Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

FAILURE MODEL OF MAIN ELEMENTS OF THE SHIP ENGINE CRANKSHAFT-PISTON ASSEMBLY

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Abstract

The paper presents a failure model of main elements of the crankshaft-piston assembly, based on failures of crankshaft-piston assembly and timing gear system of the Sulzer RD engines, retrieved from the equipment reliability data of selected ships.

***Keywords**: reliability, durability, failures*

1. Introduction

Reliability and durability of piston engines used on ships is an immensely important problem as the engines are objects of a very complex structure operating in difficult marine conditions. Therefore, extensive engine failures can cause ship disasters. Those failures are of a random event character. The available world statistics give only information on damage caused by the disasters and not the failure event data, although such information could be obtained from properly lined diagnostic parameter measurements. Such measurement lines have already been developed and used in diagnostic systems, e.g. by the big ship engine producers – German-Danish MAN Diesel and Finnish-Swiss Wärtsilä companies. Those companies have developed such diagnostic systems as CoCoS (MAN Diesel) and CBM (Wärtsilä) [10,11,15,16].

In Poland [5], in the years 1972-1977 more than 96000 data were collected on failures and inefficiency of selected engines (e.g. 58 Sulzer RD engines) installed on 105 ships owned by the Polish Ocean Lines and Polish Steamship Company. From those data indices were calculated allowing to detect weak points of the engines.

2. Analysis of failures

Mechanisms of the marine engine failures in operation can be different but are always connected with forcing factors, e.g. load force and torque, vibration, temperature changes etc.

In references [1,8], failure is defined as an event whose occurrence causes the element to cease (totally or partly) performing its functions.

The Sulzer RD engine crankshaft-piston assembly and timing gear system consist of many elements, so failure of one element need not cause inefficiency of the whole respective assembly. One of the results of an element failure in a complex system may be deterioration of the properties of other elements. This can lead to a “failure avalanche”. The second result may be deterioration of the technical condition of another element, which can lead to shorter life of the remaining system elements.

In references [1,7] a classification of failures is used depending on the extension of their effects (Table 1).

Table 1. Classification of failures [1,7]

Failure form	Immediate cause	Typical symptoms
Wear of surface layer	Wear due to sliding friction, contact loads and thermal wear	Change of dimensions, shape and surface smoothness, increased clearances, contacts, motion discontinuity, change of trajectory
Fracture, break or cracks of elements	Insufficient tensile, fatigue or impact strength	Loss of coherence, loss of functional properties, inefficiency of the whole assembly, loss of rigidity
Plastic strain, deformation of elements	Exceeded admissible loads	Change of shape or form, local indentation, elongation
Deregulations	Variable loads, vibrations	Slackened connections, knocks, loss of functional properties
Leakage	Immediate or variable loads, sliding friction wear, ageing	Loss of liquid or gas medium, loss of functional properties
Burnings	Excessive thermal loads	System inefficiency, loss of functional properties
Fouling, choking	Chemical and physical phenomena	System inefficiency, worsening of work parameters
Other	Ageing of elements, erosion, corrosion, scale, destroyed protective coatings	Change of colour, smoothness and lustre, unesthetic appearence

Failure investigations consist, among other actions, in collecting information on operation of the crankshaft-piston assembly and timing gear system by means of questionnaires and processing the information in the SONUS system [6]. The following indices have been adopted for reliability estimation:

- SCPU – mean time to failure, in hours;
- INU – standardized per 1000 hours index of the reparable equipment failure development speed;
- CZU – index of the equipment reparable failure structure.

Various engine systems were subjected to failure analysis and results are presented in tables. For instance, an analysis is shown of the Sulzer RD engine type crankshaft-piston assembly and timing gear system failures in the years 1972-1974 (Table 2) [12,13,14] and the subsystem failures that occurred in 1974 are listed (Table 3) [14].

Table 2. Failure indices and form of the RD type engine crankshaft-piston assembly and timing gear system failures [12,13,14]

Year	Number of failures, by failure form																		SCPU	INU	CZU
	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}	U_{17}	Σ			
1972	34	106	13	283	6	8	-	10	-	-	-	2	-	-	-	-	13	475	11398	0,0877	0,42
1973	37	105	13	500	20	4	-	50	-	-	1	-	6	1	-	-	17	754	10371	0,0964	0,42
1974	99	192	71	1348	36	7	4	101	1	-	12	-	15	10	3	1	11	1911	12741	0,0784	0,54

Table 3. Failure indices and form of the RD type engine crankshaft-piston assembly and timing gear system failures in 1974 [14]

