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Ship fires caused by primary failure of the fuel filter of the engine driving the generator

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Abstract

This article presents selected results of investigations on adverse events of ships throughout one year. The investigations included mainly merchant vessels used to transport bulk material and heavy objects. Ships have been divided into functional systems and elements and into navigational and machine parts. An attempt was made to classify the causes of accidents and evaluate material losses. The quantitative analysis of the causes of the events leads to different conclusions than those reached on the basis of the analyses of losses. Although the failures on-board the vessel occurred more frequently, the costs of machine adverse events were larger. The most critical consequences was fire of a ship caused by loosening of the bleed screw of the fuel filter. Auxiliary engines of the vessel were operated in different external and internal conditions, and were fed by distillation fuel. As a consequence, the evacuation of the crew and fire suppression were required, using the CO_2 installation of the ship. The ship was stopped and deprived of its primary sources of electric energy. An analysis of the event was along with the elaboration of a plan of preventive measures. The results should be useful for selecting the monitored diagnostic objects of vessels.

Introduction

The number of adverse events at sea is still high, although it maintains a long-term downward trend and ships can be considered to be increasingly safe (Brandowski, 2003; Szopa, 2009; Gerigk, 2010; Adamkiewicz, 2014). Despite the use of sophisticated diagnostic systems, adverse events concerning ships and their equipment are still verified, involving the crew and surrounding environment. An operator (navigator or engineer) is still taking the final decision and bears responsibility for the consequences. Sea ships are ranked among technical complex objects, for which control operations use indicators of reliability and safety (Gerigk, 2010). The safety of ships depends on the qualification of personnel and reliability of systems.

Risk is the possibility of the emergence of losses of goods as the result of incorrect functioning of a fragment of the overall system formed by man, technology and the environment at a specified time (Rosochacki & Pijanowski, 2012). The working environment can, in some cases, represent a threat for man.

In investigations of the safety of machinery, a risk analysis is significant. Determining the accurate level of technical risk is understood to be an important factor in economic enterprises and the inherent technical activities (PN-EN ISO 12100, 2011). Maritime safety includes the state of sea conditions, where the risk to health, property and the environment does not exceed the acceptable level of risk (Kopacz, Morgaś & Urbański, 2006).

Hazards are classified in terms of their origin or from the point of view of the nature of the potential damage. The following types of sea adverse events were singled out (PRS, 2002; Kopacz, Morgaś & Urbański, 2006): collisions, contact, fire, explosion, loss of integrity of the hull, sinking, input on stranding, no operation of the object, accidents involving power plant equipment, cargo-related accidents, accidents with dangerous substances, accidents with people.

The hazard is the possibility of the loss of protected goods, which arises due to the occurrence of single adverse event in the system man – engineering – environment or chain of successive interrelated events (Rosochacki & Pijanowski, 2012). The result of accidental events can include: deaths, injuries, loss of the ship or its failure, loss of or failure of other property, damage to the environment. The significance of the damage is determined according to the criteria of safety, performance of a task, and expenses required to repair a failure (financial, labour costs, materials) (Szopa, 2009).

Man, technique and the environment are interrelated, and their state depends on the quality of their interactions (Woropay & Bojar, 2007). External influences at sea include storms, impact of waves, ice sheets, hidden underwater objects, and other ships. With regards to technical objects, sources of risk are, for example, dangerous substances, potential sources of ignition, and electrical discharges.

One of the criteria of quality ship construction is reliability (Tarełko, 2011). Reliability is one of the characteristics of ships and one of the factors ensuring the proper functioning of the ship, guaranteeing the safety of people, cargo, and floating object and the accomplishment of tasks (Girtler, Kuszmider & Plewiński, 2003; Tarełko, 2011).

In the operation of ships it is possible to incur in situations that are normal, complicated, dangerous, emergencies or catastrophic (Girtler, Kuszmider & Plewiński, 2003). Catastrophic failure is a sudden damage causing the total inability of the object to perform all the required functions. The occurrence of different situations during the operation of the vessel depends on the condition of the crew and technical environment. The following factors affect the correct operating of the ship and the safety of the navigation (Perkis & Inözü, 1990; PRS, 2002; Girtler, Kuszmider & Plewiński, 2003):

- correct navigation − maintaining the recommended route of navigation, adapting speed and vessel course to weather conditions and routes (narrow waters, intensive motion, etc.), ensuring the stability and buoyancy of the vessel;
- reliability of equipment and systems − particularly the main, auxiliary, and emergency drives of the ship;
- safety of the cargo − keeping conditions in accordance with shipping requirements.

