation which may change the ignition pump’s calibration.
The ignition pump’s calibration has been carried out in phase of engine system test based on its final use or destination.
Check engine lubricant oil level

Only proceed with the engine stopped and at a low temperature, so as to avoid the risk of burning.

- Take all necessary action to ensure that the machine is “level”.
- Using the dipstick (2), check that the oil level is between the "Min" and "Max" levels.
- Whether it should be difficult to make the evaluation, proceed cleaning the oil level dipstick (2) using a clean cloth with no rag grinding and put it back in its slot. Draw it off again and check the level.
- If the level is insufficient, it is necessary to top up with lubricant oil which meets the international specifications API CJ-4 / ACEA E9-E6, as indicated in the REFILLING table: remove the lubricant oil cap (1) and pour engine lubricant oil through the hole.

After refilling make sure oil level does not exceed the limit "Max" on the stick.
Make sure that the oil dipstick is fully inserted and that the oil filler cap is fully tightened in a clockwise direction.
Check engine coolant level
Proceed only with engine not running and at low temperature to avoid any risk of burns.

- With the engine at low temperature, make sure that the fluid level in the expansion tank is above the minimum level.
- Visually check that the fluid level is not more than 2/3 of the height of the tank in order to enable any increase in volume of the fluid caused by the temperature increase.
- Top up the tank if necessary, using clean water. Do not use distilled water; see the REFILLING table.

If the refill operations occur frequently a diagnosis of the cooling circuit is necessary.

In the event that only the heat exchanger without the expansion tank is available on the vehicle, refill it if necessary, paying attention that the fluid does not saturate the internal volume of the exchanger in order to enable any increase in volume of the fluid caused by the temperature increase.

CAUTION!
When the engine is warm, a pressure liable to cause hot liquid to be expelled with extreme violence is created within the cooling circuits. This results in a danger of burning.

Drain water from fuel pre-filter (Component not supplied by FPT)
The high risk of refuelling with fuel that is polluted by foreign bodies and water makes it advisable to carry out this control every time you refuel.
Proceed with the engine stopped.

- Place a container under the filter or pre-filter to collect the fluid.
- Unscrew the tap plug (3) in the bottom part of the filter; in some lay-outs the plug includes a sensor to detect the presence of water in the diesel.
- Drain off liquid until only "diesel" can be seen.
- Close the plug again, tightening it completely by hand.
- Dispose of the drained fluids according to current requirements.

The components of the common rail system will be rapidly damaged if the fuel contains water or impurities. Immediately perform the operation on the pre-filter to drain the water present in the fuel supply circuit.
Check/top up electrolyte level in batteries
(Component not supplied by FPT)

Place the batteries on a level surface, then proceed as follows.

- Visually check that the fluid level is between the “Min” and “Max” limits; in the absence of references, check that the fluid covers the Lead plates inside the elements.
- Top up with distilled water only those elements in which the level is below the minimum.
- Contact specialised technical staff if the battery needs recharging.
- Have the efficiency of the battery recharging system tested if a voltage of less than 22 V is detected with the engine running.
- On this occasion, make sure that the terminals and clamps are clean, properly locked and protected by vaseline.

CAUTION!

If all the elements of the battery need refilling with a considerable quantity of distilled water, contact specialised technical personnel in order to perform a diagnostic check on the efficiency state of the recharge system and battery.

CAUTION!

The batteries contain sulphuric acid, which is extremely caustic and corrosive; always wear protective gloves and goggles when topping them up. Whenever possible it is recommended that this control be carried out by specialised personnel. Do not smoke or use live flames near the batteries during the control, and make sure that the room you are working in is adequately ventilated.

Some types of battery have a single cover for all the inspection plugs. To access the elements, use a lever as shown in the figure.
Check auxiliary members’ belt condition

Only proceed with the engine stopped and at a low temperature, so as to avoid the risk of burning.

- Check that the belt is not torn or worn, and that there are no lubricants or fuel on it. If this is not the case, replace them.

- The belt tension is adjusted automatically by the calibrated spring in the automatic belt tensioner (1). Refer to the figure below for the correct fitting of the belt.

Check the condition of the exhaust duct(s)

Visually check that the exhaust system is not blocked or damaged.

- Make sure that there is no risk of dangerous fumes within the machine. Contact the Manufacturer if necessary.

