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MATHEMATICAL MODELING AND DEVELOPMENT OF A GRAPHICAL INTERFACE (GUI) FOR SIMULATING THE ORBITAL FORGING PROCESS

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ABSTRACT

The main objective of this work was to develop a theoretical and practical tool for understanding and simulating the orbital forging process, using mathematical modeling and GUI-based graphical interfaces developed with MATLAB. This interface represents a link between theoretical analysis and practical applicability.

KEYWORDS: orbital forging, mathematical modeling, interpolation, graphical interface

1. Introduction

In the field of metal working by plastic deformation, current trends are moving towards processing methods with minimal metal and energy consumption, in particular, cold plastic deformation. A number of economic, technical and organizational considerations argue in favour of cold plastic deformation. However, in cold plastic deformation processes, high forces are required, due to the resistance of the material in the cold state, as a result of work hardening during deformation and friction on the contact surfaces between the material and the tools. These have limited the industrial use of cold working [1].

The reconsideration of conventional cold forming presses led to the adoption of different kinematics, more complex tool movements, and a focus on parts of a specific shape [1, 2].

The orbital forging process is based on the fact that the axial force acting to deform a metallic material is considerably reduced if, in the area where the tools act, the contact surface between the tools and the semi-finished product is reduced, so the pressure exerted during pressing is not applied to the entire surface of the semi-finished product, but only to an area of it, which represents approximately 20-30% of the related frontal surface [3, 4].

The terminology used in the specialized literature to define this process varies from one country to another: thus, in Great Britain the term "rotary forging" and "rocking die" are used, in the USA the process is called "orbital forging", and in Russia "stampovka obkatîvaniem" and "tsartsovoi prokatka" (a process similar in principle and developed especially in this country) [1, 4].

Mathematical modeling is the process of formulating an abstract model in terms of mathematical language to describe the complex behavior of a real system. Mathematical models are quantitative models and are often expressed in terms of ordinary differential equations and partial differential equations. Mathematical models can also be statistical models, fuzzy logic models, and empirical relationships. In fact, any description of a model that uses mathematical language can be called a mathematical model [5].

Mathematical modeling is a principled activity that has principles behind it and methods that can be successfully applied. Principles can be general principles or meta-principles formulated as questions about the intentions and goals of mathematical modeling [6].

A system of interactive visual components for a computer or system software is called a GUI (graphical user interface). GUI is the interface that uses graphical elements to allow people to interact with electronic devices, including computers, laptops, tablets, and smartphones, as required [7, 8]. In terms of human-computer interaction systems or technology, it is a very important component of software application programming, as it replaces actions with text-based commands in the system. Whether it is a text file, an object, an image, or a

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video, GUI displays all types of necessary content that a user can imagine in the system [9-11].

2. Experimental conditions

In the experiments carried out on the orbital forging machine, we used lead specimens, with dimensions Ø 15 x 40 mm.

Of the total length, 10 mm constitutes the part fixed in the mould, and the remaining 20 mm is the free end, subject to deformation.

The lead specimens were deformed with reductions per rotation, of 1 mm, 2 mm, and 3 mm.

Both the height after deformation and the characteristic diameters, D_1, D_2 and D_3, were measured (Figure 1).

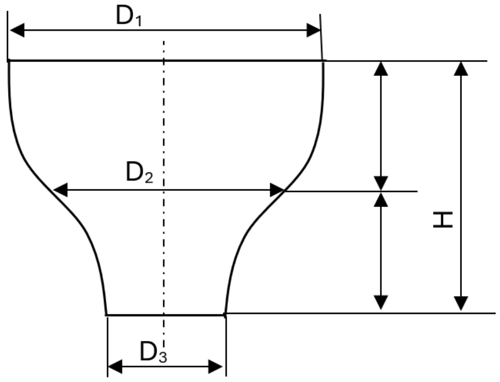

Fig. 1. *Characteristic dimensions of the part: D_1 - diameter measured at the interface of the blank - forming tool; D_2 - diameter measured at the middle of the height of the blank; D_3 - diameter measured at the base of the blank; H - Height of the blank*

The measurement results were listed in Tables 1, 2, 3.

