ADVANCED MANUFACTURING TECHNOLOGY BY METAL FORMING PROCESS FOR TWO PRESSURE CHAMBERS CARTRIDGE CASES

Paul Lixandru, Tudor Chereches, Sorin Gheorghian

[1]SC UPS PILOT ARM SRL Dragomiresti, Laminorului Street, No. 2, Tirgoviste, Romania

Corresponding author: Tudor Chereches, tudor.chereches@yahoo.com

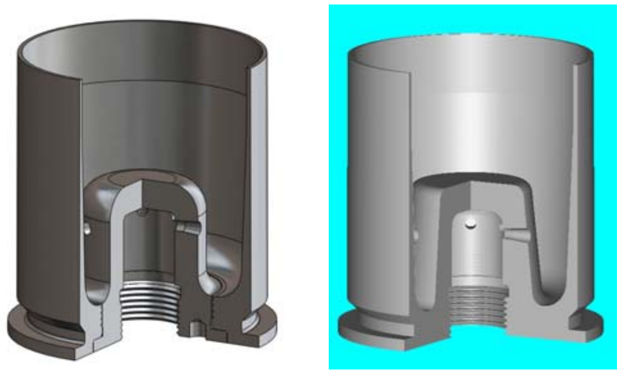
Abstract: The paper presents two important issues encountered during conception and designing of the manufacturing technology of two pressure chambers (TPC) cartridge cases made by plastic deformation from one part.
In the first part is considered the most common technology for manufacturing TPC cartridge cases from two parts, then are presented some features of technology for the same product manufactured from one part, by metal forming procedure. The two technologies are compared, especially from economic point of view, and highlight the advantages of technology for manufacturing TPC cartridge cases from one part.
The most important part of the paper is reserved for presentation of numerical simulation methodology, upon which were designed: technology, tools and devices and have established regimes of plastic deformation, provided product manufacturing with the shape and size required. The aimed goal throughout the simulated deformation process was keeping the shape and size, within manufacturing tolerances in the central region of the nozzles.
Keyword: design, simulation, shape, technology

NOTATION

$d\varepsilon_{ij}$	- strain increments;
$d\varepsilon_{ij}^{e}$	- elastic strain increments;
$d\varepsilon_{ij}^{p}$	- plastic strain increments;
$d\varepsilon$	- volumic strain increment;
$d\sigma$	- mean stress;
K	- bulk modulus;
G	- shearing modulus;
ν	- Poisson's ratio;
S_{ij}	- stress deviator components;
$\sigma_1, \sigma_2, \sigma_3$	- principal normal stresses;
σ_y	- yield stress.

1. DEFINING THE PRODUCT

TPC cartridge cases are ammunition items which differ from normal cartridge cases by several features.
Complex form (Figure 1) is an important technological disadvantage.



a) b)
Fig. 1. Two pressure chambers (TPC) cartridge cases
a- made from two parts; b-made from one part

Into high pressure chamber (inner chamber) powder burning occurs at high pressure. The combustion products flow through the nozzles into low pressure chamber. Nozzles are dimensioned to maintain pressure into low pressure chamber below a certain value, during projectile acceleration.
The main advantage of the TPC cartridge cases is to achieve a regime of stable and complete combustion inside the high pressure chamber and a pressure regime with a better distribution into time, without peaks, inside the barrel of the weapon.
Projectile protection from the action of gas jets is provided by radial or slightly inclined orientation of the nozzles, complication which lead to the manufacturing of TPC cartridge cases from two parts, assembled by crimping or screwing (Figure 1 a)
In current versions of technology applied in Romania, the two parts of the TPC cartridge case are manufactured by turning from bars, with a high consumption of material, energy and manpower. Thus, for 40 mm TPC cartridge cases, the following quantities of material are consumed:

- Ø45X50 mm bar...... 0,215 kg;
- Ø35X30 mm bar...... 0,078 kg;
- In total .... 0,293 kg.

Comparing the weight of the blanks and the weight of the final product, 0.053 kg, results a material used index of only 18%. The remaining material, 82% is deployed by cutting with a high energy and labor.
Besides the fact that manufacturing of cartridge cases

from two pieces implies very high consumption of material, much labor and energy, it presents the risk of gas leakage through threaded or crimping assembly during operation, with negative effects on the user.

