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An engine room simulator as an educational tool for marine engineers relating to explosion and fire prevention of marine diesel engines

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Key words: engine room simulator, education of engineers, crankcase, oil mist detection, explosion protection, exploitation safety

Abstract

The paper presents basic information about the prevention of explosions and fires in marine engines, with particular reference to explosions in the crankcase. It also discusses the possibility of using engine room simulators in educating marine officer engineers to prevent dangerous situations during actual marine diesel operation. Two scenarios have been shown that illustrate the developments in the case of improper operation of main bearings while the operation of an engine safety system is intact and there is lack/override/failure of safety systems. In scenario I the main engine shut down occurs and scenario II simulates an explosion in the crankcase.

Introduction

The transportation system is highly reliable owing to the safe and effective operation of vessels, which are a basic means of global transportation. In 2012, over 80% of the world volume of goods was transported by ships (Rozmarynowska, 2012). The current development of a global merchant fleet is oriented towards the operation of vessels of an increasingly bigger size to improve their deadweight tonnage.

The piston combustion engine is today the most technologically developed heat engine, reaching an overall efficiency of over 55%. High profitability and availability of petrochemical fuels make piston combustion engines the basic energy source for vessels. It is estimated that combustion engines are components of 90–92% of currently operated ship propulsion systems (Piotrowski & Witkowski, 1996; Chybowski, Laskowski & Gawdzińska, 2015). The nominal power of the biggest low-speed two-stroke diesel engines exceeds 75,000 kW. High efficiency and power are obtained when engines with an extremely large stroke are used, which leads to the bigger size of most modern engines. For instance, a 14-cylinder 14RT-Flex96C engine by Wärtsilä is 13.5 m high, 27.3 m long, weighs over 2,300 tonnes and reaches the power of 81,300 kW.

The above-mentioned parameters of modern marine engines directly lead to serious consequences with their potential damage, including fire and explosion. Main modern marine engines have to guarantee the safety of ship operation by means of the systems they consist of, enabling operation in emergency conditions (e.g. with one cylinder suspended, a failed turbocharger, etc.) and protecting against engine damage (e.g. by using fuel oil and scrapping oil drainage installations, alarm systems, slow down function, shut down function)

(Wärtsilä, 1998; Holness, 2005). They are also equipped with systems minimising the consequences of failure (e.g. explosion flaps, firefighting systems, bursting discs, safety valves) (Schaller, 2005; Chybowski & Grzebieniak, 2009a; 2009b; Hoerbriger, 2015).

Despite technological progress, ship crews are exposed to serious hazards, including fires and explosions. The prevention of emergency states in ship operation, especially in relation to the crew and transported goods, is a very important aspect (Chybowski & Grzebieniak, 2009c; Marine diesels, 2015; Schaller 2015). The process of training seafarers to become highly qualified marine engineers understanding physical and chemical phenomena, familiarised with the conditions for fire to start and aware of the consequences of an engine emergency operation state, is a very important element of fire and engine explosion prevention (Marine diesels, 2015).

Fire and explosion

Engine rooms are places that are vulnerable to fires and explosions due to the always present factors causing them (Chybowski, 2014). Fire is uncontrollable and a spontaneous oxidation of material in the process of combustion. Fire starts when a flammable material, oxidant and a source of heat with a sufficient quantity of energy are present. Flammable materials are substances that, as a result of heating, emit a sufficient quantity of gases to ignite and continue to burn in air. Oxygen, in turn, is one of the most active chemical elements that reacts with many other chemical elements and compounds. If the combustion process is rapid, it is accompanied by lighting effects and high temperatures (Schaller, 2015).

Explosion is a rapid increase in volume and release of energy, usually with generation of high temperatures, pressure, radiation emission (e.g. lighting, sparks) and acoustic waves (e.g. thunder). Explosions are the results of rapid exothermic chemical reactions (e.g. combustion), particularly branching chain reactions and rapid physical phenomena (e.g. steam boiler and gas pressure vessel explosions).

“Chemical explosions”, of fuel oils or lube oils (air mixtures) for example, result in large quantities of gas products during primary and secondary reactions and the occurrence of many physical phenomena, such as an increase of gas volume in rapidly rising temperatures, and liquid evaporation and sublimation of solids in an explosion-hazard area among other things.

