DESIGNING THERMOSTATIC DEVICES. PART 1. A BASIC THERMOSTAT MODEL

G. N. Dul'nev, P. A. Korenev,
and A. V. Sharkov

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General principles are considered for one of the first stages in designing a thermostatic devices: choosing the basic model.

Designing a thermostatic system usually involves several stages, with the basic model being chosen in the first stage [1]. The basic model for a thermostat is a general thermal model, which reflects only the most general features of the design and the characteristic thermal processes.

One particularly needs to mention the mode of heat transfer from the object and the direction of the heat flux between it and the environment [2].

In [2], a classification of thermostats has been given, with quantitative criteria for distinguishing them. Here we present an algorithm for automating the choice of basic model.

In the initial design stage, there is a restricted amount of information on the design, which is accumulated as the technical specification, which includes the maximum temperature t_e^{max} and the minimum temperature T_e^{min} of the environment, the necessary stabilized temperature t_{st}, and the error in the control Δ_t, together with the total power P from the internal heat sources in the object and the area S of the its outer surface.

Thermostats are subdivided into heating, reversible, and cooling as regards the direction of the heat flux between object and environment [2]. The mode of heat transfer at the object is related to the effective heat-thransfer coefficient at the control surface.

Newton's law gives the power P dissipated by a body as

$$P = \alpha S (t_0 - t_e). \tag{1}$$

Usually, the temperature t_e of the medium surrounding the object is determined by the thermostat, so by t_e in (1) we can take the chamber temperature. However, the thermostat design is not known at the initial stage, so the temperatures of the components are unknown quantities.

To perform estimates in the frist stage, we take t_e in (1) as the mean between the control temperature and the environment value. For a heated thermostat, the environmental temperature is taken as the maximum possible t_e^{max}, while for a cooled one it is taken as t_e^{min}, and for a reversible one, whichever of these is closer to the control temperature. Here t_0 in (1) is the required t_{st} of temperature control.

The effective heat-transfer coefficient at the surface corresponding to given P, S, t_{st}, and t_e is

$$\alpha = \frac{P}{S (t_{st} - t_e)}. \tag{2}$$

Table 1 gives the ranges in heat-transfer coefficients for various modes of heat transfer [3]; from this one can select the transfer mode corresponding to the α given by (2).

In the later stages, it is possible to revise the cooling mode, since this governs other parts of the specification, particularly the control error components [4]. To satisfy the error requirements, one can vary the design and working parameters, amongst which one includes the thermal conductance between the chamber and the object, which is directly related to the transfer mode.

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TABLE 1. Effective Heat-Transfer Coefficients Corresponding to Various Modes of Heat Transfer

Column number in Fig. 1	$M=1$	$M=2$	$M=3$	$M=4$	$M=5$	$M=6$	$M=7$
Transfer mode	Thermal insulation	Natural convection in air	Forced convection in air	Forced convection in air with fins	Natural convection in a liquid	Forced convection in a liquid	Evaporative cooling
Heat-transfer coefficient, $W/m^2 \cdot K$	<2	2—10	10—100	100—350	350—700	700—10000	10000—30000

Figure 1 collects basic models used in instrumentation; the columns show models corresponding to various transfer modes, while the rows show models relating to different forms of thermostat as regards flux direction.

Various schemes are involved in the subsequent calculations in accordance with the model chosen from Fig. 1.

Figure 2 shows a block diagram for choosing the model. One first uses the known t_{st} and the range in environmental temperature to determine the type of thermostat approximately (heating, reversible, or cooled). Each of these corresponds to a number N of a row in Fig. 1. Then (2) gives the minimum necessary effective heat-transfer coefficient. Then Table 1 is used to determine the model of transfer. Each mode corresponds to a number M of a column in Fig. 1.

When the transfer coefficient has been finally determined, one can determine the temperature rise of the object above that of the chamber if the object produces heat, which serves to define the row number in Fig. 1 (i.e., the form of thermostatic control).

At the intersection of column M and row N in Fig. 1, one gets the model used in the subsequent calculations. If the technical specification contains information on the error components and the range in heat source output in the object, one can further refine M and N and return to the choice of basic model. This is done on theoretical relationships for the dynamic and static components of the control error.