Table 1. *Specific diameters for 1 mm/revolution reduction*

Nr. crt.	Do	Ho	D_1	D_2	D_3
1	15	30	15	15	15
2	15	30	18	16	15.5
3	15	30	23	18	17
4	15	30	30	23	20
5	15	30	40	30	25

Based on these measured data, the mathematical model equations for the experimental orbital forging were developed.

Table 2. *Specific diameters for 2 mm/revolution reduction*

Nr. crt.	Do	Ho	D_1	D_2	D_3
1	15	30	15	15	15
2	15	30	17	16.5	15
3	15	30	22	20	19
4	15	30	28	25	24
5	15	30	38	33	30

Table 3. *Specific diameters for 3 mm/revolution reduction*

Nr. crt.	Do	Ho	D_1	D_2	D_3
1	15	30	15	15	15
2	15	30	17	16.5	15
3	15	30	21	20	19
4	15	30	27	25	24
5	15	30	35	33	30

Independent parameters of the orbital forging process were considered:

- x_1 is the current height;
- x_2 is the pressing speed.

The dependent process parameters are D_1, D_2, D_3.

- D_1 represents the diameter measured at the interface of the blank and the deformation tool;
- D_2 represents the diameter measured at the middle of the height of the blank;
- D_3 represents the diameter measured at the base of the blank;

The mathematical model equations obtained for D_1, D_2, D_3 are

$$D_1 = 56.25 - 1.375 * x_1 - 3.75 * x_2 + 0.125 * x_1 * x_2$$
$$D_2 = 27.5 - 0.45 * x_1 - 4.5 * x_2 + 0.15 * x_1 * x_2$$
$$D_3 = 26.25 - 0.375 * x_1 - 3.75 * x_2 + 0.125 * x_1 * x_2$$

3. Creating a graphical interface in MatLab

MatLab is a program that works with numerical data represented by fields or matrices.

To create this GUI in MatLab, we used the "uimenu" and "uicontrol" functions for elements of the "slider", "button" and "display fields" types, which help us create a GUI in which we can modify the input parameters of the process without modifying the source code each time [12].

The graphical representations were made using the "plot", "plot3" and "surf" functions, for the 2D and 3D visualization of the diameter variation depending on the deformation height [12, 13].

As an example, Figure 2 is a schematic representation of the orbital forging process and this

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image is an integral part of the graphical interface created.

The interpolated values were calculated using the "interp1" function, and the differences from the modeled values were displayed in real time. Interactivity was ensured by using callbacks associated with each control element.

To create an interface in MatLab, we used measured data obtained from the orbital forging experiment as well as the mathematical model equations for the 3 diameters D_1, D_2, D_3.

In the case of this experiment, the input parameters are the pressing speed and the desired final height for the semi-finished product.

Three different pressing speeds were used, namely 1 mm, 2 mm, and 3 mm per rotation, and the initial height of the semi-finished product subjected to forging was 30 mm.