Exemplary methods of the safety investigations of floating objects

In the analysis of adverse events affecting complex technical objects, such as sea ships, it is necessary to conduct qualitative analyses using the methods of assessment of risk, threat and operational capabilities, kinds and effects of failures, along with quantitative analyses of the methods, e.g., probabilistic, human reliability, tree of mistakes, tree of event.

The International Maritime Organization (IMO) has developed and published uniform rules of conduct for Formal Safety Assessment (FSA) and committed all the sea states that are members of the IMO to apply these principles (PRS, 2002; Girtler, Kuszmider & Plewiński, 2003; Kopacz, Morgaś & Urbański, 2006; Kontovas & Psaraftis, 2009). An example of such a document developed for the safety of bulk carriers IMO is MSC74/5/x, which concerns the integrity of the hull of bulk carriers (PRS, 2002).

The FSA constitutes a methodology whose aim is to enhance maritime security, including protection of life, health, property and the marine environment through the application of uniform rules, analysis and risk assessment, and the assessment of costs and benefits associated with lowering risks to the accepted level. This is achieved by developing a risk matrix, describing the individual levels of risk (Radkowski, 2006).

Safety investigation methods make use of artificial neural networks, and Taguchi and multi-criteria approach to decision-making (Gerigk, 2010). For the estimation of risk, the following criteria can be adopted (Gerigk, 2010):

- matrix of risk acceptance;
- the “as low as reasonably practicable” (ALARP) concept;
- F-C (frequency − consequence) curve concept.

The probability of non-survival as a consequence of vessel collision can be determined by one of four methods (Gerigk, 2010): zero-one, statistic methods based on the definition of the probability of complete survival of the vessel to collision, methods based on the assessment of the behaviour of the ship in the damaged state and identification of the characteristics of a stochastic process of lateral oscillations of the ship in damaged state, methods based on the use of fuzzy set theory. Controlling the level of risk is necessary to design, monitor and influence their significance. The level of risk may be (PRS, 2002): acceptable, moderate or not acceptable.

Many works indicate that the marine power plant is a dangerous space within the machine room of the ship; therefore, to increase the safety of the operator, the International Maritime Organization has developed relevant documents (Monieta, 2013; 2015; Adamkiewicz, 2014). Requirements for control systems of main drives are determined by regulations of classification societies. Reliability machinery and marine equipment are varied according to destination, manufacturer, operating conditions and state of operators.

It is then necessary to estimate and analyse the reliability or unreliability of object in the power plant including, for example, the probability $P_i(\tau)$ of the specific event in time τ. For a direct estimate of the probability, $P_i(\tau)$, as well as of other tress of events, experimental investigations and analysis methods are applied.

Selected measures of safety

The science of safety is developing the aspect of principles and measures of the safety. The measure used to assess the safety is the risk of losses of objects. In order to carry out a risk assessment, one should adopt specific safety criteria, which may be qualitative or quantitative (PRS, 2002).

Risk (R) is a numerical quantity given by the product of the frequency of occurrence of an accident at sea (C) and the severity of its effect (S):

$$R = C \cdot S \tag{1}$$

The frequency of marine accidents (C) is understood as the number of marine accidents occurring per unit of time, e.g. in the year (Kopacz, Morgaś & Urbański, 2006). The risk of an accident is defined as the product of the probability of the risks, P_i, and consequences of the accident, K_i (Gerigk, 2010):

$$R_w = P_i \cdot K_i \tag{2}$$

In risk analyses concerning complex technical objects such as sea ships, different methods are being used for quality evaluations: the risks, threats and operational capabilities, types and effects of failures are determined on the basis of sample holistic models of technical risk for collisions (Vanem & Skjong, 2006; Gerigk, 2010).

