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ON THERMODYNAMIC PROPERTIES OF MECHANISMS AND MACHINES

Abstract

The modern classification of thermodynamic systems considers thermodynamic processes occurring both within thermodynamic systems and between thermodynamic systems. These processes differ in their regularity, which must be taken into account when analyzing the functioning of machines as thermodynamic systems. The article describes the main patterns of processes occurring in thermodynamic systems and their consideration in the operation of various machine designs.

Keywords: classification, thermodynamic, system, active, passive, machines, mechanisms.

1. Introduction

The universe surrounding us consists of material bodies moving in a physical vacuum under the influence of endless fields created by these bodies: gravitational, electric, magnetic, thermal and a number of others.

Since all bodies interact with each other, they are always in a non-equilibrium state and there are always processes of energy and matter exchange between them. As a result of these processes, material bodies constantly move from one nonequilibrium state to another, and under certain circumstances, both energy redistribution processes and processes of converting some types of energy into others can occur between them [1, 2].

Historically, thermodynamics mainly considered the processes of energy redistribution between thermodynamic systems, which were artificially divided into classes of isolated, closed and open, which made it possible to analyze various special cases in which the processes of energy and matter transfer could be taken into account or not [1, 2]. However, in 2010, a new classification was developed in which processes are

classified both within a thermodynamic system and between thermodynamic systems [3, 4].

This paper presents theoretical substantiations of the basic properties of thermodynamic systems in accordance with the new classification and the basic requirements for mechanisms and machines as thermodynamic systems.

2. Processes inside thermodynamic systems

Processes within thermodynamic systems have two classes: passive and active [3, 4].

Passive thermodynamic systems include those in which energy redistribution processes occur, while active ones include energy conversion.

Let's consider the basic properties of passive thermodynamic systems using the example of the redistribution of thermal energy in a rod whose temperature of the left part T is greater than the right part t , shown in Figure 1.



Figure 1 – Redistribution of thermal energy in the rod

Since there is a temperature gradient between the two ends of the rod, there will be a flow of energy between them, directed from the more heated end to the less heated one due to the thermal conductivity of the material from which it is made. The instantaneous state of this process can be described by the Fourier equation of thermal conductivity:

$$J_q = -k \cdot \text{grad}T(x). \quad (1)$$

Here J_q is the heat flux vector - the amount of energy passing through a unit area (energy flux density) per unit time perpendicular to the x axis, k is the coefficient of thermal conductivity, T is the temperature.

In the case of an unsteady thermodynamic process, in which the energy of the left end of the rod is intensively transferred to the right, their temperature changes accordingly – the temperature of the left decreases, and the right increases. This process can be described by the equation:

$$J = f(\tau) = \frac{-k(T - t)}{t} \rightarrow 0. \quad (2)$$

From here:

$$\tau = \frac{-k(T - t)}{J} \rightarrow \infty \quad (3)$$

It follows from (3):

- 1) During the processes of energy redistribution within thermodynamic systems, the latter continuously strive for thermodynamic equilibrium, but never achieve it;
- 2) Thermodynamic systems in which energy is exchanged are always in an unstable nonequilibrium thermodynamic state.

Thus, the thermal energy of a passive thermodynamic system can be represented as:

$$Q_p(\tau) = Q_{plim} \pm \Delta Q_p(\tau). \quad (4)$$

Here Q_{plim} is the value of the thermal energy of the equilibrium state of the thermodynamic system to which it tends, $\Delta Q_p(\tau)$ is the residual thermal energy of the nonequilibrium state of the thermodynamic system involved in the redistribution of energy.

Let's consider the basic properties of active thermodynamic systems.

Such systems include systems in which chemical reactions occur, various types of engines: thermal, internal combustion, electric and others.

In the established process of functioning of these thermodynamic systems, their work, in accordance with the 2nd principle of thermodynamics, is accompanied by a constant release or absorption of thermal energy.

At the same time, the internal thermal energy of these systems does not change:

$$Q_{ai} = const, \quad (5)$$

and their thermodynamic state can be defined as nonequilibrium stable:

$$Q_i = Q_{ai} + W_{ic} + Q_{iT}. \quad (6)$$

Here W_{ic} is the converted energy, Q_{iT} is the thermal energy released into the environment.

