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A CONCEPT OF DETERMINING THE RELATION BETWEEN LOAD AND WEAR OF TRIBOLOGICAL SYSTEMS OF SHIP MAIN SELF-IGNITION ENGINES BY USING PROBABILISTIC APPROACH

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ABSTRACT

This paper presents a proposal of simultaneous consideration of load and wear associated with it , of tribological systems of ship main engines (intended for ship propulsion) . Based on results of investigations it was assumed that both the load Q (i.e. a cause of wear) and the wear Z (i.e. an effect of load occurrence) considered in a given time t ($0 \le t \le t_n$) are random variables Q_t and Z_t ,respectively. There was characterized operational principle of ship main engines in definite external conditions (WZ) as well as consequences of excessive load of engines. Three hypotheses highlighting relations existing between load and wear of the above mentioned systems, have been proposed. The first of them deals with explanation of stochastic relation between load and wear, the second highlights why it is possible to assume that the load Q_t and the wear Z_t are positively correlated , and the third – why it is possible to assume that coefficient of correlation between Q_t and Z_t may be taken close to one.

Keywords: combustion engine load, probability, stochastic process, self-ignition engine, random variable, statistical relation, stochastic relation

INTRODUCTION

Durability and reliability of any ship main engine depend first of all on wear of its crucial tribological systems such as main and crankshaft bearings as well as friction pairs of pistons and cylinder liners. Many factors affect such systems, but thermal and mechanical load applied to them [5, 11, 12, 13, 16, 18, 28, 29] are most important. Especially unfavourable effect onto wear of the systems results from excessive load generated during ship voyage in stormy weather conditions. Such loading may lead to extensive failures of the tribological systems of ship main engines in question, called damages [4, 12, 18, 27, 29]. It mainly concerns pistons and cylinder liners when the engine is forced to work with maximum output as well as main and crankshaft bearings in case when maximum combustion pressure values reach 18MPa and more and the mean pressure rate of rise ($\varphi_{p(śr)}$) exceeds 1,2MPa/°OWK [18. 21, 22]. There is possible to predict an excessive wear of elements of the engines in question and consequently their failures by applying appropriate diagnosing systems intended for the generating of complete diagnoses, i.e. such which cover also a forecast of their technical state. The working out of such forecast requires a. o. to determine loads which may appear during service of the engines. Today the loads of combustion engines are usually analyzed by using deterministic approach, and less often – probabilistic one. In the last case they are very simplified and as a rule limited only to statistical analyses with application of point estimation of their expected values [1, 2, 11, 14, 17, 18, 23]. However, loads on ship combustion engines are random variables appearing in determined instants t which are not random variables. Therefore the loads considered in subsequent instants t ($0 \le t \le t_n$) as the random variables Qt form the loading process $\{Q(t) : t \geq 0\}$. Hence during their examination it is necessary to take into account that the loads following in succession form the stochastic process $\{Q(t) : t \geq 0\}$ whose values are the above mentioned random variables Q_t [1, 2, 4, 16, 29, 30]. Taking into consideration the random features of loads on ship combustion engines it is worthwhile initiating actions leading to determination of probabilistic relations between load and wear of the tribological systems in question, resulting in consequence of acting loads. Hence, the wear of such systems should be considered to be the stochastic process $\{Z(t) : t \geq 0\}$ whose values in arbitrary instants t $(0 \leq t \leq t_n)$ are the random variables Z_t. As results from investigations, it is not possible to unambiguously determine values of wear (random variable Z_t), if value of random variable Q_t is known. It is necessary to assume that a stochastic relation exists between randomly varying loading (Q_t) and wear (Z_t), in an arbitrary instant t.