Specification	Number of failures, by failure form																		SCPU	INU	CZU
	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}	U_{16}	U_{17}	Σ			
Piston with rings	8	65	41	319	5	6	4	30	-	8	3	-	12	8	3	-	7	507	8959	0,1116	0,27
Piston rod with crosshead	11	69	1	33	13	-	-	2	-	2	-	-	-	2	-	-	4	136	15781	0,0633	0,07
Piston rod packing, sealing			7	6	-	-	1	32	1	-	-	-	-	-	-	-	-	445	14461	0,0691	0,23
Connecting rod	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	6	13000	0,0769	-
Crankshaft	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	4	39063	0,0255	-
Camshaft, fuel cams	14	7	-	75	8	-	-	-	-	-	-	-	-	-	-	1	-	105	17621	0,0567	0,05
Timing gear mechanism	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2	10498	0,0952	-
Exhaust valves	57	45	28	450	8	-	3	37	-	-	9	-	3	-	-	-	-	640	12381	0,0807	0,33
Valve adjustment mechanism	2	-	-	61	2	1	-	-	-	-	-	-	-	-	-	-	-	66	18101	0,0552	0,03

Where: U_1 – strain, U_2 – crack, U_3 – fracture, break, U_4 – wear, U_5 – seizure, U_6 – slackening, contact, U_7 – melting, U_8 – leakage, U_9 – fouling, U_{10} – choking, U_{11} – overheating, U_{12} – corrosion, U_{13} – burning, U_{14} – ageing, U_{15} – erosion, U_{16} – scale, U_{17} – other.

It can be estimated from the failures (Table 2) that most of the 17 forms of failure were caused by linear wear (friction, adhesion, corrosion) or volumetric wear (e.g. cracks). In the Sulzer RD engine crankshaft-piston assembly and timing gear system they made up: in 1972 - 60%, in 1973 – 66%, in 1974 – 71% of all failures. Additionally, from the share in the CZU overall failure structure: 1972 – 0.42; 1973 – 0.42; 1974 – 0.54 the increasing number of failures with increasing engine age can be seen. Therefore, Table 3 presents failures occurred in 1974.

Cracks, fractures and breaks, which may lead even to engine stoppage, took the second place in the registered failure forms. Table 3 shows that these type of failures occur most often in the piston-rings subsystem (21%) and the piston rod-crosshead subsystem (51%). Such subsystem failures require comprehensive analysis of the failure event causes as well as laboratory examinations in order to verify the operational experience conclusions.

3. Model of the piston-rings and piston rod-crosshead subsystem failures

Analysis of the Sulzer RD engine crankshaft-piston assembly and timing gear system failures indicates that subsystems requiring the most thorough examination are piston with rings and piston rod with crosshead – parts of the crankshaft-piston assembly. The two subsystems are considered operational when respective characteristics of the subsystem component elements are contained within limits defined by their work character. When one of the work characteristics [2,3,4,5,9] (e.g. working medium parameters) exceeds the admissible limits and for instance the crosshead bearing begins to work defectively, then it is treated as inefficiency.

The work characteristic of any main element of the crankshaft-piston assembly (Fig.1) gets monotonically worse under the impairing relaxation stimuli. It may be assumed that the subsystem inefficiency occurs when one of its elements exceeds the admissible limits given in the specification. The element trouble-free operation time “T” is counted until the moment when the work characteristic exceeds the assumed limit value. Fig.1 presents also a situation when single stimuli of a determined value occur at randomly selected moments. After “r” such occurrences the element as a whole appears nonoperational (inefficient). Action of a single stimulus appears as stepwise decrease of the element efficiency by a certain value “y” [2,3].

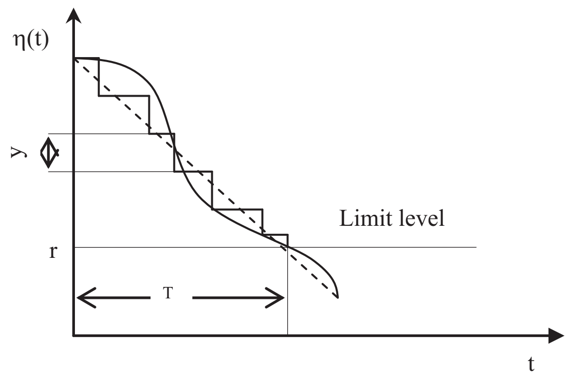

Fig. 1. Action of impairing relaxation stimuli: η(t) – operating characteristic of a crankshaft-piston element; t – time; T – trouble-free operation time, element durability; r – number of stimuli necessary to cause element ineffeiciency; y – stepwise wear

The failure model may be considered useful when it describes a stable (or normal) period of the impairing stimulus action. Then the probability of an increase of the number of failures in the time interval from ”t” to ”t+Δt” does not depend on the number of such increases in the time interval from 0 to t.

