Forming a tubular ridge by pulsed-magnetic field pressure

N V Kurlaev, K A Matveev, F M Tagoev and M E Ahmed Soliman
Novosibirsk State Technical University, Department of Aircraft and Helicopter Construction, 630073, 20 Karl Marx Avenue, Novosibirsk, Russia

E-mail: kurlaev@corp.nstu.ru

Abstract. When creating samples of new technology corresponding to the current level of development of mechanical engineering, ever higher requirements are imposed on the accuracy and quality of parts and assemblies, including thin-walled tubular parts of aircraft. To ensure such accuracy, this work proposes a magnetic pulse stamping process. In particular, for the formation of a tubular ridge, the technological process of forming in addition to calibration by a magnetic pulse field is proposed. To study the stress-strain state of the workpiece and the tool, the finite element method was applied using the ANSYS program. The calculation results were summarized in the form of a nomogram to determine the required technological modes, taking into account the material properties and the pressure amplitude of the pulsed magnetic field. The data obtained as a result of numerical simulation create the basis for identifying and subsequent accounting for the technological heredity of the material.

1. Introduction
Analysis of the nomenclature of aircraft parts shows that thin-walled tubular parts are widely used in the designs of various products [1, 2]. Among them, a special group consists of tubular parts of complex shape, which are used to connect pipelines made of materials that can be welded and soldered (figure 1). The high accuracy of parts of this group is due to the use of modern technological methods of subsequent welding, soldering and assembly of parts into units and assemblies. In particular, to ensure high quality soldering of parts with PSr solders, a uniform gap of about 0.06 mm along the perimeter between the parts is required, and for automatic butt welding of pipes, the step between them should not exceed 0.2 mm with a difference in the diameters of the welded pipe ends of no more than 0.15 mm. It is usually impossible to provide such precision with traditional shaping methods. Calibration operations make up a significant part of the overall complexity in the manufacture of thin-walled tubular aircraft parts [3]. Currently, the industry uses the following methods for calibrating tubular parts, such as: an elastic medium on a rigid tool; expanding punches and multi-sector dies; using the energy of the explosion and the electrohydraulic effect [4]. These methods do not provide the required accuracy, are low productivity and are characterized by a high technological cost of manufacturing parts, high costs of manual labor and high metal consumption of the tooling.
Figure 1. Typical tubular parts with a ridge.

In recent years, in conditions of small-scale, wide-range production, methods of magnetic-pulse stamping have been increasingly used. Advantages of the method are that: simplicity of technological equipment and its low metal consumption, absence of a transfer medium, the possibility of automation and mechanization of the technological process and short preparation time for production [5, 6]. The use of this method allows, during stamping, to simultaneously calibrate the adjacent section of the workpiece with high accuracy. A schematic diagram of the ridge forming by the method of magnetic-pulse expansion of a tubular part is shown in figure 2. Due to the low resistance of inductors for dispensing a small diameter, magnetic-pulse processing for dispensing is used for pipes with a diameter of more than 40...45 mm.

Figure 2. Scheme of ridge forming by (PMF) pressure: 1 – die; 2 – tubular part; 3 – multi-turn inductor; 4 – insulation; 5 – current leads; 6 – bandage; 7 – insulating pad; \( r_0 \) – rift radius.

2. Statement of the problem
The article discusses stamping of tubular parts with a pulsed magnetic field by the expansion method. The development of a typical technological process for manufacturing complex shape parts requires the solution of three main tasks: ensuring the accuracy of the parts obtained by the technical conditions, assessing the limiting capabilities of stamping and determining the parameters of the inductor required for deformation and a magnetic-pulse installation (MPI). To solve them, theoretical studies and analyses were carried out using the method of numerical simulation, which made it possible to identify the patterns and features of the process. Finite element analysis (FEA) is one of the main methods for analyzing the process of magnetic-pulse processing of metals, which provides the possibility of experimental verification of the calculations of the (MPI), as well as the choice of optimal designs of inductor systems that ensure the maximum productivity of the method and high efficiency [4]. The
scheme of loading by a pulsed magnetic field is shown in figure 2. The (PMF) pressure $P$ is set by a damped quadratic sinusoid only with the first half-period of the load [7]:

$$P = P_0 \sin^2(2\pi t) \exp(-\beta t)$$  \hspace{1cm} (1)

