TRANSIENT THERMAL SIMULATION OF WORKING COMPONENTS OF MECHATRONIC SYSTEM FOR DEEP DRAWING OF MOLYBDENUM SHEETS

Michal TROPP*[1], Mária TOMÁŠIKOVÁ[1], Ronald BAŠŤOVANSKÝ[1], Leszek KRZYWONOS[2], František BRUMERČÍK[1], Zbigniew KRZYSIAK[3]

[1]Department of Design and Mechanical, Faculty of Mechanical Engineering, University of Žilina Elements, Univerzitná 1, Žilina 010 26, Slovakia
[2]Lublin University of Technology, Faculty of Mechanical Engineering, 36 Nadbystrzycka Street, 20-618 Lublin, Poland
[3]University of Life Science in Lublin, Faculty of Production Engineering, 28 Głęboka Street, 20-612 Lublin, Poland

Abstract
The subject of this article is an optimization of the concept of a device for deep drawing in extreme conditions. In this case, extreme conditions represents drawing process in vacuum by high temperatures required by molybdenum sheets forming. The first part of the paper deals with the design of working components. The paper describes also boundary conditions of transient thermal simulations of working components with their results.

Key words: *deep drawing; molybdenum; thermal simulation, reinforced shell components*

INTRODUCTION
The subject of this article is an introduction of the concept of a device for deep drawing in extreme conditions. In this case, extreme conditions represents drawing process in vacuum by high temperatures required by molybdenum sheets forming. Article deals with description of possible variants of the mechanism structure and their functional changes. The paper describes also with the results of the thermal simulations by evaluating the variants.
Deep drawing is a process in which the sheet is formed into a deep container free from cracks. The design and control of deep drawing is apart of the choice of material and also on the links between forming tools, mechanisms of plastic deformation, and the device used to control the flow of material during the process. Pressure, shape and height of stamper, forming speed, lubrication, blank holder force, blank holder gap and material have the biggest influence on working process.

MATERIALS AND METHODS
Boundary conditions and design of working components
For correct process of deep drawing of molybdenum sheet, higher temperature of formed material is required, due the bad ductility of molybdenum in temperatures near the 20°C. During our process the formed material needs to be warmed in temperature range from 200°C to 300°C.
On the Fig. 1 is visible, why are required so high forming temperatures. At room temperature, strength of molybdenum is 1035MPa, while by 200°C is approx. 880MPa and by 300°C is strength of molybdenum only 800MPa. Also ductility of material raised from 3% to 12% by 300°C.
This part of paper deals with design of chosen part of device. On Fig. 2 is structure of working part of device is shown. Transparent part on picture is a vacuum chamber, which is required due the poor oxidation resistance of molybdenum by temperatures highest than 300°C. Next components are:

- a – pistons
- b – stamper
- c – punch
- d – blank holder

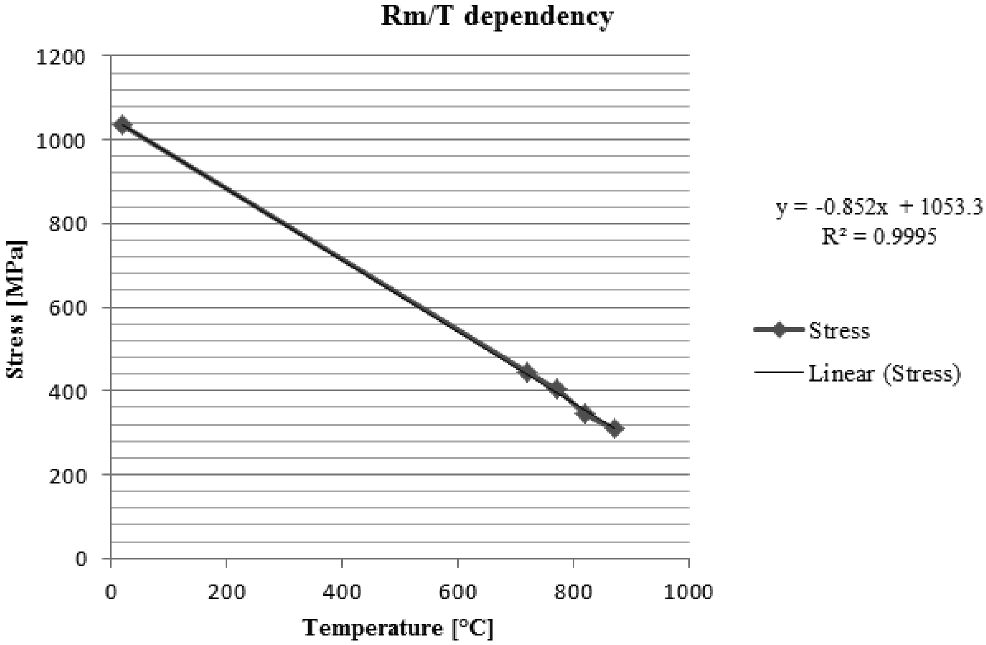

Fig. 1 Graph of Rm/T dependency of molybdenum

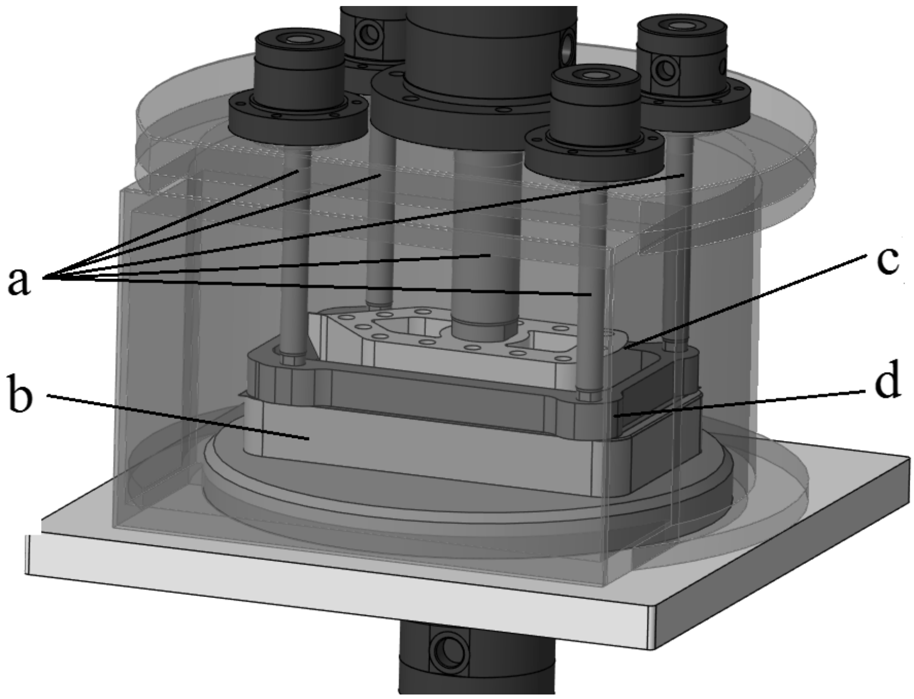

Fig. 2 Structure of working part of mechatronic system

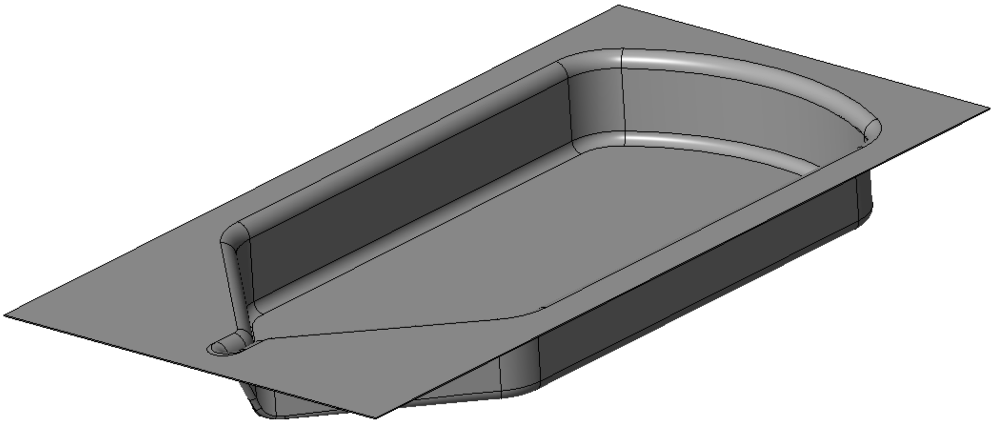

Fig. 3 3D CAD model of molybdenum sheet shaped into the finally form

Picture number 3 shows finally shape of the product. Next very necessary step in design on this mechatronic system is thermal simulation of components which are the part of working process. The most thermally stressed parts of device are punch and stamper. Simulation starts with basic models of components. Whole evolution of components shapes is possible to see on next picture.

