MARINE GAS TURBINE PERFORMANCE DIAGNOSTICS: A CASE STUDY

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Summary

The paper discusses how performance models can be used for marine gas turbines. A particular performance model, built for on board training purposes is employed to demonstrate the different aspects of this process. The model allows the presentation of basic rules of gas turbine engine behavior and helps understanding different aspects of its operation. A smart designed graphics user interface is used to present engine operation in different ways: operating line, operating points of the components, interrelation between performance variables and parameters etc. The perception of fault signatures on monitoring parameters is clearly demonstrated. Diagnostics capabilities of the existing performance model installed at the Hellenic Naval Academy Gas Turbines Virtual Lab are examined and tested using the measurement data from real marine gas turbines. A case study is discussed in this paper where the model results and the real engine conditions are compared for diagnostic purposes.

Keywords: gas turbines, performance, diagnostics.

1. INTRODUCTION

The propulsion system of a specific type of frigates consists of a conventional two shaft CODOG configuration with two MTU 956 20V TB 82 cruise diesel engines; two boost GE LM 2500 gas turbines, Renk Tacke reduction gearboxes and two Escher Wyss controllable pitch propellers.

Gas turbines are complex engineering systems and performance monitoring and fault diagnosis is a subject that has to be addressed in gas turbine related –onboard and off board- training courses for all level of personnel involved with gas turbine operation and maintenance. Time and means for education and training are limited and therefore they must be used in an optimized manner. Computer assisted training comes to provide tools to increase training efficiency and fulfil such requirements [1]. The present paper discusses how marine gas turbines condition monitoring and fault diagnosis software is used for practical purposes.

Data from a GE LM 2500 marine gas turbine is used for the examination and testing of the existing performance model installed at the Hellenic Naval Academy Gas Turbines Virtual Lab [2]. A case study is discussed where the report from the practice and the software generated malfunctions are compared. The compressor efficiency is the independent variable affecting a series of operating parameters. The error between the calculated and the actual values is finally obtained.

2. PROPULSION PLANT PERFORMANCE

LM 2500 is an aero-derivative robust engine of increased power output and high efficiency developed and manufactured by General Electric. Overall engine design includes an annular combustor with mechanically independent high pressure and low pressure rotating systems. Vessel's propeller shaft can be driven by either one or both gas turbines at any given time [3].

A computer model produces very easily a lot of information that would be difficult, expensive and some times even impossible to obtain on an actual engine. Engine behavior can be studied at all possible permissible operating conditions, while even physically non-permissible conditions can be examined, if sufficiently deep modeling is involved. Any physical quantity can be observed, without the need of expensive instrumentation, which must be used on an actual engine. Even quantities that would be impossible to obtain due to geometrical or operating restrictions can be obtained (for example, turbine entry temperature, interstage pressure for a multistage compressor or turbine etc). In addition, for given ambient conditions and turbine inlet temperature, the change in the operating parameters (mass flow rate, compressor discharge pressure, compressor discharge temperature, fuel mass flow rate, which is directly related to specific fuel consumption and thermal efficiency, and exhaust gas temperature), when the compressor is fouled, can be directly and accurately evaluated.

3. UNDERSTANDING THE EFFECTS OF MALFUNCTIONS

The advantages of computer models implementation become even more pronounced when operation under abnormal conditions, namely deteriorated engines or engines with faults, are considered. If experience is to be gained by observing actual engines this will have to happen either by (a) studying cases where faults have occurred on an operating gas turbine or (b) by setting up tests in which faults have been artificially introduced.

The understanding of the effects of malfunctions can be achieved through the simulation of component faults. Such faults are simulated by modification of the performance characteristics of the components. The modified characteristics are then introduced into the model and the deviations of cycle or performance parameters are observed. In this way one can, for example, demonstrate very easily the performance drop due to compressor fouling or exhaust gas temperature variations due to turbine nozzle erosion [1].

Map modifications are effected by using scalars, multiplying the component performance parameters. Such scalars have been, for example, introduced in the past under the term ''modification factors'' MF defined as $MF=X/X_{ref}$, where X is the current value of a parameter and X_{ref} its value for a component in intact condition [4].

Introduction of malfunctions gives several possibilities for demonstrating their effect on engine parameters. First of all, by performing simulations for healthy and faulty engines the impact of faults can be directly assessed. The important notion of "fault signature" can be very easily introduced, when the above-mentioned possibility exists. Values of measured quantities can be calculated for both healthy and faulty operation and their differences are calculated to provide the signatures. The model used is the one installed in the Hellenic Naval Academy Gas Turbines Virtual Lab and it is equipped with the capability of directly evaluating such a signature, whenever a fault is simulated. This particular application was developed by the National Technical University of Athens/ Laboratory of Thermal Turbomachines in cooperation with the Hellenic Naval Academy/Naval Engines Laboratory and features a powerful, user friendly, functional, training tool which comes up with fast and safe conclusions about engine healthy behaviour and operating trend both in moderate and extreme conditions. The detailed description of the specific capabilities of the Gas Turbines Virtual Lab and its characteristics (performance simulation and monitoring) has already been demonstrated [1, 2].