Check coolant density

Remove the cap from the expansion tank and draw off a sample of coolant using commercial densimeter for anti-freeze liquid density check.

Depending on the temperature of the fluid, check the percentage of antifreeze in the fluid on the reading scale of the instrument. The percentage should be higher than 40% and must not exceed 50%. If necessary, restore the percentage of antifreeze, bearing in mind that the fluid needs to be replaced every 2 years.

CAUTION!

When the engine is hot, pressure builds up in the cooling circuits which may eject hot liquid violently, resulting in a risk of burns. Open the filler cap of the coolant tank only when the engine is cold.
Engine EDC system check-up with diagnostic tool

The diagnostic inspection can be carried out by using the diagnostic tool supplied by the FPT Technical Service Network to the appropriate connector. The inspection could underline that the system is operating even if some problems are present. In this case make provision to carry out an exhaustive check-up.

PERIODIC MAINTENANCE - HOW TO PROCEED

Change engine lubricant oil

Only proceed with the engine stopped and at a low temperature, so as to avoid the risk of burning.

- Place a suitable container for collecting the spent oil under the oil sump (4) next to the lubricant oil drain plug (3).
- Unscrew the lubricant oil drain plug (3); afterwards extract the oil level dipstick (2) and remove the lubricant oil cap (1) to assist the flow of the engine lubricant oil.
- Wait until the oil sump (4) has completely emptied, then retighten the lubricant oil drain plug (3).
- Proceed with the refilling operation through the hole situated on the tappet cover, using lubricant oil that meets the international standards API CJ-4/ACEA E9-E6, as indicated in the REFILLING table.
- Using the oil level dipstick (2), check that the engine lubricant oil level is between the "Min" and "Max" levels.
- Whether it should be difficult to make the evaluation, proceed cleaning the oil level dipstick (2) using a clean cloth with no rag grinding and put it back in its slot. Draw it off again and check the level.
- Retighten the lubricant oil cap (1).
- Together with the replacement of the engine lubricant oil it is necessary to replace the oil filter (see paragraph CHANGE OIL FILTER).

CAUTION!

Coolant density must be checked every year before winter season and be replaced in any case every two years.
Make sure that the oil dipstick is fully inserted and that the oil filler cap is fully tightened in a clockwise direction.
Change oil filter

Only proceed with the engine stopped and at a low temperature, so as to avoid the risk of burning.
Only use filters with a filtration level equivalent to the ones you are replacing (see section FREQUENCIES table).

- Place a container for collecting the spent oil under the filter support (1).
- Unscrew and remove the filter (3) from its relative support (1) by suitable tool.
- Replace the filter element and the sealing gasket (2) contained inside the filter (3).
- Carefully clean the surfaces of the support (1) in contact with the sealing gasket (2).
- Moisten the sealing gasket (2) of the new filter (3) with a thin layer of oil.
- Manually tighten the new filter (3) on the support (1) until it comes into contact with the sealing gasket (2). Additionally tighten it using a specific tool to a torque of 20 ± 2 Nm.
- Operate the engine for a few minutes and then check the level using the dipstick. If necessary, top up to compensate for the quantity of oil used to fill up the filtering cartridge.
**Change fuel filter**

Only proceed with the engine stopped and at a low temperature, so as to avoid the risk of burning.

Only use filters with a filtration level equivalent to the ones you are replacing (see section FREQUENCIES table).

- Pay attention to the electrical fuel pre-heater (3) and relevant electrical connection.
- Place a container for collecting the diesel under the filter support (1).
- Remove the filter (5) by unscrewing it from its relative support (1).
- Replace the filter element and the O-ring seal (4) contained inside the filter (5).
- Carefully clean the surfaces of the support (1) in contact with the O-ring seal (4).
- Smear the O-ring seal (4) of the new filter (5) with oil.
- Manually tighten the new filter (5) onto the support (1) until it comes into contact with the gasket (4). Additionally tighten it using a specific tool to a torque of 20 ± 0/+5 Nm.

After the fuel filter (5) has been replaced it is possible that air bubbles get trapped inside the fuel supply circuit.