CAUSES AND CONSEQUENCES OF RANDOM VARIABILITY OF LOADING

The ship main engine (1) is able to transfer, by the propulsion shaft (2), kinetic energy from the screw propeller (3) whose task is generating the demanded thrust force T (Fig. 1). The force depends on the effective power (N_e) produced by the engine (1), and its rotational speed (n), hence also – on the rotational speed of screw propeller and ship hull resistance [20, 24, 25, 29]. The resistance overcome by the propeller thrust force T depends on the external conditions WZ (Fig. 2) randomly varying in a given instant t, and formed by such random factors as [6, 19, 25, 29]:

1) hydro-meteorological conditions: wind force and direction as well as sea state (height, length, speed and propagation direction of waves),
2) features of water area: its breadth and depth, the lay and kind of seabed (rocky, sandy),
3) kind of ship voyage: free moving, towing a ship,
4) ship hull position against water surface: draught, trim, heel,
5) state of underwater surface of ship hull: fouling of hull surface and its wear.

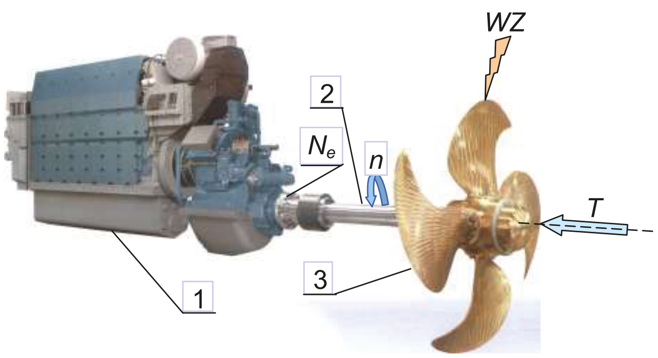

Fig. 1. Image of a ship propulsion system without reduction gear: 1 – ship main combustion, self-ignition engine, 2 – propeller shaft, 3 – screw propeller, N_e –effective power of the engine, n – rotational speed of the engine, WZ – external conditions, T – thrust force.

Energy conversion in working spaces of the ship main engine is aimed at developing the demanded effective power N_e as well as the rotational speed n of the engine and reaching such value of the propeller thrust force T in a given external conditions as to ensure a demanded speed of the ship. Large values of loads Q (mutually implicating thermal and mechanical ones) of engine tribological systems are then generated. The loads depend on ship speed and external conditions (mainly hydro-meteorological) in which transport tasks of the ship are executed. With increasing the rotational speed (n) of the engine and its effective power (N_e) and getting the external conditions (WZ) worse, the load on the engine increases. It is clearly illustrated in Fig. 2 where main engine speed characteristics (external, screw-propeller and governor ones) are presented. They made it possible to show an example change in the effective power (N_e) of the engine and its rotational speed (n) in accordance with the governor characteristics (NR_{nom} = idem). According to the characteristics, the power N_e and speed n will undergo a change from the point A to point B when the external conditions get worse from the state WZ_2 into WZ_3. In the case when the conditions (WZ) get better from the state WZ_2 into WZ_3, the engine power N_e and its rotational speed n will be determined by the point C. The above mentioned screw-propeller characteristics may be interpreted as follows: the external conditions WZ_3 are deemed the heaviest ones (stormy weather), WZ_2 – deal with less harsh ones, and WZ_1 – favourable conditionswhich may be formally written in the form of the inequality: $WZ_3 > WZ_2 > WZ_1$. Both the engine power N_e, and its rotational speed (n) are random variables which characterize its loading [6, 7, 25, 29].

