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PLANNING OF AN EXPENDITURE OF THE RESOURCE OF GAS TURBINE ENGINE IN OPERATION

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Abstract

The algorithm and the program, allowing to minimize an expenditure of a resource and fuel gas-turbine engine on a planned piece of life cycle at the expense of a choice of modes, quantity of stops and other parameters taking into account predicted weather conditions, possible pollution of flowing part is developed.

To provide engine resource management we must understand patterns according to which they are depleted.

Usually the technology to account for depletion of the engine resource is provided by the engine designer as a dependence on the equivalent working time of different factors. The account for equivalent time can be divided in to two parts. One part includes working conditions under stationary modes, the other one includes dynamic modes of non-stationary nature: start and stop of the engine, increase and decrease in load, use of different types of fuel.

It is difficult to account for these factors in analytical form and therefore they are accounted for with a number of coefficients assigned by the engine designer (T_{e_d}). And it is a natural situation as the designer knows its engine best.

At the same time a number of factors of "static nature" may be accounted for based on dependences general for all gas turbine engines (GTE) engines (T_{e_st}). These factors include intermittent static modes ($T_{\text{int}.st.}$), influence of failures of the flow part (T_{e_fl}), work under different loads (T_{e_df}), degradation of materials of the turbine blades (T_{e_dg}).

The expenditure of the engine resource lifespan in equivalent hours can be described in a general form:

$$T_{eq} = T_{e\_st} + T_{e\_d} \tag{1}$$

Accumulated time of dynamic modes:

$$T_{e\_d} = \sum T_{ei\_fli} \tag{2}$$

$$T_{e\_st} = T_{\text{int}.st.} + T_{e\_fl} + T_{e\_df} + T_{e\_dg} + T_r, \tag{3}$$

where T_r – is the time of work under the rated mode for which the engine resource is designed.

We believe that planning of and accounting for depletion of the engine resource is kept under automatic mode combined with the monitoring system and technical diagnosis of the GTE. In this case continuous evaluation of depletion of the engine resource is carried out taking into account all the assumed factors.

The "static" component is continuously updated, and the dynamic component is added according to the dependency (1) just after the completion.

The depletion of the engine resource can be easily represented in the form of engine performance as shown in figure 1.

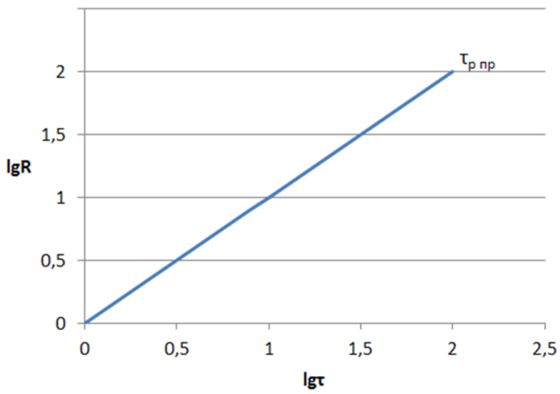


Fig.1

The form of resource expenditure dependence:

τ_d – time before destruction on modes.

Here in logarithmical coordinates: time before destruction τ, engine resource in %, the change of the engine resource can be shown from 0 to 100% (in logarithmical coordinates to 2.0) depending on the logarithm of the relative operating time $\tau_п$. That is of current time τ_i related to the time before the destruction of τ_d in this mode, taking into account possible changes in operating conditions (corrosion and other conditions) .

If the ordinate at lgR = 2.0 is equal to the logarithm of material destruction time at the rated mode the intermediate value of the spent lifetime can be formulated as follows:

$lg\ R_i = lg\tau * tgH$, or if $tgH = 1,0$ (fig.1)

in this formulation $lg\ R_i = lg\ \tau_n$

For work under intermittent static mode the time before the destruction of the material is less than for continuous work under the same mode.

Processing of empirical data under this mode of use of high-temperature-resistant materials has shown that the reduction of the time before the destruction of the material can be taken into account with use of the coefficient $K_{tgR} = 1.301 * \tau_\mu^{-0.03027}$, where τ_μ - is the duration of a working cycle. This adjustment is used when the cycle duration is less than 100 hours. The time in the working cycle in the formula is expressed in minutes.