Attempts to achieve a cartridge case from one piece were encounter difficulties in maintaining the shape and size of the center, especially nozzles.

2. PARTICULAR ELEMENTS OF THE NEW TECHNOLOGIES

The goal of the new technology for aluminum alloy TPC cartridge cases, the authors proposed and tested is to reduce material consumption, energy and manpower from current solutions. The new technology, one-piece cartridge case is made by plastic deformation by extrusion and drawing operations with appropriate heat treatment. Cutting operations required for cutting blanks, frontal cutting after drawing, collar and thread machining, calibration and finishing cut have a lower overall weight.

The new technology starts from a unique Ø40X21 mm blank, weighing 0.072 kg, plus lost weight of 0.010 kg after cutting and ends with a product weighing 0.055 kg. As a result, the material utilization index has grown to 67% and material consumption has decrease by 3.5 times. Energy consumption for cutting operations, estimated by deployed weight, is about 9 times lower than the current solution. Of course, the new technology uses energy and manpower for operations performed on cold press forming and heat treatments.

To preserve the mechanical properties of the cartridge case, the new technology uses the same material as the current technology, i.e. 6082 (AlSi1MgMn) aluminum alloy, with mechanical properties and chemical composition as are given in Tables 1 and 2.

Table 1. Aluminum alloy 6082. Mechanical properties

Temper State	0	T4	T6
Proof stress 0,2% [MPa]	60	170	310
Tensile Strength [MPa]	130	260	340
Shear Strength [MPa]	85	170	210
Elongation A5 [%]	27	19	11
Hardness Vickers [HV]	35	75	100

Table 2. Chemical Composition

Element	% Present
Si	0,7 to 1,3
Mg	0,6 to 1,2
Mn	0.4 to 1,0
Fl	0,5
Cr	0,25
Zn	0,2
Cu	0,1
Ti	0,1
Al	balance

Manufacturing technology of TPC one-part cartridge case was designed based on economic criteria related to the consumption of materials, manpower and energy. Design of tools and devices considered the product realization with form and dimensions required, in a series of plastic deformation. Tools and devices designed, attached to the new technology ensures the dimensional preservation of central region of the cartridge case where nozzles are machined. One-part cartridge case form requires drilling and reaming operations to do between the forming operations. The risk of altered central region shape and size, including nozzles, during subsequent plastic deformation was removed, the most by wisely setting of operations, of intermediate forms and of active tools - punches and dies.

Figure 2 shows the main simulated operations of the new technologies:

1. cutting and drilling the blank;
2. extrusion and machining nozzles;
3. no. 1 drawing;
4. no. 2 drawing;
5. flanging;
6. collar and thread machining, finishing and external calibration turning.

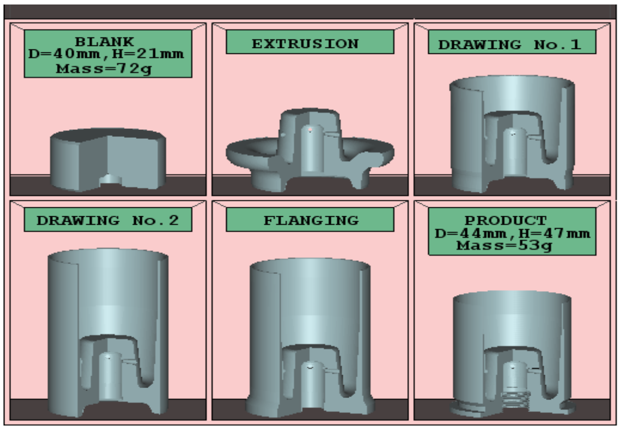


Fig. 2. Metal forming process

Fig. 3. Work pieces after each of the main operations

Cold forming operations are preceded by thermal annealing treatment to bring the material to T0 malleable state. After flanging, tempering and artificial aging treatment is applied that brings the material in T6 condition.

Annealing heat treatment to produce T0 state consists of keeping parts in the oven about 1 hour at a temperature of $(360...400)^0$C, followed by slow cooling in the oven. Hardening heat treatment is performed by heating the parts 1 hour at a temperature of $(520...540)^0$C, followed by cooling in water. Finally the artificial aging is performed at a temperature of $(155...160)^0$C, for 8 ... 12 hours.

Figure 3 shows products after each of the main operations of the new technologies, arranged in order, on the hinged door of the heat treatment furnace.