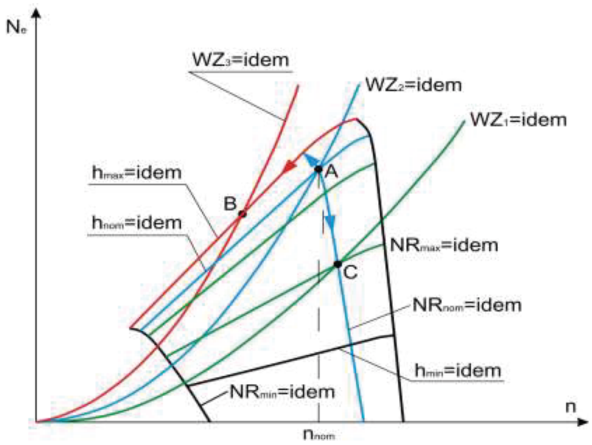

Fig. 2. Example characteristics of the main engine, which illustrate changes in engine load according to the governor characteristics NR_{nom} = idem: N_e – engine effective power, n – engine rotational speed, WZ – external conditions ($WZ_3 > WZ_2 > WZ_1$), NR_{min} – minimum setpoint of the governor, NR_{nom} – nominal (rated) setpoint of the governor, NR_{max} – maximum setpoint of the governor, h_{max} – maximum setpoint of the injection pump, h_{nom} – nominal (rated) setpoint of the injection pump, h_{min} – minimum setpoint of the injection pump, n_{nom} – nominal (rated) rotational speed of the engine.

In external conditions (WZ) varying from the most favourable (WZ_1) up to stormy ones (WZ_3), engine-propeller interaction within the range shown in Fig. 2 will run from the point B to A and back in compliance with the governor characteristics NR_{nom} = idem [4, 20, 24, 25, 29,].

Ships very rarely sail in calm water. Usually during voyage ship rolling appears due to wind and wave action and in consequence many unwanted and dangerous phenomena follow, such as: drop of ship's speed and rise of ship hull resistance in waves, shipping of water, screw propeller emerging etc. This leads to increasing load on main engines and often their overloading which results in failures of their tribological systems, especially the cylinder liner-piston systems and rings as well as crankshaft bearings and crossheads [12, 30, 31]. Examples of such failures in ship main slow-speed large-output engines are presented in Fig. 3 ÷ 6.

Fig. 3. shows the damaged surface of piston and its sealing rings due to excessive friction wear of piston ring surface and significant damage of piston rings.

Fig. 3. Image of a piston damaged due to excessive friction wear of piston ring surface and significant damage of piston rings [30]

Fig. 4. shows the damaged surface of cylinder liner due to an excessive friction wear resulting from the seizing of piston in the cylinder.

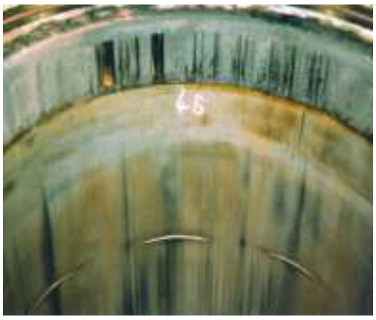

Fig. 4. Image of the damaged surface of cylinder liner due to an excessive friction wear resulting from the seizing of piston in the cylinder [30]

Fig. 5. presents the damaged surface of crosshead pin resulting from an excessive wear due to friction and corrosion.

Fig. 5. Image of the damaged surface of crosshead pin resulting from an excessive wear due to friction and corrosion [30]

Fig. 6. illustrates the damaged surface of sliding coat of crank-end bearing sleeve due to its excessive friction wear.

Fig. 6. Image of the damaged surface of sliding coat of crank-end bearing sleeve due to its excessive friction wear [30]

Such damages endanger safety of ship at sea, especially when it executes transport tasks in stormy weather conditions. In the conditions extensive waving occurs, that makes keeping the proper course by the ship difficult. Therefore, the damages of the so crucial tribological systems as the crankshaft and crosshead system bearings and piston-ring-cylinder – liner friction pairs are, do not allow to deliver an appropriately large amount of power to the screw propeller. As a result, the screw propeller is not able to produce the demanded thrust force T. Lack of the force leads first to loss of course keeping (ship's capability of ensuring desirable direction of motion, e.g. perpendicular to wave direction) and then to its possible capsizing and sinking. Such situations may be prevented only in case of application of appropriate algorithms for prediction of technical states of the above mentioned tribological systems. However, such algorithms must have programs containing relations between wear of tribological systems of main engine and its load [3, 15, 28, 30].

RELATION BETWEEN WEAR OF TRIBOLOGICAL SYSTEMS OF MAIN ENGINE AND ITS LOAD

During ship voyage the external conditions *WZ* are varying (Fig. 2), and in extreme case, stormy weather conditions may be encountered. Fig. 7 illustrates such heavy weather conditions in which a ship continues navigation.

