DIAGNOSTIC MODEL OF COMPRESSION-IGNITION ENGINE SLIDE BEARINGS FOR CONTROLLING THE CHANGES OF THEIR STATE

Piotr Bzura

Gdansk University of Technology
ul. Narutowicza 11/12, 80-950 Gdansk, Poland
tel.: +48 58 3472181
e-mail: pbzura@pg.gda.pl

Abstract

The paper presents a conception allowing to control the processes of changes of the engine operating states based on a diagnostic model of slide bearings. A topological diagnostic model was adopted as a slide bearing model, which allows to use fully the lubricating oil as one of the information carriers about the technical state of bearings. Presented is also interpretation. of the bearing operation states and it has been found that the slide bearing operation state change process is one of important parameters influencing the engine operation state control process.

Keywords: *diagnostics, model, slide bearing*

1. Introduction

In order to be able to use diagnostic tests for control of the slide bearing operation process, it is necessary to build a diagnostic model defining the slide bearing states in the engine operation phases.

The paper presents a possibility of using diagnostic tests describing the technical states of slide bearings in the compression-ignition engine operation in order to control the changes of their state. An optimum engine operation may be effected through controlling those changes of the slide bearing state.

At first, the slide bearing principle of operation is presented, with the parameters necessary for the bearing technical state diagnostic information. Those diagnostic observations allow to construct a transformed topological diagnostic model, taking into account the lubricating oil and other diagnostic signals helpful in determining the technical state of a slide bearing.

In the second part, from an interpretation of the operation states of slide bearings [3], an example has been worked out of a slide bearing operation state change process in the engine time between overhauls.

Finally, a possibility is shown of the practical application of both models to the slide bearing operation control process.

2. Possibilities of identification of the slide bearing states

In order to be able to construct a diagnostic model, an identification procedure of the slide bearing technical and energy state must be known.

Such a procedure is presented in the diagram of slide bearing, where a continuous flow of energy and information as well as diagnostic observation are shown. However, all sorts of diagnostic information distortions (interferences) should also be taken into account when a bearing state is identified.

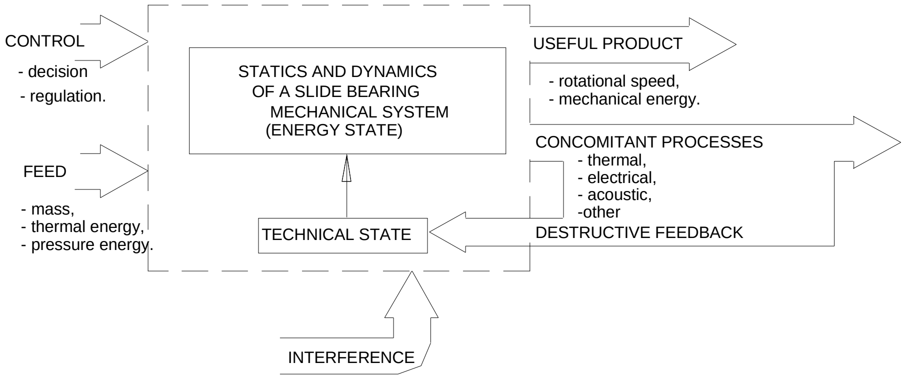

Fig.1. Diagram of a slide bearing as a system with flow of energy and information as well as with a possibility of diagnostic observation

A slide bearing diagnostic model allowing to determine the changes of technical states in the main engine operation process can be constructed mainly in connection with parameters of the concomitant processes which are an inherent part of the slide bearing operation. These are thermal, chemical, electric, acoustic and other processes. Measurements of those parameters allow to estimate the technical condition of a slide bearing without dismantling it, during its normal work.

3. Transformed topological diagnostic model of slide bearings

The transformed topological model (Fig. 3) allows to present general but more complete relations between selected technical states of slide bearings and the distinguishing diagnostic parameters. It allows also more precise analysis, by means of the graph theory and the Lorenz curve [1], of the technical states determining the slide bearing proper functioning. In the operational practice, the change of technical states of a slide bearing is a random process of a continuous positive and restrained realization. Discretization of that process leads to generating an (adequate to reality) set of technical states $S = \{s_1, s_2, s_3\}$, which may be considered a set of the stochastic process values $\{W(t): t \geq 0\}$ with constant intervals and the right-hand-side continuous realizations.

