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Effect of Brass Blanks' Pre-Heating on Magnetic Pulse-Pressing

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Abstract

Modern machinery has high requirements to the technological processes of processing of metals by pressure. Technology should ensure the production of quality products with high performance characteristics, to be economical, intensive. The intensification and increased production efficiency is a necessary condition of scientific and technical progress.

The problem of increasing productivity and saving material, human, intellectual and other resources not only in production but also on the stage of technological preparation is important.

This problem can be solved through the development of effective resource-saving technologies, where the term "resource-saving technologies" means the collection of laws, ways and means, determining quantitatively reasonable selection and construction processes and operations for producing parts at the lowest cost labor. Development of scientific ways and means of creation of resource-saving technology includes a wide range of theoretical, experimental, technological and computer-programming tasks.

Also, the main task of development of mechanical engineering is output it to a completely new resource-saving technologies, providing increased productivity, savings in material and energy resources and the environment. Largely the solution of these problems is aided by the introduction in the industry of advanced technology magnetic pulse-pressing (Kukhar & Kireyeva, 2011, pp. 41 - 50, Kukhar & Kireyeva, 2011, pp. 51 – 55), which is simple and low cost tooling, compact equipment, high quality products and environmental safety.

Magnetic pulse-pressing (Psyk et al., 2011, pp. 243-250, Psyk et al., 2008, pp. 181-190) is characterized by the fact that the pressure on the deformable metal of the workpiece is created directly by pulsed magnetic field without the participation of the intermediate solid, liquid or gaseous phone Thus, it is possible to stamp parts from polished and lacquered pieces, without damaging the surfaces, deform billet enclosed in a sealed non-metallic shell, and to perform other operations, the implementation of which by other means irrational.

One of these directions is the study of the effectiveness of pre-heating of billets at the magnetic-pulse processing (Psyk et al., 2011, pp. 787-829, Vivek et al., 2011, pp. 840-850). On the basis of theoretical and experimental data on the distribution of ring specimens with different wall thickness of the test material in different temperature-frequency modes, assesses feasibility billet heating and selection of optimal heating modes. This article estimates the efficiency of pre-heating the L63 brass blanks, using magnetic pulse-pressing.

Keywords: magnetic pulse pressing, inductor, temperature and frequency modes, blank, expanding, heating

1. Introduction

Schematic diagram of magnetic-impulse installation (Kukhar et al., 2010, pp. 44 – 46, Batygina et al., 2011, pp.72-75, Belii, 1971, p. 168) shown in Figure 1.

The inductor is the primary element of any magnetic-impulse installations and is intended for direct conversion of previously accumulated electric energy in the capacitor battery into mechanical work of deformation.

The simplest inductor (Kukhar et al., 2011, p.55) is an ordinary spiral of good conductive material (usually copper), consisting of one or more turns, a certain cross-section and diameter (Figures 2 -3).

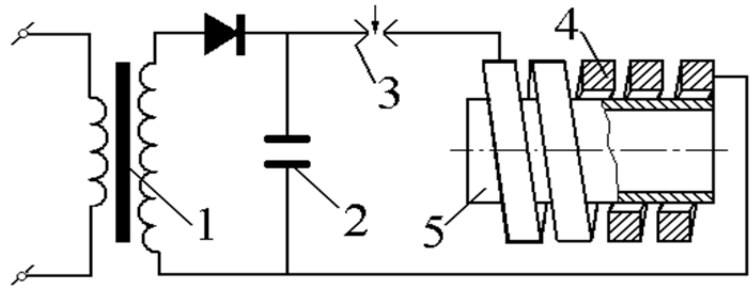


Figure 1. Schematic diagram of magnetic-impulse installation: 1 - transformer increases; 2 - energy storage device (capacitor Bank); 3-control devices (discharger); 4 - inductor; 5 – blank (Talalaev, 1992, p.143)