Fig. 7. Illustration of sea state in which a ship continues navigation

Random features of load and wear of a. o. tribological systems of ship main engines and their impact onto change of their technical state are generally presented in [8]. There was possible to demonstrate that the theory of semi-Markov processes may be applied to working out a four-state model of changes in technical states of the engines in question, which are crucial for safety of the entire ship. However, for diagnostic purposes to present more strict relations between load and wear of the engines is necessary. First of all, to formulate such relations there should be taken into account the fact that between the load Q and the wear Z mutual cause-effect relations do exist. For instance, the load Q (as a cause) results in the wear Z (i.e. an effect), but when it is important not to allow for occurrence of a failure in a tribological system (hence in the engine itself), then the wear Z (being now a cause) forces the engine's operator to mitigate the load Q (being now an effect). Because of the randomness of the load, the wear Z of tribological systems shows also random nature [9].

Interpretation of the wear occurring in such systems is presented in Fig. 8, based on Lorence curve [8, 28].

In Fig. 8. there are presented with thin lines various wear realizations $z(t)$ of five tribological systems, according to the publications [3, 9, 10, 12, 16, 23, 27]. As results from this figure, in an arbitrary instant t the wear of such systems is the random variable Z_t. Therefore, to every instant t, the random variable Z_t of the expected value $E(Z_t)$, depending on t-value, can be attributed. It means that the wear considered in function of time t is the random function $Z(t)$ forming a set of the random variables Z_t. The function is hence the stochastic process $\{Z(t)$: $t \geq 0\}$. The expected value $E[Z(t)]$ of the process is distinguished with bold line in this figure. The value is determined by a set of the expected values $E(Z_t)$ for every instant t. Worth mentioning that the expected value $E[Z(t)]$ of the stochastic process $\{Z(t)$: $t \geq 0\}$ depends on the time t, because the values $E(Z_t)$ are different for different instants t. However, it is not possible to take the expected value $E[Z(t)]$ to be random function since for a given value t the values $E(Z_t)$ are constant, i.e. for a definite value t the value $E(Z_t)$ = const [2, 4, 14, 16, 17].

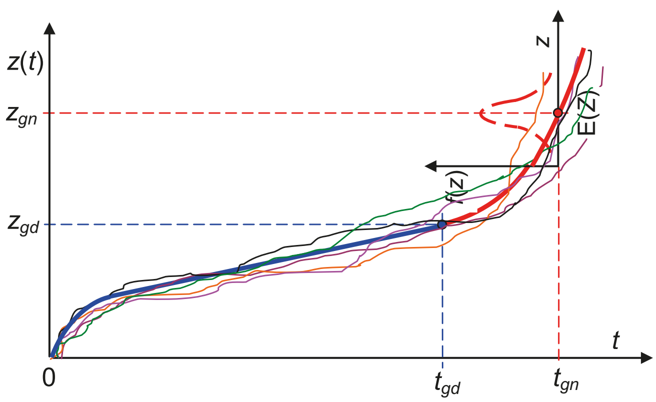

Fig. 8. Example interpretation of tribological system wear: z – wear; z_{gn} –impermissible limit wear; z_{gd} – permissible limit wear; t_{gd} – time to occurrence of z_{gn}; t_{dn} – time to occurrence of z_{gd}; t – operational time of tribological system, f(z) –density function of wear, E(Z) – expected value of wear

The loading process of the tribological systems of the engine $\{Q(t)$: $t \geq 0\}$ on which the mentioned process $\{Z(t) : t \geq 0\}$ depends, may be considered in a similar way [9].

In case if it were possible and reasonable to take into account all factors affecting the load Q and wear Z resulting from it, then the relation between Z and Q could be described by algebraic equations. Then the dependence of Z on Q would be a functional relation.