Explosion causes high-pressure waves. We talk of a true explosion when a shock wave or blast overpressure propagates at a velocity over 400 m/s but below the maximum possible velocity for a given explosive. Explosion at the maximum velocity specified for a given explosive is called detonation, while a combustion or reaction wave propagating at a velocity less than a speed of 400 m/s is called deflagration.

Marine engines are machines full of places, outside and inside, where fire or explosion can start: the crankcase, under piston spaces, scavenge air receiver, exhaust gas manifold, lubrication system, gearbox, fuel supply system, leak detection and drainage system (Wärtsilä, 1998; Chybowski & Grzebieniak, 2009b). Explosions in crankcases are one of the most serious that can occur. They are caused by improper operation of the stuffing box, fires in the scavenge air receiver and seizure of bearings in the crank system.

The first references to explosions in the crankcase date back to the beginnings of diesel engine production, as noted by Rudolf Diesel. But, more insights into the issue were provided after 1947, when a crankcase exploded on board the *Reina del Pacifico.* Twenty-eight people lost their lives there (Chybowski, 2014). At first, technologies alleviating the effects of explosions were developed. Only later were the causes of explosions and ways to prevent them considered.

Explosions in crankcases

Fuel or lubricating oils in a liquid state do not create a fire hazard but their vapours do. Evaporation requires energy. An engine compressing fuel, a hot spot or a flame might be the source. Fuel supplied to the injector under high pressure might leak in the form of a stream and get to a hot spot where it evaporates. An enlarging vapour cloud moves away from the heat source and it cools to form a mist composed of very small droplets. During formation and propagation of the mist, the part located close to the hot spot might reach the temperature of ignition and then the whole vapour cloud will ignite.

Hydraulic oil leaking from a high-pressure pipe forms a flammable mist, similarly to fuel, when it contacts a hot spot. A similar process takes place inside the engine (Figure 1), when there is a defect causing local overheating of interacting components. This phenomenon was described and explained in the 1950s when crankcase explosions were common and in the 1970s due to explosions in reduction gears used in shipping (Nowosad, 2009; Ślesicki, 2009; Patejuk, 2011).

First oil mist detectors (OMD), based on the principle of light absorption, were introduced in the early 1960s by British companies specialising in fire protection.

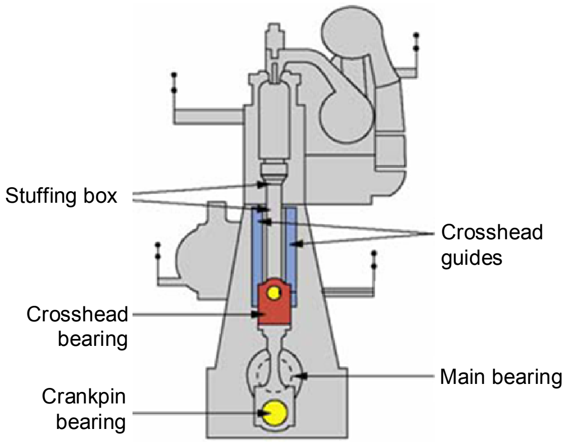


Figure 1. Functional elements of a crosshead engine where mist might be formed (Schaller, 2015)

In the 1970s, a number of ships equipped with medium speed trunk engines significantly increased in comparison to ships with crosshead engines. Both solutions reached increasingly higher powers so that they worked under higher loads. The increased load that engine components were exposed to had to be accompanied by an increase in the lubrication of interacting components. The load increase involved a higher risk of overheating engine components; therefore the requirements concerning monitoring of the oil mist level were no longer limited to the crankcase explosion prewarning. Early detection of hot spots in the crankcase became very important as it could protect the engine against serious damage.

Classification societies had special requirements for oil mist detectors installed in unmanned class engine rooms. Unfortunately, OMDs available then could not fulfill these requirements. It was caused by a lack of knowledge about the behaviour of oil mist formed around the crankcase and the limitations of OMD construction. The sensitivity of devices was too high, and analysing samples took too long, so early detection of a breakdown failed. Improper maintenance caused many false alarms (Nowosad, 2009).

Introducing new devices available at that time such as LEDs and applying simplified systems for the suction of crankcase gases gradually increased trust in these type of devices.