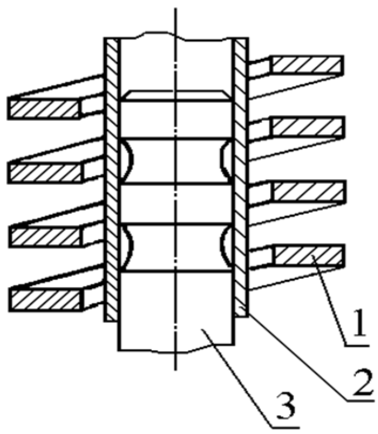


Figure 2. Typical circuit inductor crimping: 1 - inductor; 2 - blank; 3 – mandrel (Talalaev, 1992, p.143)

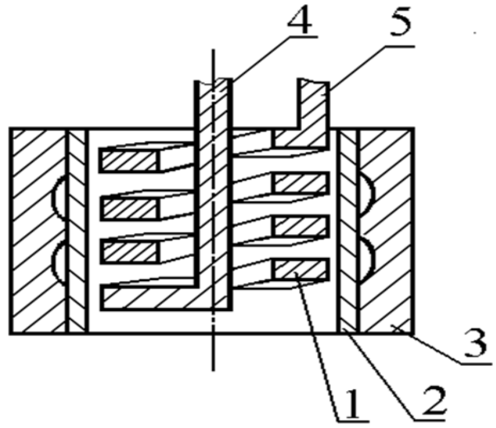


Figure 3. The processing circuit cylindrical parts "distribution": 1 - coil; 2 - blank; 3 - pot; 4, 5 - current terminals (Talalaev, 1992, p.143)

We carried out an analysis of the sources (Yu et al., 2013, Vivek et al., 2011, pp.840-850), which allowed to formulate the basic requirements for the inductance and the inductance of the magnetic pulse units.

The inductors should provide:

- high mechanical resistance to dynamic loads arising in the process of deformation of the workpiece;

- high energy conversion efficiency of capacitive drive into work of deformation of the workpiece;

- optimal distribution or concentration of the magnetic field in accordance with the shape of the workpiece or on the given section of the processing;

-leakage high-frequency pulse discharge currents in the working spiral inductors with optimum working frequency;

- high dielectric strength at minimum working clearance under significant interturn effort and a high voltage;

- the manufacturability of the design, allowing you to quickly and easily replace the spiral inductor, easy and reliable mounting of the inductor to the findings of magnetic - impulse installations;

- simple technical solution, security, service and reliability in operation.

2. Analysis of Existing Ways of Intensification of the Process Magnetic Pulse-Pressing

During the analysis of literature sources (Gnatov, 2012, pp.51-55, Schneerson, 1981, p.200, Schneerson, 1981, pp. 76-87, Talalaev, 1992, p.143), it was revealed that one of the main ways to improve the efficiency of inductors is to intensify the process of magnetic-pulse treatment of metals due to the number and shape of coils to control the shape of the pressure pulse and finding the optimal discharge frequency pulsed magnetic mounting in the process of forming details.

In the work of A. K. Talalaev (Talalaev, 1992, p.143) it was shown experimentally that the efficiency of the process of magnetic-pulse treatment has a significant influence not only the number of spiral turns, but also their shape. The shape of the cross-section of a coil must provide uniform distribution of pulse current on its surface.

The choice of the optimal shape of the cross section of a coil produced experimentally from several options (Figure 4).