Then a particular model is chosen from Fig. 1 at this stage, together with the minimum necessary heat-transfer coefficient.

For example, to control an optical crystal having $P = 5$ W and $S = 2.6 \cdot 10^{-3}$ m² with an environmental temperature range of $t_e^{min} = 15°C$ to $t_e^{max} = 35°C$ and a require control temperature $t_{st} = 45°C$, the calculations on this algorithm give the following result. As $t_{st} > t_e^{max}$, a heating control is used ($N = 1$); (2) gives 385 $W/m^2 \cdot K$, which according to Fig. 1 corresponds to forced convection in a gas with fins ($M = 4$), which is borne in mind in the subsequent calculations.

Figure 1 shows the models most often encountered, in which the object is controlled in a liquid or gaseous medium. However, when the effective heat-transfer coefficient has been estimated, one can also perform calculations for conductive transfer. The range in that case is fairly large (the corresponding models may be found in almost all the columns in Fig. 1), so the models in which this mode predominates are not fully shown in the figure. If it is necessary to employ conduction as the main transfer mode, one needs to perform an individual conversion from the calculated transfer coefficient to the design of the layer between the chamber and the object.

Thermostats with gas-filled thermal tubes relate to ones with evaporative cooling in accordance with Fig. 1, where they are not fully represented, since they belong to a separate class, which implies individual calculation for the particular working conditions [5].

This method of identifying the basic model does not always give an unambiguous result. Various heat-transfer modes can be realized with the same models, as can different forms of heat flux direction. Therefore, identical models occur in several columns and rows. In such cases, the differences lie only in the modes of operation. Conversely, given working condi-

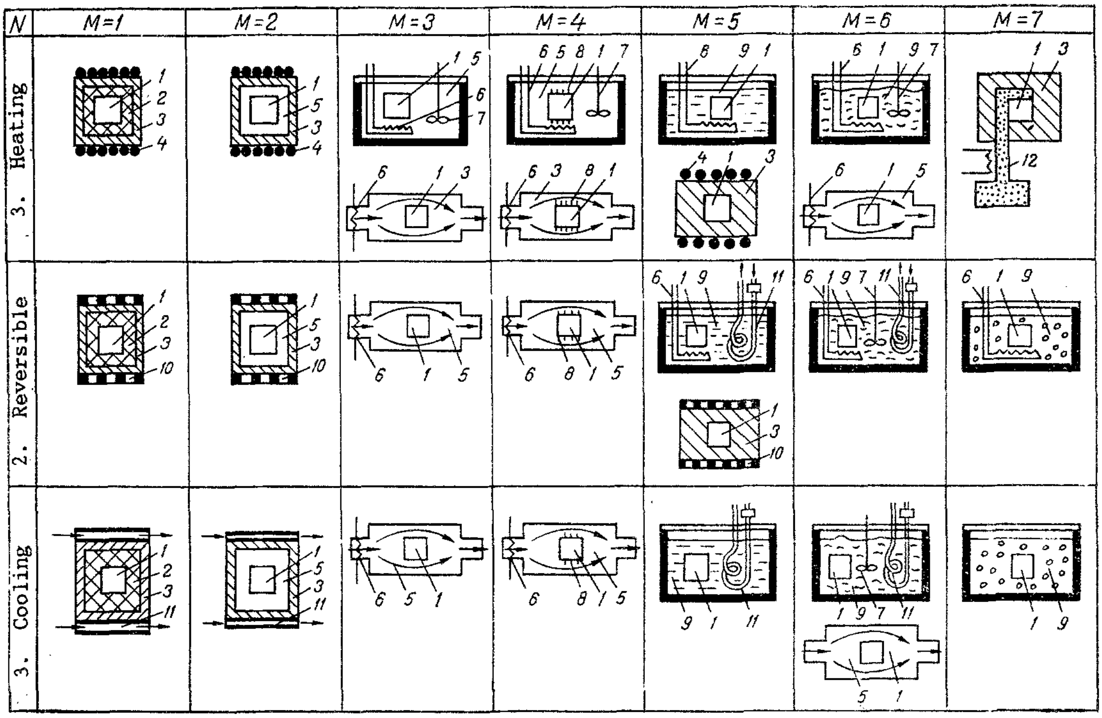

Fig. 1. Basic models: 1) thermostatic object; 2) insulation; 3) chamber; 4) surface heater; 5) gas layer; 6) volume heater; 7) stirrer; 8) fins on object; 9) cooling liquid; 10) reversible effector; 11) liquid heat exchanger; 12) evaporation-condensation system.

