

# Fault Diagnosis and Isolation of the Marine Diesel Engine Turbocharger System

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**Abstract - Due to the complexity of the ship's systems early detection and isolation of the faults is of the essential importance for realization of a safe operation and necessary level of functionality. In this paper the main objectives of fault diagnosis are presented, such as detection, isolation and faults analysis. By simulating the appropriate faults in the turbocharger of the marine two stroke diesel engine MAN B&W 5L90MC, on a simulator Kongsberg Norcontrol type PPS 2000, with high functionality and reality level, symptoms, events and variables trends in time have been studied. For treatment of the symptoms and identification of faults, different methods of conclusion within the diagnostic expert systems have been used.**

## I. INTRODUCTION

For centuries the only way of detecting and locating faults was by use of biological senses. At that time everything was based on observing, listening, smelling and touching different parts of the system. Later on a greater flow of accurate fault information was enabled by introducing measuring equipment, and now day's computers made possible a dramatic progress in fault detection and identification.

Ship's systems are highly complex and faults can be developed on any component of the system, actuator, regulator or sensors. Due to the complexity of the ship's systems early detection and isolation of the faults is of the essential importance for realization of a safe operation and necessary level of functionality.

It is well known that operation reliability and usefulness are the basic demands that are set on the marine systems. Today, it is possible to realize those demands by use of diagnostic technology.

The main objectives in fault diagnosis are [2], [3], [6], [10]:

- fault detection,
- fault isolation,
- fault analysis.

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Figure 1 shows the basic structure of the faults detection model. The principle is based on comparison of nominal and measured values, a faults residual is generated, and by use of expert knowledge the symptoms detection and fault analysis is made.

This paper is based on studying symptoms that were given by simulating of corresponding turbocharger faults.

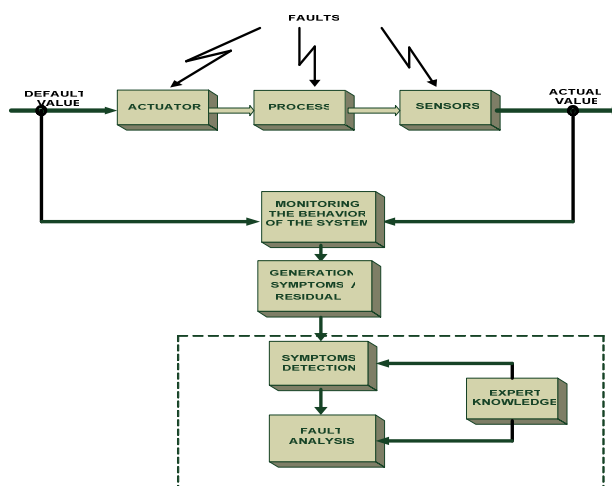


Fig. 1. Fault diagnosis and isolation procedure

This paper is based on studying symptoms that were given by simulating of corresponding turbocharger faults. The symptoms represent the change of observed parameters in relation on a normal state of the system and indicate a possibility of system faults, and can be classified [1], [11]:

- analytical; residual changes that have surpassed fault detection,
- heuristic; observations or measurements of experts and heuristic facts based on expert's experience and
- statistical symptoms; fault frequency, no fault time and fault duration time.

## II. FAULT DETECTION METHOD – FAULT TREE METHOD

Fault tree method is an efficient way for fault detection. It is a deductive process of identification of all possible relevant causes of unreliability and of determination of their interactive connection [5], [9].

The basic and necessary condition for approaching fault tree reliability analysis is to define the unwanted, that is the main event of observed technical system [5].

On the top of the tree is the system fault, and the branches lead to corresponding events and symptoms that determine the fault. Figure 2 shows a form of fault tree structure.

FTA (Fault Tree Analysis): symptoms – events – faults  
 FTA i ETA (Event Tree Analysis) are highly connected. They differentiate by that the ETA analysis allows access to reliability estimation by forward logic. It is an inductive process of displaying possible results that result from an accident event.

ETA: faults – events – symptoms

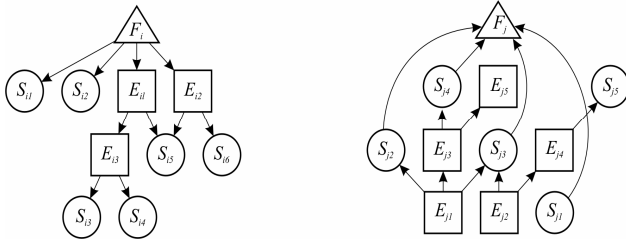


Fig. 2. Fault tree – the basis of heuristic knowledge

The symptoms are related to each other by means of logical AND / OR operations in binary or fuzzy logic. Then, the rules could be given in the form [1], [6].

if  $\langle (\sigma_i \text{ AND } \sigma_{i+1} \text{ AND } \dots \text{ AND } \sigma_\delta) \text{ OR } (\sigma_{i'} \text{ AND } \sigma_{i'+1} \text{ AND } \dots \text{ AND } \sigma_{\delta'}) \dots \text{ OR } \dots \rangle$  then  $\langle \phi_k \rangle$

$$(1.1)$$

where:  $\sigma_i \in [E_k, S_i]$  a set of events, symptoms (inputs i.e. premises),

$\phi_k \in [E_k, F_j]$ , a set of faults (outputs i.e. conclusions).

