Crankcase Explosions in Two-stroke Diesel Engines

Preface

It is generally recognized that the two-stroke diesel engine is the most economical and reliable prime mover, and MAN B&W Diesel always gives high priority to a conscientious development of the product and to providing important information to our customers, to ensure an even higher level of reliability.

Care is to be exercised when designing the engine and its safety systems. However, as there are people involved in all activities relating to the engine, the most important action could be to impart adequate information on the subject to all parties involved in producing, installing and maintaining the engine.

As there is always a certain risk involved if a crankcase explosion occurs, great efforts must be made to maintain the diesel engine and its safety systems in such a way that if there is a risk that an engine failure could occur, this will be discovered and rectified before it develops into a situation where an explosion could take place.

In the event that some components in a diesel engine are running hot, e.g. a bearing, then some of the lubricating oil will evaporate. The evaporated oil will then, when moved to colder areas, condensate into very small droplets, to form a so-called oil mist.

As oil mist is highly explosive, there will be a risk that the hot spot which created the oil mist will become the ignition point for an oil mist explosion.

In marine engines, this happens in a few cases each year, always with dramatic and even sometimes fatal consequences.

On our engines, we have, until recently, specified safety equipment in accordance with the requirements of the classification societies, trusting that this would be sufficient. However, after some serious crankcase explosions in the late 1990s, we at MAN B&W Diesel initiated our own research programme. We realised, for instance, that a large number of crankcase relief valves, although approved by the various classification societies, were in service without a proper flame arrester.

This is because the approvals from the classification societies only take the opening pressure into consideration. We therefore continued our research to ensure that the equipment installed would provide maximum safety.

As our policy in this area of safety is to share the results with other bodies involved, we have worked closely with classification societies and, through CIMAC, presented the results of our research to all users of diesel engines and also to other engine designers. Furthermore, we have sent a number of Service Letters to the users of our product, explaining our findings and recommending precautions to be taken to increase the safety margin. We intend to pursue this open-minded policy.

Cause of Explosion

As the sources of explosion vary to a large extent, this must be taken into consideration when taking precautions and selecting monitoring systems.

Below is a table of a number of accidents where the cause of explosion is known, the table includes two-stroke engines of both our design and of our competitors' designs:

***Table I**: Cases of explosions where the cause is known*

Year	Cause of Explosion	Cause of Failure
1995	Bearing in PTO gearbox	
1996	Inlet pipe for piston cooling oil falling off	Incorrect tightening
1997	Incorrect spring mounted in piston rod stuffing box	Unauthorised spare part
1997	Piston rod interference with cylinder frame	
1999	Weight on chain tightener falling off	Incorrect tightening
1999	Fire outside the engine	
2000	Main bearing	
2000	Camshaft bearing	
2000	Incorrect shaft in camshaft drive	Unauthorised spare part
2001	Crankshaft failure	
2001	Piston crown failure	
2001	Main bearing	
2001	Crankpin bearing	
2002	Inlet pipe for piston cooling oil falling off	Incorrect tightening

Consequences for Personnel

In a number of cases, the consequences have been fatal to members of the crew. In at least two of the cases listed above – both with fatal consequences – the explosions were caused by the installation of an unauthorised spare part during a repair. Also, cases with serious injuries have been reported. The hazard is particularly present if the oil mist is ignited outside the crankcase.

In the event of a crankcase explosion, the pressure wave will send a large amount of oil mist out of the crankcase and into the engine room, where the ventilation system will move it around. However, a major part will be sucked up towards the air inlet of the turbocharger.

