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Optimizing Shock Absorber Operation for Improved Hot Forging Efficiency

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Article presents a novel approach to addressing the challenge of forge-free filling of gas cylinder valve knobs in the context of the pneumatic shock absorber utilized within elevator systems. The shock absorber is a critical component responsible for ensuring accurate and efficient transportation of charge material to the electric inductor of automatic hot forging presses. Precise control of the shock absorber's operation is essential for maintaining proper system functionality and minimizing deficiencies. To investigate the system's response to changes in shock absorber operating parameters, the authors conducted a comprehensive simulation. The simulation results revealed that by identifying specific and optimal operational characteristics, the level of deficiencies can be significantly reduced. These findings offer valuable insights into system behavior, facilitating the optimization of shock absorber operation and overall improvement of the hot forging process. Implementation of the optimized shock absorber operation based on the simulation outcomes can enhance productivity, cost-efficiency, and quality in the hot forging industry.

Keywords: die forging, forging defects, differential equations, computer algebra system, computer simulations

1 Introduction

Metal forming, but in particular the various forging methods, is one of the oldest and most widespread ways of manufacturing metal products. It would seem that this makes forging so well-known and described. However, in an ever-changing economic environment, the market places ever new and increased demands on forging manufacturers, primarily in terms of the price at which they offer their products, as well as their quality.

Production of various types of semi-finished and forged products, despite the changes in the global economy and the rapid development of technology, is still widely used, in the context of many products, it is an irreplaceable and still prospective field related to the processing of metallic materials [1-2]. Technologies related to forging are still one of the most effective and often, if only because of the cost, the preferred methods of manufacturing parts and elements for very different applications.

Considering the concept of metal forming, it is impossible not to mention about one of the characteristic properties of metals and alloys - plasticity, thanks to which, under the action of external forces, they have the ability to permanently deform without disturbing the cohesion of the material. Pressure is exerted on the object with the initial shape by means of a properly selected tool, which causes displacement of the elementary volumes of this object, and consequently the formation of a new, desired final shape.

Depending on the temperature, hot and cold plastic working is distinguished. In the case of hot working, the process is above the recrystallization temperature. Heating the initial object is aimed at lowering its yield point, which reduces the forces needed to shape it. In turn, as a result of cold working, when the process runs below the recrystallization temperature, the mechanical properties of the material, such as strength or hardness, are improved. According to various forecasts, the forging market is expected to grow by around 40% by 2029.

The advantages of modern plastic forming include [3-6]:

- Obtaining final products whose dimensions correspond to the finished product or require minor machining operations,
- High degree of material use, minimizing waste, which reduces production costs and protects the natural environment,

- The possibility of obtaining products of complex shapes,
- High efficiency of the process, which translates into a relatively low unit cost (assuming large-scale or mass production),
- Ease of automating the work of machines and devices.

The main disadvantage of this type of technology is the significant cost of forging tools and equipment.

In the past, the authors dealt with the modeling and computing of mechanical systems in a number of other scientific works, which helped in solving this work [7-10].

2 Description of the engineering problem - non-forged filling of the knob for propane-butane gas cylinders valve

The forging process, as one of the oldest methods of shaping metal products invented by man, is relatively well known and widely described in the available literature, yet it is still considered a prospective process [11-13]. Particular expectations are related to the further development of die forging, including fine forging, where the technology used allows for reducing the weight of the input material or obtaining products with a high accuracy class. Thanks to this, it becomes possible to minimize the final machining or completely eliminate it [14-15].

Matrix forging is widely used in the case of serial and mass production of machine and device components.
It consists in exerting pressure on the metal located between two cooperating die halves. The flow of plastically deformable metal is limited by the die surfaces, which ensures obtaining the desired shape of the forging.