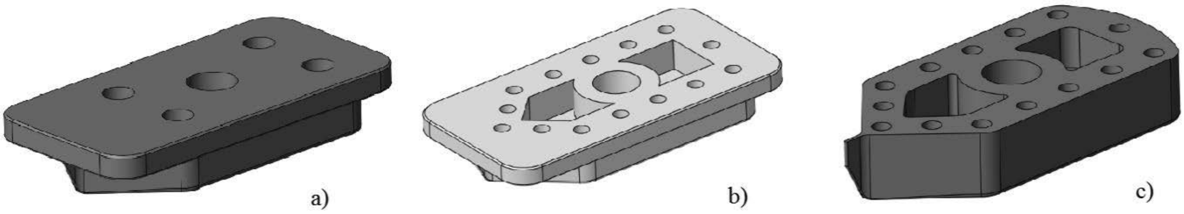

Fig. 4 Changes of shape and mass of punch

Process of optimization of punch and stamper was based on lightening of component (Fig. 4). The very first model of punch (a) was made only with drilled holes for piston and four heaters. The second model (b) has drilled more holes and also milled two more holes near the central area of unloaded part of component and at the end third model of punch was milled and drilled such like second one, but edges of punch was also removed.

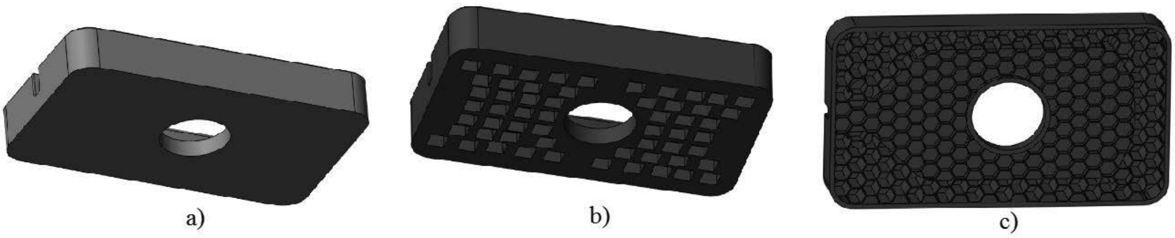

Fig. 5 Changes of structure of stamper

By lighten of stamper, other principle was used (Fig. 5). First model (a) was only a solid geometry without some structure. The second model (b) was lightening by using a simply pattern of square shaped holes. The last model (c) of stamper was made as a shell which is reinforced by honeycomb structure. This structure is light and sufficiently strong in one axis of strain.

RESULTS AND DISCUSSION

Process and results of simulations

This part of paper describes transient thermal simulations. In this case was there a four simulations in which every fall had a different configuration of stamper and punch. The aim of those calculations was an influence of mass loss of working component of the pre-process temperature of molybdenum sheet. All components was during the simulation in heating position, which means that blank holder, stamper and punch was in the contact with an undistorted plate of molybdenum sheet. Heating power was specified on $6000W.s^{-1}$ and duration of simulation was 1800s.

Of course all components near the source of heat was influenced by high temperatures, but for deep drawing process more is important the temperature of forming material. That is, why in the following results, temperatures of components are ignored.

On the Fig.6 we can see a result of simulations. Each simulation had the same heating power and duration. On Y-axis represents the temperature of material and on X-axis time of simulation. For the first simulation were used punch and stamper the both in the a) variants. Maximal temperature of molybdenum sheet on the end of the simulation was 322.59°C. This temperature was then set as the reference temperature. The gradient of temperature is shown on upper left side of Fig. 6.