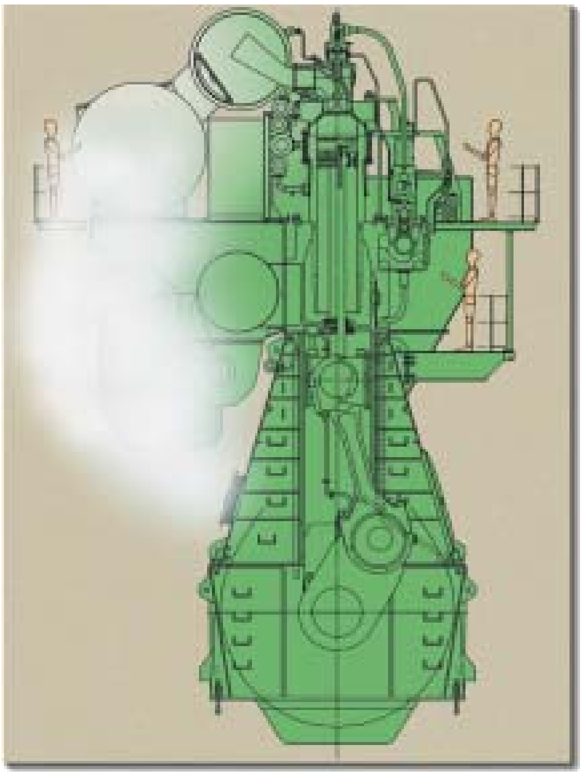

***Fig. 1**: Oil mist*

If the oil mist meets a hot spot, there is a risk that it will be ignited. Therefore, it is important to carefully maintain the insulating material around the exhaust pipes.

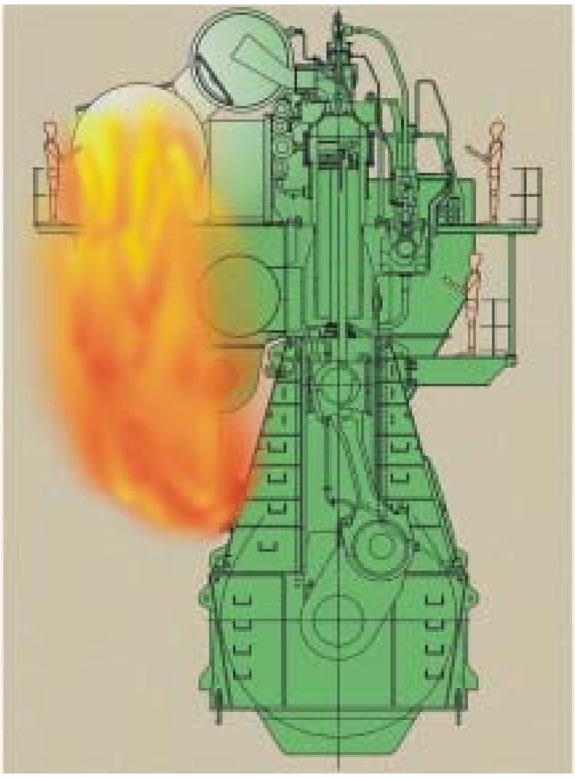

***Fig. 2**: Oil mist blast*

Of course, the largest risk of igniting the oil mist would be if the flame arrester on the relief valve did not function properly. In that event, the flame front from the explosion in the crankcase can ignite the cloud of oil mist in the engine room. We have therefore developed our own relief valve specification. Only relief valves approved according to this specification are accepted on engines ordered after the 1st of May 1999.

Consequences for the Plant

In most cases, the damage has been limited to the engine proper. However, in cases where the oil mist is ignited outside the crankcase, the blast can cause severe damage in the engine room, especially to the electrical equipment. In some cases, in narrow engine rooms, the pressure wave has caused damage to mechanical items. Doors and lifts have been damaged and, in rare cases, also floor plates have been torn loose and thrown around.

PRECAUTIONS AGAINST CRANKCASE EXPLOSIONS

Maintenance

In general, keep the engine in good condition, and follow the engine builder's instructions regarding check of components, especially bearings.

When overhauling, follow the engine builder's instructions. Incorrect tightening of bolts has caused a number of accidents. Another item that should be given attention is thick shell bearings. The top clearance must be adjusted by means of shims. We have seen cases of damage as the result of bearings having been assembled with insufficient top clearance, thereby restricting the flow of lube oil and leading to overheating of the bearing.