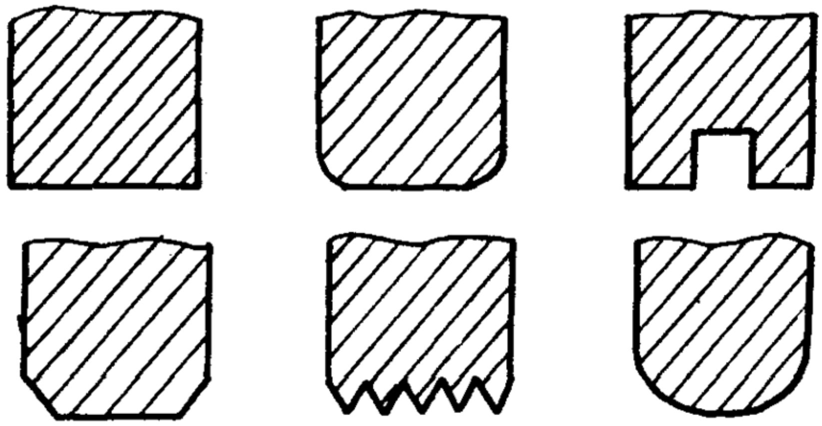


Figure 4. Options design options section spiral inductor

The most successful forms of profile cross-section was circular and rectangular with rounded edges for a radius of 1.5-2 mm, which are excluded sharp edges hub power and sources of formation of fatigue cracks.

For more uniform distribution of current load on the working surface of the inductor is advisable to make the spiral grooves of rectangular profile, the depth of which is greater than the depth of penetration of the current into the metal of the inductor in 1,5 - 2 times. The number of spiral grooves depends on the height of a coil. When the height of the coil 10-12mm is one groove width 3-4mm in the middle part of the spiral inductor.

In addition, Talalaev A. K. (Talalaev, 1992, p.143) experimentally shown that the efficiency of the process of magnetic-pulse treatment has a significant influence not only the number of turns of the spiral inductor and their geometry, but also the shape of the spiral inductor. In particular for the operation of the crimping of the tubular workpieces were found the most effective inducer hub of the magnetic field in which the geometry of the spiral inductor is the concentration of the magnetic field in the treatment zone. Unlike inductors with plug hub of the magnetic field, this type of inductor provides a greater efficiency of the crimping process.

Having the advantages of the magnetic field concentrator in combination with high resistance and manufacturability, such inductors are widely used to perform Assembly and welding operations, reduction and shaping.

In (Talalaev, 1992, p.143) describes another approach to this question lies in finding the optimal frequency of discharge of magnetic-impulse installations where maximum forming blanks with minimum energy consumption. In addition, it was shown that there is a discharge frequency magnetic-impulse installations in which the maximum degree of deformation of the material is maximum. The value of this frequency is almost independent from the mechanical characteristics of the material and diagrams of the stress state, and depends on the size a damping ratio: the increase of the damping ratio leads to an increase in the optimal frequency and limit the degree of deformation, deformation of blanks on the high-frequency installations achieved a large degree of deformation for one transition.

The value of the limit the degree of deformation at the optimum frequency of the discharge current is influenced by the mechanical properties of the workpiece material, its geometrical dimensions and diagrams of the stress state.

However, these works did not take into account the voluminous nature of the ponderomotive forces acting on the workpiece.

To intensify the process of crimping is also possible by control of the pulsed magnetic fields.

There are two independent control method of pulsed magnetic fields during magnetic-pulse stamping:

1. Control of the shape of the plot of pressure, it is possible by varying the design of the induction system, the geometry of the current-carrying sections, as well as the introduction of special screens.

2. Control of the shape of the pulse pressure, which is possible if the change in the process of loading parameters of the discharge circuit or the imposition of multiple pulsed fields with different parameters.

In (Tolokonnikov, 1979, p.318, Cheglov, 1974, pp. 33-34) techniques have been developed to control the shape of the pressure pulse of a pulsed magnetic field in the process forming parts by programmable discrete changes of the parameters of the discharge circuit, is applied in several fields and imposing currents, allowing you to set the desired kinematics of deformation process. The obtained calculated dependences describing the shape of the pulse when programmatically changing the parameters of the discharge paths.

Numerical simulation showed the possibility of intensification of the processes of magnetic-pulse treatment of metals under optimal programming and control of the shape of the pressure pulse. This allows 1.5-2 times increase the accuracy of the details in the modes of an elastic collision with pliable (transformed) snap-in.

