Thermographic study of the heating of a pulse-controlled magnetic-technological device

Angel PETLESHKOV, Svetlana TZVETKOVA, Yavor LOZANOV

Technical University of Sofia, Faculty of Electrical Engineering, 1000 Sofia, Bulgaria,
e-mail: apetl@tu-sofia.bg, stzvet@tu-sofia.bg, ylozanov@tu-sofia.bg

Abstract — **The results from a thermographic study of the heating of a permanent magnet technological device with pulse control are presented in the paper. An analysis, of the obtained thermographic images, has been made, and the values, of the temperature rise in the magnetic-technological device, have been determined. Also, the change of temperature along the length and width of the magnetic-technological device have been considered.**

Keywords* — *magnetic-technological devices, pulse control, thermography

I. INTRODUCTION

Magnetic devices with permanent magnets have been widely used in the past years, including for equipping of various types of metal cutting machines. The use of magnetic devices allows solving a number of complicated technical tasks related to the machining of details - processing details with a complex shape, obtaining high precision in processing, etc. The intention to simplify their control and reduce the physical effort of the operator is the cause for the development of devices for electric-pulse control and of magnetic technological devices with additional control magnets [1].

In most cases, magnetic-technological devices (MTDs) are designed for clamping and holding of ferromagnetic details of different configuration, size, and material. Therefore, both in design and operation stage, it is not possible to take into account all the factors that affect their work. The easiest way to assess the influence of these factors is experimentally by testing laboratory models.

One of the main problems with conventional electromagnetic clamping devices is the heating of the device and, in particular, its windings. This heat results in negative consequences, including breakdowns in winding insulation and failure of the device. In magnetic-technological devices, this problem is avoided to some extent, since the current flows only when the workpiece is being gripped or released from the device. However, the presence of an internal heat energy source (magnetizing and neutralizing windings) is a sufficient prerequisite for studying the heating of this type of equipment. The temperature rise of the magnetic-technological devices leads to intensive aging of the winding insulation and the related damages. On the other hand, the temperature rise should be taken into account when designing the magnetic-technological device, because of the temperature stability of the used permanent magnets. Hence, the heating of the MTD is a very topical issue, especially in modern MTDs using permanent magnets with a low maximum operating temperature [2, 3].

Theoretical calculations for the thermal mode of operation of magnetic-technological devices are associated with great difficulties due to the fact that the values of the heat transfer coefficient and the thermal time constant of the MTD depend on a number of constructive and exploitation factors [4].

II. STRUCTURE AND CHARACTERISTICS OF THE OBJECT OF STUDY

The examined magnetic technological device is intended for clamping of flat ferromagnetic details. Its structure is shown in Fig. 1. It consists of four rectangular cast magnets of type CONIAL-44A, placed between steel magnetic cores that transfer the magnetic flux to the adapter plate and from there to the held detail. A set of windings is mounted on cast magnets and serves for their magnetizing and demagnetizing.

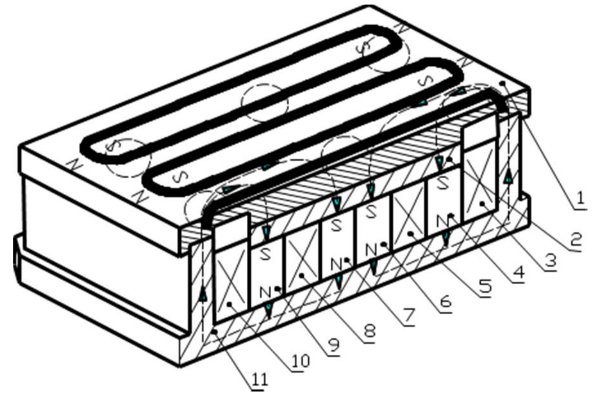

Fig. 1. Structure of the magnetic technological device.

Structurally, the device is made up of additional (controllable) permanent magnets 6 and 7, magnetizing winding 3 and 10, neutralizing winding 5 and 8, main permanent magnets 9 and 4, central pole 2, all of which are housed in a common housing 11 and are covered by adapter plate 1.

When detail is being clamped, a single current pulse with a defined polarity, amplitude, and duration is supplied to the magnetizing winding. The excited magnetic field magnetizes the controllable magnets codirectionally with the main permanent magnets. The magnetic flux is closed through the detail and holds it to the adapter plate. A single current pulse with reverse polarity to the neutralizing winding is supplied to release the held detail. The controllable magnets are being magnetized contradirectional to the main magnets. Magnetic flux closes inside the magnetic system, and the detail is released.

Magnetic cores of the device are made of steel and all the contact surfaces between the permanent magnets, the

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magnetic cores, and the adapter plate are polished with a roughness of 0,63. The adapter plate has a working surface of 630/200 mm.

