

DIAGNOSTIC RELATIONS BETWEEN STATE PARAMETERS AND OPERATIONAL PARAMETERS OF MARINE GAS TURBINE ENGINE

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Abstract

This article presents the basis of construction of diagnostic relations between the technical condition of the object and diagnostic symptoms. Terms: "relation" and "functional relations" describing diagnostic relations were defined. Using a one-rotor gas turbine engine as an example, construction of diagnostic relations for chosen operational parameters and the state of the engine, described by its power, has been shown.

Keywords: *ships, power plant, gas turbine engine, diagnosis*

1. Introduction

The term "relation", according to Wikipedia, the free encyclopaedia may refer to: a relation - a person to whom one is related, a generalization of arithmetic relations, such as "=" and "<", international relations and many others [1, 4].

The term "diagnostic relations" generally applied in diagnostics refers to relationships between the states of an object, X , and parameters of a diagnostic signal, Y . The state of the object may be defined as a set of structure parameters (eg. parameters describing operational or regulation tear) or in the sense of reliability: fit for use or unfit (faulty). Diagnostic relations can be determined on the basis of results from experiments carried out on real object/objects or basing on simulation research, when there is a model that well represents chosen states of the objects.

The aim of this paper is to study the relations between chosen state parameters and diagnostic parameters (signals) of marine gas turbine engines operating in a ship power plant.

2. Meaning of a relation

Any subset of a cartesian product of n sets is called a relation with n arguments. These sets have to be identical. A relation means a connection between elements of a set. If a relation is denoted as ρ , then $\rho \subset X_1 \times X_2 \times \dots \times X_n$. Relations included in the n -th cartesian power of one set are a special case [1, 4]:

$$\rho \subset X \times X \times \dots \times X = X^2, \quad (1)$$

In practice one-argument relations, i.e. subsets of the X set, are more common. However the most common relations are the binary ones. They are the sets of ordered pairs of the $\langle x, y \rangle$ type. If $\langle x, y \rangle \in \rho$ then we write $x\rho y$ (where x is in ρ relation with y). In mathematics one can encounter the following special relations:

- mathematical function,
- partial ordering,
- accurate ordering,
- transitive relation,
- symmetric relation,
- ant symmetric relation,
- equivalence relation,
- reflexive relation

and many others. Diagnostic relations usually appear in the form of function relations (mathematical function). Functions as relations of two sets X (states) and Y (symptoms) are defined as in [3]:

If a binary relation $\rho \subset X \times Y$, fulfils the condition that for each $x \in X$ there is exactly only one element $y \in Y$, then $x\rho y$ is called a function.

It relates to one element x of the X exactly one element of the Y set, so it is a function reflecting the X set into the Y set according to the definition of a function. Moreover the X set (states) and the Y set (symptoms) should meet the requirements of equivalence, symmetric and transitive relations which allows using in the simulation diagnostic research the reverse task i.e. simulating different states of the object and obtaining their symptoms.

In technological diagnostics, relations between the states of the object X and the diagnostic parameters (symptoms) Y , are most frequently studied using regression. It is a functional relation between the random variable X (states as a describing variable) and the variable Y (symptoms as a described variable) with the accuracy equal to a random error ε whose expected value is zero. Formally it is represented in the following way:

$$Y = f(X) + \varepsilon, \quad (2)$$

where:

- Y – random variable,
- $f(X)$ – regression function,
- X – any variable (or a set of variables),
- ε – random disturbance, $E(\varepsilon)=0$.

Regression is used to study the relations between parameters (qualities) X and Y . In diagnostic practice a relation between a describing variable X (states) and a described variable Y (diagnostic signal) is searched for. To determine the intensity of the relation between real parameters of a diagnostic signal Y and the estimated values \hat{Y} , a determination coefficient

$R^2 = R^2(Y, \hat{Y})$ given as:

$$R_i^2(Y, \hat{Y}) = \frac{\left[\sum_{k=1}^n (Y_k - \bar{Y})(\hat{Y}_k - \bar{Y}) \right]^2}{\sum_{k=1}^n (Y_k - \bar{Y})^2 \sum_{k=1}^n (\hat{Y}_k - \bar{Y})^2} \quad (3)$$

is used.

The determination coefficient, as a standardised measurement of intensity of linear relation between the diagnostic signal and the states of units of which the object is comprised, makes the basis for the choice of equations. Equations with determination coefficient values closest to one should be chosen. A small value of the determination coefficient indicates a poor relation between the real parameters of the diagnostic signal, Y and its estimated values, \hat{Y} .

3. The object of the research

An auxiliary one-rotor gas turbine engine of the GTU-6A type, whose cross-section is shown in Fig.1., was chosen as the object of the research.