In binary logic is:  $\sigma_i = 0$  ili  $\sigma_i = 1$ , so  $\phi_k$  can be determined in this way:

$$\phi_k = 1 - \prod_{j=1}^{\gamma} \left( 1 - \prod_{i=1}^{\delta(j)} \sigma_i \right) \quad (1.2)$$

Where:  $\gamma$  - number of conjunction (union);  $\delta(j)$  – number of elements by conjunction.

Symptoms, events and faults can present in the form of fuzzy set, which defines the respective functions and affiliation (often subjective assessment experts, operator):

$0 \leq \mu(\sigma_i) \leq 1$  for symptoms ;  $0 \leq \mu(\phi_k) \leq 1$  for faults.

### III. FAULT AND SYMPTOMS RELATIONS

The relations between diagnostic signals (symptoms) and faults are an effective way to detect and localize system component faults. They can be presented in different ways, as table, by diagnostic matrix, analytical, etc. However, despite the presentation form of relations between symptoms and faults their relation is generally expressed as follows [1], [8]:

$$DFS = \{F, S, V, r_v\} \quad (1.3)$$

$$F = \{f_i : i = 1, 2, \dots, I\} ;$$

$$S = \{s_j : j = 1, 2, \dots, J\} \quad (1.4)$$

$$V = \bigcup_{s_j \in S} V_j ;$$

$$r_v = F \times S \rightarrow r(V) \quad (1.5)$$

where:  $F$  - a set of engine components faults.

$S$  - a set of diagnostic symptoms.

$V$  - a set of diagnostic signals values.

$r_v$  - function defined as a Cartesian product set  $F \times S$ , giving to each fault - symptoms  $\{f, s\}$  pair, one or more values for each separate fault:

$$r_v(f_i, s_j) = V_{ij} \subset V_j \quad (1.6)$$

In the simplest case, diagnostic signals values can be in binary form  $V_j = \{0, 1\}$ , when diagnostic scheme may be in

matrix or table form with faults in columns and symptoms in rows. Fault signature or a description of  $i$ -th fault is defined by a set of possible diagnostic signals with associated values:

$$D(f_i) = \{s_{ij}, v_{ik} : j = 1, 2, \dots, J; k = 1, 2, \dots, K\} \quad s_{ij} \subset S ; v_{ik} \subset V_j \quad (1.7)$$

Table I illustrates a simple example of binary relations between faults and symptoms to show the reasoning principle in faults detection.

TABLE I  
 BINARY RELATIONS BETWEEN SYMPTOMS AND FAULTS

F/S	f <sub>1</sub>	f <sub>2</sub>	f <sub>3</sub>	f <sub>4</sub>	f <sub>5</sub>	f <sub>6</sub>	f <sub>7</sub>	f <sub>0</sub>
s <sub>1</sub>	1	0	1	1	1	0	1	0
s <sub>2</sub>	0	1	0	1	1	0	0	0
s <sub>3</sub>	1	0	0	0	1	1	0	0
s <sub>4</sub>	1	1	1	0	0	1	1	0
s <sub>5</sub>	0	0	1	1	0	0	1	0

Fault detection procedure or reasoning rules in this case could be in the following form:

If  $s_j = v_{jk}$  then  $f_i ; i = 1, 2, \dots, I; j = 1, 2, \dots, J;$

$k = 1, 2, \dots, K$  (1.8)

For instance, fault  $f_1$  occurred, then the rule looks like:

If  $s_1 = 1$  and  $s_2 = 0$  and  $s_3 = 1$  and  $s_4 = 1$  and  $s_5 = 0$  then  $f_1$ .

### IV. SIMULATION CASE

In this case faults in ship's propulsion diesel engine MAN B&W 5L90MC turbocharger system have been simulated by use of marine engine simulator PPS 2000. Figure 3 shows marine diesel engine turbocharger system.

