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FAULT DETECTION AND IDENTIFICATION OF MARINE DIESEL ENGINE USING EXPERT KNOWLEDGE AND FUZZY LOGIC APROACH

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ABSTRACT
Marine propulsion engine is the most important system onboard ship for ship's successful mission. Therefore, it's very useful to estimate its future state and availability.
In this paper, one effective method for marine diesel propulsion engine faults detection and identification based on fuzzy logic, expert knowledge and experience in real conditions at sea will be presented. The faults diagnosis method is based on real-time diagnostic signals i.e. symptoms and events and their relation to faults in an extended manner with tracking process relevant variables during normal as well as faulty operation and times of symptoms and events occurrence. Engine expert knowledge and especially long time experience will be used as key decision method in fault detection and identification process. The effectiveness and power of this method has been evaluated simulating faults of engine bearings. The simulation has been done using real ship's propulsion plant simulator "Kongsberg, Full mission engine room simulator". The simulation results has been compared with expert decision in faults diagnosis. This paper represents a part of research results conducted within scientific project "New technologies in diagnosis and supported by Ministry of Science, Education and sports of the Republic of Croatia[1].
Keywords: fault, detection, identification, diesel engine, fuzzy logic

1. INTRODUCTION
Diesel propulsion plant for large ships is very complex process with strong demands on its reliability and availability. Figure 1. shows the main components of diesel engine ship'S propulsion system [1]. Its basic structure consists of interdependent and connected subsystems with a large number of different components. Proper operation of marine engine propulsion system is directly related to faults, failures and malfunctions on any component of the system. Therefore, for improving reliability, availability and safety of marine engine propulsion system, fault diagnosis methods becomes of increasing importance and research interest [2], [3]. Diagnosis and fault analysis process includes analytic and heuristic symptoms observation and heuristic recognition and inference by expert knowledge about process health and operability. Fault can appear in any propulsion system part, so it's necessary to monitor different variables through time (variable trend) to detect fault appearance, its characteristics and influence to other parts and whole system.

[1] *The resuls presented in the paper have been derived from the scientific project "New technologies in Diagnosis and Control of Marine Propulsion Systems" supported by the Ministry of Science, Education and Sports of the Republic of Croatia.*

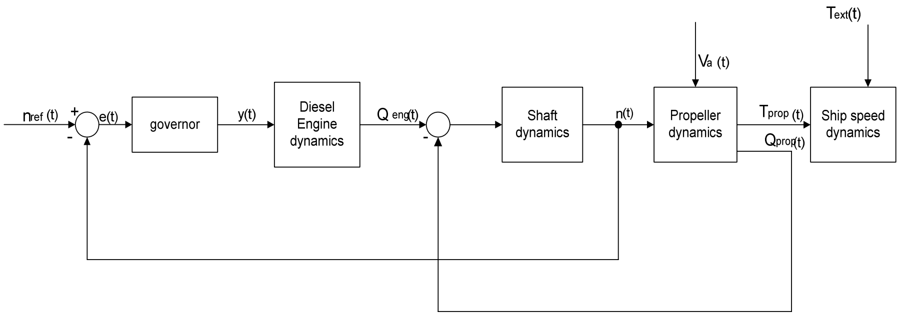

Figure 1. Block diagram of diesel engine ship's propulsion system

2. FAULTS DIAGNOSIS

The overall concept of fault diagnosis consists of the following three essential tasks [1], [5]:

- fault detection: detection of the occurrence of fault in the functional units of the process, which lead to undesired or intolerable behavior of the whole system;
- fault isolation: localization i.e. isolation of different faults;
- fault analysis or identification: determination of the type, magnitude and cause of the fault.

The diagnostics procedure here is based on the observed symptoms and expert knowledge, figure 2.

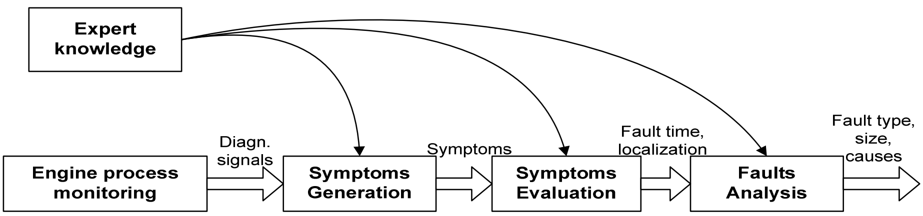

Figure 2. Faults diagnosis procedure

Very effective diagnosis method is the fault tree method [1]. Two approaches are used (fig. 3): FTA - fault tree analysis (backward reasoning) and ETA - event tree analysis (forward reasoning).
In this work ETA method has been used.