In this paper special attention is paid on the software diagnostic capabilities.

A layout of the screen related to the GE LM 2500 performance is given in the following Fig. 1.

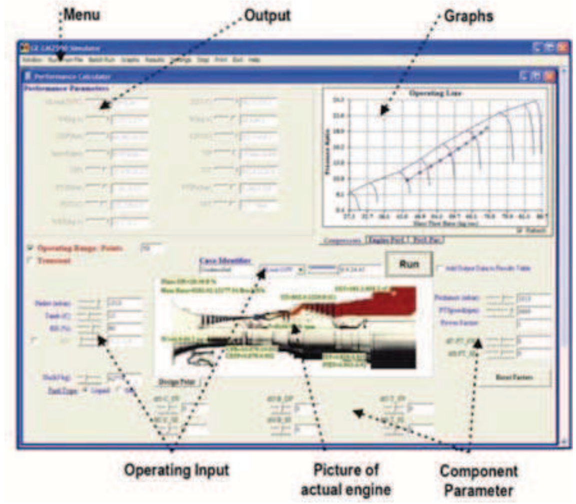

Fig. 1. GE LM 2500 performance layout

4. GAS TURBINE PERFORMANCE AND ASSUMPTIONS

The information provided for the GE LM 2500 is based on engines having clocked 2500 working hours and on PLA actuator (torque motor located on the GT main fuel pump) value of 72. PLA value corresponds to 72 % propulsion plant control levers – engine loading conditions, 2500 RPM power turbine rotating speed and 22 knots vessel's speed. Controlled pitch propeller variations were negligible and the ratio P/D attained a constant value of 1.45 [5, 6].

The following assumptions were made regarding the real gas turbine operation and the software simulation:

4.1. No inlet or exhaust losses

The pressure drop through the inlet air barrier screen is estimated to be about 4 in H_20 at maximum flow rate. The maximum total pressure loss is estimated not to exceed 12 in H_20 measured at the inlet bell mouth, while the back pressure is estimated to be about 6 in H_20 and not to exceed 20 in H_20, static pressure, measured at the exhaust extension outlet [5, 6].

4.2. Constant atmospheric pressure

Atmospheric pressure at sea level is considered to be constant getting a default value of 1013 mbars.

4.3. Fuel heating value

The fuel used has a lower heating value (LHV) of 42800 KJ/Kg which refers to F-76 fuel properties, regularly feeding marine gas turbines.

5. RESULTS AND DISCUSSION

A series of runs was performed and the results are compared to the actual values (measurements) available from the practice. To simulate the existence of a malfunction, modification factors with values different from unity are introduced.

In the case study examined in this paper the compressor has ''experienced'' a change in efficiency as a percentage of the reference value, namely -3%, -1%, +1%, +3%.

The influence of the four different efficiency levels on five different parameters is examined, i.e. mass flow rate (W), compressor discharge pressure (CDP), compressor discharge temperature (CDT), fuel mass flow rate (W_f), which is directly related to specific fuel consumption (SFC) and thermal efficiency (η_{th}), and exhaust gas temperature (EGT). Load is the sixth parameter demonstrated in the fault signature, although load assumed to remain constant throughout the entire case study.

In the following fig. 2 the effect of a 3% reduction in the compressor efficiency on the gas turbine performance is presented.

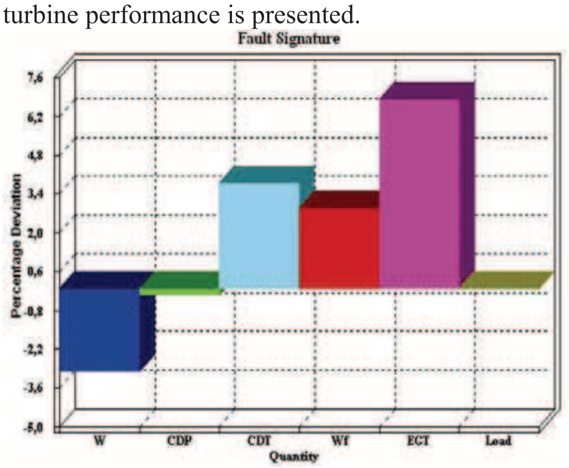

Fig. 2. 97% of the reference compressor efficiency

In the following fig. 3 the effect of a 1% reduction in the compressor efficiency on the gas turbine performance is presented.