It may be concluded from the results of failures of the piston with rings and piston rod with crosshead assemblies that usefulness of the presented wear model may be accepted and that the wear model is well described by the gamma distribution [2,4,5,9]. Then the value of the subsystem trouble-free operation probability for time t can be determined in a simple way from the nomogram presented in Fig.2 [3].

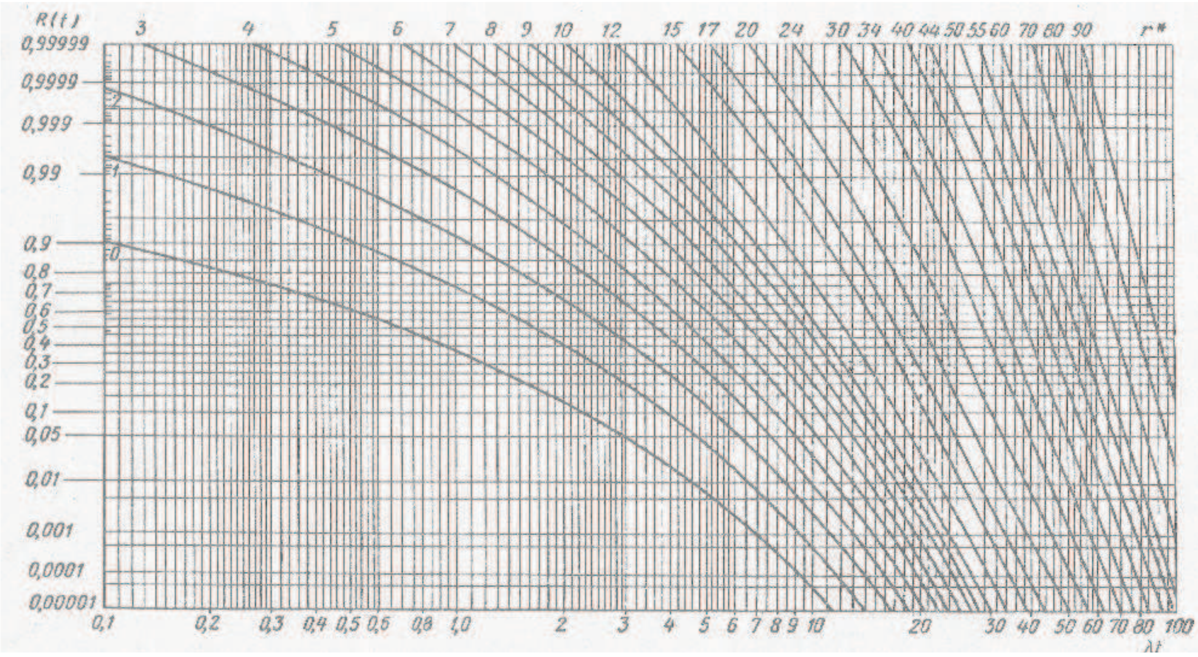

Fig.2. Nomogram for reliability R(t)=P(T>t) determination in accordance with the gamma distribution: r=r-1 [3]*

The above presented considerations allow to estimate the probability values of trouble-free operation of the piston with rings and piston rod with crosshead assemblies. From data given in Table 3 the λ (i.e. the failure intensity) and r (i.e. the number of stimuli necessary for inefficiency to occur) parameters can be estimated [2]. Probabilities of trouble-free operation during $t_1 = 1$ year (8760 h) and $t_2 = 3$ years (26280 h) determined by means of the nomogram in Fig.2 are presented in Table 4.

Table 4. Probabilities of trouble-free operation

Subsystem	P(T>8760h)	P(T>26280h)
Piston with rings	0,7	0,2
Piston rod with crosshead	0,9	0,5

Conclusions regarding the failures indicate that the most important elements are piston with rings.

4. Conclusions

1. The analysis of failures and the constructed wear model have shown that the main elements (piston and rings) belonging to the crankshaft-piston assembly should be investigated in the laboratory conditions by the accelerated wear methods in order to determine the causes of crack, fracture or break.

2. The reliability investigation statistical data are useful for increasing the reliability level of the crankshaft-piston assembly and timing gear system elements in the design and manufacture phase.

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