Establishing new technology was based on finite element numerical simulations. All plastic deformation operations were numerically simulated, in several converging variants to the optimal solution. For each numerical simulation it was analyzed the interaction between tools and semi-plastic material. When appropriate, the shape and size of tools (punches, dies) were adjusted accordingly to achieve the optimal solution (Figure 4). Also, the deformation regime was established in condition of keeping the boundary integrity of semi-manufactured products, and therefore was the main factor that determined the number of forming operations.

Fig. 4. Main tools of the new technology

Fig. 5. Material samples

An important objective of numerical simulations was to maintain the shape and size of the tube, especially in the central area throughout the application of technology.

3. NUMERICAL SIMULATION OF METAL FORMING PROCESSES

The simulation of metal forming processes is based on theory of plastic flow, which establishes incremental relations between strain, stress and some parameters of plastic state. The assumptions of plastic flow theory are (Hill, R., 1998):

1 - The body is isotropic.

2 - The infinitesimal change of volumic strain is elastic and proportional to infinitesimal mean stress,

$$\mathrm{d}\varepsilon = \frac{1}{K}\mathrm{d}\sigma \qquad (1)$$

3 - The total increments, of the strain are made up of elastic strain increments, and plastic strain increments,

$$\mathrm{d}\varepsilon_{ij} = \mathrm{d}\varepsilon_{ij}^{e} + \mathrm{d}\varepsilon_{ij}^{p} \qquad (2)$$

4 - Elastic strain increments are given by general Hooke's law,

$$\mathrm{d}\varepsilon_{ij}^{e} = \frac{1}{2\mathrm{G}}\left(\mathrm{d}\sigma_{ij} - \frac{3\nu}{1+\nu}\delta_{ij}\mathrm{d}\sigma\right) \qquad (3)$$

5 – The plastic strain increment deviator is proportional to stress deviator,

$$\mathrm{d}\varepsilon_{ij}^{p} = \mathrm{d}\lambda\,\mathrm{S}_{ij} \qquad (4)$$

where is an infinitesimal scalar factor. In other words, the stress state determines the instantaneous increment of plastic strain. The infinitesimal factor is related to incremental plastic work and yield stress on flow surface. In many flow codes the flow surface is accepted to by a cylinder, whose axis is straight line , hydrostatic axis, in principal stress space.

For von Misses yield condition, the yield surface is a circular cylinder,

$$(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2 = 2\sigma_y^2 \qquad (5)$$

When material works in hardening conditions, the yield (loading) surface is not fixed, but somehow expands and moves as work hardening develops. In general, the yield surface shape and position depend on the current stress state, but also whole previous strain history (Kachanov 1974, Hill 1998). In case of isotropic hardening, the yield surface undergoes a uniform expansion during plastic deformation. The assumption of isotropic hardening was used for material formulation in all numerical simulations.

When plastic work depends only on stress intensity, plastic properties of materials are established by simple tests of tensile and compression, in form of real characteristic diagram. In theory of plasticity is very important the dependence of effective stress on effective plastic strain, established using data from experimental characteristic diagrams.

This theory of plastic flow is implemented in most used finite element programs (ABAQUS, ANSYS, COSMOS, LS-DYNA, NASTRAN, etc.). The incremental form of the equations used in theory of plastic flow is perfectly suited to numerical analysis methods, (Paunoiu, V., et al., 2011, Ursescu, G., et al., 2011).

3.1 Material analysis

A good solution of metal forming process simulation is obtained only if the properties of material are correct established for all states of deformation, up to failure. The metal analysis consists of number of tests for chemical composition, hardness in different heat treating and material properties used in applied procedures (Fig. 5). Many tests of tensile and compression were developed for this application. Figure 6a shows a sample of conventional characteristic diagram. By transforming this diagram there is obtained real characteristic diagram (Figure 6b). The conventional characteristic diagram relates the engineering-defined stress and strain. In the real characteristic diagram are used more complex-defined variables as effective stress and effective strain which can be written by (Ogden, R.W., 1997).

$$\sigma_{eff} = \sqrt{\frac{3}{2}}\sqrt{S_{ij}S_{ij}}\ ,$$

$$\varepsilon_{eff} = \int_0^t \mathrm{d}\varepsilon_{eff}\ , \qquad (6)$$

$$\text{where, } \mathrm{d}\varepsilon_{eff} = \sqrt{\frac{2}{3}}\sqrt{\mathrm{d}\varepsilon_{ij}\mathrm{d}\varepsilon_{ij}}$$

Before neck beginning, the stress state in the testing specimen is uniform and axial and consequently, the effective stress becomes Cauchy stress and effective strain –natural (logarithmic) axial strain, but this state may be very short in comparison with all deforming process (see diagrams).

