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Mahshid, Rasoul; Hansen, Hans Nørgaard; Arentoft, Mogens

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Towards mass production by high performance transfer press in micro bulk forming

Rasoul Mahshid[a,]*, Hans Nørgaard Hansen[a], Mogens Arentoft[b]

[a]Technical University of Denmark, Department of Mechanical Engineering, Building 427A, 2800 Kgs-Lyngby,Denmark
[b]IPU, Productionstorvet, Building 425, 2800 Kgs-Lyngby, Denmark

Abstract

Multi-step micro bulk forming is characterized by complex processes and high precision requirements. Several process parameters influence on accuracy of micro forged parts where small tolerances in the order of few μm are in demand. The paper introduces a high performance transfer press for micro cold bulk forming. A methodology for selection of linear motors on the bases of the process parameters was obtained. In order to examine the effectiveness of the machine, specific geometry was investigated for production. Kinematic parameters were found for a production rate of 200 strokes per minute. A forged part with three different diameters in height was produced in a two-stage forming process using the introduced transfer press.

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Keywords: Micro cold forming; Press design; Transfer press

1. Introduction

When manufacturing miniaturized metallic components in mass production by multi-stage micro cold forming, one of the challenges is to have an appropriate production line with high speed and high precision. This need has been met primarily by principles used in conventional transfer presses. However, the new specifications apply for new requirements in forming machines.

* Corresponding author. Tel.: +45-4525-4891; fax: +45-4525-4870.
E-mail address: ramah@mek.dtu.dk

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Depending on the geometrical complexity in size and precision of the part, traditional machines can be costly and less efficient. In order to address these problems, a new high performance transfer press must be developed which allows manufacturing of micro parts with new requirements.

Traditionally, in a conventional transfer press, an eccentric shaft drives not only the main slide but also the transport device. If the same principle transfers for production of micro parts, several notable drawbacks are introduced due to the reduced overall size of the machine. These include small tolerances, increased complexity and higher function density of the mechanism. Overcoming these drawbacks usually significantly reduces the part cost associated with energy, cycle time and equipment.

In the early 2000s, researchers began investigations how to process parameters in micro forming. As this research has progressed it has been found that the automation and machine (production line) can influence significantly accuracy and quality of the forged part.

In 2001, Geiger et al. published a document addressing the scaling effects and solutions for tool manufacturing and explored general aspects and challenges in micro forming [1]. Moreover, they developed a cross transportation system which was able to transfer the cylindrical parts with diameter of 0.85 mm and positioning accuracy of 15 µm. The handling device worked with production speed of 260 strokes per minute. Wafios AG manufactured a machine for a multi-stage micro bulk forming which works on the basis of a rotary transfer system and horizontally rotor with eight dies [2]. This machine transfers cylindrical parts with diameter down to 0.5 mm and the output rate of 400 parts per minute. From studies conducted by Kuhfuss the properties of seven known presses in micro metal forming were explained [3].

2. Previous works

A high performance transfer press in micro forming pertains to transferring the workpieces throughout a multi-step former automatically. Cropping the billets, feeding the specimens, workpiece transport, press force and stroke control, part ejection and stacking of finished parts as well as monitoring and control of the entire transfer press are fully automatic in the machine. When the components are downscaled, new challenges are implied to all above mentioned operations. Recently, Roehlig investigated to apply small machines to fabricate small workpieces [4]. Therefore, the principle behind construction and design of a micro cold forming transfer press is to decrease the size of the machine by technologies not commonly found in current machines instead of only down-scaling approach. By doing so, less force and energy is required to fabricate micro parts and cost effectiveness increases. For this machine, the characterization of the products is specifically of interest to ensure the flow of operations as smooth as possible without strong vibration and impact noise. A second goal is to increase the maximum achievable production speed with quick start-up of the machine. Increasing this speed raise the profitability of the process. However, it has several potential drawbacks in terms of precision, such as higher errors due to the reduced cycle time and consequently increasing the acceleration.

Previous study indicated a micro forming press included a cropping tool for billet preparation, and a micro forming press with an integrated transfer system [5]. The gripping principle of transport device was fabricated on the basis of surface tension force. The handling device achieved maximum production rate of 50 strokes per minute. The concept implemented for micro billet cropping machine proved to be successful with respect to the volumetric deviation of the billet within a ±1% margin. However, the speed of production was slow for mass production of micro parts.

In previous study, when higher acceleration is applied to the carrier, the positioning accuracy is altered in static mode. It also is shown that the acceleration is directly proportional to the distance between die centers and production speed squared [6]. In following study, characterization of the handling system is performed on gripper unit consisted of the fingers and components [7]. In order to achieve high output rate, the gripper unit mechanism is manufactured while minimizing the weight.

In a recent study, a full description of the transfer precision inside the forming press was obtained [8]. This research involved a methodology for the analysis of the handling system in a static as well as dynamic mode. The positioning accuracy in dynamic mode leads to find the optimal controller parameters and perform a transfer study of the machine as shown in Fig. 1. It is important to note that the curve determines when the main slide must start the downward movement in order to minimize the cycle time and avoid collision in the system.

