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The Integral Models of Gradient Heat Flow Receivers

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ABSTRACT: The problem of constructing a model of heat flux receivers is of great importance for many experimental studies and technological processes. It should be noted that approaches to the solution of the above problem are associated with significant analytical and algorithmic difficulties, since multilayer inhomogeneous materials are used in gradient heat flux receivers whose properties are poorly identified.
Under realistic conditions, the gradient heat flux receivers are usually placed in a protective envelope, so that they are a complex system consisting of a core, i.e. Its own sensing element, and the protective layer. Depending on the properties of this shell, the dynamic characteristics of the receiver can vary greatly. If we assume that the shell is homogeneous in its physical properties and that there are no temperature gradients in it, as well as inside the sensitive element itself, ie, At any given time the temperature at all points of the receiver is the same, then the dynamic properties of such a receiver can be described in the form of an ordinary differential equation.

I. INTRODUCTION

It is known that it is not possible to compose for each receiver a differential equation that adequately describes its dynamic properties. The main difficulty arising in this case is, as a rule, due to the lack of a sufficiently complete methodology that would allow an exhaustive description of the structure (the order of the differential equation) and estimate the value of the design parameters that enter into the coefficients of the differential equations. The determination of the coefficients of the differential equation from experimental data, measured with an error, as noted above, is also not an easy task. In this connection, it is more expedient to approach this problem by calculating the parameters of the IDM model, which is equivalent to the original differential equation.

II. ESSENTIALS OF PERFORMANCE

$$\Phi = \sum_{i=1}^{m}[y(t_i) + \sum_{j=1}^{n} q_j \left(\int_0^{t_i} \frac{(t_i - s)^{j-1}}{(j-1)!} y(s)ds - \sum_{k=0}^{n-j-1} c_k \frac{t^{k+j}}{(k+j)!} \right) - \int_0^{t_i} \frac{(t_i - s)^{n-1}}{(n-1)!} f(s)ds - \sum_{j=0}^{n-1} c_j \frac{t_i^j}{j!}]^2, \quad (1)$$

Expression (1) allows us to propose a method for constructing the receiver model from the measured input and output signals. The values of the input and output signals are presented in Tables 1.4, 1.5, and the corresponding graphs are given in Figures 1.2, 1.3. Solving the calculation problem at the beginning, we assume that the model of the gradient receiver is of the first order. In this case the functional (1) takes the form (2)

$$\phi = \sum_{i=1}^{n} \left[y(t_i) + q \int_0^{t_i} y(s)ds - \int_0^{t_i} y(s)ds - c_0 \right]^2 \quad (2)$$

Hence, according to the method of least squares, taking into account that $c_0 = 0$, we have

$$\frac{\partial \phi}{\partial q} = 2\sum_{i=1}^{n} \left[y(t_i) + q \int_0^{t_i} y(s)ds - \int_0^{t_i} y(s)ds \right] \int_0^{t_i} y(s)ds = 0 \quad (3)$$

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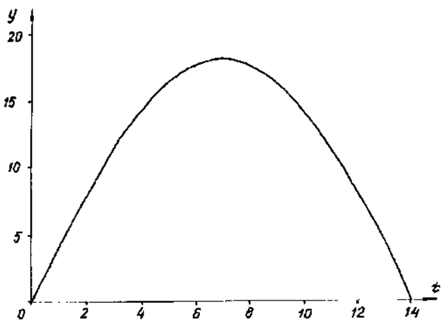

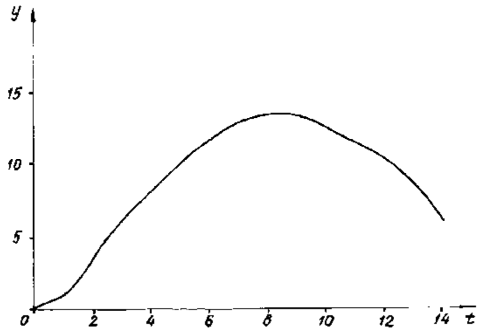

Fig.1.1Input signal valueFig.1.2Output signal value

n	*t*	*f*	*n*	*t*	*f*	*n*	*t*	*f*
1	0	0	11	5,0	16,2252	21	10	14,072
2	0,5	2,0153	12	5,5	16,9978	22	10,5	12,7348
3	1	4,0054	13	6	17,5579	23	11	11,2292
4	1.5	5,9154	14	6,5	17,8665	24	11,5	9,5845
5	2	7,8109	15	7	18,01	25	12	7,3145
6	2,5	9,5795	16	7,5	17,8665	26	12,5	5,9454
7	3	11,2274	17	8	17,5579	27	13	4,068
3	3,5	12,7348	18	8,5	16,9996	23	13,5	2,0169
9	4	14,0802	19	9	16,2270	29	14	0
10	4,5	15,2412	20	9,5	15,2490			

Table. 1.3Input signal value

n	*t*	*y*	*n*	*t*	*y*	*n*	*t*	*y*
1	0,00	0,00	11	5,00	10,20	21	10,0	12,44
2	0,50	0,51	12	5,50	10,93	22	10,5	11,78
3	1,00	0,79	13	6,00	11,58	23	11,0	11,35
4	1,50	2,06	14	6,50	12,23	24	11,5	10,87
5	2,00	3,60	15	7,00	12,75	25	12,0	10,22
6	2,50	4,76	16	7,50	13,14	26	12,5	9,48
7	3,00	5,84	17	8,00	13,30	27	13,0	8,60
8	3,50	6,91	18	8,50	13,33	28	13,5	7,59