Effect of brass blanks' pre-heating on magnetic pulse-pressing is ambiguous: on the one hand, material's resistance to deformation is reduced while blank is heated, on the other hand, electrical resistance of the metal drastically increases, thus leading to magnetic field's pressure reduction. These two controversial phenomena may lead to an increase of blank's deformation as well as to its reduction due to heating. Besides it is known that the thickness of the blank's wall and the discharge frequency significantly affects magnetic field's pressure level, while the same physic-mechanical properties of the blank and the parameters of the magnetic pulse processing are applied.

3. Study of Preheating the Workpiece before Magnetic Pulse-Pressing

3.1 Experimental Studies

The estimation of L63 brass blanks' pre-heating efficiency was performed, basing on the results of experimental studies on expanding ring specimens by pressure of pulse magnetic field (Kukhar & Kireyeva, 2014, p. 42, Kukhar & Kireyeva, 2009, p. 160).

The specimens were the ones with inner diameter of 55 mm, 20 mm height, with wall thickness of 1, 2, and 3 mm, being expanded within the temperature range of 20 – 600 °C, at 5, 15 and 25 kHz operating discharge frequency of magnetic pulse installation

For this purpose, experimental equipment, shown at Figure5, was used.

Insulating bushing 3, 3mm thick, made of flexible micaceous laminate with good electrical and heat insulation properties, is placed on the Inductor 5, therefore isolating the Ring specimen 2 from Inductor 5. To provide equal pulse magnetic field pressure, shading rings 1 and 4 were installed on the Inductor 5.

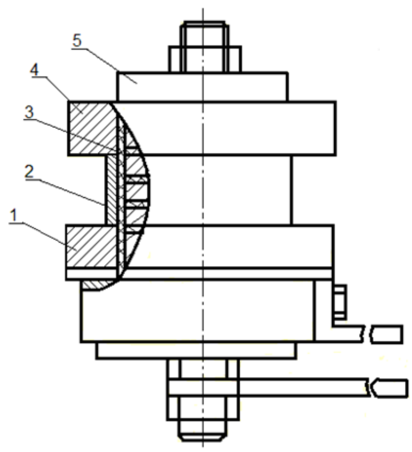


Figure 5. Experimental equipment: 1, 4 – shading rings; 2 –specimen; 3 – bushing; 5 – inductor

Expanding was performed on MIU 20/2 HPI, the operating frequency was changed by varying the number of turns of the inductor (Kukhar & Kireyeva, 2011, p. 90, Kukhar et al., 2012, pp. 38-43, Talalaev, 1992, p.143).

The inductors (Kukhar & Kireyeva, 2009, p.160, Kukhar & Kireyeva, 2011, p.90) were of the same construction (Figure 6). They consisted of single-point spiral (1) with flange (4), the turns of which are isolated by shims made of fiber-glass plastic (2). Spiral is strapped by pin (3) through the axis of the inductor, and serves as one of the current leads. The second current lead is attached to the flange of inductor's spiral (5).

Before expanding, the specimens were heated for 10-15 minutes in an oven with temperature control by chromel alumel thermocouple.

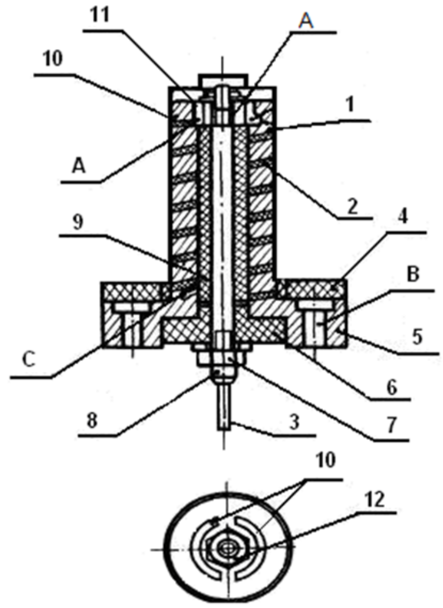


Figure 6. Construction of inductor for expanding: 1 – inductor's spiral, 2 - isolation; 3 – pin; 4 - flange; 5 - flange; 6 - holes, 7 -bushing; 8 - screw-nut; 9 - rod; 10 - bushing; 11 – cam slot; 12 - flange; 13 - screw-nut; 14 - hole; a, b, c - through holes

3.2 Theoretical Studies

Expanding of samples of the same thickness over the entire temperature range at each discharge frequency was carried out at a fixed value of the stored energy (Table 1).