As a result formula (4) will take the following form:

$$lg\ R_i = lg\tau * K_{tgR}, \qquad (5)$$

or

$$lg\ R_i = lg\tau * 1.301 * \tau_\mu^{-0.03027} \qquad (5a)$$

If as a result the gas temperature has risen due to a failed flow part during operation, and the temperature of turbine blade has risen, and the working mode of the engine has not changed (σ=const), the following step are made.

In Larson-Miller coordinates τ_p is evaluated at the new temperature based on the alloy properties $\sigma_i = f\ (T_i \cdot (lg\tau_{pi} + 20))$. The temperature of the material is evaluated based on the gas temperature with use of dependencies resulted from the temperature measurements provided that $\sigma_1 = \sigma_0$.

As a result we have $lg\ \tau_{p1} = T_0/T_1\ (lg\ \tau_o + 20) - 20$.

We can see similar performance as a result of intermittent static mode.

The estimated depletion of the resource must be brought to equivalent hours of work under the rate mode for which the resource is designed. (4)

Equivalence of working hours can be determined based on expenditure of the safe resource share before destruction of the material.

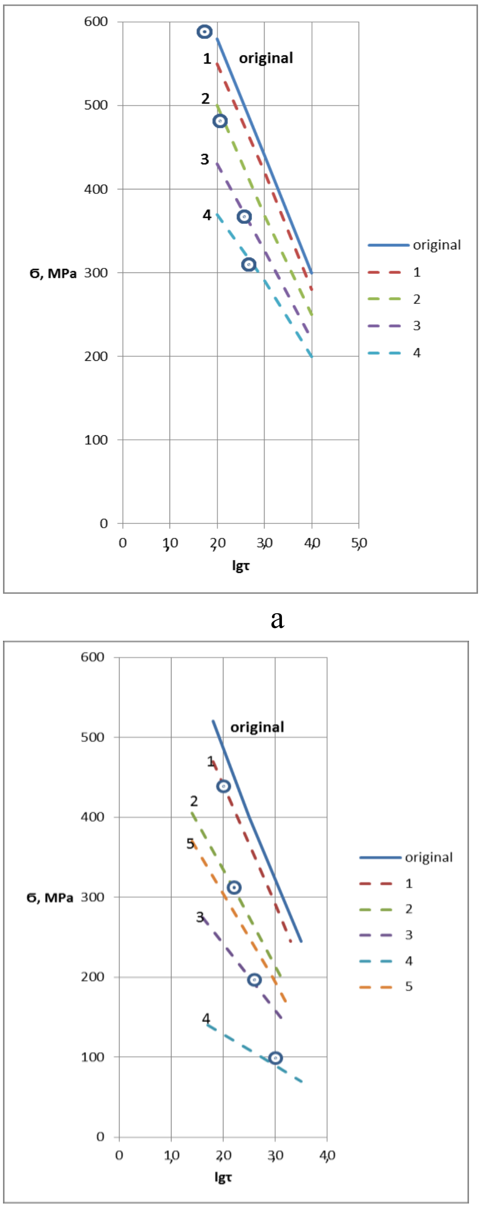
For equal values of logarithms of R

$lg\tau_e = lg\ \tau_{p1}$ or

$$lg\tau_e = lg\ \tau_{p1} \qquad (6)$$

Operation under different modes corresponds to other relations of the temperature of materials and current stresses. If the mode is less than the rated one the stresses impacting turbine blades are less than the rated ones, and the time before the destruction is typically more. Working hours at the share mode to the rated one is brought based on formula (6). As a result equivalent hours decrease as compared with the actual one.

As a result of operation of the GTE onboard or at a sea facilities accelerated degradation of the material of turbine blades and decrease of their durable strength occur. An example of such change in durable strength of the JS6K alloy can be seen at figure 2.



a

b

Fig.2

Long-term strength characteristics of the alloy JS6K after corrosion resistance testing depending on the amount of lost mass q (мg/cм^2).

a – temperature 800 °C, 1 – 11 мg/cм^2 2 – 15 мg/cм^2 , 3 – 27 мg/cм^2 , 4 – 36 мg/cм^2 ;

b – temperature 850 °C, 1 – 20 мg/cм^2, 2 – 26 мg/cм^2, 3 – 32 мg/cм^2, 4 – 49 мg/cм^2, 5 – 27 мg/cм^2 to recalculate;

⊙ - experimental values.