- Bleed residual air from the fuel filter (5) by loosing the vent plug (2) connecting it to a suitable container by a transparent flexible hose.
- With the hand pump of the fuel pre-filter pump until fuel completely free of air bubbles flows from the vent plug (2).
- Tighten the vent plug (2) to prescribed torque.
- Start the engine and allow it to run at minimum for a few minutes to expel any remaining air.
Do not fill up the new filter before it is fitted to the support, to avoid inserting harmful impurities into the injection system and circuit.

**CAUTION!**

Do not smoke or use open flames during this operation. Do not inhale the vapours that exit the filter.

Eliminate the consumables and any materials in contact with them (for example, filters) in accordance with current regulations. The FPT Technical Service Network workshops are equipped for this purpose.

**CAUTION!**

Ensure that any fuel coming out of the vent plug does not dirty the auxiliary members’ drive belt and is not dispersed into the environment. Never loose connectors of the high-pressure fuel pipes and of the common rail in any way.

If it is necessary to speed up the residual air bleeding phase, use the hand pump also while starting.

**Change fuel pre-filter**

*(Component not supplied by FPT)*

Only proceed with the engine stopped.

- Should the filter be fitted with a sensor to detect the presence of water (3), remove the whole sensor from its seat.
- Remove the pre-filter by unscrewing it.
- Check that the new filter has performance levels that satisfy the needs of the engine (e.g. by comparing them with the old one)
- Damp the new filter seal with diesel or engine oil.
- Hand screw the new filter into place until the seal gasket touches the support, then lock by a further 3/4 of a turn.
- Place the water presence sensor in its seat, taking care to couple the threads correctly.
Loosen the bleeder screw (1) on the pre-filter support and activate the hand pump (2) until the supply circuit is full. Ensure that any fuel coming out is not dispersed into the environment.

Lock the bleeder screw tightly.

Start the engine and run it at idle for a few minutes to eliminate any residual air.

If it is necessary to speed up the residual air bleeding phase, use the hand pump also while starting.

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**Change blow-by filter**

Only proceed with the engine stopped and at low temperature, in order to avoid the risk of burning.

- Unscrew the flanged nuts (1) from dual shank screws (6) and remove the tappet cover (4), recovering relevant gasket (7) and spring dowels (10).
- Unscrew the ring nut (3) and remove the blow-by breather pipe, rotating it to release it from the bayonet coupling.
- Unscrew the self-locking screws (8) and remove blow-by control valve (9) and filter element (5) from the inner side of the tappet cover (4).
- Replace the blow-by filter element (5).
- Fit the control valve (9) equipped with a new O-ring together with the new filter (5) inside the tappet cover (4) and tighten the self-locking screws (8) to a torque of 6 Nm.
- Partially screw in the ring nut (3) on the filter element, insert the pipe rotating it to until the filter element engages with the bayonet connection and tighten the ring nut (3).
- Refit the tappet cover (4) after having interposed a new gasket (7) and tighten the flanged nuts (1) after having interposed the spring dowels (10) on the dual shank screws (6).
Change air filter and clean housing
(Component not supplied by FPT)
Refer to the instructions provided for air filter cleaning.

Clean the air filter
(Component not supplied by FPT)
Only proceed with the engine stopped.
- Remove the filter cover (1) after first unscrewing the locking handle.
- Remove the external cartridge (2), after unfastening the second locking handle; during this operation, take care to ensure that no dust get into the sleeve.
- Check that there is no dirt. If there is, clean the filter element as indicated below.
- Blow dry compressed air through the filter element, from the inside outward (maximum pressure 200 kPa). Do not use detergents; do not use diesel.
- Never use tools to beat the filter element, and check its condition before replacing it.
- Replace the filter if any breakages or tears are found.
- Check that the gasket at its base is in good condition. Some filter systems are fitted with a second filter element (3) which does not require cleaning; this must be replaced at least once every 3 changes in the main element.
- Reassemble by repeating the above operations in reverse order.
- Set up the mechanical blockage indicator for operation by pressing the button located on the top part of the indicator. This operation is not necessary if there is an electrical sensor.
Change engine coolant

Only proceed when the engine is not turning and is at low temperature in order not to run the risk of burns.

- Use suitable containers to ensure that the coolant is not dispersed in the environment.
- Loosen the retaining elements and remove the sleeves that couple the engine circuit with the heat exchanger and wait for them to empty completely. Once emptied, restore the condition of the circuit, ensuring the perfect seal of the sleeves.