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9	4,00	8,01	19	9,00	13,19	29	14,0	6,11
10	4,50	9,16	20	9,50	12,89			

Table. 1.4 Output signal value

For an unknown parameter, we get the calculated expression

$$q=\frac{\sum_{i=1}^{n}\left[\int_0^{t_i} f(s)ds-y(t_i)\right]\int_0^{t_i} y(s)ds}{\sum_{i=1}^{n}\left[\int_0^{t_i} y(s)ds\right]^2} \quad (4)$$

Calculating the integrals, $\int_0^{t_i} f(s)ds$, $\int_0^{t_i} y(s)ds$ we find the values of the unknown parameter q. Substituting the found value of the parameter in (4) and realizing an equivalent integral model, we obtain the value of the output signal at the measurement points.
Repeating these calculations for second- and third-order models, we find the optimal structure of the model that delivers a minimum to a functional of the form (1).

$$\frac{d^2y(t)}{dt^2}+q_1\frac{dy(t)}{dt}+q_2y(t)=q_3f(t) \quad (5)$$

When using a discrepancy of the form

$$\Phi=\sum_{i=1}^{n}\left[y(t_i)-c_0-c_1t_i+q_1\int_0^{t_i} y(s)ds-q_1c_0t_i+q_2\int_0^{t_i}(t_i-s)y(s)ds-\right.$$
$$\left.-q_3\int_0^{t_i}(t_i-s)y(s)ds\right]^2 \quad (6)$$

III. RESULTS

The system for finding unknown parameters takes the form:

$$q_1\left(\int_0^{t_i} y(s)ds\right)^2+\left[q_2\int_0^{t_i}(t_i-s)y(s)ds-q_3\int_0^{t_i} f(s)ds\right]\times$$
$$\times\int_0^{t_i} y(s)ds=\sum_{i=1}^{n}\left[c_1t_i\int_0^{t_i} y(s)ds-y(t_i)\right]\int_0^{t_i} y(s)ds, \quad (7)$$
$$q_1\sum_{i=1}^{n}\int_0^{t_i} y(s)ds\int_0^{t_i}(t_i-s)y(s)ds+q_2\sum_{i=1}^{n}\left[\int_0^{t_i}(t_i-s)y(s)ds\right]^2-$$

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$$
\begin{gathered}
-q_3\sum_{i=1}^{n}\int_0^{t_i}(t_i-s)f(s)ds\int_0^{t_i}(t_i-s)y(s)ds=\sum_{i=1}^{n}\left[c_1t_i\int_0^{t_i}(t_i-s)y(s)ds-y(t_i)\right]\int_0^{t_i}(t_i-s)y(s)ds,\\
q_1\sum_{i=1}^{n}\int_0^{t_i}y(s)ds\int_0^{t_i}(t_i-s)f(s)ds+q_2\sum_{i=1}^{n}\int_0^{t_i}(t_i-s)y(s)ds\int_0^{t_i}(t_i-s)f(s)ds-\\
-q_3\sum_{i=1}^{n}\left[\int_0^{t_i}(t_i-s)f(s)ds\right]^2=\sum_{i=1}^{n}c_1t_1\int_0^{t_i}(t_i-s)f(s)ds-y(t_i)\int_0^{t_i}(t_i-s)f(s)ds
\end{gathered}
\qquad (8)
$$

In Fig. 1.5 for j = 1.3 the output signal of the model and the actual output signal are represented. Numerical experiments showed that the dynamical properties of the gradient receiver most accurately $(\delta < 8\%)$ describe a second-order model with parameter values $q_1 = -0{,}0075$, $q_2 = 0{,}1197$, $q_3 = 0{,}0671$, which quite well satisfies practical needs.

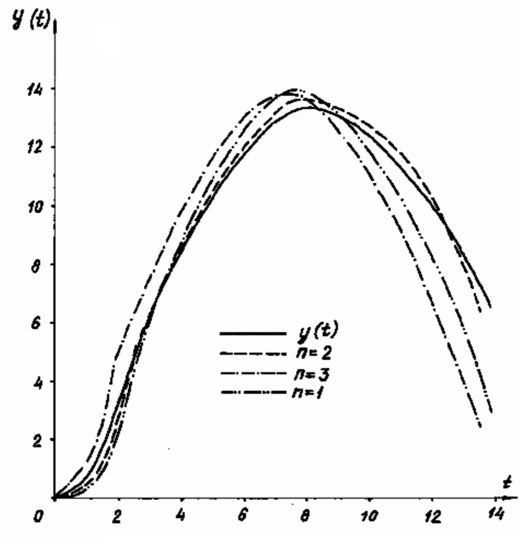

Fig.1.5 The output signal of the model

IV. CONCLUSION

Thus, the problem of constructing a model of gradient heat flow receivers is solved with the search and definition of a mathematical model. The model allows subsequent use for solving problems of restoring input signals of receivers.

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