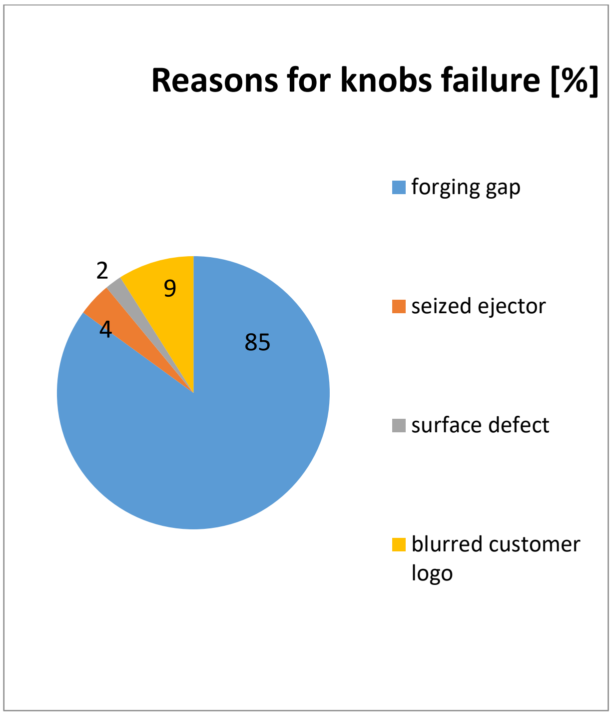
Fig. 1 *Forging gap of the gas valve knob - view of the top surface*

In the analyzed case, the non-forged filling of the gas cylinder valve knob (Figure 1 and Figure 2) is a quality defect that disqualifies it as a product compliant with the assumed requirements and makes it impossible to use it at a later stage of production.

Fig. 2 *Forging gap of the gas valve knob - view of the side surface*

The lack of forging fill of the knob is the reason for its classified as a deficiency. Due to the fact that the forging process is carried out in an automatic station (Figure 3), which is not constantly supervised by an employee, and defective pieces appear irregularly, it is possible that the forging worker at the end of the shift will release the batch for further processing without catching inconsistent details. Damaged knobs begin to be successively eliminated at further stages of production, until the last assembly operation, where a thorough selection takes place (the introduction of a vision system for the analysis of this type of errors was abandoned due to high costs). The selection takes time (approx. 20 - 30 minutes on each production shift) and thus reduces the efficiency of the process, and in the case of assembling a knob with a defect, it is the reason for the final shortage of the finished valve (increased costs). In addition, due to the scale of the phenomenon, which is difficult to predict, it will happen that in the case of short series of dedicated knobs (customer's logo on the front surface), there are not enough components to complete the entire order, which results in delays in deliveries (up to 30 days) and the need to restarting an additional batch of products on a press that is also intended for the production of other products, and therefore its availability is limited.

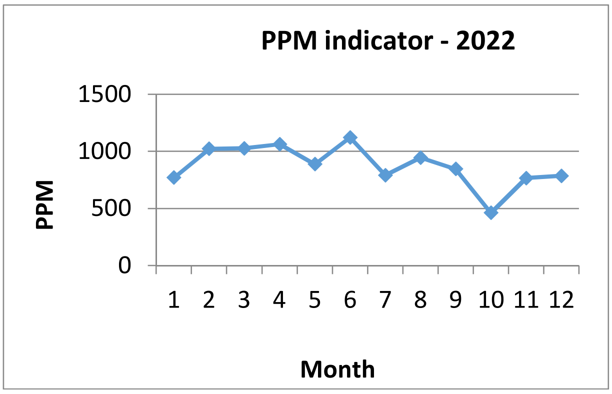
Fig. 3 *Automatic hot forging station equipped with a Mecolpress press with a pressing force of 200T*