The duration of the magnetizing pulses for a defined structure of the magnetic circuit of the MTD can be determined by the equation:

$$t_p = \int_0^t dt = \int_0^{\Phi_0} w \frac{d\Phi}{U_0 - iR} = w \int_0^{\Phi_0} \frac{d\Phi}{U_0 - iR}, \qquad (1)$$

where w is the number of turns in the magnetizing coil,
Φ - momentum value of the magnetic flux,
U_0 - rms value of supply voltage,
i - momentum value of current in the winding,
R - winding resistance.

The magnetic table control is accomplished by means of a pulse-control device. The pulse-control device used is based on a three-phase bridge rectifier with a reverse diode. The duration of the generated pulses is t_p=1s. The value of the current flowing through the MTD's winding during magnetization or remagnetization can be determined by the equation:

$$I = \frac{\sqrt{2}\pi U_r}{3R(1+\cos\alpha)}, \qquad (2)$$

where U_r is the rated value of the supply voltage,
α - delay angle of the thyristors.

The energy dissipated as heat in the MTD during magnetization and re-magnetization can be written as:

$$Q = I^2 R t_p = \frac{2\pi^2 U_r^2}{9R(1+\cos\alpha)^2} t_p. \qquad (3)$$

III. THERMOGRAPHIC SURVEY OF THE HEATING OF A MAGNETIC-TECHNOLOGICAL DEVICE

The temperature of the magnetic table has been measured for 30 minutes. During that period magnetizing and demagnetizing pulses have been fed to the device every 10 seconds. Such an intense work regime is rare, making the results credible and real. The temperature of the magnetic device has been measured by using a FLIR E60 thermal imaging camera.

The thermographic images, of the studied magnetic-technological device, were made with set values of the measurement parameters, given in Table 1.

TABLE I. SETTINGS OF THE MEASUREMENT PARAMETERS

Parameter	Value
Emissivity	0,93
Reflected temperature	20°C
Distance to the object	1m
Atmospheric temperature	20°C
Relative humidity	55%

The thermographic and photographic images, of the magnetic device prior to the beginning of the study, are shown in Fig. 2 and Fig. 3.

From the comparison of the two images, it is clear that the "hot spot" areas in the active part of the magnetic device prior to the beginning of the study are due to differences in emissivity rather than real temperature rise.

The average temperature of the active part of the MTD obtained from the thermographic image before beginning the study is 20,1°C.

The thermographic image of the MTD, after 30 minutes of operation, is shown in Fig. 4.

Fig. 2. Thermographic image of the magnetic-technological device at the beginning of the study.

Fig. 3. Photographic image of the studied magnetic-technological device

Fig. 4. Thermographic image of the magnetic-technological device at the end of the study.

The average temperature of the active part of the magnetic imaging device obtained from the thermographic image at the end of the study is 21,5 ° C.

Thermographic images, of the longitudinal side of the magnetic device prior to the beginning of the study, and at the end of the study, are shown in Fig. 5 and Fig. 6 respectively.

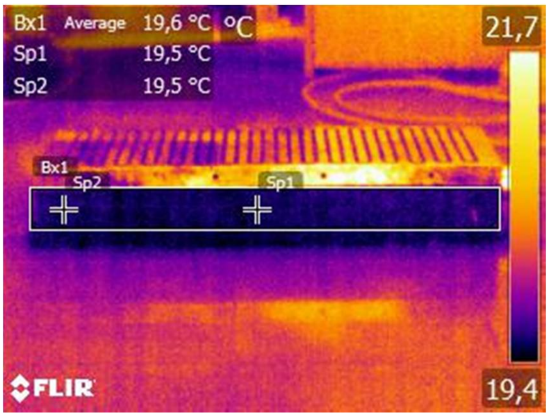

Fig. 5. Thermographic image of the longitudinal side of the magnetic device at the beginning of the study

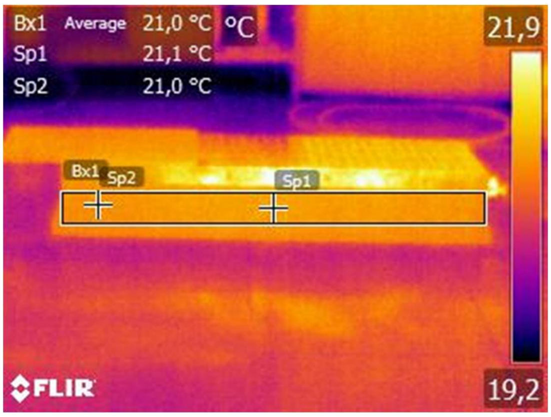

Fig. 6. Thermographic image of the longitudinal side of the magnetic device at the end of the study

At the beginning of the study, the average temperature of the longitudinal side of the MTD has been 19,6 ° C, and at the end of the study, the temperature has risen to 21,0 ° C. This means that the temperature rise on both sides of the device after 30 minutes of operation is 1,4 ° C.

The values, of temperature and temperature rise at specific points of the magnetic-technological device, are given in Table 2.