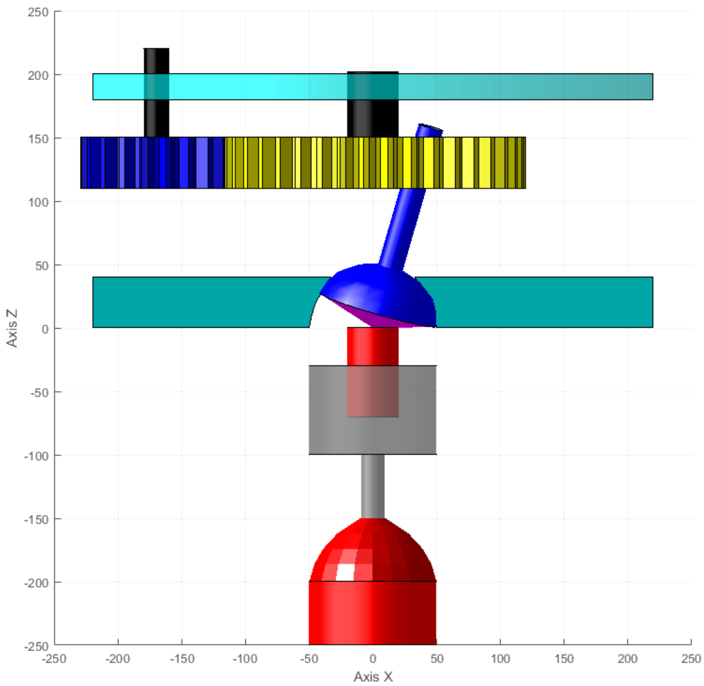

Fig. 2. *Schematic representation of the orbital forging process*

Figure 3 shows the calculated values for the specific dimensions D_1, D_2 and D_3 following a simulation of the orbital forging process, at a current height H = 29 mm. For each diameter, three types of values are displayed:

• Interpolated values - results from interpolation of experimental data, using the "spline (interp1(..., 'spline'))" method;

• Modeled values - calculated based on the process-specific regressive mathematical model (polynomial);

• Difference - represents the deviation between the interpolated and modeled value (Difference = Interpolated - Modeled).

SPECIFIC DIMENSIONS

	INTERPOLATED	MODEL	DIFFERENCE
D1 [mm] =	15.98	16.25	-0.27
D2 [mm] =	15.1744	15.75	-0.5756
D3 [mm] =	15.1744	15.5	-0.3256
	Hcurrent =	29	[mm]

Fig. 3. *Specific dimensions D_1, D_2 and D_3*

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Figure 4 illustrates the variation of the values for D_1, D_2, D_3 as a function of the semi-finished product height values, as obtained by simulation using the GUI graphical interface. This variation is the same as the variation of the measured values.

In Figure 5 we have an overview of the graphical interface created in MatLab that displays the results of the orbital forging process simulation (the values of the diameters D_1, D_2, D_3 obtained both by interpolation and by calculation using the equations of the mathematical model) for a semi-finished product height of 29 mm.

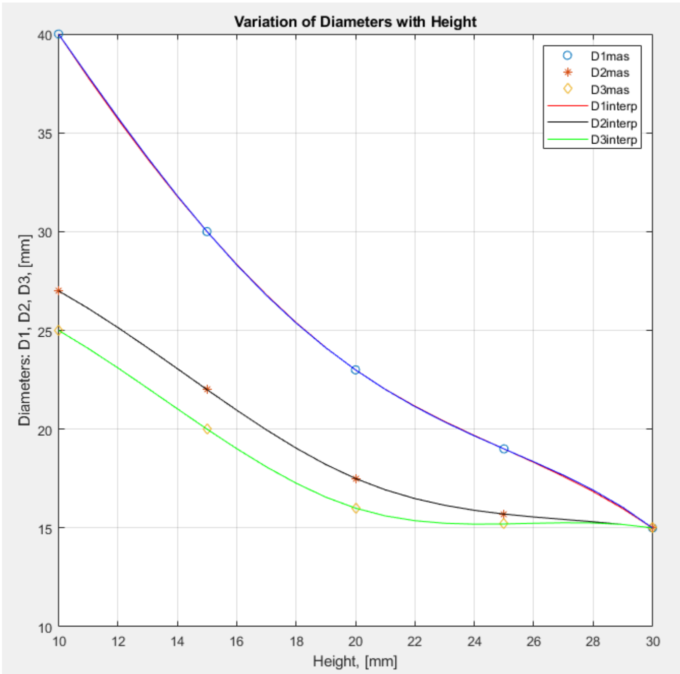

Fig. 4. *Variation of values for D_1, D_2, D_3 depending on the height values of the semi-finished product, values obtained through simulation using the GUI graphical interface*