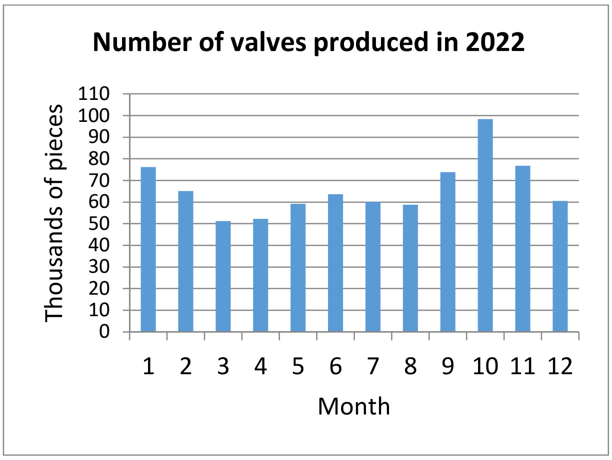
Graph 1 *Gas valve knob – failure reasons*

The analysis of the current state shows that the lack of forging filling of the gas valve knob is the main reason for its failure (Graph 1). In turn, the scale of the problem can be presented by comparing the monthly production for this type of assortment in 2022 (Graph 2) together with the PPM indicator (Graph 3).

In order to diagnose what may be the reason for the irregular appearance of the knob infill during the hot stamping operation, an analysis of the entire process was carried out using the 5 x why method, the results of which are presented in Figure 4.



Graph 2 *Number of gas cylinder valves produced in 2022, detailing individual months*



Graph 3 *Number of failure knobs per million gas valves produced in 2022, detailing individual months*

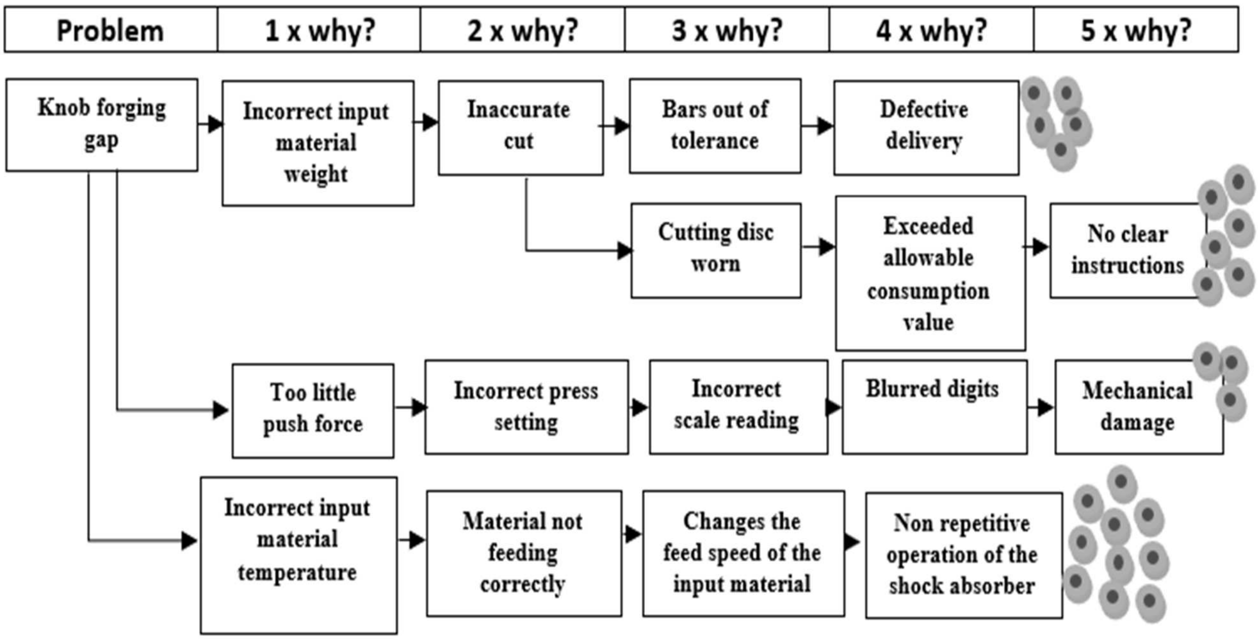


Fig. 4 *A series of questions in the 5 x why? method along with an indication of the potential cause of the forging gaps in the knob*

Fig. 5 *General view of the system transporting the preforms to the exciter*

The obtained results (most indications) direct further analyzes towards observation of the operation of the pneumatic shock absorber mounted in the elevator system, transporting the input material to the electric inductor of the automatic hot forging press (Figure 5 and Figure 6).