- Refill the circuit according to the requirements specified in the REFILLING table.
- Refill the engine and the exchanger until the exchanger is completely filled.
- With the filler plug open, start the engine and idle it for approx. 1 minute. This phase helps to completely bleed the air contained in the cooling circuit.
- Stop the engine and then top up the incomplete quantity.
- When the engine is cold, make sure that the coolant level is a few centimetres below the filling hole.

In the event of an externally located level indicator as regards the heat exchangers, proceed with the top up operation by making sure that the coolant does not overfill the internal volume of the exchanger in order to allow the expansion of coolant volume during increases in temperature.

The failure to observe the aforesaid procedure does not guarantee the presence of the correct quantity of coolant in the engine.

CAUTION!

When the engine is hot, pressure builds up in the cooling circuits which may eject hot liquid violently, resulting in a risk of burns.
Open the filler cap of the coolant tank only if necessary and only when the engine is cold.

CAUTION!

Take care to ensure that the parts are reassembled correctly. Imperfect assembly might result in unfiltered air being sucked into the engine, causing serious damage.
EXTRAORDINARY MAINTENANCE - HOW TO PROCEED

**Turbocharger visual inspection**

Only proceed when the engine is not turning over. Visually check that the turbine and compressor impellers and the relative inlet and outlet ducts are not obstructed or damaged, otherwise replace them.

**Adjustment of valve/rocker arm clearance**

The adjustment of the clearance between the rocker arms and the intake and exhaust valve control rods must be strictly carried out using an Allen wrench (1), box-end wrench (3) and a feeler gauge (2).

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**Change auxiliary members' belt**

- Pull the automatic belt tensioner (6) by using appropriate tool (7) and remove the auxiliary members' belt (2) from alternator (8), water pump (2), crankshaft pulley with damper (4) and fixed guide rollers (1 and 5).
- Replace the worn belt (2) with new one.
- Fit the auxiliary members' belt (2) on the pulleys and fixed guide rollers.
- Use the appropriate tool (7) on the automatic belt tensioner (6) in order to fit the new belt (2) in the operating position.
- Additional adjustments are not required. The belt (2) tension is adjusted automatically by the calibrated spring in the automatic belt tensioner (6).
ENGINE HANDLING
The engine must only be disconnected and reconnected by Service Centre personnel.
To hoist the engine only, use the eyelets indicated in this manual in the ENGINE TECHNICAL DATA section.
It must be hoisted using a rocker arm that keeps the metal ropes that support the engine parallel, using all the provided eyelets at the same time; the use of a lower number of lifting eyelets is not permitted.
The capacity and dimensions of the engine hoisting system must be suitable for the engine weight and dimensions; make sure there is no interference between the hoisting system and the engine components.

The hoisting eyelets are sized to support only the weight of the engine. Do not hoist the engine before removing the transmission components coupled to it.

DISPOSAL OF WASTE
The engine consists of parts and elements that can cause ecological damage if disposed of in the environment.
The materials listed below must be delivered to authorised collection Centres:
- Starter batteries.
- Spent lubricant oils.
- Water and antifreeze mixtures.
- Filters.
- Auxiliary cleaning material (e.g. rags soaked in or moistened with fuel).
The laws in force in the various countries provide for severe penalties for lawbreakers.
ATS SYSTEM PERIODIC MAINTENANCE - HOW TO PROCEED

Change Supply Module main-filter

To prevent damage to the pump and dosing module, the supply module contains a filter which removes any impurities from the AdBlue.

Please refer to the following procedure for replacement of the filter.


Filter disassembly

- Unscrew and remove the filter cover (1).
- Remove the equalizing element (2).

During installation of the supply module on the vehicle, take into account the minimum aperture for filter replacement. The minimum value is approx. 155 mm.
- Insert the appropriate tool (1) in the correct direction in the filter, based on the colour of the filter supplied.
- Insert the appropriate tool (1) until a click is felt which indicates the complete engagement of the filter (2).
- Remove the filter (2).

**Filter assembly**
- Carefully clean with water the contact surface (1).
- Oil gasket (3) and assembly the new filter (2).
- Assembly a new equalizing element (2).
- Carefully clean the filter cover (1).
- Tighten the filter cover (1) to a torque of $20 \pm 5 \text{ Nm}$.