Second simulation was made with punch of b) type, with a) stamper. Result of simulation – upper left side of the same picture, 272,54°C. Althought the mass of the working components was lower then in first simulation, finally temperature was lower then before. That was caused by different pattern of sources of heat, which ca be considered as a mistake in simulation process.

Third simulation represents b) type punch and b) type stamper. Pattern of heating devices was returned to the first layout. That causes better comparative ability of results. The results of simulation, shows on the left bottom side of Fig.6, that the highest temperature of foming material before process is 358,74°C. Now is visible, that a mass loss brings a positive outcome.

In the last simulation was used c) model of punch with c) model of reinforced shell model of stamper.

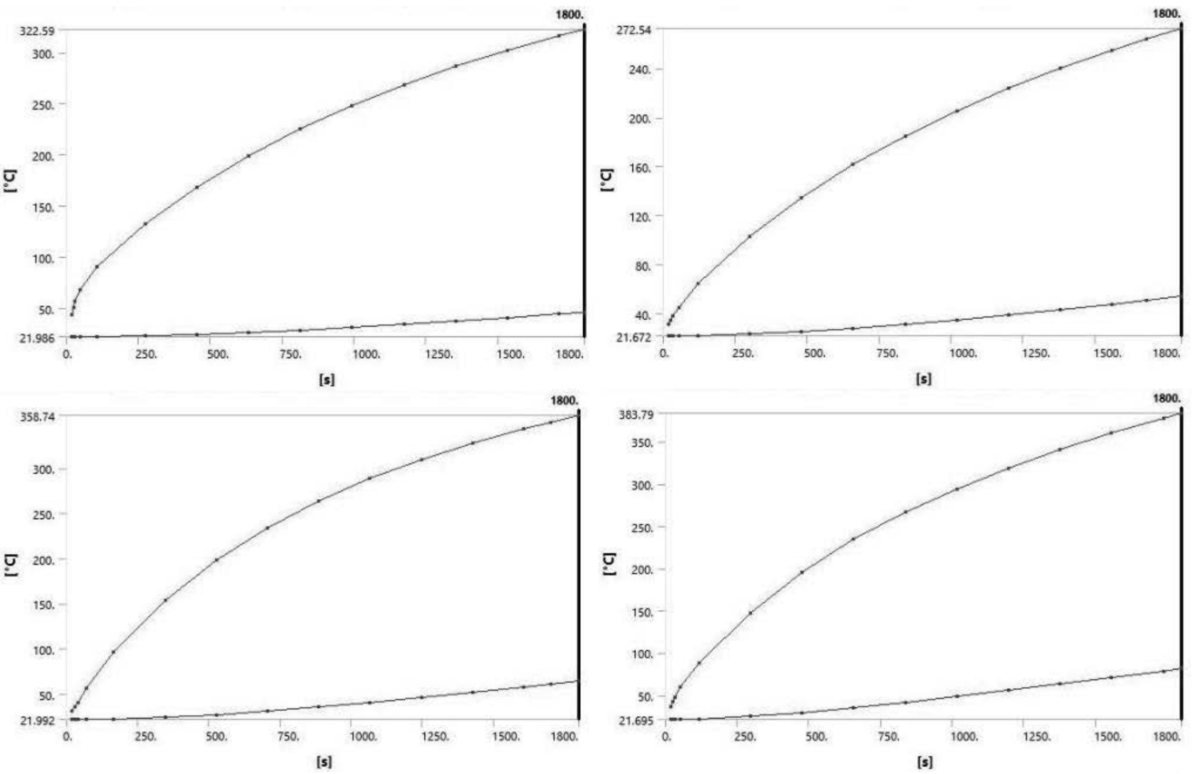

Fig. 6 Gradients of temperature in simulations

CONCLUSIONS

Universal method for transient thermal simulation of mechatronic system for deed drawing in extreme conditions was determined. The estimation can be based only on dimensions and type of working material. This procedure can be useful when the temperature of working material is specified and temperatures of working component are required.

ACKNOWLEDGMENT

This paper presents results of work supported by the Slovak Scientific Grant Agency of the Slovak Republic under the project No. VEGA 1/0077/15.