Using the results of preliminary experiments, the following input factors were chosen: the operating frequency setting - f; blank heating temperature - T; blank thickness - S.

The quantity, characterizing the heating efficiency at a given frequency of the discharge current – N, which was determined by the formula (1), was adopted as an output parameter (the response function):

$$N = \varepsilon_g / \varepsilon_x , \quad (1)$$

where ε_g, ε_x are the deformations of the sample in a hot and cold condition.

Table 1. Energy levels, frequencies of discharged current and sample thickness

Wall thickness δ_0, mm	Processing frequency, f, kHz	Dependent energy W, kJ
	5	7000
1	15	2800
	25	3300
	5	11800
2	15	6100
	25	6100
	5	15000
3	15	11600
	25	10000

To describe the above dependency the second-order polynomial model was chosen (2):

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (2)$$

where y_1 is output parameter value (the response function)b_0, b_i, b_{ii}, b_{ij} are the regression coefficients; x_i, x_j are coded values of input factors.

Input factors for natural and coded values are defined by the following:

$$x_1 = \frac{(X_1 - X_{10})}{\Delta X_1}, \tag{3}$$

where X_1 is a natural value of the factor; X_{10} is a natural value the basic level:

$$X_{10} = \frac{(X_{1max} + X_{1min})}{2}, \tag{4}$$

where X_{1max} is a maximum natural value of the factor; X_{1min} is a minimum positive value of the factor; ΔX_1 is a variation interval of natural values.

$$\Delta X_{10} = \frac{(X_{1max} - X_{1min})}{2}. \tag{5}$$

As experiment plan for establishing parameter's dependence on three main factors, the three-way plan (Rechtshafner plan) (Arsov & Novik, 1980, p.304) was used, the matrix of which is given in Table 1. In this matrix -1, 0, +1 respectively denote the lower, main and upper levels of the considered factors (Table 2).

Table 2. Matrix of experiment planning

f (X_1)	T (X_2)	S (X_3)
-1	-1	-1
+1	+1	-1
-1	+1	+1
+1	-1	+1
-1	+1	-1
-1	-1	+1
+1	-1	-1
0	0	+1
+1	0	0
0	+1	0

Table 3. shows the levels of three factors corresponding to the real values of the operating frequency of the installation, the heating temperature and the thickness of the blank.

Table 3. Factor levels and their variation intervals

Factor designation	x_1	x_2	x_3
Name of the factor	f	T	S
Field of experiment			
Main level	1	30	2
	5	0	
Variation interval	1	20	1
	0	0	
Lower level	5	10	1
		0	
Upper level	2	50	3
	5	0	

Necessary calculations to determine the regression coefficients were performed by RAM_3_10.exe program, developed by the MPF Department of TSU.

Dispersion of reproducibility (of the experience) was taken with a 5% deviation on randomly chosen lines of the plan. Significance of the coefficients in obtained mathematical model was verified by Student t-test at 5% significance level.

The resulting regression equation (6) makes it possible to determine the effectiveness of the pre-heating of the sample in any combination of these factors out of their domain.

