STATE PROCESSING FOR COMPLEX HEAT-ENGINEERING SYSTEMS

V. V. Malozemov and V. A. Tomskii

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State forecasting is considered for complex heat-engineering systems, especially in relation to on-line monitoring and control.

A large volume of data processing is involved in monitoring the working parameters of a complex heat-engineering system, which inevitably tends to distract the operator and affect his decisions. This is clearest during the stage of commissioning and testing, where it is difficult to establish how far any deviation of system parameters from the nominal values may be critical. This requires means of reducing the volume of data reaching the operator and also of predicting the system behavior under changing conditions; it is also necessary to predict the consequences of any possible failures.

These purposes can be achieved by inserting computing facilities between the object and the operator, with most of the signals from the transducers processed by the computer, which controls the process and provides the operator with reasonably clear information as to system operation, while also forecasting the system state and indicating the consequences of any failures. Inclusion of a computer in the control loop requires a mathematical model for the system, in which the input data are processed and compared with the forecast, which provides for early detection of any failure or indication of the remaining working time. Also, one can specify an acceptable risk of not completing the measurement program and define a set of measures to offset any disadvantages from failure.

Of course, forecasting is only one of numerous problems that can be handled by the mathematical model; others are research on system functioning at a variety of stages, research on different styles of system operation and control techniques, and system optimization by parameter adjustment.

Then a mathematical model for the system is a major requirement in research and optimization, as well as in on-line monitoring and control. The simulation error and the response rate largely determine the performance in handling such topics.

When such a model is being drawn up, the first requirement is to have models for the individual elements, namely, the controlled object proper, the thermal protection, the heat exchangers, and the control circuits.

There are many papers in the scientific literature on mathematical simulation of heat-engineering elements; research has been directed in the main to means of linearizing the initial systems of differential equations. Various methods have been used to approximate the transfer function [1]. On the other hand, there are only a few papers dealing directly with the initial nonlinear equation systems, although this is of considerable significance in research on the characteristics of systems that have to work over a wide range in the external and internal parameter.

Therefore, in the first stage we devised precise mathematical models for each of the elements, i.e., wrote ALGOL-60 procedures for solving the nonlinear differential equations in partial derivatives. This set of calculation schemes provided a simple basis for choosing system designs and making detailed studies. The system structure was specified by matching the boundary conditions for the corresponding systems of equations.

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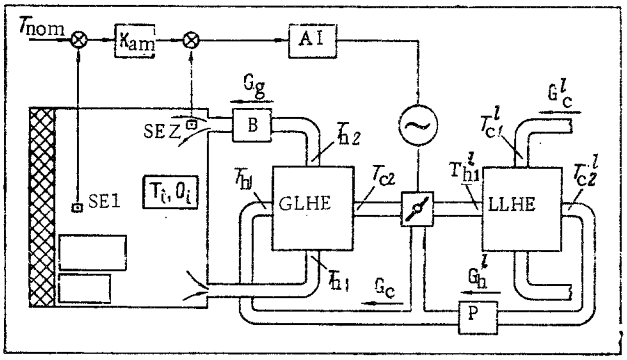

Fig. 1. System with input coolant-temperature feedback; GLHE and LLHE gas — liquid and liquid — liquid heat exchangers; B, blower; P, pump; AT, amplifying transducer.

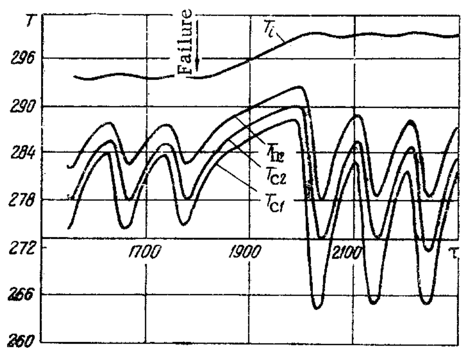

Fig. 2. Simulation of object-temperature transducer failure (T, °K; τ, min).

As an example we considered forecasting for the system shown in Fig. 1, in particular, for the case where the temperature transducer SEI fails. Here failure consisted in a jump in the systematic error by −5° with simultaneous increase in the internal heat production.

The mathematical model for this system was written as follows:

Control object:

$$(cm)_i \frac{dT_i}{d\tau} = \alpha_i F_i (T - T_i) + \sum_{i \neq j}^{N} \alpha_{ij} F_{ij} (T_j - T_i) +$$

$$+ \sum_{m \neq i}^{N} \varepsilon_{mi} \sigma_0 F_{mi} (T_m^4 - T_i^4) + \sum_{k=1}^{K} (c_p G)_k (T_{\text{in }k} - T_{\text{out }k}) + Q_i(\tau); \quad (1)$$

$$i = 1, 2, 3, \ldots, N; \; k = 1, 2, 3, \ldots, K.$$

Thermal protection,

$$\frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right). \quad (2)$$

GLHE (LLHE)