The primary measure of safety is the size of the losses due to the occurrence of adverse events. For the test set of ships, the measure of the loss in the period of time (τ, $\tau + \Delta\tau$) are collective losses, referring to the group of vessels that can be presented in relative terms, and expressed as part of a unity or in percentages (Szopa, 2009; Monieta, 2015):

$$S_{zi} = \frac{S_i}{S(\tau, \tau + \Delta\tau)} \tag{3}$$

where: S_i are collective loss, due to the occurrence of the i-th adverse event in the period (τ, $\tau + \Delta\tau$), and

$$S(\tau, \tau + \Delta\tau) = \sum_{i=1}^{n(\tau, \tau+\Delta\tau)} S_i \text{, } n = 1,2, ..., \infty,$$

is the number of adverse events in this period.

Risks can be controlled by taking actions for their mitigation using an active (impact on the cause) or passive (protection against possible losses) approach. These measures should apply to the entire anthropotechnic system: man – technical object – environment.

The indicator of the relative significance of the factor-criterion, K_{ri} over K_{rj}, is expressed as the number a_{ij} (Downarowicz et al., 2000):

$$a_{ij} = \frac{e_i}{e_j} \quad \text{for} \quad i, j = 1,2,\ldots,n \tag{4}$$

where: e_i is the rank absolute criterion K_{ri} matrix; e_j is ruthless rank of the K_{rj} matrix, where $a_{ij} \in$ (1, 2, 3,..., n).

The equation of safety, defining the minimum probability of failure, can be written as (Radkowski, 2006):

$$Z = O_{b\dot{z}} - O_b \tag{5}$$

where: $O_{b\dot{z}}$ is the load capacity, for example durability; O_b is the load, for example stresses.

In a previous article (Adamkiewicz, 2014) the complexity of maintaining elements of the energy system of the ship was presented in terms of ensuring the safety of its operation and inadequate use of this risk analysis. The previously used strategies for maintaining the elements of power systems of ships in the risk analysis did not constitute supporting information in decision making. They are selected and considered as essential safety measures.

Objects and methodology of investigations

The objects of investigations were merchant ships of one selected ship owner throughout one year. The selected ships navigated in rivers, lakes, seas and oceans around the world. Determined threats were associated with the area of swimming. The ships were divided hierarchically, where functional systems and sub-assemblies were singled out (Monieta, 2013). In this period, 108 adverse events were registered. Observations of the adverse events and their consequences on the operation of ships have been made. Adverse events have been recorded by the ship owner's insurance and some were also considered by the marine chamber. Accidents involving the crews were also investigated, as described in a previous work (Monieta, 2006). The computer program Amos was used on ships a computer programs Amos were applied for the archiving of data.

Ships were divided in deck, machine parts, and functional systems (Monieta, 2013). Determined systems were assigned to the machine and deck crew. Disruptions in the production process of the ship include changing parameters of movement or detention of the ship, extension of time in port, stop in shipyard, or temporary withdrawal from operation. External conditions such as air humidity, air temperature, air pressure, pollution, biotic hazards (in terms of plant, animal and bacterial microflora), swimming conditions, horizontal visibility, terrain swimming, sea state, direction of the wind, immersion and state of covering of the body, varied considerably.

The ship, on which the catastrophic adverse event occurred, was of type B 542. It was the handysize ship type with a capacity of 33,780 t, deadweight built in the national shipyard in 1986. The vessel was driven by a slow-speed engine and three engines driving the generator 6AL20/24 type with the parameters listed in Table 1.

Table 1. Specifications of the 6AL20 engine

No.	Engine type	AL 20
1	The type of structure	In-line engine
2	Bore	200 mm
3	Piston stroke	240 mm
4	Stroke volume	0.007540 m^3
5	Compression ratio	1:12.7
6	Rated engine speed	750 min^{-1}
7	Rated power	70 kW/cyl.
8	Brake mean effective pressure	1.5 MPa

The up state of the object is the state in which it can carry out tasks in accordance with the requirements under the specific impact of the environment (Girtler, Kuszmider & Plewiński, 2003; Tarełko, 2011). Systems and assembly ships are assigned to use or operate the machine and crew members on board, in individual stations. The tasks were carried out by the ship's crew in accordance with the certificate of safe manning.

Selected results of investigations

The analysis of adverse events of the merchant vessels were used in selected measures of safety (risk) and economic (the size of losses and harms) consequences of adverse events (Kontovas & Psaraftis, 2009; Rosochacki & Pijanowski, 2012; Monieta, 2013; 2015), including the number of failures, the off-time of operational use, repair time and cost of repair.