Check that the filter cover and the contact surface of the supply module are not cracked or damaged. If necessary, replace any damaged components.
LONG PERIODS OF INACTIVITY

PREPARING THE ENGINE FOR A LONG PERIOD OF INACTIVITY

In order to prevent oxidation of the internal parts of the engine and of certain components in the injection system, when the engine is expected to be inoperative for periods of more than two months, the following operations must be carried out in preparation for this:

1. Drain the lubricant from the sump, after first warming up the engine.
2. Fill the engine with protective oil type 30/M, up to the "minimum" level indicated on the dipstick. Start the engine and keep it running for approximately 5 minutes.
3. Drain the fuel from the injection circuit, from the filter and from the injection pump pipes.
4. Connect the fuel circuit to a tank containing CFB (ISO 4113) protective fluid, and feed in the fluid by putting the circuit under pressure and running the engine for approximately 2 minutes, after first disabling the injection system. This operation can be performed by polarising terminal 50 of the starter motor with a positive voltage equivalent to the rated voltage of the system, using a conductor provided for that purpose.
5. Nebulise approximately 45 g of 30/M protective oil (10 g per litre displacement) into the turbocharger suction inlet, during the pressurised filling operation described in the previous point.
6. Close all the suction, delivery, ventilation and bleeder openings in the engine with suitable plugs, or seal them with adhesive tape.
7. Drain the residual 30/M protective oil from the sump. This oil can be used again for a further 2 preparation operations.
8. Fit signs reading "ENGINE WITHOUT OIL" to the engine and to the on-board control panel.
9. Drain the coolant, if it has not been mixed with suitable antifreeze and corrosion inhibitors, and affix a sign to indicate the fact.

In the event of prolonged inactivity, the operations described must be repeated every 6 months, following the procedure given below:
A) drain the 30/M protective oil from the sump;
B) repeat the operations described from point 2 to point 7.

Should you intend to protect external parts of the engine, proceed by spraying OVER 19 AR protective liquid on unpainted metal parts, such as the flywheel, pulleys and the like, avoiding belts, connector cables and electrical equipment.
RESTARTING THE ENGINE AFTER A LONG PERIOD OF INACTIVITY

1. Drain the residual 30/M protective oil from the sump.

2. Fill the engine, as prescribed, with lubricant of the type and amount indicated in the table REFILLING table.

3. Drain the CFB protective fluid from the fuel circuit, carrying out this operation as indicated under point 3. of PREPARING THE ENGINE FOR A LONG PERIOD OF INACTIVITY.

4. Remove the plugs and/or seals from the suction, delivery, ventilation and bleeder openings in the engine, restoring it to a normal state of use. Connect the turbocharger suction inlet to the air filter.

5. Connect the fuel circuits to the machine’s fuel tank, completing the operations as indicated in point 4. of PREPARING THE ENGINE FOR A LONG PERIOD OF INACTIVITY. During filling operations, connect the fuel return pipe to a collection tank, so as to prevent any residual CFB protective fluid from flowing into the machine’s fuel tank.

6. Check the engine and fill it up with coolant as prescribed, bleeding it if necessary.

7. Start the engine and keep it running until the idling speed rate has stabilised completely.

8. Check that the instruments on the on-board control panel/s are showing plausible values, and that no alarms are shown.

9. Stop the engine.

10. Remove the “ENGINE WITHOUT OIL” signs from the engine and from the on-board control panel.
ENGINE MALFUNCTIONS

The electronic unit overseeing management and control of all operation of the engine is capable of recognising any malfunctions that may occur, and of adopting strategies that will allow you to proceed in full safety.

The event, signalled by light-up of the EDC MALFUNCTION indicator on the on-board control panels, results in programmed limitation of power within certain thresholds, set according to the severity of the case.

In the case of temporary malfunctions the reduction in performance will remain in force until the engine is stopped.

EDC anomaly signalling modes

The different switch-on modes of the EDC indicator light show different anomaly states:

Off
Regular operation or temporary data absence compensated by the safety strategy.

On
An anomaly has been detected and a power limitation has occurred but it is possible to continue driving slowly. Contact the Technical Service Network and ask for instructions.

Blinking
A serious anomaly has been detected and the engine must be stopped. It is possible an emergency stop generated by the electronic unit. Reach a safety condition, stop the engine, and call out the Technical Service Network.