As a result of weight loss in the JS6K alloy the time before its destruction has considerably decreased.

Elementary composition of the JS6K alloy in %: 4.5 Co, 11.5 Cr, 2.8Ti, 5.5 Al, 4.0 Mo, Ni.

If the Larson-Miller property is known under the assumed stress for the work in open air, P_{orig}, and the specific weight lost as result of corrosion q is known, the change in the Larson-Miller property is equal to

$$P_{rel} = P_d/P_{orig} = 1.113 * q^{-0.0469}, K \quad (7)$$

Therefore the value of the property after corrosion effect can be evaluated as

$$P_d = P_{rel}*P_{orig} = P_{orig} *1.113 * q^{-0.0469}, K \quad (8)$$

In case of use of another alloy the structure of the coefficient of account for corrosion remains the same but values can differ.

Let's evaluate the time before the destruction as a result of corrosion.

$$T_d\,(lg\tau_d+20) = T_{orig}\,(lg\tau_{orig}+20) * 1.113*q^{-0.0469}$$

$$lg\tau_d = T_{orig}/T_d(lg\tau_{orig}+20) *1.113* q^{-0.0469} -20 \quad (9)$$

The time before destruction decreased.

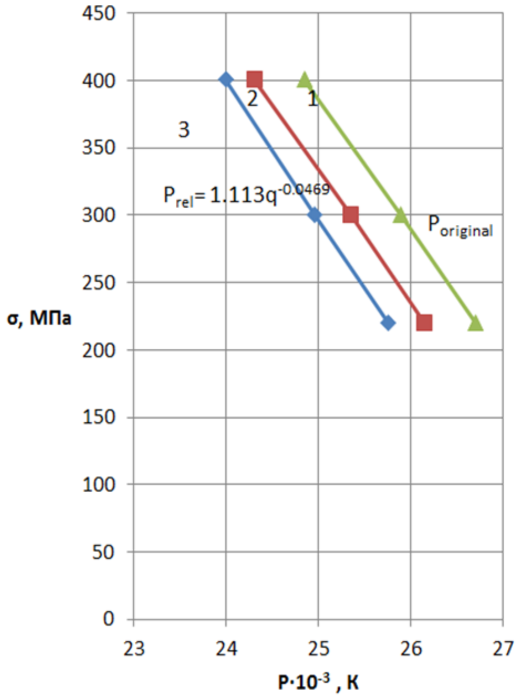


Fig.3

Long-term strength characteristics of the alloy in various states JS6K:

1-original; 2- q=15 mg/cm^2 ; 3- q=26 mg/cm^2

- Characteristic 1 is obtained to metal temperatures 800 °C and 850 °C;
- Characteristic 2 is obtained according to the results of corrosion damages with mass loss 15 mg/cm^2 at t_m=800 °C;
- Characteristic 3 is obtained according to the results of corrosion damages with mass loss 26 mg/cm^2 at t_m=850 °C.

The loss in the alloy weight is a non-measured parameter in this process. The account of the loss in weight is kept continuously since the start of the engine. For this the metal temperature and duration of work at this temperature, as well as results of testbed tests (preferably at gas-dynamic testbed) based on the weight loss of the considered alloy and protective coating are used.

To plan depletion of the engine resource during the life cycle of the engine the mathematic simulation model allowing to generate parameters of the engine for different modes including modes with faulted flow part of the engine is used.

For the rated mode of engine operation the ways of implementation of the current tasks, engine work modes are designed.

To get an optimal solution alternative options are designed.

According to statistics dynamic modes of work are planned.

As a result with use of parameters generated by the simulation model an array of initial data is formed to be processed with the diagnostic system based on the principles as mentioned above. These principles were tested under the technical monitoring, diagnostic and forecast system for conditions of the GTE in the process of bed and acceptance tests.

The results have shown possibilities for control of spent lifetime of turbine blades under automatic mode. We can also simulate the life cycle of GTE to evaluate its performance during operation which provides more comprehensive simulation.

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