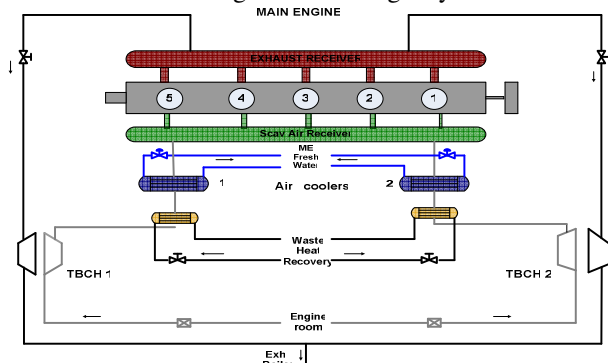


Fig. 3. Turbocharger system

Simulation was conducted by simulating three turbocharger system faults that are described in the following table II.

TABLE II  
SIMULATED FAULTS IN TURBOCHARGER SYSTEM

FAULTS	DESCRIPTION
$f_1$	Main Engine Turbocharger 1 Exhaust Turbine Dirty, set = 50%
$f_2$	Main Engine Turbocharger 1 Air Cooler Dirty, set = 50%
$f_3$	Main Engine Turbocharger 2 Air Compressor Dirty, set = 50%

By simulating faults tracking of symptoms that are described in table 3 has been made possible. Symptoms are defined as a change of variables in time.

TABLE III  
VARIABLES THAT ARE CONSEQUENCES OF GIVEN FAULTS  $f_1$ ,  $f_2$  AND  $f_3$ , THAT ARE CONTINUOUSLY MONITORED DURING THE SIMULATION

VARIABLES	DESCRIPTION
$V_1$	Turbocharger 1 speed
$V_2$	Turbocharger 1 exhaust temperature
$V_3$	Turbocharger 1 out flow
$V_4$	Turbocharger 2 out flow
$V_5$	Engine speed
$V_6$	Air cooler 2 air pressure

Table IV displays the binary relation between faults and symptoms in observed turbocharger technical systems.

TABLE IV  
BINARY RELATION BETWEEN FAULTS AND SYMPTOMS

	$s_1$	$s_2$	$s_3$	$s_4$	$s_5$	$s_6$
$f_1$	1	1	1	1	0	0
$f_2$	1	1	1	1	0	0
$f_3$	1	1	1	1	0	1

The faults that have identical description, that is the same row in the diagnostic matrix can not be differentiated, that is localized. An example are faults  $f_1$  and  $f_2$  from table IV. Better localization and faster fault detection are accomplished by analyzing table V, because it is more detailed when representing symptoms – faults relation. Because it is displaying the magnitude of increase or decrease of observed parameter values in time.

TABLE V  
CHANING OF PARAMETERS OF THE SIMULATION PERIOD

FAULTS	MONITORED PARAMETERS					
	$s_1$	$s_2$	$s_3$	$s_4$	$s_5$	$s_6$
$f_1$	--	++	--	-	0	++
$f_2$	-	++	-	-	0	+
$f_3$	-	++	-	-	0	--

Where: -- indicates significant drop, ++ indicates significant raise, 0 indicates no change.

With faults  $f_2$  and  $f_3$  the monitored variables change almost identical, apart the pressure in air cooler  $s_6$  causing increase at  $f_2$  and decrease in  $f_3$  in relations to the beginning value. In conclusion: differentiation of faults  $f_2$  and  $f_3$  is based on observing  $s_6$  in time. By observing all values of symptoms  $s_2$ ,  $s_4$  and  $s_5$  therefore those symptoms are not enough for accurate identification of the fault.

This table can be made by fuzzy logic that ensures a formal methodology for displaying manipulation and expert knowledge implementation regarding process regulation problem.

IF  $s_1$  significant drop AND  $s_6$  significant raise, THEN is fault  $f_1$ ;

IF  $s_1$  significant drop AND  $s_6$  raise, THEN is fault  $f_2$ ;

IF  $s_1$  drop AND  $s_6$  significant drop, THEN is fault  $f_3$ .

## V. CONCLUSION

Failure frequency on large ship's depends on a lot of factors, for example construction and material quality maintenance, cruising conditions, time of exploitation, etc. In this paper an example of diagnosis and fault isolation in the turbocharger of the marine two stroke diesel engine MAN B&W 5L90MC, on a simulator Kongsberg Norcontrol type PPS2000. The importance of this simulation is in its possibility of detecting faults without consequences (material damage and financial loss). Because of frequently of faults in engines turbocharger system in conditions that is exploitation conditions (up to 14%), this paper analyzed turbocharger system behavior, as one of the most important engine components, after simulating three different scenarios of most frequent faults. The changes of parameters values have been constantly monitored and given symptoms have been analyzed.

At the end we can conclude that more seriously introduction on – line surveillance system and diagnostics, whose simulation results are implemented into the system, gives more expert knowledge that is of the outmost importance for more effective fault diagnostics.

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