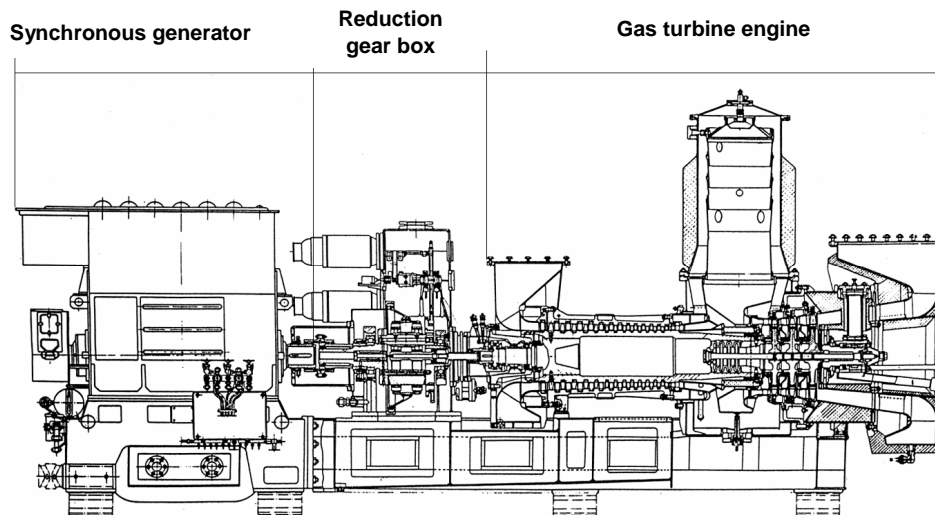


Fig. 1. A cross-section of a one-rotor gas turbine engine of the GTU-6A type in an auxiliary power unit

The GTU-6A engine, through a planetary reduction gear drives a synchronic generator of the MSK 750/1500 type. On a ship there are four engines of this type, placed in separate machine compartments, which cooperate with the ship power system through a sectioned bar. Designed properties of the GTU-6A gas turbine engine are shown in Tab. 1.

Tab.1. Designed properties of the GTU-6A gas turbine engine

Parameter/ Symbol	Unit	Load range					
		Idle run	0,5	0,7	0,8	1,0	1,1
P_e	kW	–	300	430	480	600	660
T_3	K	791	870	930	970	1033	1097
T_4	K	508-538	608-638			708-738	>793
π_c	–	3,2-3,5	3,8-4,1			4,1-4,4	5,35
n	min ⁻¹	12150	12150	12150	12150	12150	12150
P_{fuel}	MPa	4,5-5,2	4,8-5,5			5,1-5,8	
P_{oil}	MPa	0,28-0,3	0,28-0,3			0,28-0,3	
\dot{m}_{air}	kg/s					6,64	

4. Operational studies

Operational studies on a one-rotor gas turbine engine were carried out according to a passive diagnostic experiment in which engine operational parameters are studied while state parameters (structure parameters) are unknown. There is a possibility of regulating the control vector. The choice of passive experiment was due to technical considerations connected with the tasks performed by the ship during its operation.

Specifics of gas turbine engine operation in marine conditions leads to representing the diagnosed engine states by discrete sequences of diagnostic signals, recorded in uneven time periods. These signals comprise the measurements representing [2]:

- effective energy flow,
- energy state of the engine,
- energy fluxes driving the engine.

Operational parameters considered as measurable ones, were the input and output observable variables of engine subunits, which due to technical conditions could have been measured and recorded during the engine operation. On-line controlled operational parameters of the main and auxiliary gas turbine engines in ship power systems of chosen vessels are presented in Tab. 2.

Tab. 2. Observed operational parameters of auxiliary gas turbine engines of the GTU-6A type

Subunit	Operational parameter	Symbol	Accessibility
Air inlet duct	Atmospheric air pressure	p_0	1
	Atmospheric air temperature	T_0	1
	Air pressure loss on the filter	Δp_F	1
Compressor	Rotor speed	n	1
	Air temperature at the compressor	T_1	1
	Air pressure behind the compressor	p_2	1
Combustion chamber	Exhaust gas temperature behind the combustion chamber	T_3	0
Compressor turbine	Exhaust gas temperature behind the turbine	T_4	1
Control system	Fuel pressure at the burner	$P_{fu.at.burn}$	1
	Overflow fuel pressure	$P_{fuel.overfl}$	1
	Oil pressure behind the regulator	$P_{ol.contr.}$	1
	Fuel pressure behind the supply pump	P_{fuel}	1
	Fuel pressure loss on the filter	$\Delta p_{fuel.F}$	1
Oil and cooling system	Oil pressure at the engine inlet	$P_{ol.eng.I}$	1
	Oil temperature behind the cooler	$t_{ol.eng.I}$	1
	Compressor bearing temperature	$t_{bearingC}$	1
	Turbine bearing temperature	$t_{bearingT}$	1
	Water temperature behind the oil cooler	$t_{w.ol.CO}$	1
	Oil pressure at the reduction gear	$P_{ol.R}$	1

1 – measured parameters,

0 – parameters experimentally inaccessible

Measured and recorded, by the subsystems of the 61 MP “SLAN” control network, were the average values of the operational parameters at stationary random energy states of engines. The measurements were carried out for random engine loads at the atmospheric air parameters, p_0 , T_0 and the relative air humidity, ϕ_0 . During one observation, at a single time sequence, from more than 10 to over 20 recordings of diagnostic signal parameters were taken, trying to include the possibly widest range of loads, from idle run to the possibly biggest powers.