Approved Spare Parts

Original spare parts should always be used. A number of explosions, some with fatal consequences, have been caused by the use of unauthorised spare parts. In one accident, the piston rod stuffing box was mounted with springs supplied by an unauthorised supplier. Since they were of a wrong dimension, they jammed and caused heating of the piston rod and, finally, a crankcase explosion occurred. In that case, two people lost their lives because of a spare part which might have been believed to be of secondary importance to the functioning of the engine.

Inspections

Visual inspection of the engine is important for early discovery of any risk of failure, especially so in the case of inspection for white metal fragments inside the crankcase. This inspection can reveal the start of a bearing failure before it develops into a risk of a crankcase explosion. It is therefore part of our recommendations in the instruction book that any time the crew enter the crankcase they should make such visual inspection. If any white metal is found, we recommend that the edges on all bearings in this part of the engine are checked for damage.

Furthermore, it is important to regularly check the safety systems and other components related to safety. On one plant, a crankcase explosion caused an engine room fire because the flame arrester in the crankcase relief valve had suffered mechanical damage.

Monitoring

As a crankcase explosion can result from various components, and not only from the bearings, we specify as standard, the installation of an approved Oil Mist Detector (OMD), which is to be installed and connected to the safety system. If required by the customer, a bearing monitoring system can be specified as an additional precaution.

We do not agree with the rules of the classification societies, as they only require temperature monitoring of the bearing or, as an alternative, an oil mist detector.

As an alarm for high oil mist level triggers actions in the safety system and, as explained below, also in the future system for suppression of oil mist explosions, it is important that OMD makers improve their product to lower the risk of false alarms.

Suppression of the Risk of Crankcase Explosions

The engines are equipped with crankcase relief valves sufficient for protecting the engine against the impact of an oil mist explosion by relieving the pressure inside the crankcase.

In the event of an oil mist explosion in the crankcase, the very fast propagating pressure wave will send large amounts of yet unburned oil mist out into the engine room. The relief valve is equipped with a flame arrester to quench the much slower propagating flame front, thereby preventing any outside ignition and fire.

Even when the problems with outside ignition of the oil mist are solved, the mechanical impact from the pressure wave can give big problems by throwing floor plates around, and blowing doors out of their panels.

In some cases, also the lift car has been blown up to the top of the shaft. Such events jeopardize the crew and have, in rare cases, had fatal consequences.

In rare cases, on engines where there is a large enough space/length, an oil mist explosion could cause increased pressure ahead of the moving reaction zone and, thereby, increase the risk of a stronger explosion development there, i.e. the well-known self-perpetuating phenomenon called "pressure piling".

This creates extreme pressures that cannot be relieved through the valves and which, in some cases, have thrown off doors on the engine and caused an engine room fire.

The purpose of the system for suppression of an oil mist explosion is to reduce the damaging and hazardous effects of a crankcase explosion and remove the jeopardy for the crew.

The system will start acting when the oil mist monitoring system recognizes a too high oil mist level in the crankcase.

In such a case, we recommend reducing the engine load in order to minimise any further creation of “OIL MIST”. On a ship, this will not have any significant immediate effect, since the propeller will rotate the crankshaft for some time after that. Thus, the risk of a crankcase explosion will still be present during the load reduction process.

In other areas, inert gas is used to ensure that the oxygen content is reduced to a level where a flame front propagating is not possible.

On large diesel engines, the use of inert gas creates a new risk to the personnel, as venting of the crankcase compartments is rather difficult.

We have therefore made large efforts to develop a system for suppression of an oil mist explosion ***without the use of inert gas!***

The initial development of the explosion suppression system, based on the use of water mist, was started in the beginning of 2001.

The use of water mist is harmless to the personnel and, in addition, the water can be removed in the course of the normal lubricating oil cleaning process.

By the inflow of a preheated liquid medium under pressure, a well-dimensioned sharp-edged nozzle design, with an appropriate length of the outlet pipe designed for the actual medium and its inlet thermo-dynamical conditions, is able to force a localized evaporation of the medium inside the nozzle, utilizing the natural proper-ties of the liquid medium and, thereby, to produce a flow at the nozzle outlet of the medium in vapour state. This outflowing vapour condensates into very small droplets, partly because of the increasing pressure, and partly because of the mix with the surrounding relatively cooler gases, and thereby forms a mist of the liquid medium.