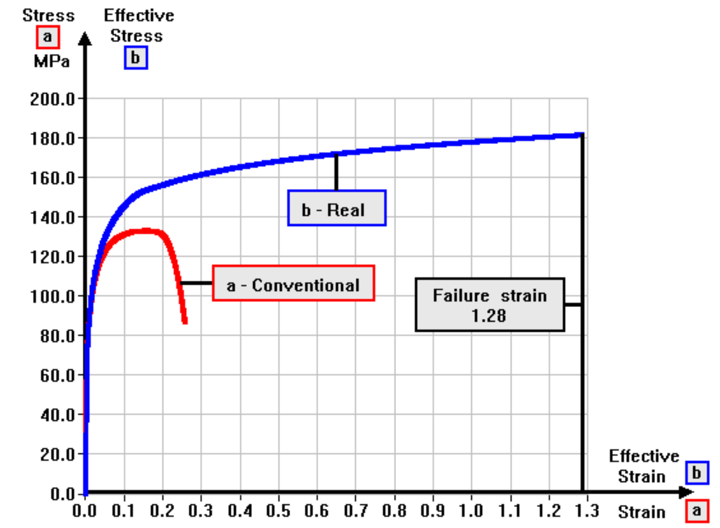


Fig. 6. Characteristic diagrams

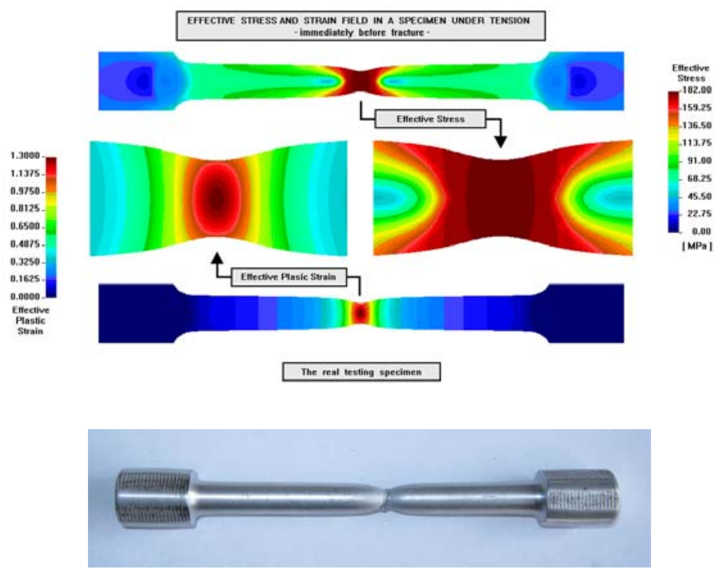


Fig. 7. Effective stress and strains field

This conversion after neck beginning is not so simple due effect of specimen necking in tensile test. When necking begins, the stress distribution is no longer uniform. For plastic metal it is necessary a deformation analysis up to failure, in neck region of tensile specimen, which extends the real characteristic diagram up to fracture. The deformation analysis has performed, using the experimental data, by iterative numerical Finite Element Simulations. In these simulations, one of control parameters was the necking diameter in final stage and other, the final load and the final elongation. The real characteristic diagram extension in necking domain has been controlled by feed-back adjustment.

Strain state and stress state analysis, by numerical simulations (Fig. 7) has been permitted to obtain the real characteristic diagram, up to failure, for using material (Fig. 6).

3.2 Process modeling and simulation preparing

For the numerical simulation of plastic deformation processes was used professional software finite element numerical analysis COSMOS / M.

Because of the complexity of objects analyzed, was required 3D modeling using Solid-8N volume elements, as the sample in Figure 8. In nozzle area, a denser mesh was used (Fig. 9).