However such case is not possible to occur for the following reasons, a. o.:

- not all the factors affecting load and wear of engine's tribological systems are known and not all – measurable quantities,
- the taking into account a large number of factors may complicate considerations to such a degree that it would be impossible to carry out them even with using contemporary computer technique.

In this case a combined consideration of the load Q and wear Z implicated by it, requires to consider the random variable U which is a two-dimensional random variable (Q, Z). In view of that measurements are conducted from time to time only the random variables Q and Z are step like (not continuous), whose realizations are q and z, respectively. Hence, the pair (q, z) is the realization of the random variable (Q, Z). Therefore the variable takes values (q, z) with a definite probability $p(q, z)$, i.e. the probability of simultaneous occurrence of the events: $Q = q$ and $Z = z$.

The set of the mentioned probabilities p(q, z) constitutes the two-dimensional distribution of the random variable (Q, Z), which satisfies the following condition [1, 9, 1]:

$$\sum_{i=1}^{r}\sum_{j=1}^{r} p(q,\ z) = 1 \tag{1}$$

The boundary distribution of the random variable Q is the following:

$$p(q) = \sum_{j=1}^{r} p(q,\ z) \tag{2}$$

And, the boundary distribution of the random variable Z has the following for:

$$p(z) = \sum_{i=1}^{r} p(q,\ z) \tag{3}$$

In view of that the load (Q) and wear (Z) considered in the instant t ($0 \leq t \leq t_n$) are random processes it can be concluded that a stochastic relation between their values Q_t and Z_t should be expected. In order to highlight the relation, the following hypothesis H_1 may be formulated: „**a stochastic relation exists between the load Q_t and wear Z_t of an arbitrary tribological system of ship main engine because definite variants of one of the random variables are accompanied by different**

variants of the second variable". Hence it can be concluded that the relation between the load $Q(t)$ and wear $Z(t)$ cannot be described by algebraic equations. The conclusion deems to be true as the load depends on a large number of factors including also those which cannot be measured [4, 5, 13, 16, 18, 26]. A degree of dependence between the variables essential in this case, i.e. intensity (strength) of stochastic relation between Q and Z can be determined by using Czuprow convergence coefficient (4). Therefore during empirical investigations the strength of the stochastic relation between Q and Z may be determined by making use of the following relation [1]:

$$T_{MC}^2 = T_{CM}^2 = \frac{\chi^2}{N\sqrt{(k-1)(l-1)}} \tag{4}$$

where:

k – number of variants of the variable Q; l – number of variants of the variable Z, N – limit number of variants of the variable Q or Z, χ^2 – a value calculated from the chi-square formula, $T_{(\cdot)}^2$ –Czuprow convergence coefficient.It can be proved,[14], that T_{MC} takes values from the interval [0,1]. The coefficient is equal to zero ($T_{MC} = 0$) when there is no relation between values (Q and Z) of the process, while the coefficient equal to one ($T_{MC} = 1$) demonstrates that such relation exists. To state if the random varaiables Q and Z are dependent is possible by examining the probabilities defined by the formulae (1) ÷ (3).

The necessity of searching for stochastic relation between Z and Q may be substantiated also graphically by using the example stochastic relation between the load q and wear z, presented in Fig. 9.

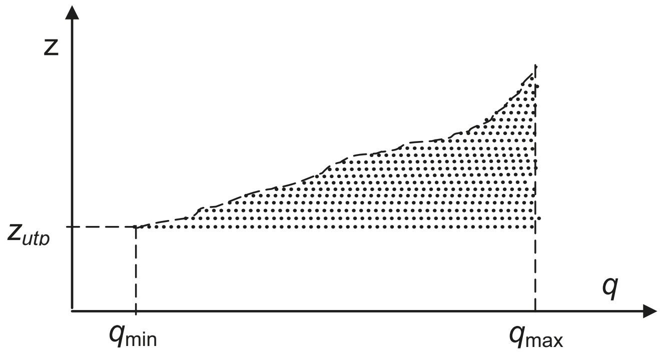

Fig. 9. Graphical interpretation of the example stochastic relation between the load q and wear z; z_{utp} – wear (small) resulting from oxidation during liquid friction, q_{min} – minimum load, q_{max} – maximum load

Investigation of a stochastic relation between load (Q) and wear (Z) may be very difficult when their distributions (also conditional ones) greatly differentiate to each other by variability, concentration and asymmetry. In such case it is better to examine a statistical relation between Q_t and Z_t. Then it is possible to assign, to particular values of one of the variables, mean value of the other variable [14].