Today we know how dangerous oil mist is, and therefore, an understanding how it is formed, what properties it has and what mist concentration is needed to cause an explosion, really matters. Droplets are more flammable because their surface-volume ratio is higher. Thus, a droplet is more sensitive to heat from a potential source of ignition and a greater surface, compared to the liquid, has contact with the oxygen contained in the air. The rule is – the smaller the droplets, the lower the temperature of ignition and the greater risk of explosion.

Droplets can be divided into three categories according to their size. The first group is very small droplets with a diameter below 1 μm. The mist composed of such droplets is blue and is formed as a result of oil contacting very hot surfaces (over 800°C). The second group is droplets with a diameter of 1–10 μm, which are formed when the temperature is between 200 and 600°C. Finally, there are droplets with a diameter of over 50 μm, which mechanically form aerosol (e.g. as a result of leakages from high-pressure pipes). It must be added though, that this droplet classification is arbitrary and is not commonly accepted.

Research shows that the longer the way of flame propagation, the more powerful the explosion, and modern two-stroke marine engines have crankcases frequently exceeding the volume of 500 m^3. When there is an explosion, the flame front directs down together with the shock wave. Whirlings caused by moving engine components result in mixing of the vapours, and so they intensify the speed and size of the flame, which increases the pressure. Oxygen depletion as a result of combustion decreases the pressure inside the crankcase to below the ambient pressure and the air is sucked from the outside through explosion flaps. Another explosive mixture is formed and another explosion might take place. The second explosion is much stronger. The crankcase door is detached from the wall. On the other hand, if explosion flaps are not activated, the door is detached from the crankcase wall during the first explosion, which will result in the sucking of more air and will bring about an even stronger explosion. The shock wave will transport big amounts of oil mist into the engine room and the fire will propagate outside the crankcase. In extreme cases, the mist expelled in this way might be sucked by the turbine and might ignite as a result of the exhaust gas temperature, leading to more serious damage.

Between 1990 and 2001, the Lloyd's Register of Shipping (Nowosad, 2009; Laskowski, Chybowski & Gawdzińska, 2015), containing about 20% of the global merchant fleet, noted 143 explosions in the crankcase, which is proportional to about 715 explosions associated with the whole fleet and 65 explosions a year. It must be added that these explosions were registered, i.e. they caused serious damage or someone was injured. Less serious explosions were probably not reported by crews. It is estimated that the real number of explosions is even double what was reported, i.e. 3 explosions a week. The construction and operational properties of two-stroke crosshead engines very often prevent explosions (lower speed and separation of the crankcase from the cylinders), but the results of an explosion might be more disastrous. Therefore, marine engine manufacturers adopt many solutions to predict a potential explosion and when it happens, to minimise its results.

Educating marine engineers by means of engine room simulators

The Standards of Training, Certification and Watchkeeping Convention contain specific requirements for the training of seafarers. This document allows training and testing in three basic forms, i.e.:

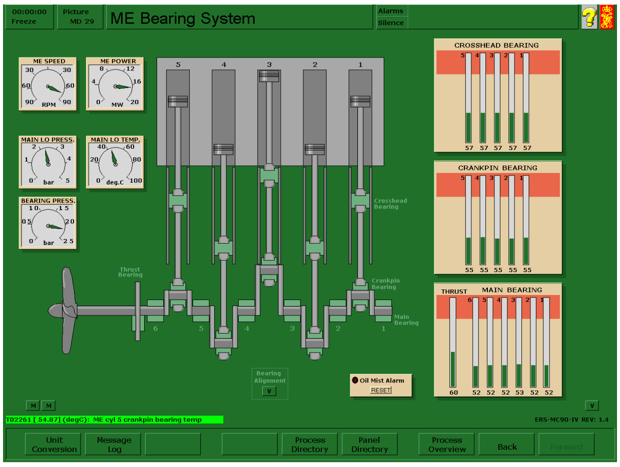
- Using laboratory equipment;
- Using full mission simulators of the engine room with high quality representation of reality in real time;
- Onboard and at sea.

