Forming the straight flange of a rib by pulsed-magnetic field pressure

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Abstract. In the production of aircraft, the most common method of manufacturing a straight flange is magnetic-pulse stamping, since it is highly efficient in small-scale production due to its high versatility and simplicity of technological equipment. Among the sheet metal parts of the aircraft, there is a fairly large number of parts with straight sides, which are made of a flexible elastic medium. In this paper, the straight flanging of the D16AM aluminum alloy during magnetic pulse forming was investigated by using the LS-DYNA simulation program. The operation of sheet bending is used to form the side wall of the part. If the bent side has a straight shape, then bending stresses occur along the bend radius, and the side wall remains unstressed. This operation is called «straight flange bending». With impulse shaping, there is a great possibility to control the shape of the workpiece during deformation by distributing pressure over its area. Excessive pressure is created on the workpiece after it adjoins the die. This pressure contributes to the redistribution of stresses and equalizes them along the height of the section of the workpiece, while inertial forces change the stress-strain state of the workpiece. This study, in particular, concerns an example of numerical simulation of the electromagnetic forming of a straight flange with the obtained mesh shape of a workpiece and the results of its calculations were summarized in the form of a nomogram.

1. Introduction
A positive feature of pulsed method of metal processing is a more uniform distribution of deformations over the wall thickness of the part being stamped, which in some cases allows achieving greater degrees of metal deformation than with quasi-static stamping methods [1–4]. Flanging by electromagnetic pulse is usually used to provide stiffness for hidden joints, avoid sharp edges and to strengthen the edges of parts such as aircraft wing ribs. The process of designing the technological process of straight flange bending is reduced for determining two deformation-force parameters of the process: the required pressure and the value of the spring angle. The required bending pressure is determined from the condition of the moments equality of internal and external forces. After the bending operations, the springing effect of the bending elements appears, which leads to unstability in deviation of the bending angle, i.e. the angle of bevel gauge due to the physical and mechanical properties of the material and its thickness within the tolerance [5]. When performing bending operations of a straight flange, an undesirable thinning of the material is formed in the bending zone. An increase in stress is concentrated in the zone of the recessed bend. Thinning reaches 15% and more, which is associated with the bending radius and the bending method, which depends on the thickness of the material. Thus, thinning increases in the radius zone of the workpiece with decreasing bend radius [6–8]. Thinning leads to unwanted
defects such as reduced fatigue strength and reduced workpiece rigidity [9]. In our case, the springback was very small and within tolerance. Thus, simulation can be used to predict the forming process by using software program LS-DYNA.

2. Materials and methods

2.1. Experiment setup
The electromagnetic coil is decisive for electromagnetic forming and must be designed to be positioned under the metal sheet as shown in figure 1, to generate electromagnetic forces equally.

2.2. Analysis of the results
A flat spiral coil comprising 8 turns with a 2 mm gap was made from copper wire with a rectangular cross section of 12.5 mm × 13.5 mm. At the end of the simulation, a graph of the voltage on the coil with a value of 2700 Volts with attenuated amplitude is displayed (figure 2).

![Grid model of a rib at the initial moment of time: 1 – flat EM coil; 2 – blank; 3 – hard boundary die.](image1)

![Coil voltage graph.](image2)
Figure 3. Plastic deformations on the workpiece at different stages of forming from time to time: а – 0 sec., b – 1.3e-4 sec., c – 2.6e-4 sec., d – 3.3e-4 sec.

Figure 4. Deformed straight flange with control zones.

The thickness calculation, according to the control points, showed that the greatest thinning occurs in the radius zone (thickness 1.43 mm), along the straight zone of the flange, the thickness is 1.48 mm and along the flat zone of the workpiece is approximately 1.5 mm.
Springback angle is significantly influenced by the ratio of the yield strength to the modulus of elasticity. Strengthening increases the yield strength, so the work-hardened metal is more springy than the annealed one. More intensely hardenable metals have a greater springback. The springback angle $\Delta \theta$ can be expressed as follows [7]:

$$
\Delta \theta = \beta_0 r_0 \left( \frac{1 - \nu^2}{E} \cdot \frac{3\sigma_0}{t} \cdot \frac{6}{n + 2} \cdot \left( \frac{K(1 - \nu^2)}{E} \cdot \left( \frac{\delta_0}{2r_0} \right)^n \frac{1}{t} \right) \right)
$$

(1)

Where $\sigma_0$ represents the yield strength, $E$ is Young’s modulus, $\nu$ is Poisson’s ratio, $\delta_0$ is the initial sheet thickness, $K$ is the strength coefficient, $n$ is the strain-hardening exponent, $r_0$ is the initial die radius, $\beta_0$ is the die angle.

During the deformation, the temperature also rises. The highest temperature is concentrated in the zones of maximum deformation (radius zone) and reaches 37 degrees Celsius.
Calculation of plastic deformations from the control points showed that the deformation is 2% along the flat control point, 12% along the radius zone, and 1% along the straight zone.

The results of numerical simulation of the straight flanging forming process with optimization of the pulsed loading parameters of the workpiece to obtain parts of the required shape were summarized in the form of a nomogram [1-3]. A nomogram for determining the optimal pressure (P) of (PMF) depending on the dynamic yield stress of the workpiece $Y_{ow}$ and its geometric parameters: thickness $\delta_0$, flange height $H_f$ and bend radius $r_b$ during straight flanging, which are presented in figure 8.

**Figure 7.** Change in the magnitude of plastic deformation on the control elements of straight flanging.

**Figure 8.** Nomogram for determining the optimal pressure amplitude (P) of (PMF) for forming a straight flange at various parameters of the workpiece $Y_{ow}$, $\delta_0$, $H_f$, $r_b$. 
3. Results
In our case, the springback force of the straight flange with magnetic pulse stamping is less than mechanical stamping due to the absence of frictional force. The simulation results are in good agreement by using LS-DYNA so, the model can be used for a real case.

Calculation of the thickness of the straight flange, according to the control points, showed that the greatest thinning occurs in the radius zone by 0.05 mm, less than in the straight zone and by 0.07 mm, less than in the flat zone.

Calculation of plastic deformations based on control points showed that the greatest deformation occurs in the radius zone and estimated with 12%.

During the deformation process, the temperature rises to 37 degrees Celsius, which therefore does not affect on the forming process.

After several calculations in the pressure value at which the deformation time was 3.3e-4 sec., we can find out that the suitable EM calculation pressure in this case is 22 MPa.

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