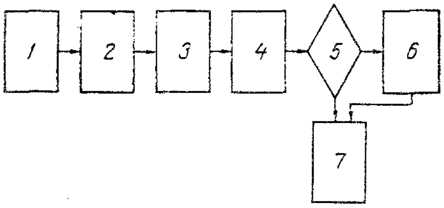

Fig. 2. Sequence in choice of basic model: 1) approximate determination of thermostat type, i.e., row number N in Fig. 1; 2) determination of thermostat type, i.e., row number N in Fig. 1; 2) determination of minimum necessary heat-transfer coefficient; 3) determination of transfer mode, i.e., M in Fig. 1; 4) refinement of N; 5) is there any information on the error components?; 6) refine model in accordance with error components; 7) pass to next design stage.

tions can correspond to several forms of model. However, the method is based on the principle indicating that the less the numbers of the columns and rows in Fig. 1, the simpler and cheaper the model in practice.

Thus minimal information on the object and environment can be used with a minimum of simple calculations to identify the main lines of the thermostat.

The subsequent treatment concerns the mathematical model for the basic design, implementation, and optimization.

NOTATION

t_e^{max}, t_e^{min}, maximum and minimum values of the ambient temperature; t_{st}, temperature of thermostating; P, total power of internal heat sources in the object; S, surface area of the thermostating object; α, heat transfer coefficient from the thermostating object surface; M, N, numbers of columns and rows in the table of basic models.

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THE ROLE OF THE MAGNETIC MACROSTRUCTURE IN HEAT LOSS IN TRANSFORMER STEEL

I. I. Branovitskii, P. P. Galenko,
and T. A. Branovitskaya

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Measurements have been made on the magnetic macrostructures in electrotechnical steel for various states of magnetization and degree of elastoplastic deformation.

Advances in electrical engineering and electronics have meant that the uses of electrotechnical steel have steadily extended. The output of this steel is now millions of tons a year. Some of the electrical energy required for magnetization reversal is dissipated as heat. Loss reduction is a difficult problem not only as regards the unified physical theory but also from the technical viewpoint [1-4]. No complete physical explanation has been given for all the losses in ferromagnetics on reversal.

There are certain additional or neglected losses, which make it difficult for metallurgists to design new high-grade ferromagnetic meterials.

This requires further research on reversal related to the crystal and magnetic structures, the internal stresses, and various other factors.

Magnetic metallography provides a means of examining the losses in a ferromagnetic material in relation to texture perfection, since it enables one to examine the domain structure changes during reversal. It has been shown to be possible to examine not only domain structures but also lattice defects [5-7] arising during elastoplastic strain. In [8-10], magnetization curves were used to explain the magnetic anisotropy in crystals of silicon iron, and ways were demonstrated of optimizing the losses in textured transformer steel.

The domain structures were examined at high magnification. However, it has been shown [11, 12] that the magnetic macrostructure can be observed with the unaided eye. In that case, the magnetic suspension is replaced by a finely divided dry ferromagnetic powder.

We have used the macrostructure in researching textured transformer steel given various mechanical and magnetic treatments; the steel contained 3% silicon. The specimens were cut as plates of 400 × 100 × 0.35 mm with surfaces close to (110) planes and with the rolling direction coincident with the [100] easy magnetization axis.

Each specimen was magnetized with two identical flat coils at its ends. The field directions coincided with the rolling ones. The middle part, between the coils, was magnetized fairly uniformly.

The macrostructure was examined with the dry powder, which may consist of fine iron filings, ferromagnetic $\gamma\text{-Fe}_2O_3$, or finely ground ferrite. The best results were obtained with ferrite powders. We used ones of grain size 50-100 μm. Higher contrast was provided by coating the specimen with a thin layer of white paint. The powder was sieved onto the specimen, and then light tapping revealed the figures.

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