For many years the Maritime University of Szczecin has used simulators to teach (Chybowski & Idziaszczyk, 2014; Żółkiewski & Pioskowik, 2014; Laskowski, Chybowski & Gawdzińska, 2015). One of the training sessions its students do is based on a programmed scenario of causing and preventing explosions in the crankcase of marine engines. The students analyse the situations when there is fire or explosion hazards in the engine and they observe the systems protecting the engine against fire (Ślesicki, 2009). The simulations are carried out on a Konsberg Neptune ERS-MC90-IV simulator. It is a simulation of the engine room of a ship equipped with a two-stroke crosshead diesel engine MAN B&W 5L90MC possessing all auxiliary systems and equipment.

The simulated engine had the following equipment protecting the crankcase against explosion:

- An OMD recording oil mist concentration in the crankcase in real time;
- Temperature sensors for crank system bearings, directly recording the temperature of each bearing;
- A propulsion control system, *Autochief*, acquiring the information from the sensors and protecting the engine by means of a slow-down, shut-down and load-limit function.

The conditions of a fully loaded ship running ahead with an engine speed of 74/min were simulated. The starting conditions (00:00:00 hrs) of the crank system are shown in Figure 2. The temperature of all bearings was normal.



T02261 [54.87] (degC): ME cyl 5 crankpin bearing temp

Figure 2. Working parameters of the crank system – starting conditions

During an exercise performed by means of the engine room simulator, a decrease in the capacity of lubrication of the main bearings in the main engine was simulated. After simulating the malfunction, the behavior of the OMD in the crankcase was observed, together with the temperature of main bearings and reactions of *Autochief* protecting the engine against a serious failure. Two cases reflecting selected exploitation states were analysed:

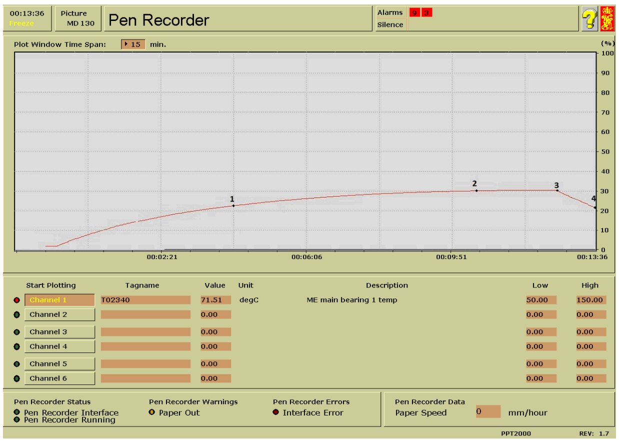
- The seizure of the main bearing during normal operation – a decrease in the capacity of lubrication of main bearing No. 1 in the main engine was simulated, all *Autochief* safety functions were off;
- The engine operation using highly contaminated lubricating oil and simulating extreme ignorance of the crew relating to the procedures of safe engine room operation.

Simulation of engine operation – scenario I

In scenario I, the capacity of lubrication of main bearing No. 1 decreased by 30% when it came to nominal conditions. The temperatures of all bearings in the main engine were recorded continuously (with a temperature monitoring system for the crank system bearings), together with the oil mist concentration inside the crankcase (with an OMD). *Autochief* fully controlled the engine operation. Figure 3 shows a temperature plot and particular moments when the alarm and/or safety system were activated.

Successively, the following events took place:

1. 00:03:34 hrs – as a result of insufficient lubrication, the temperature of main bearing No. 1 exceeded 72°C, which activated the high temperature alarm of main bearing No. 1;
2. 00:10:27 hrs – the temperature of main bearing No. 1 reached 80°C, the safety system activated the ME SLOW DOWN prewarning alarm;
3. 00:12:27 hrs – the temperature of main bearing No. 1 remained at the same level of 80°C, ME SLOW DOWN was activated by *AutoChief*;
4. 00:13:36 hrs – the speed decreased to 58 rpm, the load decreased and the temperature of the bearing dropped below 72°C, the high temperature alarm of main bearing No. 1 was deactivated.