The analyses include an estimate of the consequences of accidents to property and the environment. The collective losses due to adverse events, S_{zi}, defined by formula (4), were three times larger in the deck than in the marine propulsion plant (Kontovas & Psaraftis, 2009; Monieta, 2015). This does not mean, however, that the focus should be only on deck objects. Figure 1 shows the maximum collective losses due to individual events occurring in one year. The difficulty in estimating the losses was related to quoting the costs of the events estimated in various currencies. Therefore, calculations were carried out in a common currency, taking into account the dynamics of exchange rates.

Figure 1 shows that a few initiating events (primal events in the sequence of events leading to the accident) led to large collective losses. The greatest loss, and the third in temporary order, was caused by the fires. The second largest collective loss arose as the result of the collision. The losses were calculated with different currencies, depending on the location of the incident and repair. At that time, the PLN was also changed significantly. The event causing the largest losses in the main drive was not considered until the end, while the third event was the most dangerous and required the evacuation of the crew.

The third event was described in terms of collective losses. The fire was the result of the loosening of a vent cork of the fuel filter of the internal-combustion engine driving the generator. As a result of

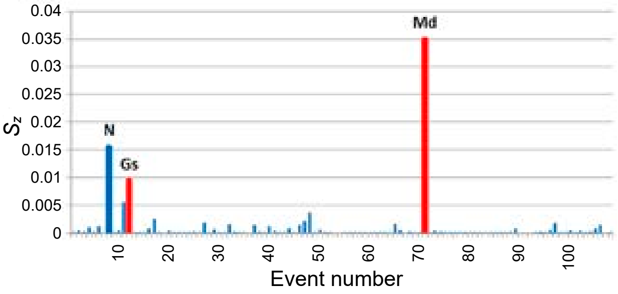

Figure 1. Collective losses of individual adverse events, where adverse event were initiated in the system: N – navigation, Gs – generating station, Md – main drive

the fire, the crew was evacuated and fire suppression was required from the CO_2 installation of the ship. In view of the catastrophic nature of the event, it was analysed in the present study. The view of the auxiliary engine from the side of the filter of fuel is showing Figure 2.

Figure 2. View of an auxiliary engine from side of the fuel filter on the ship from the series B-542: 1 – fuel filter, 2 – filter cover, 3 – turbocharger

The event happened around 22:00. After the alarm system set off, the fire was found in the auxiliary engines room. There was a strong spread of fire in the generating sets compartment and upwards, following the ventilation system. This was the reason for which the crew decided to discharge CO_2 gas into the engine room. As a consequence of the fire and the resulting destructions, the ship was immobilized and deprived of the main sources of electricity.

After towing the ship to the port, the local shipyard conducted the service after the fire under the supervision of the classification society. The cause of the fire, according to the decision of maritime chamber, was flow of the fuel from the filter of auxiliary engine No. 1 to the turbine of the turbocharger. Costs of the event were refunded by the institution with which the ship was insured.

Conclusions

This article established the identification of sources causing threats to the security of the transport system of a ship owner as the result of failures of technical objects. The greatest losses have been caused by fires of components of the marine propulsion plants. Fires and failures of the propulsion system of ships lead to major losses, so they should be kept to the minimum. The examples of adverse events were described, with a particular focus on essential losses and influence on the safety of the crew and the environment. Initiated fires were detected too late, not extinguished in the bud and led to large losses.

Based on the results of the evaluations, neither the quantitative nor the economic analyses were satisfactory. Some of the frequently occurring adverse events bring small losses, and the outcome of the economic analysis depends on market situations and exchange rates. It is therefore necessary to seek measures that account for the threat and risk. Managing the safety of floating objects is based among other things on risk assessment and on risk management. Set rates of the risk of sea ships should be of help for developing the strategy of the operation and the method of keeping the technical state. Application of scientific research immediately after the adverse events, especially of the diagnostic genesis, should bring useful information.

Credible diagnosis should be used to monitor teams that faced large losses, especially as a result of fire hazards. The improvement in the state of anti-collisions systems is also recommended, because of the large frequency of collisions in the navigation.

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