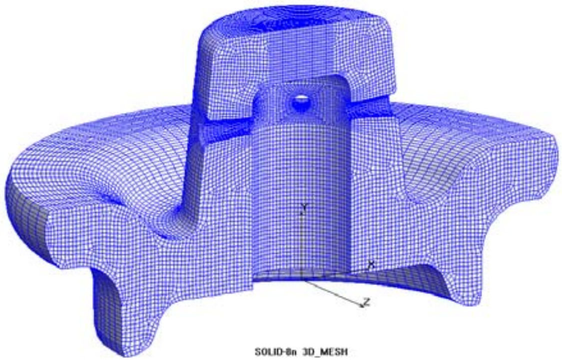


Fig. 8. Solid 3D mesh

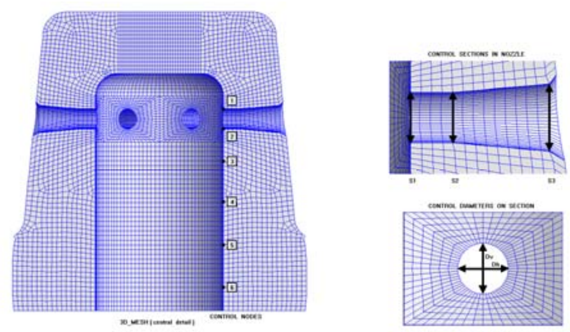


Fig. 9. Solid 3D mesh - details

The shape and size of semi-finished part were studied throughout the simulation of forming operations. Special attention was given to the central area of the part and nozzle. In order to control the diameter of central bore were established six control nods. Controlling the shape and size of nozzles was made in three control sections. On each section were modeled two perpendicular control diameters. Control nodes, sections and diameters are shown in Figure 9 with details.

Variations of control dimensions were recorded for each step of calculation and accumulated in the transition from one operation to another.

Defining material was done by introducing the mechanical properties of used alloy material and the material curve obtained from real characteristic diagram, by removing the elastic component of effective strain in the form often used in incremental numerical applications.

$$\sigma_{eff} = f\left(\varepsilon_{eff}^{p}\right) \quad (7)$$

Active tools and work pieces were modeled with finite elements that were to undergo plastic deformation by operation included in the technology.

3.3 Carrying out numerical simulations

As specified in the definition of technology, simulations aimed at optimizing the forming operations, in term of product realization in the dimensional limits and the prescribed form. Optimization of technology was done by using at admissible limit the plastic properties of material. Thus, by repeated numerical simulations, for each operation separately, were adjusted shape and size of punches and dies and was established working regime in order to achieve states of deformation at the material endurance limit. For example, considering that the effective plastic strain to failure is 1.28, according to value given in Figure 6b, which was neglected elastic component of 0.0025, the high degree of deformation of the material required by the regime has led to values of the effective plastic strain up to 1.1, a value that corresponds to a consumption of about 86% of the reserve of plasticity of the material. In the maximum deformation area, the characteristic diagram (Figure 6b) it greatly reduces its slope, which justify maintaining equivalent stress near failure value, with very little sensitivity to strain. This is highlighted on Figures 7 and 8.

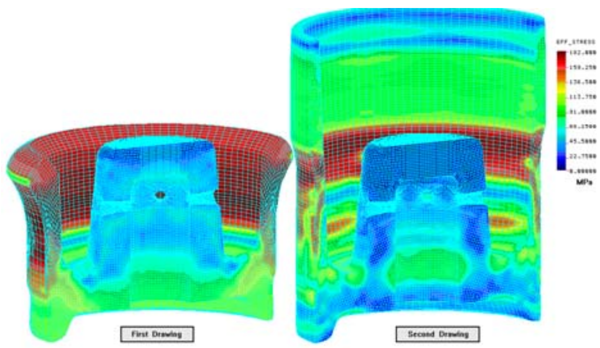


Fig. 10. Effective stress field simulated

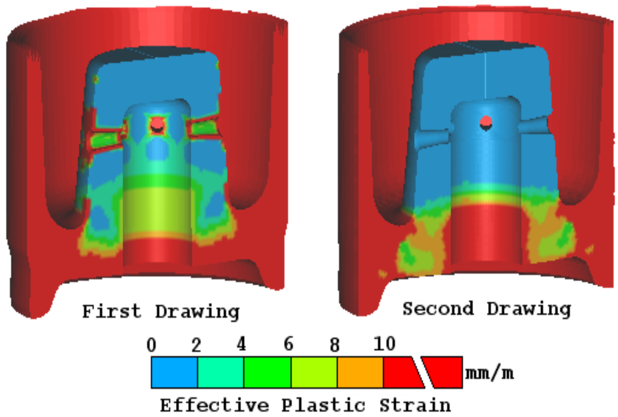


Fig. 11. Plastic strain after drawing operations

Figure 10 shows two examples of intermediate tension states during simulation of drawing operations.