Start Plotting	Tagname	Value	Unit	Description	Low	High
Channel 1	T02340	71.51	degC	ME main bearing 1 temp	50.00	150.00
Channel 2		0.00			0.00	0.00
Channel 3		0.00			0.00	0.00
Channel 4		0.00			0.00	0.00
Channel 5		0.00			0.00	0.00
Channel 6		0.00			0.00	0.00

Pen Recorder Status
● Pen Recorder Interface
● Pen Recorder Running

Pen Recorder Warnings
● Paper Out

Pen Recorder Errors
● Interface Error

Pen Recorder Data
Paper Speed 0 mm/hour

PPT2000 REV: 1.7

Figure 3. The temperature plot for main bearing No. 1 under scenario I (Ślesicki, 2009)

Figure 4 presents a simulator screen shot during the ME SLOW DOWN prewarning alarm activated by *Autochief,* while Figure 5 shows an ALARM LOG screen shot that took place in the simulation.

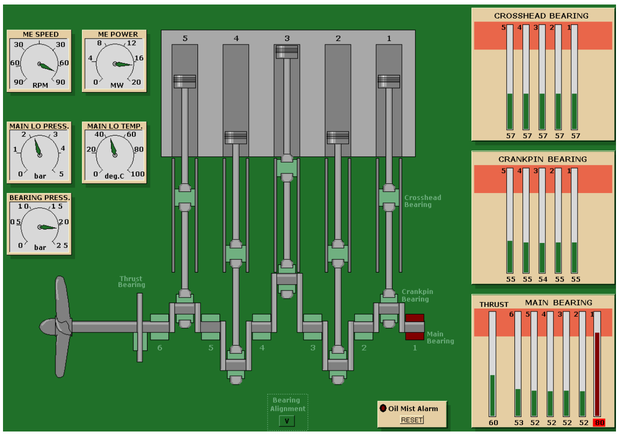
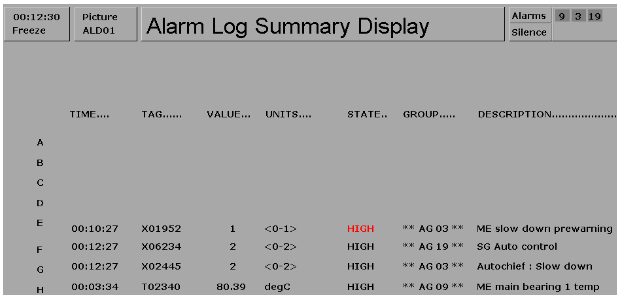


Figure 4. Prewarning Working parameters of the crank system – *Slow Down Prewarning*

In the simulation, the safety system protected the engine against serious damage. When a decrease in the capacity of lubrication of the main bearings in the main engine was simulated, the bearing temperature increased up to 80°C and then rose only insignificantly. *Autochief* initiated the main engine slow down before the bearing reached a temperature sufficient to form oil mist in the crankcase, which might have been registered by an OMD.

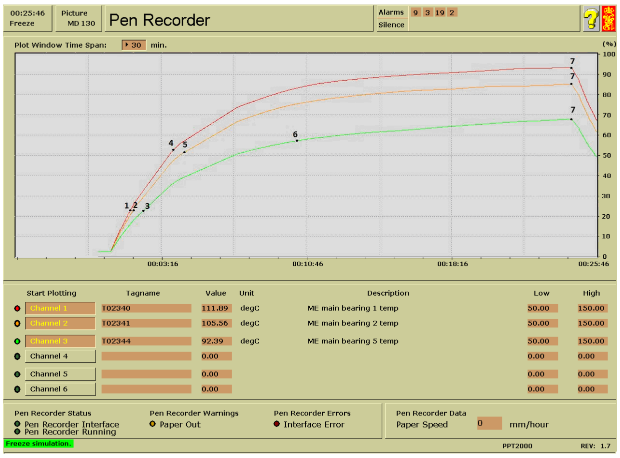


	TIME....	TAG......	VALUE...	UNITS....	STATE..	GROUP.....	DESCRIPTION..................
A							
B							
C							
D							
E	00:10:27	X01952	1	<0-1>	HIGH	** AG 03 **	ME slow down prewarning
F	00:12:27	X06234	2	<0-2>	HIGH	** AG 19 **	SG Auto control
G	00:12:27	X02445	2	<0-2>	HIGH	** AG 03 **	Autochief : Slow down
H	00:03:34	T02340	80.39	degC	HIGH	** AG 09 **	ME main bearing 1 temp

Figure 5. The alarm list under scenario I

Simulation of engine operation – scenario II

In scenario II, the decreased capacity of lubrication was simulated for: main bearing No. 1 (decrease of 90%), No. 2 (80%) and No. 5 (60%). Additionally, all engine protection systems initiated by *Autochief* were switched off. Figure 6 shows the temperature plots for main bearings No. 1, 2 and 5 and particular moments when the alarm and/or the safety system were activated.