Fig. 6 *Pneumatic shock absorber - view of the working wheel*

3 Pneumatic shock absorber model

The considered shock absorber, used in elevator system, can be modeled as a parallel connection of a damper with a damping coefficient b and a spring with a spring coefficient k [16]. The spring represents the elastic element following Hooke's law that stores potential energy [17] where damper represents the damping element of the shock absorber that dissipates energy, typically as heat [18]. Representation of the pneumatic shock absorber mounted in the elevator system, with a fixed wheel of mass m, is shown in Figure 7. Parallel connection of mentioned elements implies that they share the same displacement, therefore, the total force of the shock absorber is the sum of the spring force described with equation:

$$F_{spring} = k * y(t), \quad (1)$$

And the damping force with given equation:

$$F_{damper} = b * y'(t), \quad (2)$$

Where:
k…Spring coefficient [N/m],
b…Damping coefficient [kg/s].

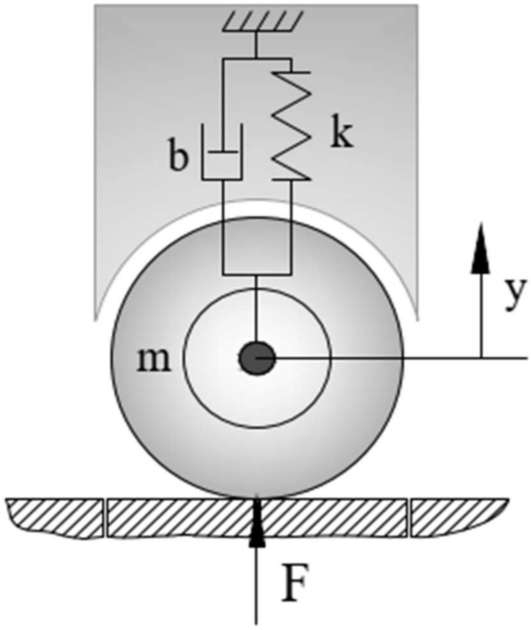


Fig. 7 *Schematic representation of the shock absorber system*

Presented model is a simplification and does not capture all the details of a real shock absorber, such as the non-linear behavior at large displacements. In tested scenario this phenomenon was neglected due to the limited stroke of the absorber. It was assumed that the input signal of this system is the ground reaction force *F(t)*, on which the wheel rolls (reduced by the weight of the object). The vertical displacement of the wheel *y(t)* relative to the equilibrium position was assumed as the output signal.

The process of modeling commenced with the formulation of the general system's dynamics equation:

$$m\frac{d^2y(t)}{dt^2} + b\frac{dy(t)}{dt} + ky(t) = F(t), \quad (3)$$

This is a second-order linear differential equation whose solution is the vertical displacement of the wheel y(t). Assuming zero initial conditions (y(0) = 0 m and y(0) = 0 m s-1), the equation was transformed into the operator domain:

$$Y(s)(ms^2 + bs + k) = F(s), \quad (4)$$

Where Y(s), F(s) are the Laplace transforms of the input and output signals. Using simple algebraic transformations, the following form of the operator transfer function was obtained:

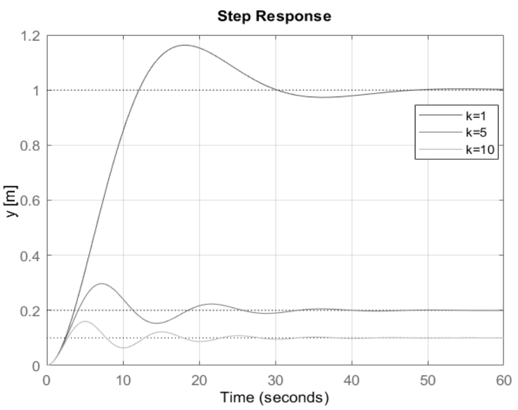
$$G_3(s) = \frac{Y(s)}{F(s)} = \frac{1}{ms^2+bs+k}. \quad (5)$$

The considered model is an example of an oscillating object.