Operation at reduced performances, as a result of AdBlue run out

According to harmful emission containment laws, imposing the efficient operation of “antipollution” devices adopted for different engines, if the known additive AdBlue is not regularly topped up and it runs out, the electronic unit will manage the engine at reduced performances.

Accelerator electronic circuit malfunction

When certain problems are recognised, the Electronic Unit controlling the engine adopts a strategy that will enable running/work to continue in emergency mode.

The possible operating modes of the strategy, known as “accelerated minimum speed running”, are as follows:

A. The accelerator does not “respond”: the running speed stabilises at a speed higher than the idle to allow the machine to proceed slowly and be manoeuvred simply by engaging the clutch on and off, without accelerating.

B. The accelerator “responds partially”: when the accelerator is moved to approximately half way, the speed gradually increases up to 2000 rpm; releasing the accelerator the speed rapidly decreases up to the idle.
Malfunction in the battery recharging system

The Electronic engine control units are programmed to increase the minimum running speed if the voltage in the electrical system reaches values considered to be at the limits of efficiency. In this case, check the efficiency of the battery(ies) and if necessary perform a check-up on the system components.

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**CAUTION!**

The engine electronic control unit can adopt safety strategies at any time during use of the machine or vehicle, should conditions arise that are considered to put the engine at risk. When conditions of this kind occur, proceed only if necessary and with the greatest possible care and attention.

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**CAUTION!**

Do not leave vehicles or machines with the engine running without first putting the parking lock or brake on.
BEHAVIOUR IN AN EMERGENCY

The user of a machine that has been constructed according to safety regulations, when following the instructions provided in this manual and the indications given on the engine labels, will be working in safe conditions. Should improper conduct result in accidents, always request the intervention of trained first aid specialists immediately. In an emergency and while awaiting the arrival of first aid specialists, follow the instructions given below.

In case of fire
Extinguish the fire using the fire-fighting equipment foreseen, and in the manner indicated by Fire prevention authorities (fire-fighting equipment for certain machines and equipment is compulsory under current safety legislation).

Burns and scalds
- Extinguish any flames on the burned person’s clothing, by:
  - throwing water over them;
  - using a powder fire-extinguisher, without directing the jet at the person’s face;
  - covering with blankets or rolling the victim on the ground.
- Do not attempt to remove pieces of clothing that may have stuck to the skin;
- In the case of scalding, immediately but carefully remove any clothing that may be soaked in the hot liquid;
- Cover the burn with a special burn dressing or sterile bandage.

Carbon monoxide intoxication (CO)
Carbon monoxide from the engine exhaust is without smell, and is dangerous both because it causes intoxication, and because when combined with air it forms an explosive mixture. In closed rooms, carbon monoxide is extremely dangerous, as it can reach critical concentrations within a very short time. When assisting an intoxicated person in a closed room:
- Ventilate the room immediately, to reduce the concentration of gas.
- When entering the room, hold your breath, do not light flames, lights or ring electric doorbells or phones, to avoid the risk of explosion.
- Carry the intoxicated person out into the fresh air or into a well ventilated room, resting him on one side if he is unconscious.

Electrocution
The engine’s electrical 12 V or 24 V electrical system does not involve the risk of electrocution, however, in the event of a short-circuit caused, for example, by a metal tool, there is a risk of burning due to overheating of the object through which the electrical current runs. In these circumstances:
- Remove the object that caused the short-circuit, using means that provide sufficient heat insulation.
- Switch off the power at the main switch, if there is one.
Injuries and fractures

The vast number of possible circumstances and the specific nature of operations required means that the intervention of a medical team is necessary.

- In the event of bleeding, keep the edges of the wound pressed together until help arrives.
- If there is any suspicion of a fracture, do not move the injured part and only move the patient if absolutely necessary.

Caustic burns

Caustic skin burns are caused by contact with extremely acid or alkaline substances.

For electric maintenance technicians these are typically caused by acid from batteries; in these circumstances, proceed as follows:

- Remove any clothing soaked in the caustic substance.
- Wash the area with lots of running water, avoiding parts that have not been burned.

If either battery acid, lubricants or diesel come into contact with the eyes: wash the eyes with water for at least 20 minutes, keeping the eyelids open so that the water flows over the eyeball (move the eye in all directions to wash more thoroughly).