Analyzing values of states of the processes $\{Q(t): t \geq 0\}$ and $\{Z(t): t \geq 0\}$ in an arbitrary instant t, one is able to state that there exists stochastic relation between value (state) of the load Q_t and value (state) of the wear Z_t (being random variables in the instant t). The fact that such relation between the random variables exists does not mean that knowing a value of the random variable Q_t (cause) one is able to unambiguously determine a value of the random variable Z_t (effect). Such unambiguous dependence could be stated only in the case of existence of a dependence of these variables in usual sense or by assuming that Q_t and Z_t are random variables which constitute values (states) of the deterministic processes $Q(t)$ and $Z(t)$, i.e. those having prediction error equal to zero.

A stochastic dependence between the variables Q_t and Z_t should be meant as an influence of one of the variables, e.g. Q_t on distribution of the other variable, i.e. Z_t or vice versa, namely – an influence of the variable Z_t on distribution of the variable Q_t. It means that a correlation between the random variables exists.

In the case if the random variables Q_t and Z_t were not independent then their boundary distributions would not differ from conditional ones. In view of that the load Q_t and the wear Z_t are measurable in an arbitrary instant t ($0 \leq t \leq t_n$), they can be considered to be step-like random variables. They can be considered this way because both the measurement operations performed to find their values and the measuring instruments make it possible to obtain discrete values from the measurements. In view of that, to state independence of the random variables Q_t and Z_t it is possible to use conditional probabilities and unconditional ones by employing the following relations [1, 14, 17]:

$$p(q_i/z_j) = p(q_i); \quad p(z_j/q_i) = p(z_j) \tag{5}$$

hence

$$p(q_i/z_j) = p(q_i)p(z_j) \tag{6}$$

Therefore in case if the random variables Q_t and Z_t fulfil the condition (6) it will mean that they are stochastically independent random variables, otherwise they must be considered stochastically dependent, i.e. correlated.

The random variables Q_t and Z_t may be also considered continuous random variables. Then, in case of their independence, the following formulae are obtained [1, 14, 17]:

$$f(q/z) = f(q) \text{ oraz } f(z/q) = f(z) \tag{7}$$

hence

$$f(q,z) = f(q)f(z) \tag{8}$$

and

$$f(z)=\int_{\beta}^{\infty} f(q,z)dq \tag{9}$$

where $\beta = \begin{cases} -\infty \text{ for oscilating loads} \\ 0, \text{ for pulsating loads} \end{cases}$

The conditional expected values for a definite instant t: : $E(Q/z)$ and $E(Z/q)$ are then equal to the unconditional expected values, namely [1, 14, 17]:

$$\mathrm{E}(Q/z)=\mathrm{E}(Q)=m_{1Q}; \quad \mathrm{E}(Z/q)=\mathrm{E}(Z)=m_{1Z} \tag{10}$$

Also, the conditional variances $D^2(Q/z)$ and $D^2(Z/q)$ are then equal to respective unconditional variances, i.e.:

$$\mathrm{D}^2(Q/z)=\mathrm{D}^2(Q)=\delta_Q^2; \quad \mathrm{D}^2(Z/q)=\mathrm{D}^2(Z)=\delta_Z^2 \tag{11}$$

And, the convariance is then equal to zero, i.e.:

$$\mathrm{Cov}(Q,Z)=\mathrm{K}(Q,Z)=\mathrm{E}(Q,Z)-\mathrm{E}(Q)\mathrm{E}(Z)=0 \tag{12}$$