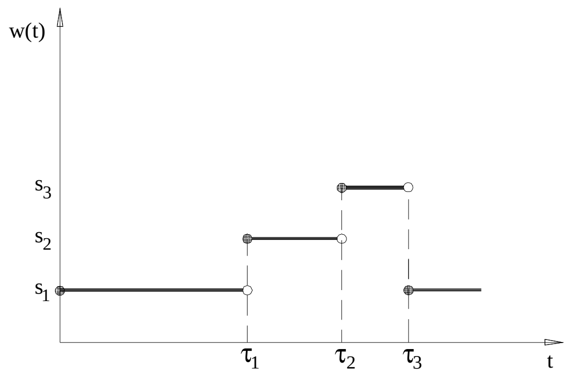

Fig. 2.. Example of realization of an engine slide bearing $\{W(t):t\geq 0\}$ process, where: s_1 - state of full ability, s_2 - state of partial ability, s_3 - state of inability;$[0, \tau_1)$, $[\tau_1, \tau_2)$, $[\tau_2, \tau_3)$ – state duration intervals.

As determination of the technical state of a slide bearing is connected with a high level of disturbances of the diagnostic signals, the reliability of diagnosis is essential for decision taking. Therefore, the diagnostic signals should be treated in the categories of probability and the use of a probabilistic diagnostic matrix is advisable.

The three-element set of technical states $S=\{s_1, s_2, s_3\}$ consists of a sum of the following three diagnostic matrices:

- State of full ability s_1

$$M_p^{s_1} = \begin{array}{c} \\ s_{11} \\ \vdots \\ s_{15} \end{array} \begin{array}{c} \begin{array}{ccccc} k_1^{(1)} & k_2^{(1)} & k_3^{(1)} & \dots & k_{15}^{(1)} \end{array} \\ \begin{bmatrix} p(k_1^{(1)}|s_{11}) & p(k_2^{(1)}|s_{11}) & p(k_3^{(1)}|s_{11}) & \dots & p(k_{15}^{(1)}|s_{11}) \\ \dots & & & & \\ p(k_1^{(1)}|s_{15}) & p(k_2^{(1)}|s_{15}) & p(k_3^{(1)}|s_{15}) & \dots & p(k_{15}^{(1)}|s_{15}) \end{bmatrix} \end{array} \tag{1}$$

where: $k_1^{(1)}, k_2^{(1)}, k_3^{(1)}, \dots, k_{15}^{(1)}$ - the $s_1=\{s_{11}, \dots, s_{15}\}$ state defining diagnostic parameters.

From the probabilistic diagnostic matrix expressed in the form of formula (1) the probability of occurrence of states $s_{1i} \in s_1$, $i = \overline{1,5}$, may be determined by means of formula [2]:

$$p\left(s_{1i} \middle| k_{1i}^{(1)}, k_{2i}^{(1)}, k_{3i}^{(1)}, \dots, k_{15i}^{(1)}\right) = \frac{p(s_{1i}) \cdot p\left(k_{1i}^{(1)}, k_{2i}^{(1)}, \dots, k_{15i}^{(1)} \middle| s_{1i}\right)}{p\left(k_{1i}^{(1)}, k_{2i}^{(1)}, k_{3i}^{(1)}, \dots, k_{15i}^{(1)}\right)} \tag{2}$$

where: $k_{1i}^{(1)}$ - value of parameter $k_1^{(1)}$ meaning the existence of state s_{1i}.

- State of partial ability s_2

$$M_p^{s_2} = \begin{array}{c} \\ s_{21} \\ \vdots \\ s_{24}^{*} \end{array} \begin{array}{c} \begin{array}{ccccc} k_1^{(2)} & k_2^{(2)} & k_3^{(2)} & \dots & k_{15}^{(2)} \end{array} \\ \begin{bmatrix} p(k_1^{(2)}|s_{21}) & p(k_2^{(2)}|s_{21}) & p(k_3^{(2)}|s_{21}) & \dots & p(k_{15}^{(2)}|s_{21}) \\ \dots & & & & \\ p(k_1^{(2)}|s_{24}) & p(k_2^{(2)}|s_{24}) & p(k_3^{(2)}|s_{24}) & \dots & p(k_{15}^{(2)}|s_{24}) \end{bmatrix} \end{array} \tag{3}$$

where: $k_1^{(2)}, k_2^{(2)}, k_3^{(2)}, \dots, k_{15}^{(2)}$ - the $s_2=\{s_{21}, \dots, s_{24}\}$ state defining diagnostic parameters.