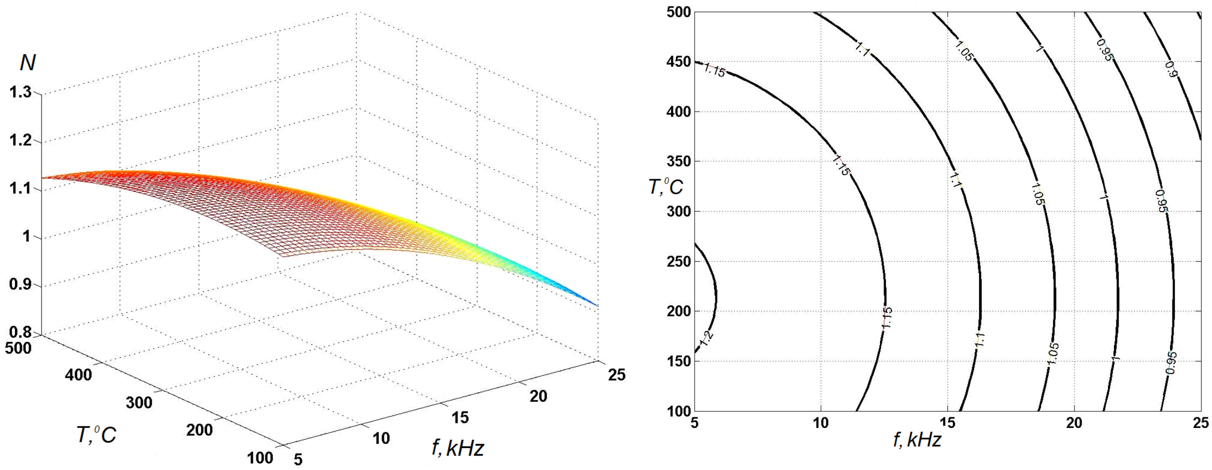
$$y_1 = 1.162 - 0.011x_1 + 0.076x_2 + 0.016x_3 + 0.017x_1x_3 + 0.033x_2x_3 - 0.056x_1^2 - 0.038x_2^2 + 0.044x_3^2. \quad (6)$$

4. Results

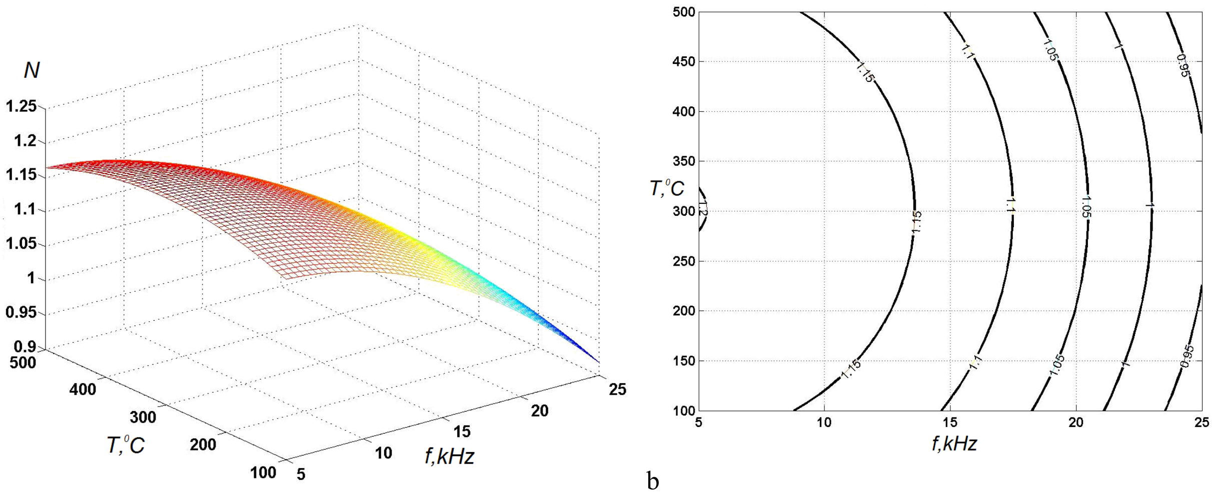
With the help of regression equations, surface and cross section (Figure 6) were obtained, reflecting the dependence of the efficiency of sample's pre-heating from the operating frequency of the installation, heating temperature, and the thickness of the blank.