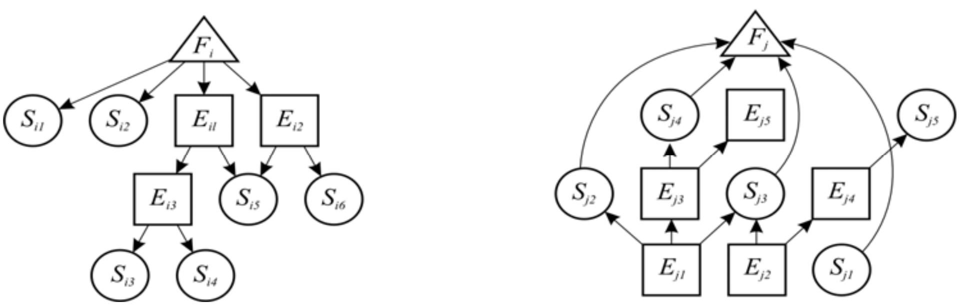

Figure 3. Fault-tree diagnosis methods

Both reasoning methods can be expressed in the form of the rules: *IF <condition> THEN <conclusions>/<action>*. The symptoms are related to each other by means of logical AND/OR operations in binary or fuzzy logic form. Condition part (premise) contains facts in the form of symptoms and events S as input and the conclusion part includes fault F as a logic cause of the facts. Then, the rules could be given in the form (1):

if<(σi AND σi+1 AND...AND σδ) OR (σi' AND σi'+1 AND...AND σδ')...OR...>then<ϕk> (1)

where: $\sigma i \in [Ek, Si]$ a set of events, symptoms (inputs i.e. premises),
$\phi k \in [Ek, Fj]$, a set of faults (outputs i.e. conclusions).
In binary logic is: $\sigma i = 0$ or $\sigma i = 1$, so ϕk can be determined in this way, expression (2):

$$\phi_k = 1 - \prod_{j=1}^{\gamma} \left(1 - \prod_{i=1}^{\delta(j)} \sigma_i \right) \tag{2}$$

where: γ - number of conjunction (union); $\delta(j)$ – number of elements by conjunction.
Symptoms, events and faults can be presented in the form of fuzzy set, which defines the respective functions and affiliation as in expression (3), (often subjective assessment of experts, operators):

$$0 \le \mu(\sigma_i) \le 1 \text{ for symptoms ; } 0 \le \mu(\varphi_k) \le 1 \text{ for faults} \tag{3}$$

where μ is membership function.

3. SIMULATION CASE – Engine bearings faults

The simulation was done using Full Mission Engine Room Simulator with 2-stroke marine diesel engine of type MAN B&W 5L90MC on the VLCC ship sailing at open sea. Engine bearings faults were simulated through 3 faults scenarios: 1. – faulty lubricator of first engine cylinder (pure lubrication - Fault $F_{4,1}$, fig. 4.); 2 - faulty lubricator of second engine cylinder (pure lubrication - Fault $F_{4,2}$, fig. 4).