Start Plotting	Tagname	Value	Unit	Description	Low	High
Channel 1	T02340	111.89	degC	ME main bearing 1 temp	50.00	150.00
Channel 2	T02341	105.56	degC	ME main bearing 2 temp	50.00	150.00
Channel 3	T02344	92.39	degC	ME main bearing 5 temp	50.00	150.00
Channel 4		0.00			0.00	0.00
Channel 5		0.00			0.00	0.00
Channel 6		0.00			0.00	0.00

Pen Recorder Status
● Pen Recorder Interface
● Pen Recorder Running

Pen Recorder Warnings
● Paper Out

Pen Recorder Errors
● Interface Error

Pen Recorder Data
Paper Speed 0 mm/hour

Freeze simulation.

PPT2000 REV: 1.7

Figure 6. The temperature plots for main bearings No. 1, 2 and 5 under scenario II (Ślesicki, 2009)

Successively, the following events took place:

1. 00:01:46 hrs – the temperature of main bearing No. 1 exceeded 72°C, the alarm went off;
2. 00:01:49 hrs – the temperature of main bearing No. 2 exceeded 72°C, the alarm went off;
3. 00:02:14 hrs – the temperature of main bearing No. 5 exceeded 72°C, the alarm went off;
4. 00:03:45 hrs – the OMD signals high concentration of oil mist in the crankcase, compartment of

main bearing No. 1, and the temperature of bearing No. 1 equals 104°C at that moment. Seven seconds later, the general alarm was activated that warned of oil mist in the crankcase;

5. 00:04:15 hrs – the OMD signals high concentration of oil mist in the crankcase, compartment of main bearing No. 2, and the temperature of bearing No. 2 equals 102°C at that moment;
6. 00:07:05 hrs – the OMD signals high concentration of oil mist in the crankcase, compartment of main bearing No. 5, and the temperature of bearing No. 5 equals 108°C at that moment;
7. 00:24:24 hrs – an explosion in the crankcase, the simulator informs very serious engine damage.

Figure 7 presents a simulator screen shot during the high oil mist concentration alarm, while Figure 8 shows an ALARM LOG screen shot that took place in the simulation.

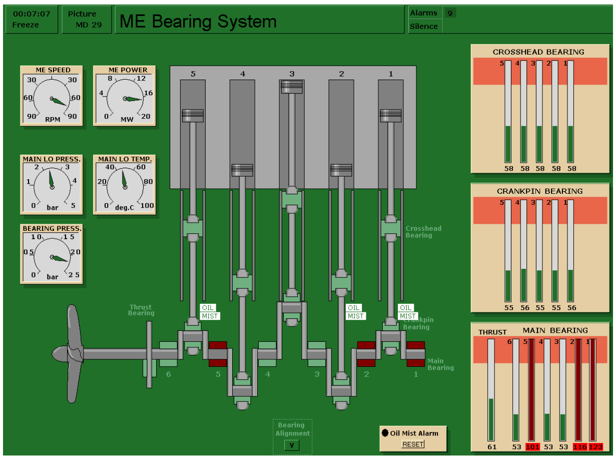
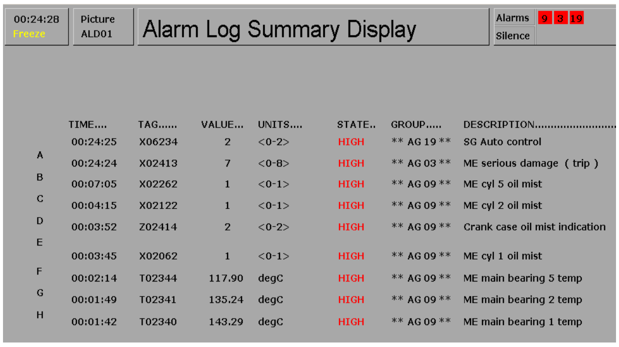