5. Diagnostic relations

For the parameters presented in Tab. 2, relations of a function type were established, where for the set of states, X , engine power was used (describing variable) and as the set Y (symptoms) the measured parameters (Tab. 2) were taken. To determine the relation between the X and Y sets the least squares method was applied and as the criterion of the best relation (the strength of the relation) R^2 . In Fig. 2. and Fig. 3. exemplary relations for exhaust gas temperature T_3 and T_4 and fuel mass flow \dot{m}_{fuel} , supplied to the combustion chamber are given.

The presented relations show that there are diagnostic relations between the measured operational parameters of marine gas turbine engines and the parameters characterizing their technical condition. Such relations allow, after performing the reverse task, to estimate the condition of the engine (in this case expressed as the power) basing on the recorded parameters of engine operation.

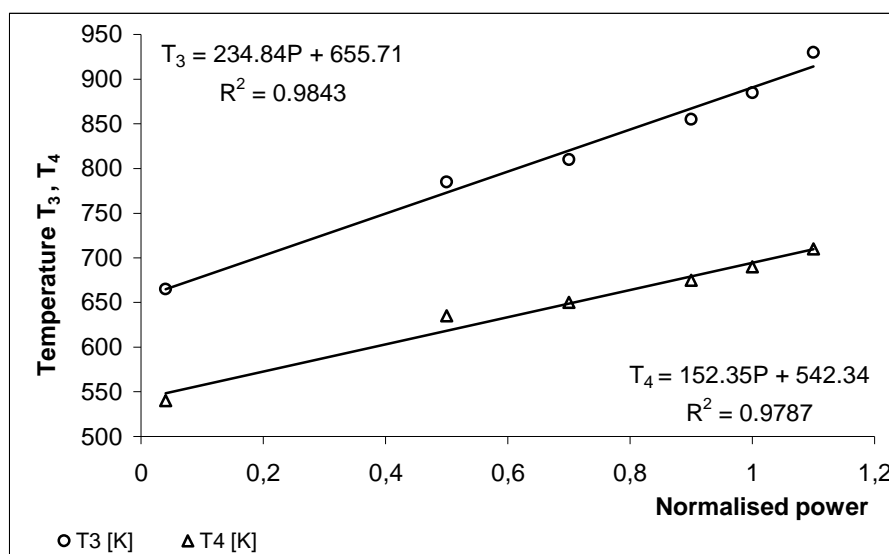


Fig. 2. Diagnostic relations between the exhaust gas temperature behind the combustion chamber and the turbo-compressor and the engine power

6. Summary and conclusions

This study presents the essence of constructing diagnostic relations between diagnostic parameters and state parameters. Basing on literature, the meaning of a relation has been presented. Special relations applied in pure mathematics were listed. In diagnostics the term “diagnostic relation” means the relation between the states of the object, X , and the parameters of the diagnostic signal Y . Example of established diagnostic relations have been presented for chosen operational parameters of marine gas turbine engines and their technical condition. Diagnostic relations have been constructed applying regression analysis and the least square method.

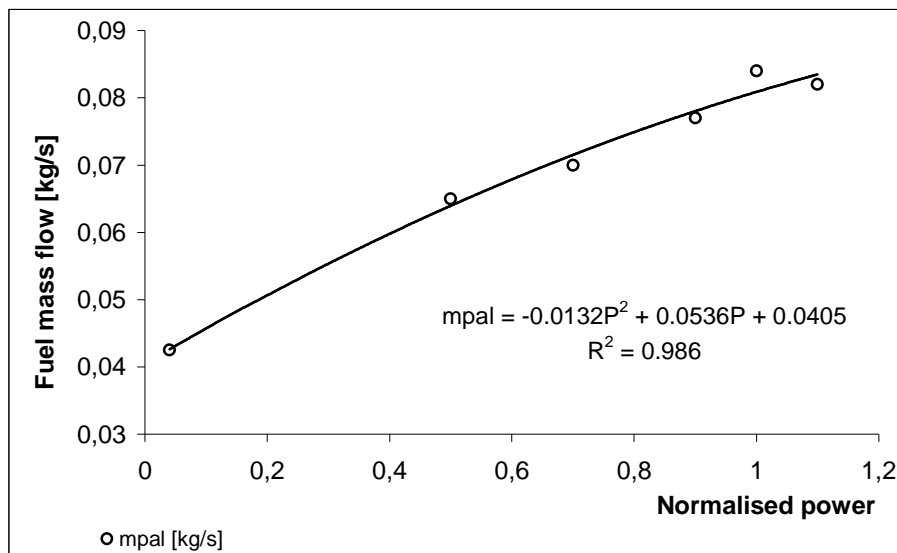


Fig. 3. Diagnostic relations between the mass of fuel supplied to the combustion chamber and the engine power

The exemplary diagnostic relations presented in this study and the method of constructing such relations can be applied to:

- establishing the strength of relations between the state of the object and diagnostic parameters,
- the choice of diagnostic parameters which best represent the state of the object,
- diagnosing the object basing on a model.

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