Equivalent stress distribution in the material, represented in Figure 10 shows the high degree of utilization of plasticity reserve of material, about 85%. It is true that in certain areas or in some moments, at the beginning and at the ending of the operation, the use of reserve of plasticity is lower.

Figure 10 highlights also the protection that tools ensure to the central area. Generally, in the central area, the effective stress is lower than the yield. Because some plastic deformations occur, a definite conclusion on the objective regarding preservation of shape and dimensions is possible only after the analysis of control quantities.

3.4 Analysis of simulation results and quantities

During numerical simulations tools and material behavior were studied.

Continuously, based on findings from previous simulation, the necessary corrections were made to the technological process, tools and devices and even blank. An example is the introduction of a ring to limit the operation of extrusion, initially free on the contour. 3D simulation of extrusion free on the outer contour revealed some deviations from circular outer edge of the work piece, which would be transferred and amplified in subsequent operations.

Also during simulations for extrusion operation, has found that the work piece must be well centered on punch. For this an Ø 11x4 bore was machined into the originally blank to center on the secondary punch.

Tracking of the main objective of the process of designing a new technology for machining one-part TPC cartridge case, i.e. preserving the shape and size of central area and nozzles, was done in all simulations of metal forming operations which follow extrusion and drilling of the 6 nozzles.

First, was studied, throughout the simulations, remaining plastic strain at the end of deformation operations. After forming operation, the effective plastic strain field gives some information on the state of residual strains.

To highlight the effect of propagation of plastic strain in the protected area, representation scale (Fig. 11) in the local interest was changed by 1%, using five colors. Residual plastic strains above 1%, out of scale and are represented with red color.

In areas marked by the color blue, plastic strains are zero or negligible, with values up to 0.2%. (below the yield technique limit). Qualitative analysis of the distribution of residual strain, shown in Fig. 11, supports the conclusion maintaining the shape and size of protected area throughout the application of metal forming process. It is noted that inside the material near the nozzles are locally induced remaining plastic strains in limited space areas. The phenomenon is justified by the concentration of stress in holes.

The unfavorable global, integrated, effect of the residual plastic strains around the nozzle is limited by the presence of extensive areas with elastic state (blue) which prevent propagation. Total residual strains of the final product are the result of their accumulation in all subsequent extrusion forming operations. It is noted a higher contribution of the first drawing, when the blank is subjected to significant changes in shape, which strongly propagates inside the material.

Quantitative analysis of the influence of residual deformations on the shape and size of interest area was based on graphs of changes in control diameters (Figure 12) and displacement of control nodes (Figure 13). In both figures, the effects were cumulated on two drawing operations. Analysis of the results represented in Figure 12 shows good dimensional stability of the nozzles during the forming operations.

In the final state, the calibrated portion of the nozzle, the deviations are within the specified tolerance for the product. For the situation shown in Figure 12, cumulative deviations from diameters do not exceed ± 5 µm.

Regarding the central bore, was found by analyzing representations of the type shown in Figure 13 that in time, elastic plastic displacements occur with values of order of hundredths of millimeter. Entry nodes ND1 and ND2 in nozzles have the smallest displacement. As the distance from the nozzle increases the nodal displacements are increasing.

Because the central bore provided thread cutting operations, representations for Nd5 and Nd6 remain only for information.

