Heat distribution in the deep drawing device components working by high temperatures

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Abstract. The subject of the article is a simulation of heat affected components of a device for deep drawing by extreme conditions in vacuum by high temperatures required for forming of crystallization containers made from thin molybdenum sheets. The simulation is focused on the distribution of heat in particular components in relation with their shape. There are presented the design of working components and the boundary conditions of transient thermal simulations with the results.

1. Introduction
The improvement of the optical and laser single crystals production technology from the melt of leucosapphire and yttria-allumina garnet (YAG) largely determines the success of the most important directions in the development of microelectronics, energy, optoelectronic and laser technology. The range of positive properties of sapphire monocrystalline is very wide - generation, amplification and transmission of electromagnetic waves. Such widespread use of single crystal sapphires is possible due to their unique properties - high optical uniformity and clarity in a wide range of light wavelengths, radiation resistance and also high mechanical, thermal and dielectric properties [1].

The technology of crystal growth with the horizontal single crystal sapphire crystallization method (also called as the Bagdasarov method) is based on putting the crystal seed into the front of a crucible resistant to temperatures up to 2150°C, which is commonly produced from molybdenum sheets. The production technology of such special container made from thin molybdenum sheet is the key to the productive exploitation of horizontal crystallization systems in the engineering practice [2].

The subject of this article is an introduction of the concept of a device for deep drawing in extreme conditions represented by drawing process of such molybdenum containers in vacuum by high temperatures [3, 4]. The article deals with description of possible variants of the key drawing mechanism components and their functional changes. The paper describes also results of the thermal simulations of the selected drawing device components.

2. Molybdenum drawing temperature
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 depends on the choice of the deformed material and also on the
links between the forming tools, mechanism of plastic deformation and the device used to control the flow of material during the process. The pressure, shape and height of the punch and die, forming speed, lubrication, blank holder force, blank holder gap and material have the biggest influence on working process [5].

For a correct process of deep drawing of molybdenum sheet, the higher temperature of formed material is required, due the bad ductility of molybdenum in temperatures near the 20°C. During the drawing process, the formed material needs to be warmed to the temperature range from 200°C to 300°C.

Figure 1 shows, why such high forming temperatures are required. At the room temperature, the strength of molybdenum is 1035MPa, while by 200°C the strength value is approx. 880MPa and by 300°C the strength of molybdenum is only 800MPa. The ductility of the material raises from 3% by 20°C to 12% by 300°C [6].

![Figure 1. Graph of Rm/T dependency of molybdenum.](image.png)

3. Simulation model description
The transient thermal analysis is useful tool for machine design. This procedure can be helpful with determination of the process boundary conditions (mainly the heat flow, because the heat conduction and the radiation are the material properties) and also by the simulation of thermal stresses in the developed or analyzed drawing device structure [7 - 9].

The simulations goals can be divided in two groups. The first goal of the simulations is to observe the blank temperature after the pre-heating process performed before the drawing and also the dependence between the drawing parts shapes and the final blank temperature value.

The second goal of the simulation is to observe the drawing device parts temperatures after the pre-heating of the blank. These results verify the choice of the material of the main device working components to resist the temperatures generated by the pre-heating of the molybdenum blank.

This part of paper deals with design of chosen part of the drawing device. Figure 2 shows the structure of the working part of the device. The transparent part on picture is a vacuum chamber, which is required due the poor oxidation resistance of molybdenum by temperatures higher than 300°C [4, 5].

Next components are:
- a – pistons
- b – stamper
- c – punch
- d – blank holder
4. Transient thermal simulations of the blank

Figure 3 shows the final shape of the product – a crystallization container made from molybdenum blank. A very important step by design process of this mechatronic system is a thermal simulation of the components, which are taking part by the working process [6, 7]. The most thermally stressed parts of the device are the punch and the die, so the simulation started by modeling these components variants. The process of the components shapes evolution is shown in Figures 4 and 5. The process of the optimization of the punch and die was based on lightening of the components.