TABLE II. TEMPERATURES AND TEMPERATURE RISES AT SPECIFIC POINTS

	Measurement point		
	1	2	3
Initial temperature, °C	19,5	19,5	20
Final temperature, °C	21,1	21	21,6
Temperature rise, °C	1,6	1,5	1,6

The values, obtained from all the measurements at the individual points, are averaged. Measurements at the three control points indicate that the average temperature rise recorded by the thermal imaging camera is 1,567°C. The values obtained correspond to those set forth in [1], with the difference in temperature rise recorded by the two temperature measuring devices being 0,234°C.

Further processing, of the thermographic images, has been made, from which the temperature distribution, along the length, width, and height of the active part of the examined MTD, has been determined.

The change of temperature along the longitudinal side of the MTD is shown in Fig. 7. Temperature values are obtained in a step of 2,5 mm.

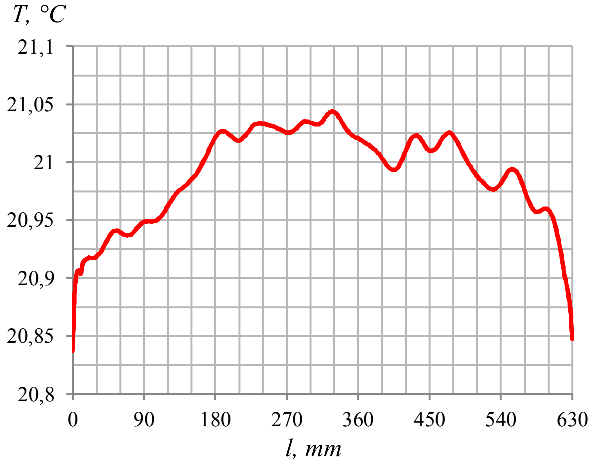

Fig. 7. Temperature distribution along the longitudinal side of the magnetic device

The temperature distibution along the crosswise side of the MTD is shown in Fig. 8. Temperature values are measured at an interval of 1,25 mm.

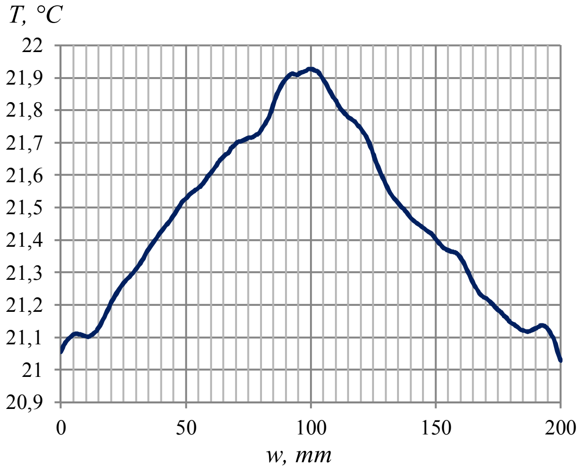

Fig. 8. Temperature distribution along the crosswise side of the magnetic device

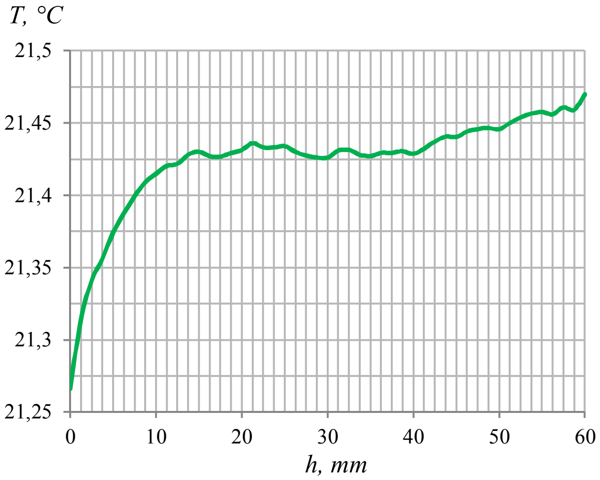

Fig. 9. Temperature distribution along the height of the magnetic device

The change in the temperature along the MTD's height is shown in Fig. 9. The temperature values are obtained at an interval of 1,25 mm.

The resulting temperature distributions along the length and width of the MTD show that the highest temperature values are achieved in the middle of the respective side of the device. The magnitude of the temperature change along the MTD's longitudinal side is 0,206°C, and on the crosswise side of the MTD is 0,898°C.

It is apparent from Fig. 8 that the temperature slightly increases along the height of the active part of the MTD. The sudden change in temperature in the range of 0-10 mm is due to the intensive heat exchange between the MTD and the surface on which it is placed.

CONCLUSION

With the pulse control method of the MTD, the magnetization of the system is done in a short time (t_p=1s), the current flow through the coils only in this short period of time. Therefore, there is a small consumption of electrical energy and there is no significant heating of the windings and the cast magnets. This means that there won't be any thermal affects on the magnet characteristics.

Temperature distributions show that temperature differences along both sides of the MTD are less than 1°C.

Overheating of the windings could occur if the pulse-control device fails to stop the current through one of the windings. Another reason for overheating might be the resultant heat from the cutting process.

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