The deviation of the size and shape of the calibrated parts from the size and shape of the tooling is determined by the combination of actions of four main factors: elastic rebound, elastic springback, elastic compliance of the tooling material and thermal deformations of the part. Under the influence of two factors, the deviations increase, and under the influence of the third - decrease. The effect of thermal deformations is practically manifested only when processing a workpiece without fixtures. The factors that determine the precision capabilities of magnetic-pulse stamping manifest themselves independently of each other, but at the same time and to varying degrees depend on the processing parameters of the workpiece, its geometric dimensions, dynamic stiffness of the workpiece materials, etc. Therefore, it is very difficult to determine the optimal parameters of the technological process. To solve this class of problems, numerical simulation was used by using the ANSYS finite element complex. The used numerical model is based on the variational principles of mechanics using the theory of plastic flow, the modified finite element method (FEM), and the discrete element method (DEM) [8, 9].

3. Numerical simulation

To assess the required minimum pressure $P$ (hence, the required minimum discharge energy) and to determine the regularity of the distribution of deformations under various processing modes, the process of magnetic-pulse expansion was simulated on the basis of the ANSYS software package. Aluminum alloys with different dynamic yield stress ($Y_0 = 80...350$ MPa), different diameters ($D_0$) and thickness ($\sigma_0$) were chosen as the workpiece material (table 1). The mechanical properties of the die were consistent with those of structural steel taken from the ANSYS materials library. Figure 3 shows a model of the electromagnetic stamping process in ANSYS / Explicit Dynamics. The ridge shaping is carried out by expanding the pipe blank into the die using (PMF). The working contour of the die in the closed state must correspond to the contour of the part. The rift radius in the calculations varied from $r_0 = 3...6$ mm. When forming the ridge, the length of the original workpiece decreases. The length of the original workpiece should be approximately equal to the length of the forming part with the ridge.

![Figure 3. Cross section of the model: 1 – die; 2 – blank; P – (PMF) pressure.](image-url)
Table 1. Determination of the optimal pressure value (P, MPa) at the rift radius $r_0 = 5$ mm.

| $\delta_0$ | $Y_0$, MPa | $D_0 = 50$ mm | $D_0 = 55$ mm | $D_0 = 60$ mm |
|------------|------------|---------------|---------------|---------------|
| 1          | 185        | 24            | 25            | 26            |
|            | 200        | 25            | 27            | 27            |
|            | 250        | 27            | 28            | 30            |
|            | 325        | 32            | 34            | 37            |
| 1.5        | 185        | 27            | 29            | 31            |
|            | 200        | 30            | 31            | 34            |
|            | 250        | 34            | 35            | 41            |
|            | 325        | 41            | 42            | 57            |
| 2          | 185        | 33            | 34            | 36            |
|            | 200        | 34            | 36            | 37            |
|            | 250        | 39            | 40            | 43            |
|            | 325        | 51            | 53            | 66            |

Figure 4 shows the result of modeling the formation of a tubular ridge by the pressure of ($P_{MF}$) on a fixed die made of structural steel. The workpiece material is aluminum alloy 3004 (AMr-6) with an outer diameter of 60 mm and a thickness of 1 mm. The rift radius was 5 mm. At the optimum pressure values equal to 63 MPa, it is possible to obtain a detail with minimal wall-thinning in the ridge zone. A further increase in pressure will lead to a thinning of the blank wall and a deviation from the required pipe length. Thus, numerical simulation shows the possibility of obtaining parts with the most accurate characteristics. The visualization of the forming processes occurs simultaneously with the calculation, which allows immediately interpret the results obtained and make the necessary changes to the technology.