$$(c\gamma\delta)_{\text{w}}^{(1)} \frac{\partial T_{\text{w}}^{(1)}}{\partial \tau} = \alpha_{\text{h}}^{(1)} (T_{\text{h}}^{(1)} - T_{\text{w}}^{(1)}) + \alpha_{\text{c}}^{(1)} (T_{\text{c}}^{(1)} - T_{\text{w}}^{(1)});$$

$$\left(\frac{c_p G}{v}\right)_{\text{h}}^{(1)} \left(\frac{\partial T_{\text{h}}^{(1)}}{\partial \tau} + v_{\text{h}}^{(1)} \frac{\partial T_{\text{h}}^{(1)}}{\partial x_1^{(1)}}\right) = \alpha_{\text{h}}^{(1)} \frac{F_{\text{ef}}^{(1)}}{l_{\text{h}}^{(1)}} (T_{\text{w}}^{(1)} - T_{\text{h}}^{(1)}); \quad (3)$$

$$\left(\frac{c_p G}{v}\right)_{\text{c}}^{(1)} \left(\frac{\partial T_{\text{c}}^{(1)}}{\partial \tau} + v_{\text{c}}^{(1)} \frac{\partial T_{\text{c}}^{(1)}}{\partial y_1^{(1)}}\right) = \alpha_{\text{h}}^{(1)} \frac{F_{\text{ef}}^{(1)}}{l_{\text{c}}^{(1)}} (T_{\text{w}}^{(1)} - T_{\text{c}}^{(1)}).$$

Pipeline section,

$$(c\gamma\delta)_{\text{w}} \frac{\partial T_l}{\partial \tau} = \alpha_{l\,l} (T_{l\,l} - T_l) + \alpha_l (T_{\text{e}l} - T_l);$$

$$\left(\frac{c_p G}{v}\right)_{l\,l} \left(\frac{\partial T_{l\,l}}{\partial \tau} + v_{l\,l} \frac{\partial T_{l\,l}}{\partial \xi}\right) = \alpha_{l\,l} \pi D_l (T_l - T_{l\,l}). \quad (4)$$

Sensing element,

$$(cm) \frac{dT_{\text{se}}}{d\tau} = (\alpha F)_{\text{se}} (T_i - T_{\text{se}}). \quad (5)$$

Effector mechanism,

$$\omega = K_{at}\left(K_{am}(T_{se1} + \Delta_1 + \delta_1) - (T_{se2} + \Delta_2 + \delta_2) + T_{nom}\right); \tag{6}$$

$$G_c = K_G\left(\int_0^\tau \omega(\tau)\,d\tau + \varphi_0\right).$$

Initial conditions,

$$\tau = 0,\ T_i = T = T_w = T_w^{(1)} = T_h = T_h^{(1)} = T_c = T_c^{(1)} = T_l =$$
$$= T_{ll} = T_{se1} = T_{se2} = T_0;\ \omega = 0;\ \Delta_1 = \delta_1 = \Delta_2 = \delta_2 = 0. \tag{7}$$

Perturbation,

$$\tau = 1800\ \text{min},\ \Delta_1 = -5°. \tag{8}$$

Boundary conditions,

$$x = 0,\ -\lambda\frac{dT}{dx} = \alpha(T - T_\infty) + \varepsilon_{re}\sigma_0(T^4 - T_\infty^4);$$

$$x = \delta,\ -\lambda\frac{dT}{dx} = \alpha_i(T_i - T) + \varepsilon_{rei}\sigma_0(T_i^4 - T^4);$$

$$x_1^{(1)} = 0,\ T_h^{(1)} = T_{h1}^{(1)};\ y_1^{(1)} = 0,\ T_c^{(1)} = T_{c1}^{(1)}; \tag{9}$$
$$\xi = 0,\ T_{ll} = T_{ll1}.$$

Figure 2 shows the results.

It is clear from the results that failure in the temperature sensing element has a fairly marked effect on the general system functioning pattern. For instance, the changes in the temperature at the object are accompanied by an increase in the amplitude of the temperature fluctuations in the coolants, which result in a periodic fall in the temperature in the liquid loop below 0°C even under conditions of elevated internal heat release. The time available before the temperature in a section deviated from the nominal temperature by ±5° was about 130 min, while the temperature in the liquid loop fell below 0°C within 220 min.

State forecasting can similarly be performed for other types of failure; an examination of the forecast provides a basis for on-line monitoring and control, which is very important in improving reliability.

NOTATION

T, temperature; τ, time; cm, heat capacity; F, heat-transfer area; ε_{re}, reduced emissivity; σ_0, Stefan'–Boltzmann constant; c_p, specific heat at constant pressure; G, coolant flow rate; Q, internal heat release; λ, thermal conductivity; α, heat-transfer coefficient; v, velocity; l, coolant flow length; K_{at}, K_{am}, K_G, amplification factors of control-loop elements; ω, gate-valve speed; Δ, δ, systematic and random errors of measurement; i, m, j, numbers of controlled elements; k, coolant flow number. Subscripts: w refers to heat-exchanger walls; h, c refer to hot and cold lines; (1) refers to liquid—liquid heat exchanger; l refers to number of pipeline section.

LITERATURE CITED

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