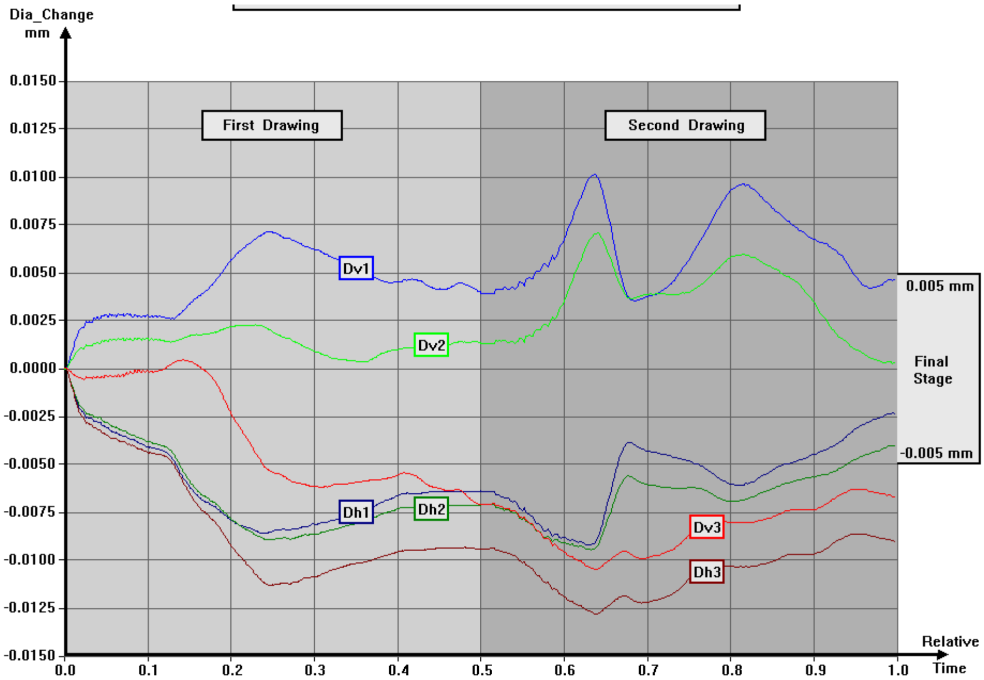


Fig. 12. Control diameters change in metal forming process

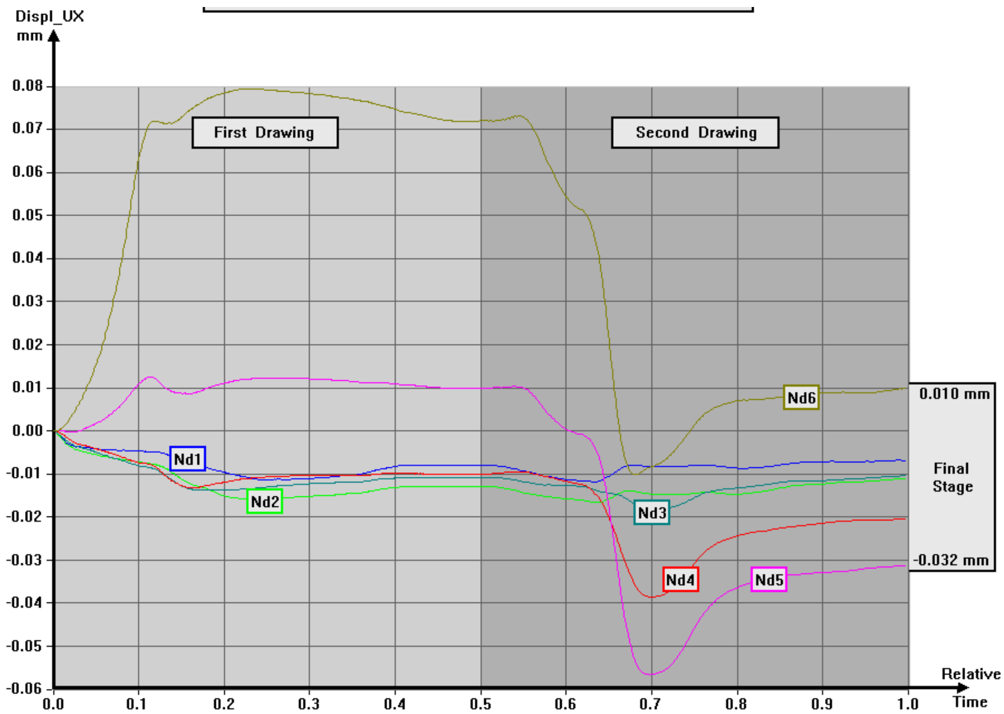


Fig. 13. Control nodes displacement in metal forming process

Note that heat treatment operations inserted between plastic deformation operations relaxes residual stresses, without significant effects on remaining strains. This allowed the accumulation of residual deformations produced during drawing operations.
The entire analysis, qualitative and quantitative of residual strain state obtained by numerical simulation supports the idea that if measures are taken when designing technology and the operating regime, machining one-part TPC cartridge case is possible.