The pressurized hot water (15 bar and 180^{o} C), which is controlled by the oil mist monitoring system, is injected into the crankcase, through special sharp-edged nozzles, where it is transformed into small droplets of a size below 10 microns.

The water mist system replaces the use of inert gas and, thereby, completely removes the risk of choking due to the lack of oxygen. The use of water mist is harmless to the personnel, and the water can be removed in the normal lubricating oil cleaning process. The water mist cannot prevent an explosion. However, practical tests with explosions in an air/methane mixture have shown that the pressure rise, as can be seen in Fig. 3, is considerably reduced, thereby eliminating the risk of mechanical damage caused by the pressure wave.

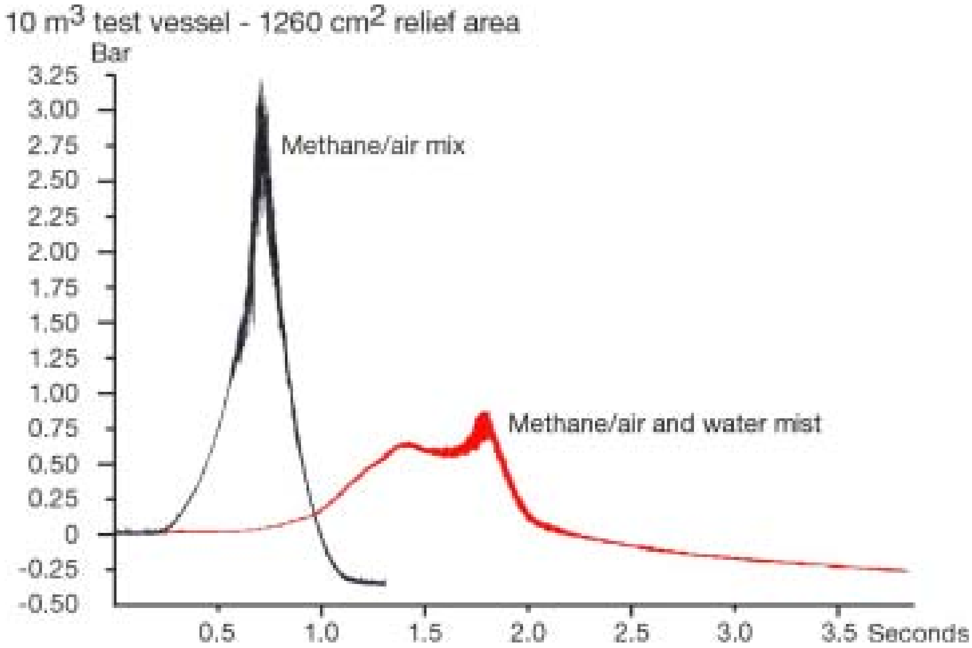

***Fig. 3**: Explosion test in tank with and without injected water mist*

New development

The system for injecting water mist requires constant attention, as it is constantly needed to maintain the pressure and temperature of the water in the system. Furthermore, the amount of water mist to be injected must be large enough to ensure that the whole crankcase is covered.

Lately, we have started development work based on the idea of creating the water mist the same way as the oil mist. This can be achieved by adding the water to the lubricating oil before it is delivered to the engine.

In order to be capable of immediately reducing the temperature on the spot affected by hot running when an excessive “OIL MIST” level has been measured, freshwater is injected into the lube oil at a volume of 1-5% of the amount of oil being **delivered** to the engine. Since the boiling point of water is lower than that of oil, the water will evaporate before the oil starts boiling. Because water has a very high specific heat of evaporation, the hot spot will be cooled in the course of this process. This will reduce or eliminate the evaporation of oil.

Alternatively, on plant with temperature monitoring of the bearings, water injection can be triggered by excessive temperatures in individual bearings, and water injection can be effected in the specific oil supply to the bearing in question, also in this case at a volume of 1-5% of the supplied lube oil amount. However, this requires a more complex installation.