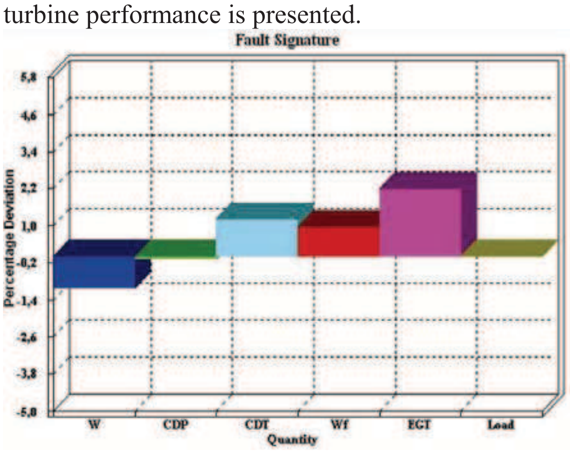

Fig. 3. 99% of the reference compressor efficiency

In the following fig. 4 the effect of a 1% improvement in the compressor efficiency on the gas turbine performance is presented.

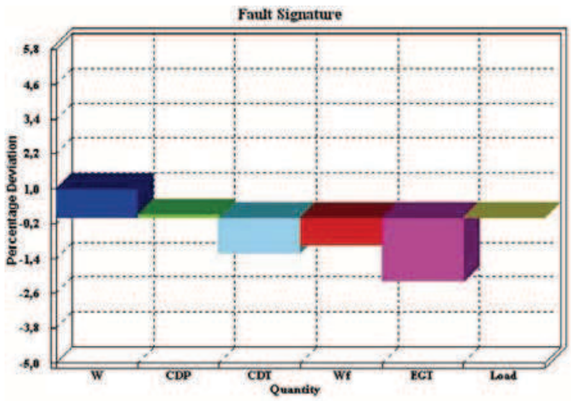

Fig. 4. 101% of the reference compressor efficiency

In the following fig. 5 the effect of a 3% improvement in the compressor efficiency on the gas turbine performance is presented.

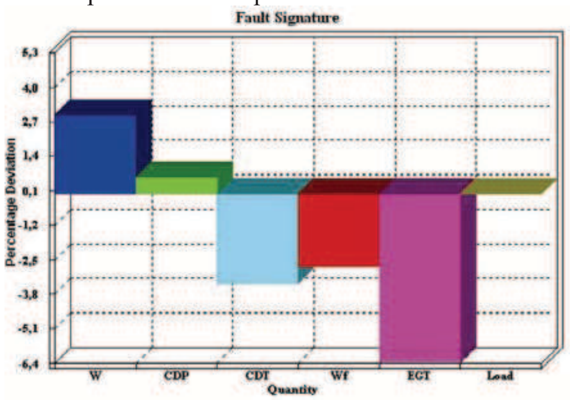

Fig. 5. 103% of the reference compressor efficiency

According to the previous figures when the compressor efficiency changes from 97% to 103% of the reference value, the following results are obtained. Mass flow rate (W) changes from 97% to 103% of the reference value. There is a very slight deviation on the compressor discharge pressure (CDP) related to the reference value. Compressor discharge temperature (CDT) changes from 104% to 96% of the reference value. Fuel mass flow rate (W_f) changes from 103.5% to 96.5% of the reference value. Finally, exhaust gas temperature (EGT) changes from 106.5% to 93.5% of the reference value.

In the following table data from the practice (real gas turbine behavior) and simulation program results (prediction of the virtual gas turbine behavior) are being presented and compared. The error is derived through the following equation:

$$\%error = \frac{calculated\ value - actual\ value}{actual\ value} \times 100$$

The calculated and actual values used for the estimation of the error are related to the specific case when a reduction of 3% on the compressor efficiency is observed.

Table 1. Error between calculated and actual values

OPERATING PARAMETER	ERROR %
Mass flow rate (W)	-1.8
Compressor discharge pressure (CDP)	-2.5
Compressor discharge temperature (CDT)	+3.9
Fuel mass flow rate (W_f)	+2.7
Exhaust gas temperature (EGT)	+4.2

The error obtained shows that the simulation software underestimates W and CDP and overestimates CDT, W_f and EGT.

6. CONCLUSIONS

The Hellenic Naval Academy Gas Turbines Virtual Lab is used in order to act as a malfunction generator and a diagnostic tool. Data from the practice is used in order to evaluate the accuracy of the simulation software calculated values. As a case study the change in the compressor efficiency is considered.

Particular aspects, which can benefit from the use of computer models, have been discussed. Specific simulation software designed and developed for training and – potentially- diagnostic purposes has been used, examined and evaluated. The evaluation results presented a significant accuracy when the software is used as a malfunction generator and diagnostic tool, since the error obtained is less than 4.5% for the parameters chosen to be under observation.

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