Probability of occurrence of states $s_{2i} \in s_2$, $i = \overline{1,4}$, by means of formula [2]:

$$p\left(s_{2j} \middle| k_{1j}^{(2)}, k_{2j}^{(2)}, k_{3j}^{(2)}, \dots, k_{15j}^{(2)}\right) = \frac{p(s_{2j}) \cdot p\left(k_{1j}^{(2)}, k_{2j}^{(2)}, \dots, k_{15j}^{(2)} \middle| s_{2j}\right)}{p\left(k_{1j}^{(2)}, k_{2j}^{(2)}, k_{3j}^{(2)}, \dots, k_{15j}^{(2)}\right)} \tag{4}$$

where: $k_{1j}^{(2)}$ - value of parameter $k_1^{(2)}$ meaning the existence of state s_{2j}.

- State of inability s_3

$$M_p^{s_3} = \begin{array}{c} \\ s_{31} \\ \vdots \\ s_{33} \end{array} \begin{array}{c} \begin{array}{ccccc} k_1^{(2)} & k_2^{(2)} & k_3^{(2)} & \dots & k_{15}^{(2)} \end{array} \\ \begin{bmatrix} p(k_1^{(3)}|s_{31}) & p(k_2^{(3)}|s_{31}) & p(k_3^{(3)}|s_{31}) & \dots & p(k_{15}^{(3)}|s_{31}) \\ \dots & & & & \\ p(k_1^{(3)}|s_{33}) & p(k_2^{(3)}|s_{33}) & p(k_3^{(3)}|s_{33}) & \dots & p(k_{15}^{(3)}|s_{33}) \end{bmatrix} \end{array} \tag{5}$$

where: $k_1^{(3)}, k_2^{(3)}, k_3^{(3)}, \dots, k_{15}^{(3)}$ - the $s_1=\{s_{31}, \dots, s_{33}\}$ state defining diagnostic parameters.

Probability of occurrence of states $s_{3l} \in s_3$, $i = \overline{1,3}$, by means of formula [2]:

$$p\left(s_{31} \middle|\ k_{1l}^{(3)}, k_{2l}^{(3)}, k_{3l}^{(3)}, \ldots, k_{15l}^{(3)}\right) = \frac{p(s_{31}) \cdot p\left(k_{1l}^{(3)}, k_{2l}^{(3)}, \ldots, k_{15l}^{(3)} \middle| s_{31}\right)}{p\left(k_{1l}^{(3)}, k_{2l}^{(3)}, \ldots, k_{15l}^{(3)}\right)} \tag{6}$$

where: $k_{1l}^{(3)}$ - value of parameter $k_1^{(3)}$ meaning the existence of state s_{3l}.

The presented topological model may be treated as a diagnostic model (MD) of slide bearings in a compression-ignition engine including a probabilistic diagnostic matrix:

$$MD = M_p^{s_1} \cap M_p^{s_2} \cap M_p^{s_3} \tag{7}$$

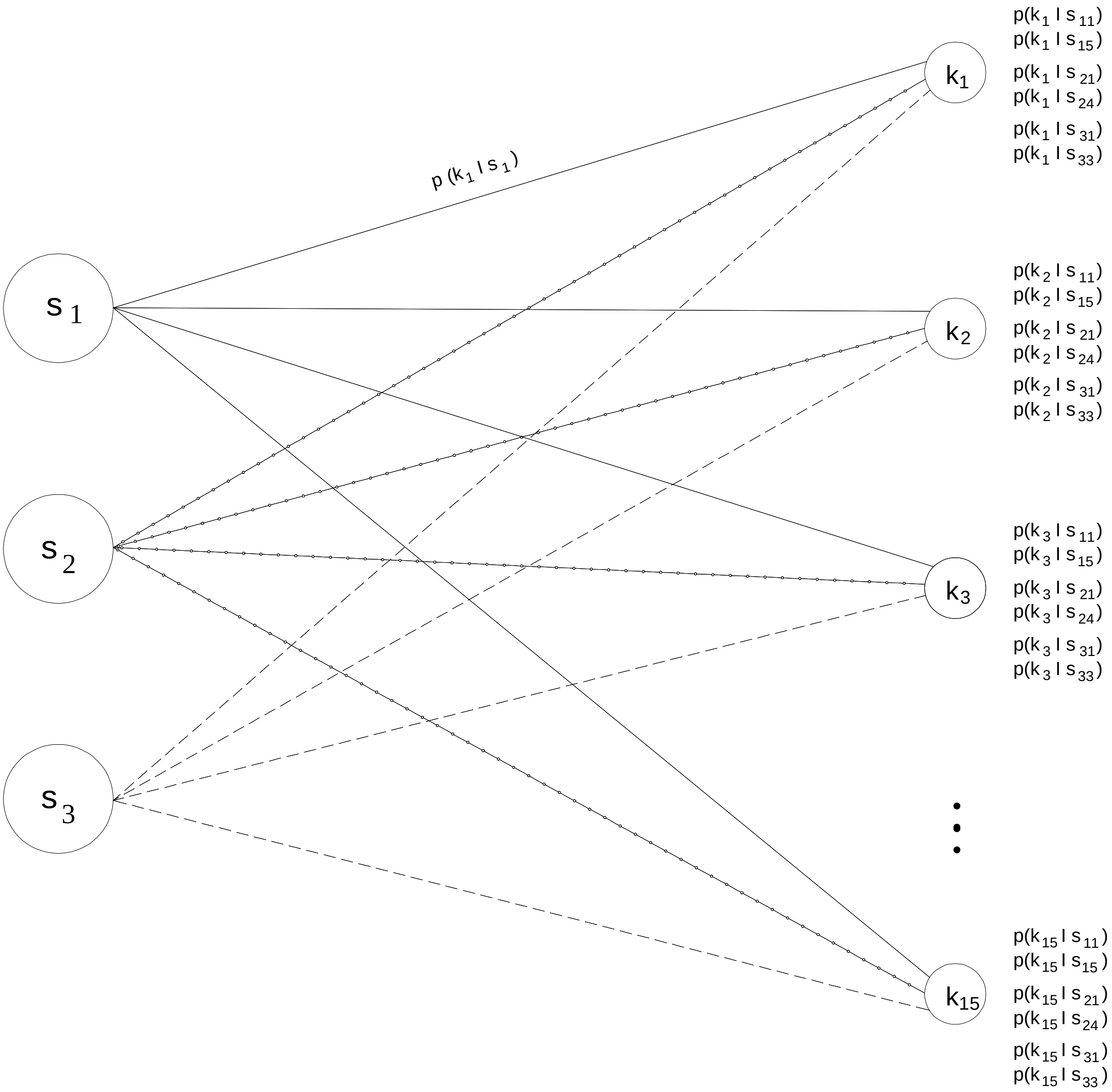

Fig.3. Examples of relations necessary to construct a transformed topological diagnostic model, where: k_1 – kinematic viscosity; k_2 – absolute viscosity; k_3 – base number; k_{15} – thickness of oil film; s_1 – state of full ability; s_2 – state of partial ability; s_3 – state of inability, s_{11} – fresh lubricating oil; s_{15} – less than admissible bearing slackness, the bearing shell and crank pin surfaces without significant traces of wear; s_{21} – lubricating oil with content of water within the range from admissible to limiting; s_{24} – lubricating oil with physical and chemical properties not worse than those admissible; s_{31} - excess linear wear, i.e. bearing slackness greater than the limiting value; s_{33} – lubricating oil with physical and chemical properties not meeting the requirements; $p(k_1|s_{11})$ – the probability of a change of the k_1 parameter value when the s_{11} state occurs.

The processes of changes of the slide bearing technical states are closely connected with the process of changes of their operational conditions.

4. Process of changes of a slide bearing operational states

Proper use of a compression-ignition engine with due attention given to the durability and reliability of slide bearings means that certain rules and principles have to be observed. An example of the interpretation of a slide bearing operational states e_1, e_2, e_3, e_4 may be the following:

State of an active use (e_1)

- introducing a constant oil centrifuging process to all the ship compression-ignition engine lubricating systems,
- using oil filters of the purifying accuracy corresponding to the bearing bushing type and checking those filters in connection with the oil pressure drop value.

State of non-operation (e_2)

- turning the crankshafts and lubricating the idle engine bearings at least once a day,

State of a planned maintenance (e_3)

- periodic checking of the oil physical and chemical properties, including solid impurities,
- periodic checking of journal smoothness and cleanness of the assembly during the preventive maintenance services.

State of forced maintenance (e_4)

- replacement of damaged crank bearing shells,
- replacement of a damaged lubricating oil pump.

The set of operation states $E=\{e_1, e_2, e_3, e_4\}$, as well as the set of technical states, may be treated as a set of the stochastic process $\{X(t):t\in T\}$ values with constant intervals and the right-hand-side continuous realization.

Fig. 4 presents an example of realization of a process of the slide bearing operation state changes in the time between overhauls.