The very first model of the punch (Figure 4a) was made only with drilled holes for the piston and four heaters. The second model (Figure 4b) has more holes drilled and also milled two more holes near the central area of the unloaded part of the component. The third generation of the punch (Figure 4c) model was milled and drilled like the second one, but edges of the punch were removed.

By lightening of the die, another principle was used. The first model (Figure 5a) was only a solid geometry without some internal structure. The second model (Figure 5b) was lighted by using a simply pattern of square shaped holes. The last model (Figure 5c) of the die was made as a shell which is reinforced by the honeycomb structure. This structure is light and sufficiently strong in one axis of strain.

Four simulations with different configuration of the die and punch were performed. The aim of those calculations was to observe the influence of the working components mass loss to the initial pre-process temperature of the molybdenum sheet. All components were during the simulation in the heating position - that means, the blank holder, the die and the punch were in the contact with an
undeformed blank of molybdenum sheet. The heating power was specified overall to 6000W.s⁻¹ and the duration of the simulations was set to 30 min (1800 s).

All components located near the source of the heat were influenced by high temperatures. Figure 6 shows according the first simulation goal only the molybdenum blank temperature rise by the pre-heating process.

![Figure 6. Gradients of the molybdenum blank temperature during simulations.](image)

5. Transient thermal simulation of the device components

The simulation of the device working components temperature field requires the whole assembly of the device parts including pistons, working components and vacuum chamber. Working components of the third generation with the honeycomb structure described above were used. This simulation can help by choosing process of the vacuum sealing type, which needs to be located in vacuum chamber joint and places, where the moving parts and the chamber are meeting.

![Figure 7. Complete device model.](image)

![Figure 8. Middle cross-section of the model.](image)

Boundary conditions for the final blank temperature simulation and also the device components temperature field simulation remained the same.

Figure 9 shows the results of the second simulation – the thermal simulation of the complete drawing device with all working components and vacuum chamber. It is clearly visible, that the heat...
transfer between the heated components and the vacuum chamber walls is so small, that the chamber do not need any additional cooling system because the temperatures at the chamber body remain close to the ambient temperature (20°C).

6. Conclusion
By the first simulation the punch and the die the a) variants (Figure 4 and 5) were used. Maximal temperature of the molybdenum sheet at the end of the simulation was 322.59°C. This temperature was then set as the reference temperature. The gradient of the temperature is shown on upper left side of Figure 6.

The second simulation was performed using the punch of b) type and the a) type die. The final temperature of 272.54°C after 1800 s was observed – upper left side of the Figure 6. Although the mass of the working components was lower then in the first simulation, the finally temperature was lower then by the first one combination. That was caused by different pattern of the heat sources, which can be considered as a mistake in the simulation process.

The third simulation used the b) type punch and b) type die. The pattern of the heating devices was returned to the first layout. That causes better comparative ability of results shown at the left bottom part in Figure 6. The highest temperature of the molybdenum blank before the drawing process reached 358.74°C. Now it is visible, that a mass loss of the drawing device parts leads to the highest blank temperature.

The last simulation used the c) type model of the punch with c) type model of a reinforced shell model of the die. The temperature of the molybdenum blank before the drawing process rised to 383.79°C, which can be seen in right bottom part of Figure 6.

The transient thermal simulation of the device components gives the answer to the question, which type of vacuum chamber sealings should be used. The locations of the sealings are marked with red arrows in the Figure 9. The sealings have to resist the temperature about 60°C. Sealing heat resistance temperature with the security coefficient of 2 has then the value of 120°C. The reason of the security coefficient value choice is the fact, that if the sealing fails, the vacuum in the chamber is released and the molybdenum blank will be damaged due its oxidation.

Acknowledgments
This study was supported by Cultural and Educational Grant Agency MŠVVaŠ under the contract no. 046ŽU-4/2018
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