We found that magnetic pulse processing of blanks with a wall thickness of 1 mm is most effective within the temperature range of 150-300 ^{0}C (Figure 7a) for L63 brass. And the greatest efficiency is manifested at the discharge frequency of 5 and 15 kHz, in this case, the deformation increases due to heating. With 2 mm thickness of the blank wall and the frequency of the discharge current of 5 kHz, maximum deformation is achieved by heating the blank to 300 ^{0}C.

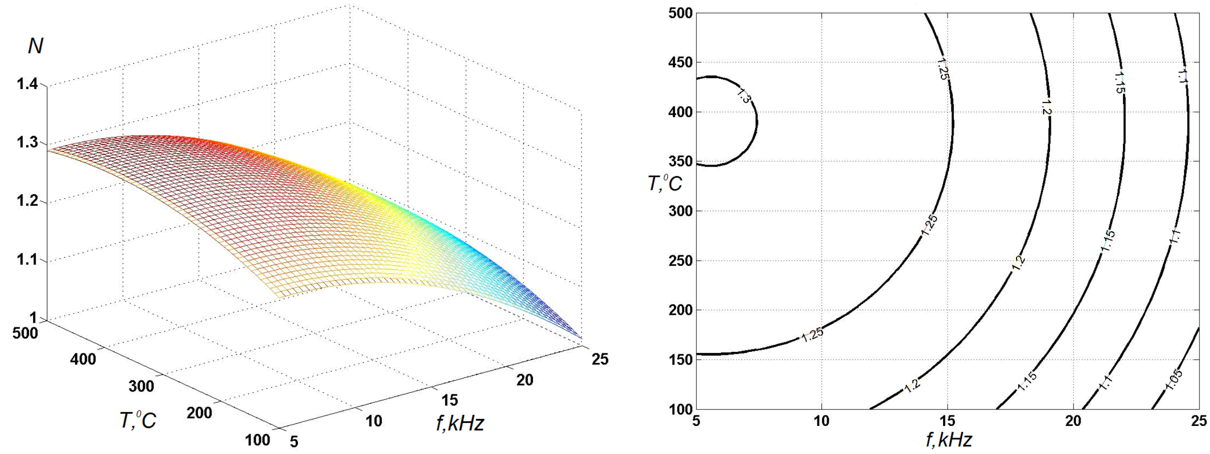
At higher frequencies, the heating efficiency continuously increases with temperature (Figure 7b) . Similar pattern is observed in the expanding of parts with wall thickness of 3 mm (Figure 7c) with increasing preheating temperature, heating efficiency increases continuously throughout the frequency range of the discharge current .



a



b



c

Figure 7. Dependence of efficiency of the pre-heating of the sample *N* on the operating frequency setting, the heating temperature and the thickness of the blank: a- 1 mm, b - 2 mm, c - 3mm

5. Discussion

We found that efficiency of blanks' preheating grows with the increase of the blank's wall thickness, and the effect of the frequency of the discharge current in this case is weakened. At small blank thicknesses, optimum temperature mode of processing depends strongly on the frequency of the discharged current. Lower frequencies correspond to a lower optimum temperature mode of processing.

6. Conclusion

Considered heating method throughout the thickness of the blanks increases the penetration of the magnetic field into the blank material, i.e. increases the value of the equivalent of the gap between the magnetic field source and the blank, which reduces the amount of pressure occurring in the process of interaction between the magnetic field and the current flowing in the blank.

The pressure drop may be avoided for non-simultaneous heating of the blank's side, opposite to the pressure application of the pulsed field, for depth that does not exceed the thickness of the blank minus its skin layer. Heating the blank to a certain depth allows to reduce the resistance to deformation of the material, without increasing the magnetic field penetration depth (skin layer thickness).

The resulting recommendations will be used in developing a number of new manufacturing processes and products put into production at the enterprises of the Tula region.

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