Figure 7. Working parameters of the crank system – the alarm of high oil mist concentration in the crankcase activated, compartments of bearings 1, 2 and 5



```
      TIME....   TAG......  VALUE...  UNITS....   STATE..  GROUP.....    DESCRIPTION........................
      00:24:25   X06234        2      <0-2>       HIGH     ** AG 19 **   SG Auto control
 A
      00:24:24   X02413        7      <0-8>       HIGH     ** AG 03 **   ME serious damage  ( trip )
 B
      00:07:05   X02262        1      <0-1>       HIGH     ** AG 09 **   ME cyl 5 oil mist
 C
      00:04:15   X02122        1      <0-1>       HIGH     ** AG 09 **   ME cyl 2 oil mist
 D
      00:03:52   Z02414        2      <0-2>       HIGH     ** AG 09 **   Crank case oil mist indication
 E
      00:03:45   X02062        1      <0-1>       HIGH     ** AG 09 **   ME cyl 1 oil mist
 F
      00:02:14   T02344     117.90    degC        HIGH     ** AG 09 **   ME main bearing 5 temp
 G
      00:01:49   T02341     135.24    degC        HIGH     ** AG 09 **   ME main bearing 2 temp
 H
      00:01:42   T02340     143.29    degC        HIGH     ** AG 09 **   ME main bearing 1 temp
```

Figure 8. The alarm list under scenario II

In the simulation of scenario II, the lubrication capacity was much lower than in scenario I. Additionally, the decrease of lubrication capacity concerned three out of the five main bearings. It reflects improper maintenance of the crank system components as well as lack of care for the circulating oil purification. The sensors recorded bearing temperatures continuously and the safety system signalled the bearing malfunction when the preset temperature of 72°C was exceeded. No reaction from the safety system that was switched off entailed an increase of bearing temperature, and successively, oil mist concentration. The OMD signalled high oil mist concentration two minutes after the alarm of high temperature of bearing No. 1 set off. In the case of bearing No. 5, for which the simulated decrease of lubrication capacity was smaller, the OMD registered high oil mist concentration much later. The temperature of every bearing exceeded 100°C when oil mist was detected around them by the OMD. The explosion of oil mist in the crankcase occurred 20 minutes after the alarm of high concentration of oil mist was activated by the OMD.

Conclusions

There is no doubt that simulators are the safest and the least expensive form of training and testing. Moreover, they have appropriate software to simulate the operation of different types of engines and analyse hazardous situations leading to loss of life or undermining the health of the crew during normal operation of the ship. Such an approach helps to realise the consequences of seemingly unconnected events during engine room operation. Neither a laboratory nor any ship can provide such possibilities.

The scenarios described above might well be used to train marine officer engineers and make them aware of a cause and effect chain of events leading to a safety hazard, causing explosions in the crankcase and teaching the function of main engine auxiliary systems.

As a result of simulations, students get to know that temperature sensors make it possible to locate quickly and exactly where the operational conditions for the crankcase bearing are abnormal and let them protect the engine against an explosion (Wärtsilä, 2009; Kongsberg, 2015). The OMD, on the other hand, identifies problems only in the crankcase internal space but it works well when bearing damages are really serious and big amounts of oil mist are formed in a relatively short time (Kidde, 2005; Wärtsilä, 2006). Besides, the OMD protects the engine against an explosion in a situation when oil mist is not generated by bearings (it applies for over 50% of all explosions in crankcases what is connected with improper operations of the stuffing box or fire in the crankcase or around the engine (Smith, 2001)).