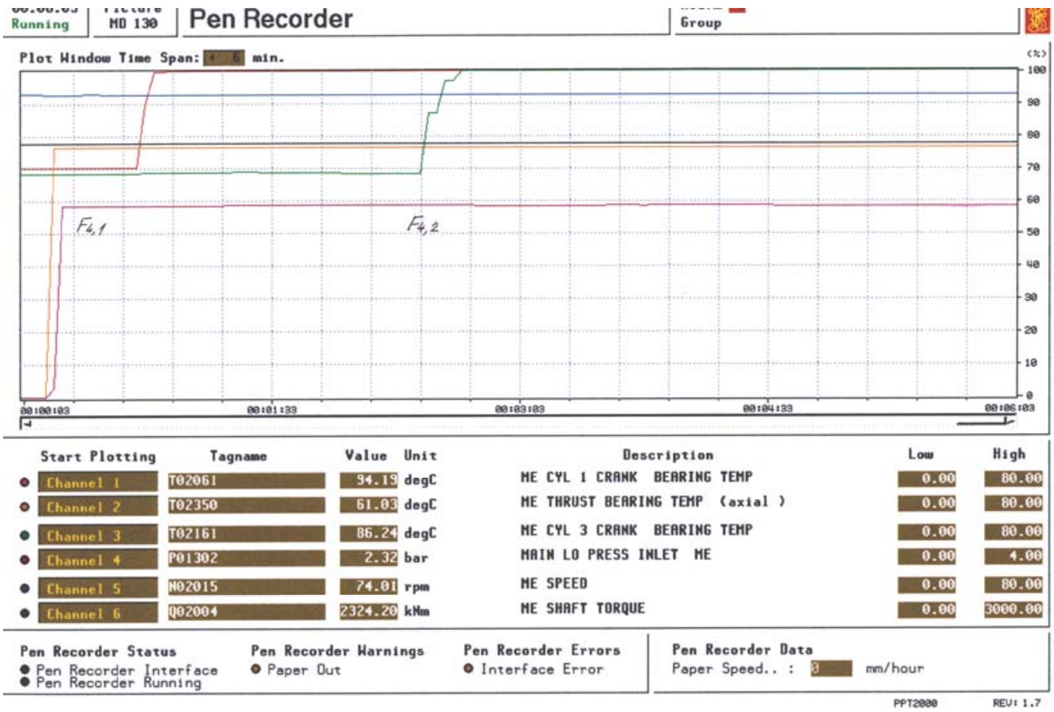

Figure 4. Simulation of marine diesel engine cylinder bearings faults

Table 1. shows simulated engine bearings faults and observed symptoms and events. This form of presentation together with variables curves trends allows easier visualization of relations between the selected faults and symptoms and events through simulation time period [5].

Table 1. Simulated faults and observed symptoms and events

FAULTS	SYMPTOMS & EVENTS
$F_{4,1}$: faulty lubricator of 1st cylinder bearing. $F_{4,2}$: faulty lubricator of 3rd cylinder bearing.	$S_{4,1}$: sudden bearing temperature increase of 1st cylinder. $E_{4,1}$: too high temperature of crankshaft bearing of 1st cylinder. $S_{4,2}$: weak oscillations of engine shaft. $S_{4,3}$: sudden bearing temperature increase of 3rd cylinder. $E_{4,2}$: too high temperature of crankshaft bearing of 3rd cylinder.

Table 2. Fuzzy relations between fault and symptoms- events

Fault	Symptoms and Events				
	$S_{4,1}$	$E_{4,1}$	$S_{4,2}$	$S_{4,3}$	$E_{4,2}$
$F_{4,1}$	LI	LI	SI	SI	NL
$F_{4,2}$	LI	SI	SI	SI	LI
$F_{4,3}$	SI	SI	SI	SI	SI

In this simulation scenarios and faults diagnosis 5 fuzzy linguistic variables have been used, table 2.: (NL – no significant variable change; SI – small increase ; LI – large increase ; SD – small decrease ; LD – large decrease).

In the stage of faults detection and identification fuzzy expert knowledge and experience have been used. Fuzzy production rule base has been established and expert reasoning method used. Here is the example for fuzzy expert rule in case of fallt $F_{4,1}$.(table 2).

$$If\ S_{4,1}\ is\ LI\ and\ E_{4,1}\ is\ LI\ and\ S_{4,2}\ is\ SI\ and\ S_{4,3}\ is\ SI\ and\ E_{4,2}\ is\ NL\ \ Then\ F_{4,1} \quad (4)$$

The engine expert made such his decision in fault detection and identification with 95 % confidence.

4. CONCLUSION

Early fault detection and identification is necessary for timely taking preventive and corrective actions, thus protecting and prolonging engine operational time and finally ship's propulsion reliability and availability [4]. Combining results from simulations and human expert knowledge and experience should be very promising method in faults diagnosis.

The simulation could be useful, especially in the diagnostic system design stage and control system implementation. Using simulator, training the knowledge, experience and safety during work have been obtained, since this method enables simulation of certain faults and failures and working engine conditions without human or material damage or loss.

5. REFERENCES

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