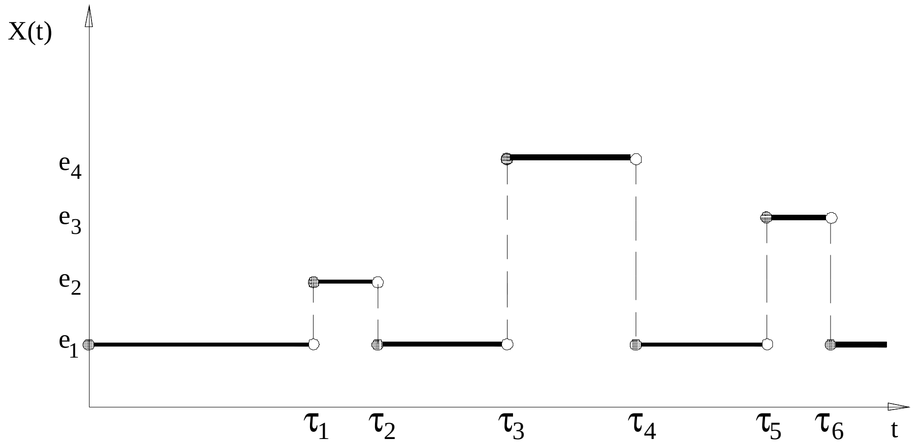

Fig. Example of realization of a slide bearing $\{X(t): t\geq 0\}$ process

5. Slide bearing operation process

Realization of the $\{W(t):t\geq 0\}$ process (Fig. 2) and the $\{X(t): t\geq 0\}$ process (Fig. 4) are interdependent realizations, therefore, like in [2], a two-dimensional process should be considered with the W(t) and X(t) processes as its components. A process in the form of a Cartesian product of the S and E states has been used. The combined use of both sets of states, which may occur simultaneously, allows to create a set of the slide bearing operation states:

$$Z = S \times E = \{(s_1, e_1), (s_1, e_2), (s_1, e_3), (s_2, e_1), (s_2, e_3), (s_3, e_4)\} \quad (8)$$

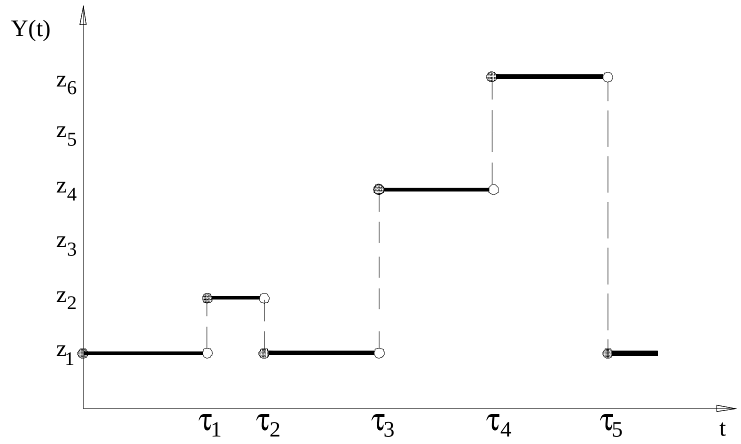

Fig.5. Example of a slide bearing {Y(t): t≥0} process realization, where: {Y(t): t∈T} – the slide bearing operation process $z_1 = (s_1, e_1), z_2 = (s_1, e_2), z_3 = (s_1, e_3), z_4 = (s_2, e_1), z_5 = (s_2, e_3), z_6 = (s_3, e_4)$

The slide bearing s_1 state will last from $\tau_0 = 0$ to τ_3. In the $[\tau_0 = 0, \tau_1)$ time interval the slide bearing was in the e_1 state. At the τ_1 instant the slide bearing found itself in the e_2 state (the engine stopped) and after restarting the engine it returned to the (s_1, e_1) state at the τ_2 instant. Then in the $[\tau_2, \tau_4)$ time interval the bearing was in the e_1 state and at the τ_4 instant it was damaged. Earlier, at the τ_3 instant the slide bearing technical state underwent a change s_2 (partial ability) and the engine load was not changed, which caused a damage in the $[\tau_3, \tau_4)$ time interval. At the τ_4 instant the s_3 state (inability) occurred and lasted during the $[\tau_4, \tau_5)$ time interval, i.e. as long as the e_4 operation state when the s_1 state was restored.

6. Concluding remarks

The analysis presented in this paper suggests that it may be worthwhile to use the transformed topological diagnostic model of slide bearings in the combustion engine operation control process.

References

[1] Bzura, P., *Topological diagnostic model of the main slide bearings of a compression-ignition engine,* (in Polish), XXVII Sympozjum Silowni Okretowych, Szczecin 2006, p.145-152

[2] Girtler, J., *Control of the ship combustion engine operation process by a decision diagnostic model,* (in Polish), ZN AMW, nr 100A, Gdynia 1989.

[3] Kicinski, J., *Selected problems of the construction and operation of large-size slide bearings in combustion engines,* (in Polish), Instytut Maszyn Przepływowych PAN, Gdansk.