Making use of the formulae (6) and (8) one can show that when the random variables Q and Z are independent to each other, then:

$$\mathrm{E}(Q,Z)=\mathrm{E}(Q)\mathrm{E}(Z) \tag{13}$$

i.e. according to the formula (12):

$$\mathrm{K}(Q,Z)=0 \tag{14}$$

When the random variables Q and Z are independent then, taking into account their features, one can also write that [1, 16]:

$$\mathrm{D}^2(Q+Z)=\mathrm{D}^2(Q)+\mathrm{D}^2(Z) \tag{15}$$

The relations (12)÷(15) may be also applied in the case when value of the wear Z is signalled by a diagnostic symptom of the wear which is a physical quantity not susceptible to changes in values of the load Q. When the conditions (6) and (12) are not fulfilled, i.e. when the conditional distributions of the random variables Q and Z are differ from the boundary distributions, then it means that the random variables are correlated to each other (i.e. a stochastic relation exists between them). In such case the conditions (10) and (11) are also not fulfilled. Therefore, the following relations exists:

$$\mathrm{E}(Q/z)=F(z) \tag{16}$$

$$\mathrm{E}(Z/q)=F(q) \tag{17}$$

$$\mathrm{D}^2(Q/z)<\mathrm{D}^2; \quad \mathrm{D}^2(Z/q)<\mathrm{D}^2 \tag{18}$$

$$\mathrm{K}(Q,Z)=\mathrm{E}(Q,Z)-\mathrm{E}(Q)\mathrm{E}(Z)\neq 0 \tag{19}$$

The relation (16) is a regression equation of the variable Q against the variable Z, whereas the relation (17) is a linear equation of regression of the variable Z against the variable Q. In the case of the maximum coupling of the random variables Q and Z their regression lines coincide. If they are straight lines (i.e. when influence of the load Q on conditional expected value of the wear Z is constant), they form one straight line of the slope factor $\delta=\frac{\sigma_Z}{\sigma_Q}$. In the case when the variables Q and Z are independent then the regression lines (being straight lines) are parallel to coordinate axis and cross the point of the coordinates (m_{1Q}, m_{1Z}). Fig. 10 shows an example course of the regression lines.

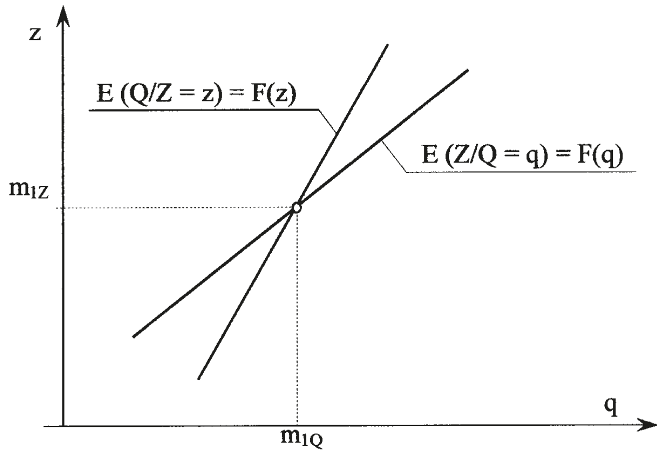

Fig. 10. Graphical illustration of the course of regression straight lines: m_1 – 1st order zero moment (expected value), m_{1Z} = E(Z), m_{1Q} = E(Z), respectively; E(Q/Z=z) – expected value of the variable Q dependent on the value z of the variable Z, E(Z/Q=q) –expected value of the variable Z dependent on the value q of the variable Q, z – realization of the variable Z (wear), q – realization of the variable Q (load).

As a correlation measure (mutual dependence) of the random variables Q and Z the correlation coefficient r_{QZ} (i.e. covariance of the standardized random variables Q^* and Z^*) determined by using the relation [1, 3, 14, 17], may also serve:

$$r_{QZ}=\frac{\mathrm{K}(Q,Z)}{\sigma_Q\sigma_Z} \tag{20}$$

and:

$$Q^*=\frac{Q-\mathrm{E}(Q)}{\sigma_Q}, \quad Z^*=\frac{Z-\mathrm{E}(Z)}{\sigma_Z}$$

The use, in addition, of the correlation coefficient makes it possible to determine whether the correlation is positive or negative. As results from the presented considerations it should be positive.