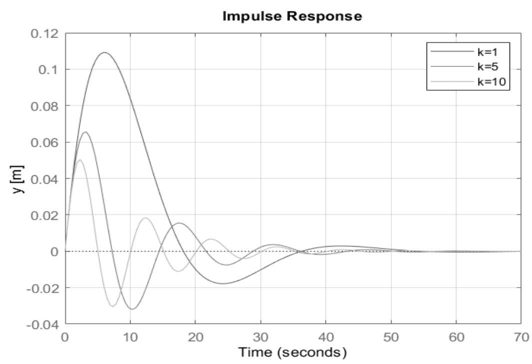
Model of the pneumatic shock absorber described with equation (5) was implemented using the function tf() in MATLAB version: 9.14.0 (R2023a) environment. Simulations of the system were performed in response to step excitation and impulse excitation, for the assumed parameters k = {1, 5, 10} Nm-1, b = 5 kgs-1, m = 5 kg. Listing of used code is presented below:

```
m=5; %declaration of weight in kg
b=5; %declaration of damping factor kg/s
k=[1 5 10]; %declaration of spring coefficients N/m

%below the simulation of response to step input
for i=1:3 %start of for loop
   G3=tf([1], [m b k(i)]); % create a transfer function with given parameters
   step(G3) %giving forcing signal
   hold on %turns on the command that allows to plot several waveforms in one window
end %end of for loop
ylabel('y [m]') %Y axis description
legend('k=1', 'k=5', 'k=10') %create a legend
grid on % enable grid
hold off %disables the command that allows to plot several waveforms in one window
figure %open a new window for the chart

%below the simulation of response to impulse excitation
for i=1:3 %start of for loop
   G3=tf([1], [m b k(i)]) % create a transfer function with given parameters
   impulse(G3) %giving forcing signal
   hold on %turns on the command that allows to plot several waveforms in one window
end %end of for loop
ylabel('y [m]') %Y axis description
legend('k=1', 'k=5', 'k=10') %create a legend
grid on % enable track
hold off %disables the command that allows to plot several waveforms in one window
```

***Fig. 8** Listing of used code*



***Graph 4** System response to step excitation*



***Graph 5** System response to impulse excitation*

Thanks to the simulation, a graphical representation of the step excitation system (Graph 4) as well as impulse excitation (Graph 5) was obtained.

4 Conclusions

The research has shown that the operation of the pneumatic shock absorber in the elevator system transporting the input material to the exciter is one of the key elements of the indicated process flow of the hot forging process. The correct and, above all, constant speed of the input material during its heating with the use of eddy currents during its passage through the entire length of the inductor determines its appropriate temperature necessary for effective die stamping, which will result in a properly filled gas valve knob. The appropriate speed is ensured by a wheel mounted on a pneumatic shock absorber. Too fast passage of the batch material through the inductor, and thus too short residence time of the material inside it, causes failure to reach the process temperature, which is the cause of defects. With the help of the simulations, it is possible to check the reaction of the entire system to a change in the operating parameters of the shock absorber, and thus to determine specific and correct characteristics for its operation. The simulations conducted in the study have shown that these characteristics can be determined and implemented to eliminate the problem of forge failure, and subsequently, reduce the level of shortages. This research contributes to the understanding and improvement of the hot forging process, with significant implications for the production of machine and device components.

Modern die forging methods use advanced technology and computer simulations to optimize the process and improve efficiency. This has led to increased precision, reduced material waste, and the ability to produce complex shapes with tight tolerances. Overall, die forging remains a vital and growing field in the manufacturing industry, playing a critical role in the production of high-quality, high-performance components. Further research could focus on developing more advanced control systems that integrate real-time monitoring and feedback mechanisms to adjust the shock absorber's operating parameters and inductor's temperature based on the input material's properties and the desired quality of the final product.

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