REFERENCES

1. Arab. N., Nazaryan E. A., Arakelyan M.: Investigation to production molybdenum container to growth single crystals by deep drawing process. International Journal of Mechanical and Materials Engineering (IJMME), Vol. 5 (2010), No. 1, 116-122.
2. Brumercik F., Brumercikova E., Bukova B.: Mechatronic and Transport System Simulation. Applied mechanics and materials, Vol. 803 (2015), pp. 201-206.
3. Faturik L., Trsko L., Hrcek S., Bokuvka O.: Comparison of structural design in high and ultra-high cycle fatigue regions. Transactions of FAMENA, Vol. 38, No. 4 (2014), pp. 1-12.
4. Cheng J., Nemat-Nasser S., Guo W.: A unified constitutive model for strain-rate and temperature dependent behavior of molybdenum. Mechanics of materials 33 (2001) 603-616.
5. Kołtunowicz T. N., Zukowski P., Sidorenko J., Bayev V., Fedotova J. A., Opielak M., Marczuk A.: Ferromagnetic resonance spectroscopy of CoFeZr-Al2O3 granular films containing “FeCo core – oxide shell” nanoparticles. Journal of Magnetism and Magnetic Materials, 421 (2017) 98–102.
6. Krolczyk G. M., Nieslony P., Krolczyk J. B., Samardzic I., legutko S., Hloch S., Barrans S., Maruda R. W.: Influence of argon pollution on the weld surface morphology. Measurement 70 (2015) 203-213.
7. Krolczyk J. B., Gapinski B., Krolczyk G. M., Samardzic I., Maruda R. W., Soucek K., Legutko S., Nieslony P., Javadi Y., Stas L.: Topographic inspection as a method of weld joint diagnostic. Technical Gazette 23, 1(2016), 301-306.
8. Martikan, M., Brumercik F., Bastovansky R.: Development of Mechatronic Deformation System. Applied mechanics and materials, Vol. 803 (2015), pp. 173-178.
9. Meng B., Wan M., Wu X., Zhou Y, Chang Ch.: Constitutive modeling for high-temperature tensile deformation behavior of pure molybdenum considering strain effects. journal of refractory metals and hard materials 45 (2014) 41-47.
10. Meng B., Wan M., Wu X., Zhou Y.: Development of thermal deep drawing system with vacuum environment for difficult-to-deformation materials. Trans. Nonferrous Met. Soc. China. 22 (2012), pp. 254−260.
11. Meng B., Fu W. M., Wan M.: Drawability and frictional behavior of pure molybdenum sheet in deep-drawing process at elevated temperature. Journal of advanced manufacturing technology, 78 (2015) 1005-1014.
12. Rudawska A.: Influence of the thickness of joined elements on lap length of aluminium alloy sheet bonded joints. Advances in Science and Technology Research Journal, Volume 9, No. 27, 2015, 35–44.
13. Sawicki B., Miaskowski A.: Nonlinear higher-order transient solver for magnetic fluid hyperthermia. Journal of Computational and Applied Mathematics, 270 (2014) 143–151.
14. Swić, A., Draczew, A., Gola, A.: Technology of heat treating-straightening of long shafts with low rigidity. Advances in science and technology-research journal 2016, Vol. 10 Is. 31 pp. 207-214
15. Swić, A., Draczew, A., Gola, A.: Method of achieving accuracy of thermo-mechanical treatment of low-rigidity shafts. Advances in science and technology-research journal, 2016 Vol. 10 Is. 29 pp. 62-70.
16. Walczak M., Pieniak D., Zwierzchowski M. The tribological characteristics of SiC particle reinforced aluminium composites. Archives of Civil and Mechanical Engineering, 15(1), 2015, 116–123.
17. Walczak M., Zwierzchowski M., Bieniaś J., Caban J.: The tribological characteristics of

Al-Si/graphite composite. Tribologia 1/2017, pp. 97–104.
18. Zmindak, M., Donic, T., Jurik, P.: Numerical simulation of rectangular deep draw containers made from thin molybdenum sheet. IOP conference series: Materials science and engineering. 159 (2016) [8] pp.

Corresponding author:
Ing. Michal Tropp, Univerzity of Žilina, Faculty of Mechanical Engineering, Department of Design and Mechanical Elements, Univerzitná 1,Žilina 010 26, Slovakia, e-mail: michal.tropp@fstroj.uniza.sk