Acknowledgments

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References

1. Chybowski, L. & Grzebieniak R. (2009a) Method of marine diesel engine starting air valves technical state evaluation. *Ekonomika i Organizacja Przedsiębiorstwa*. 5 (712). CD-ROM (in Polish).
2. Chybowski, L. & Grzebieniak, R. (2009b) The method and the system for diagnosis of diesel engine starting valves, especially the marine version. Patent No. 217302. Polish Patent Office, 19.03.2009.
3. Chybowski, L. & Grzebieniak, R. (2009c) Explosion threat in starting air system of marine diesel engines. *Ekonomika i Organizacja Przedsiębiorstwa*. 5 (712). CD-ROM (in Polish).
4. Chybowski, L. & Idziaszczyk, D. (2014) Is design thinking useful in educating engineers? In Milewska, E. & Żabińska I. (Eds.). *Systemy Wspomagania w Inżynierii Produkcji. Inżynieria Systemów Technicznych*. Gliwice: P.A. NOVA. pp. 43–55 (in Polish).
5. Chybowski, L. (2014) Components Importance Analysis in Complex Technical Systems. Instytut Technologii Eksploatacji – Państwowy Instytut Badawczy. Radom: Wydawnictwo Naukowe ITE-PIB (in Polish).
6. Chybowski, L., Laskowski, R. & Gawdzińska, K. (2015) An overview of systems supplying water into the combustion chamber of diesel engines to decrease the amount of nitrogen oxides in exhaust gas. *Journal of Marine Science and Technology*. Springer [DOI: 10.1007/s00773-015-0303-8].
7. Hoerbiger (2015) Hoerbiger Explosion Relief Valves: Optimum Protection Against the Effects of Oil Mist and Gas Explosions. [Online] Available from:
8. Holness, M. (2005) Oil Mist Detection In The Atmosphere Of The Machine Rooms. New Regulations for Atmospheric Oil Mist Detection. *Marine Propulsion Conference in Bilbao*. http://www.hoerbiger.com/upload/file/ev_oil_mist_en.pdf. [Accessed: 07th February 2015].
9. Kidde Fire Protection Services LTD (2005) Graviner Mk 6 Oil Mist Detector. Installation, operation and maintenance manual.
10. Kongsberg Maritime (2015) BearingMaster. A complete standalone alarm and monitoring system for bearings in slow-speed diesel engines. [Online] Available from: http://www.km.kongsberg.com [Accessed: 07th February 2015].
11. Laskowski, R., Chybowski, L. & Gawdzińska, K. (2015) An engine room simulator as a tool for environmental education of marine engineers. *New Contributions in Information Systems and Technologies. Advances in Intelligent Systems and Computing*. 354, Springer International Publishing, pp. 311–322.
12. Marine diesels (2015) Horror Stories. [Online] Available from: http://www.marinediesels.info [Accessed: 07th February 2015].
13. Nowosad, G. (2009) *Explosion protection of crankcases in modern marine combustion engines*. BSc thesis supervised by Leszek Chybowski. ITESO, Faculty of Marine Engineering, Maritime University of Szczecin, Szczecin.
14. Patejuk, K. (2011) *Explosion protection of crankcases in the low-speed main engines*. BSc thesis supervised by Leszek Chybowski. IESO, Faculty of Marine Engineering, Maritime University of Szczecin, Szczecin.
15. Piotrowski, I. & Witkowski, K. (1996) *Marine combustion engines*. Gdynia: Trademar (in Polish).
16. Rozmarynowska, M. (2012) Global economic crisis and its implications for maritime trasnportation. *Studies of the Faculty of Navigation of Gdynia Maritime University*. 27. pp. 21–34.
17. Schaller (2015) Crankcase Explosions in Two-stroke Diesel Engines. MAN B&W Diesel A/S. [Online] Available from: http://www.schalleramerica.com/pdf/documentation-other/21.pdf. [Accessed: 07th February 2015].
18. Schaller Automation (2005) ABC handbook for all VISATRON oil mist detector user's.
19. Ślesicki, O. (2009) *An analysis of fire and explosion protection in RTA Sulzer engines*. BSc thesis supervised by Leszek Chybowski. ITESO, Faculty of Marine Engineering, Maritime University of Szczecin, Szczecin.
20. Smith, B. (2001) Oil Mist Detection as an Aid to Monitoring an Engine's Condition. QMI Multiplex.
21. Wärtsilä (2006) Service Bulletin Technical Information to all Owners / Operators of Sulzer RTA and RT-flex Engines Graviner Mk 6 Oil Mist Detector Sample Probe Exchange.
22. Wärtsilä (2009) Big end bearing temperature monitoring system. Technical bulletin.
23. Wärtsilä NSD Switzerland LTD (1998) Drains from Piston Underside. Piston Rod Gland Box and Air Receiver. Service Bulletin.
24. Żółkiewski, S. & Pioskowik, D. (2014) Robot control and online programming by human gestures using a kinect motion sensor. *Advances in Intelligent Systems and Computing. New Perspectives in Information Systems and Technologies*. 275. Springer. pp. 593–605.