By mixing the water into the oil, we ensure that whenever the oil meets a hot spot, where an oil mist can be created, water will also be present and, as described above, boil off using the heat and, thereby, restrict or even hinder the evaporation of the oil.

Method

During operation of the diesel engine, the oil mist level in the crankcase is constantly monitored by detectors (11) in the individual spaces. A signal is sent from here to a monitor (12) in the engine control room (ECR). In the event of an increasing level exceeding a predetermined limit, the monitor will activate the engine alarm system, which will then activate other systems that will reduce the engine load. However, there is a time delay in this system, because various conditions relating to the safe operation of the ship have an influence on this process. In order to quickly achieve a safe situation against a crankcase explosion, the monitor will send a signal to the above-described system at the same time as it sends a signal to the alarm system.

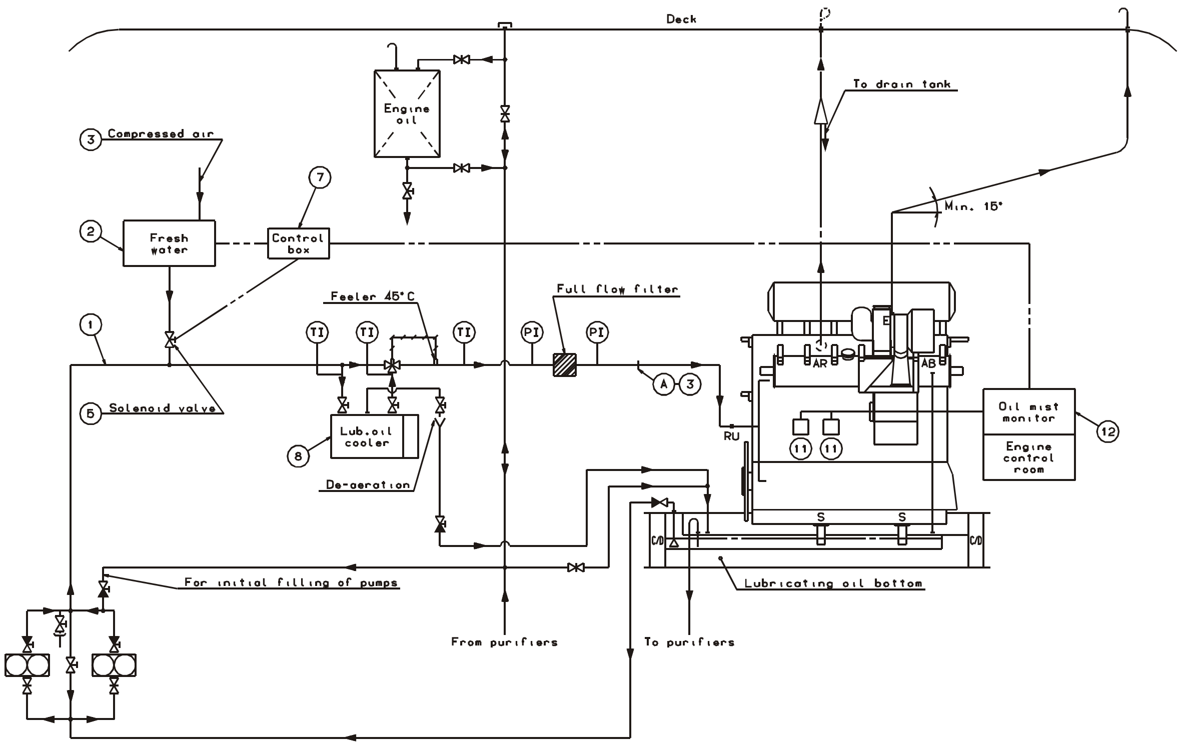

***Fig. 4**: Injection of water into the lube oil*

A freshwater tank (2) is kept under constant pressure with compressed air at min. 2 bar abs. and max. 10 bar abs.

Alternatively, the tank is not pressurised until a signal is received from control box (7).