Thus, active thermodynamic systems in the process of their functioning are always in a stable nonequilibrium thermodynamic state.

3. Processes between thermodynamic systems

The processes between thermodynamic systems are divided into three classes: isolated, closed and open.

Isolated thermodynamic systems do not exchange energy or matter with other systems.

Closed thermodynamic systems exchange energy, but do not exchange matter.

Open thermodynamic systems exchange both energy and matter with other systems.

The state of the external environment around thermodynamic systems is continuously changing as a result of the continuous movement of material bodies forming thermodynamic systems in space under the action of infinite gravitational, electromagnetic and thermal fields formed by all material bodies of the Universe.

In this regard, thermodynamic processes between systems are also continuously changing – from weakly nonequilibrium to strongly nonequilibrium, up to phase transitions, as a result of which new flows of energy and matter are created.

If we consider thermodynamic processes between two closed or open thermodynamic systems, then their regularity is almost similar to the internal processes occurring in passive thermodynamic systems.

In the presence of a temperature gradient between thermodynamic systems, an energy flow occurs directed from a more heated system to a less heated one. In a steady-state thermodynamic process, for example, between two infinitely large thermodynamic systems I and II with temperatures T_1 and T_2 , respectively, whose state is practically independent of time, it can be described by the Fourier thermal conductivity equation given in formula (1)

In the case of an unsteady thermodynamic process, in which two thermodynamic systems I and II with initial temperatures T_1 and T_2 , respectively, exchange thermal energy with each other, and at the same time the temperature of these systems changes accordingly, the latter can be described by the equation

$$J = f(\tau) = \frac{-k(T_1 - T_2)}{t} \rightarrow 0. \quad (7)$$

From here:

$$\tau = \frac{-k(T_1 - T_2)}{J} \rightarrow \infty \quad (8)$$

It follows from (8):

- 1) The material bodies of thermodynamic systems continuously strive for thermodynamic equilibrium, but never achieve it;
- 2) Thermodynamic systems between which energy is exchanged are always in an unstable nonequilibrium thermodynamic state.

Thus, the thermal energy of each of these two thermodynamic systems can be represented as:

$$Q_e(\tau) = Q_{\text{elim}} \pm \Delta Q_e(\tau). \quad (9)$$

Here Q_{elim} is the value of the thermal energy of the equilibrium state of the thermodynamic system to which it tends, $\Delta Q_e(\tau)$ is the residual thermal energy of the nonequilibrium state of the thermodynamic system involved in energy exchange.

4. Features of thermodynamic processes in mechanisms and machines

The main purpose of the mechanisms is to transform the movement of the components and parts included in them. At the same time, there are no energy processes in them, except for friction losses and plastic deformations.

Therefore, in most cases, the mechanisms are thermodynamic systems of a passive type, always striving for an equilibrium state with the environment.

Unlike mechanisms, the main purpose of machines is the conversion of one type of energy into another. This process is possible only with their continuous unequal state.

Therefore, in order to produce work, the machines must initially be brought into a non-equilibrium state, and then continuously maintain it.

Depending on the principle of operation and design of the machines, the process of bringing them into a non-equilibrium state is performed in various ways.

In steam engines, steam was preheated for this purpose, and then fed into a spool or valve, which alternately switched the directions of its supply in different directions from the piston.

The same principle is used in the designs of a number of pneumatic and hydraulic impact machines [5].

In most internal combustion engines, manual or electric starters and starters are used for this purpose.

In addition to the modes in which the required work is performed, they also require an idle mode, which ensures a continuous non-equilibrium state [6].

Electric motors assume a nonequilibrium state at the moment they are connected to the power grid, since the corresponding magnetic field instantly arises [7].

5. Conclusions

1. The application of a new classification of thermodynamic systems makes it possible to determine the necessary non-equilibrium conditions of the state of engines, under which they provide energy conversion during start-up and steady-state operation;
2. The fact of energy conversion from one type to another indicates the tendency of engines to a non-equilibrium state during their operation.
3. The lack of energy conversion indicates the desire of the engine to an equilibrium state with the environment;
4. The degree of the necessary non-equilibrium state of the engines during start-up depends on their design and principle of operation;
5. The non-equilibrium state of the engines during their operation must be continuous. Even a short-term equilibrium state leads to their stopping.

6. List of references

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