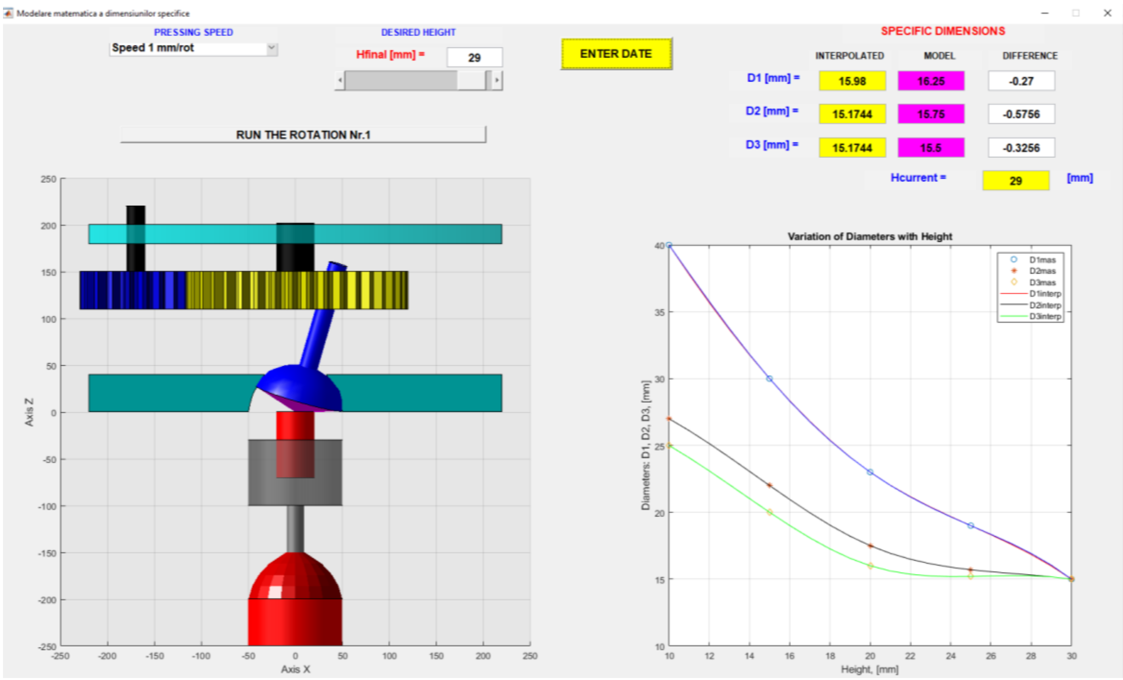

Fig. 5. *Overview of the graphical interface made in Matlab*

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4. Conclusions

The main objective of this paper was to develop a theoretical and practical tool for understanding and simulating the orbital forging process, using mathematical modeling and GUI graphical interfaces. This integrated approach reflects the current trend of modern engineering, in which numerical analysis, simulation and visual interaction become essential for optimizing technological processes and for making decisions in a fundamental way.

During the paper, a review of the main characteristics of the orbital forging process was carried out, highlighting the advantages it offers compared to conventional forging, such as: reducing deformation forces, improving the surface quality of the finished part, increasing tool durability and the possibility of cold and semi-hot processing of materials. At the same time, the complex nature of the kinematics of this process was emphasized.

In this context, mathematical modeling has proven to be an indispensable tool for describing and understanding the mechanical behavior of the semi-finished product during forging.

Another significant contribution of the work consists of the development of an interactive graphical interface in MatLab, which integrates the formulated mathematical models and allows the visual simulation of the orbital forging process. This interface represents a connecting point between theoretical analysis and practical applicability. Through it, the user can enter different input parameters and visualize in real time the effects of the changes, being able to interpret the results intuitively. The interface thus becomes not only an educational tool, but also one for industrial research and development.

In conclusion, the work reflects a relevant contribution in the field of simulation of plastic deformation processes, by combining theory with practical application in a coherent and applicable manner.

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