Figure 4. Formed tubular part with a ridge.

The numerical simulation which used in the study carried out to assess the required minimum discharge energy and to determine the regularity of the distribution of deformations under various processing modes. The use of this method makes it possible to trace the parameters of the stress-strain state of the workpiece without using a large number of samples, to dispense with the operation of the magnetic-pulse installation and tools, complex equipment, and thus increase the economic efficiency of the technological process. The results of numerical simulation of the forming and calibration of a tubular part were summarized in the form of a nomogram [7]. Nomogram for determining the optimal pressure value ($P$) depending on the dynamic yield strength of the workpiece $Y_0$, the geometric parameters of the part ($D_0$, $\delta_0$) and the radius of the rift $r_0$ are presented in figure 5.
Figure 5. Nomogram for determining the optimal pressure amplitude (P) of (PMF) for forming of tubular ridge at various parameters of the workpiece $Y_0$, $r_0$, $\delta_0$, $D_0$.

4. Results

144 cases of pressure loading of the (PMF) were analyzed. The optimal pressure for each case has been determined. Based on the results of numerical calculations, a nomogram of pipe beading was constructed to determine the most effective (PMF) pressure depending on the properties of the material, geometric parameters of the workpiece and the die.

The results of numerical simulation show that the ridge formation for tubular parts with a diameter greater than 50 mm ($D_0 \geq 50mm$) and a thickness of more than 2 mm ($\delta_0 \geq 2mm$) without thinning in the walls of the workpieces and occurs when the rift radius of the die is ($r_0 \geq 5mm$).

An analysis of the current state of the process of expanding tubular blanks by a magnetic-pulse field has been carried out. Numerical research by the finite element method (FEM) significantly expands the scope of these methods in modern mechanical engineering as a promising means of implementing the process of expanding tubular blanks.

Acknowledgments

The reported study was supported by the Department of Aircraft and Helicopter Construction, NSTU in accordance with order No. 144 of 01/30/2020. Project code included in the thematic plan of the Research Work for 2020 No. TII-CBC-1_20.

References

[1] Feoktistov S I, Maryin B N, Maryin S B and Kolyhalov D G 2013 Theory and practice of manufacturing aircraft pipelines elements (Komsomolsk-on-Amur: KnASTU Press) p 88

[2] Mirkin A Z and Usinsh V V 1991 Pipeline systems. Calculation and computer-aided design Handbook (Moscow: Khimiya Publ.) p 256

[3] Isachenkov V N, Samokhalov V A, Glushchenkov V I and Pesotskiy V I 1989 Magnetic-pulse calibration of thin-walled hollow parts: J. Forge. and Stamp. Prod. Mat. Working by Pressure (KShP) 7 5-7
[4] Isachenkov E A 1967 *Rubber and liquid stamping* (Moscow: Mashinostroenie) p 368

[5] Bobruk E V, Semenova I P and Valiev R Z 2015 *Modern methods of deformation-heat treatment: from traditional materials to nanostructured* (Ufa: USATU) p 113

[6] Glouschenkov VA 2012 *Special types of stamping 2 Dynamic methods of deformation* Textbook (Samara: SSAU) p 108

[7] Kurlaev N V, Gulidov A I, Ryngach N A and Krasovsky V V 2002 Closure of discontinuities in the materials structure of parts during magnetic-pulse processing *Scientific Bulletin of NSTU* 12(12) 131-40

[8] Kislookiy V N 1966 Algorithm for numerical solution of problems of statics and dynamics of nonlinear systems: *Applied mechanics* 2 87-91

[9] Li Qiu, Yantao Li, Yijie Yu, Yao Xiao, Pan Su, Qi Xiong, Jinbo Jiang and Liang Li 2019 Numerical and experimental investigation in electromagnetic tube expansion with axial compression *The Int. J. of Adv. Manuf. Technol.* 104 3045-51