In the case when the random variables Q and Z are independent, then $r_{QZ}=0$. For the random variables Q and Z the coefficient takes values from the interval (0, 1], i.e.:

$$0<r_{QZ}\le 1 \tag{21}$$

if generally increasing value of the wear Z is associated with increasing values of the load Q. The occurrence of such case means that a positive correlation between the load Q and the wear Z exists.

Hence, the following hypothesis H_2 may be postulated: **the load of an arbitrary tribological system of engine, in the time t, constitutes the random variable Q_t positively correlated with its wear, i.e. the random variable Z_t, because with the load increasing the wear of the engine grows**.

The presented hypothesis may be considered equivalent to the following hypothesis H_3: **the wear of a tribological system of engine and its load are, in an arbitrary instant of its working time (t), random variables between whose such relation exists that the correlation coefficient $r_{QZ} \approx 1$, because the engine wear increases first of all with increasing the load**.

As results from the considerations, correlation (stochastic dependence) between random variables which stand for the load Q and the wear Z may be determined by using:

a) regression lines which illustrates the dependence of mean value of one of the variables on value of the other of the variables in question, i.e.: $E(Q/Z = z)$ and $E(Z/Q = q)$;
b) correlation coefficient defined by the relation (20).

Achievement of zero-value of the correlation coefficient ($\rho_{QZ} = 0$) is a prerequisite, but not a sufficient condition to deem the random variables Q and Z to be independent on each other if their distributions are different from normal. Zero- value of the coefficient does not prove that the random variables are independent if they do not have normal distributions. Possession of zero-value of the correlation coefficient ρ_{QZ} is the sufficient condition for considering random variables independent only if their distributions are normal [2, 14, 17].

FINAL REMARKS AND CONCLUSIONS

In this paper there was undertaken an attempt to determine relation between load and wear of tribological systems of an arbitrary ship main engine (intended for ship propulsion) by applying probabilistic approach. It was justifed that application of such approach is necessary in view of a random character of load exerted on ship main engine by ship screw propeller driven by the engine. There were presented examples of excessive wear suffered by selected tribological systems of such engines, in consequence of their loading in highly unfavourable (stormy weather) conditions. It was signalled that the load depends on many factors, mainly hydrological conditions, which results in that a stochastic relation between load and wear of the mentioned tribological systems, exists. For examination of intensity (force) of the stochastic relation it was proposed to use Czuprow convergence coefficient.

In this paper it was proved that in investigations of tribological systems of an arbitrary ship main engine in an arbitrary instant t it should be strived to express probabilistically relations which occur between their load Q and wear Z.

It was proposed to consider the load Q and wear Z to be a two-dimensional random variable (Q, Z) by assuming that the variables Q and Z are step – like (non-continuous) variables or continuous random variables; however it was also mentioned that to examine a relation between step-like variables is simpler.

In the presented considerations it was proved that load and wear in an arbitrary instant t should be considered to be realizations of the load process $\{Q(t)\colon t \geq 0\}$ and the wear process $\{Z(t)\colon t \geq 0\}$. The realizations (Q_t and Z_t) should be examined assuming that they are random variables. In the case of the process $\{Q(t)\colon t \geq 0\}$ its realizations are the random variables Q_t of the expected value $E(Q_t)$ and variance $D^2(Q_t)$, while in the case of the process $\{Z(t)\colon t \geq 0\}$ its realizations are the random variables Z_t of the expected value $E(Z_t)$ and variance $D^2(Z_t)$. Hence, the variables are values (states) of these stochastic processes.

There were proposed the hypotheses highlighting the facts that a stochastic relation between load and wear exists and that it is possible to assume that the load Q_t and wear Z_t are positively correlated to each other with a correlation coefficient whose value may be taken close to one.

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