When control box (7) receives a signal from the engine's monitoring system, warning of an excessive oil mist level, alternatively of an excessive bearing temperature, the following will occur:

- If tank (2) is not pressurised, a signal is sent to valve (3), which then opens for access to the ship's compressed air system and, thereby, tank (2) is pressurised.
- A signal is then sent to solenoid valve (5), which opens for the access of water to oil pipeline (1).

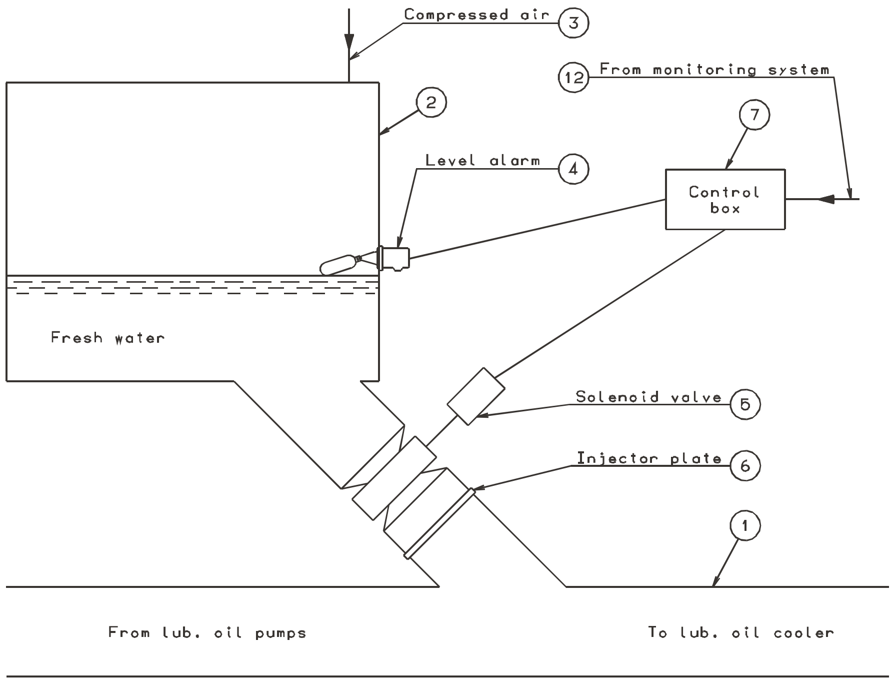

***Fig. 5**: Injection of water into the lube oil*

The water is pressed through a number of nozzle holes in the injector plate (6), thereby vaporising the water and thrusting it into the oil as small droplets. Further mixing occurs when the oil/water mix passes the lube oil cooler (8). The predetermined mixture ratio between oil and water is controlled by the size and number of holes in the injector plate (6), and by the pressure level in the tank (2).

On plant where tank (2) is pressurised, a signal is sent directly from control box (7) to valve (5).

Valve (5) is kept open until the freshwater level in tank (2) reaches the level where level control (4) sends a signal to control box (7), which then sends a signal to valve (5), which is closed, thereby cutting off the connection between tank (2) and oil pipe (1).

The size of tank (2) has been adjusted to ensure the supply of freshwater at a volume which is sufficient to cool the hot spot areas. This will eliminate the risk of a crankcase explosion.

After such an event, the water is removed from the oil in the course of the normal cleaning process, using the lube oil centrifuges.

Summary

In view of the seriousness of the subject, and of the fatal consequences that may be inflicted on personnel and machinery if a crankcase explosion does occur, it has been natural for us to carry out this research work as a matter of priority and with very careful and in-depth tests and experiments.

We feel confident that, with the new knowledge thus achieved, safety can be enhanced, and it has been equally natural for us to disclose all test results to all implicated parties, whether these are concerned with diesel engines of MAN B&W or other makes.

In continuation of that policy, we will not restrict any party in utilising our ideas in practical applications.

In cooperation with the classification societies and other interested partners, we will continue our research work in this field, and the publication of further results can be expected when available at a later stage.