3.5 Metal forming devices and tools

The numerical simulation of metal forming process for TPC cartridge case has been finished by design and manufacture of necessary tools and devices used in new technology operations. Extruding tools and devices are shown in Figure 14. In the same figure, are represented some main sequences of extruding process.
The shape of used tools is so, that, in final stage, the work piece is adequate for nozzle drilling and taper boring on radial direction and for following drawing operations.

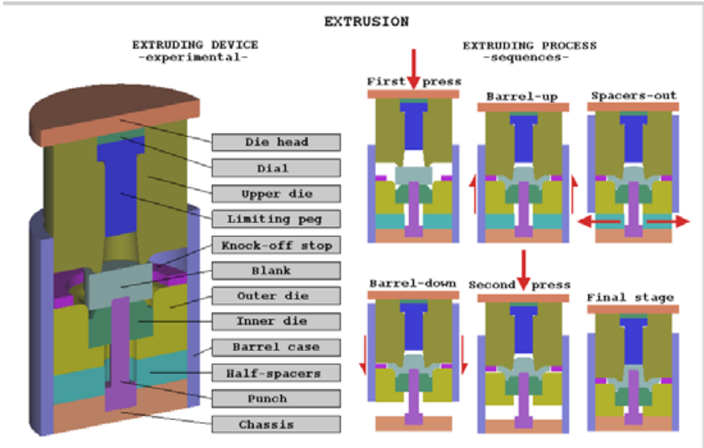


Fig. 14. Extruding tools and devices of the new technology

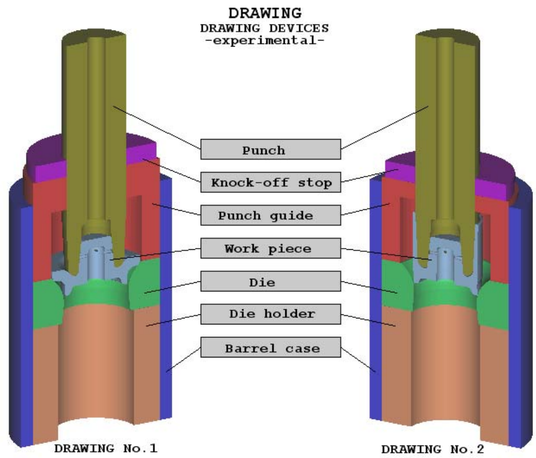


Fig. 15. Drawing device

In Figure 15 are shown devices for drawing operations, but active tools only. The work piece shape at first drawing has been obtained after extruding operation and nozzle drilling and boring. A few experimental tools used for metal forming processes were shown in Figure 4.

4. CONCLUSIONS

Design methodology of technological processes based on modern methods of simulation provides a direct, economic way to reach the goals.

Manufacturing technology of one-part TPC cartridge case was first fully simulated in detail. During the simulations were made all necessary corrections to achieve a certain optimizations. After building virtual solutions they were transformed into real practice.

Only after simulations of forming processes were finished the design and development of devices and tools were done.

The resulted real technology is an exact copy of the "virtual technology" used in the simulations.

With approximate or incomplete data successful simulations cannot be assured.

Technology established using numerical simulations of forming processes, has been applied experimentally by the authors, successful, practical, without no changes.

5. REFERENCES

1. Hill, R., (1998). *The Mathematical Theory of Plasticity*, Clarendon Press, Oxford.
2. Kachanov, L.M., (1974). *Fundamentals of the Theory of Plasticity*, Mir Publishers, Moskow.
3. Ogden, R.W., (1997). *Non linear Elastic Deformation*, Dover Publication, Dover.
4. Păunoiu, V., Maier, C., Virgil, T., Găvan, E., (2011). *Numerical analysis of multipoint forming process*, International Journal of Modern Manufacturing Technologies, Vol. III, No. 2, pp. 85-90.
5. Ursescu, G., Ciofu, C.D., (2011). *Flow analysis of a formula SAE car using FEA simulation*, Proceedings of ModTech2011 International Conference, D. Nedelcu et. al., (Eds.,), pp. 1125-1129, Vadul Lui Voda, Republic of Moldova.

Received: January 25, 2012 / Accepted: June 8, 2012 / Paper available online: June 10, 2012 © International Journal of Modern Manufacturing Technologies.