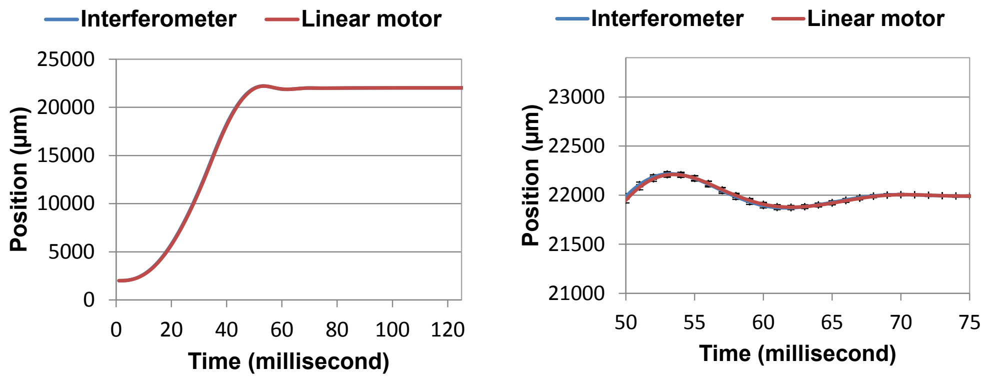


Fig. 1. Displacement-time curve connected to optimal controller parameters; Left: half-cycle time; Right: the region of concern. Error bars indicate ± 1 standard deviations [8].

In this research, a new development of high performance transfer press in micro cold forming was planned. For a transfer press, handling system, feeding the billets and discharge the finished forged parts must be fully automatic. This research aims to implement the developed handling system in a multi-stage cold former. The purpose of this research is to investigate the automation of all components integrated into the machine. More specifically, the research discussed herein examines if the accuracy of the forged part is altered by the new machine. To examine this possibility, it is important to design a two-stage forming process when the feed and discharge stages need pick and release operations respectively while in the forming stages both pick and place must be performed by the handling device. While forming the billet in the forming stages, the initial diameter of the billet changes into two different values in order to examine the effectiveness of the transport device. It also should be noted to use the same combination of optimal parameters obtained in previous study for the handling system.

3. Experimental setup

Linear servo motors are now widely used in construction of small presses. They offer a fast motion and are accurate in positioning. The recent development of the technology has enabled the use of the servo motors in forming machines for bulk metal forming applications [9]. The three major parameters for selection of a linear servo motors are the maximum force, the positioning accuracy and maximum stroke length. The better positioning accuracy makes the less maximum achievable force and stroke. Therefore, the current linear servo motors with high precision and speed are appropriate to be used for low force micro forming applications such as punching foils, polymer straps and bulk forming of soft materials. A methodology for selection of linear servo motors applicable to a press with two axis movement (forming and transferring axes) is shown in Fig. 2.

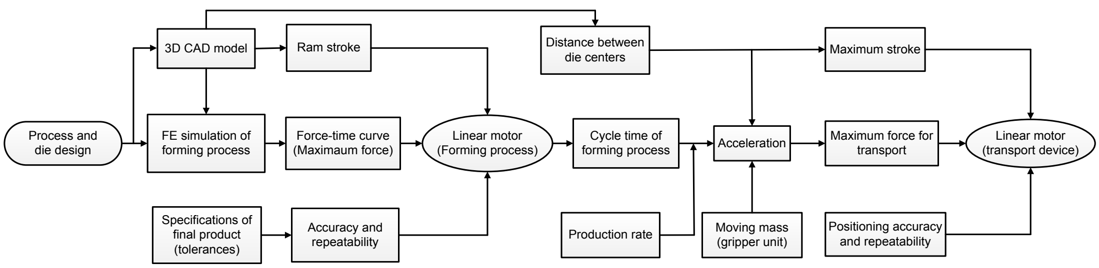


Fig. 2. Methodology for determining characteristics of linear motors (main slide and transporter) in transfer press.

As can be seen, process design, product specifications, maximum output rate and weight of gripper unit influence the linear motors. Therefore, an optimization for the parameters is required in order to maximize the cost effectiveness of the machine.

The prototype is an existing micro forming press with maximum capacity of 5kN [10]. For the testing described herein, billets were transferred using a transport device consisted of a linear servo motor (Max. capacity 12N) and a gripper unit [11]. The system relies on a mechanism included stiff fingers with elastic hinges which support the workpieces during transport. The gripper actuation principle is the linear motor for positioning and the grippers work on the basis of self-centering and friction principle. The feeder moves workpieces through a feeding channel by means of constant force DC motor into the first station where ejectors insert the workpiece into grippers. Subsequent workpiece transport is performed by grippers. The gripper unit arranges the workpieces from one station to the next. The first stage is for charging the forming zone with the new billet and the last stage is designed for unloading the forged part from the last pair of fingers of gripper unit. While the setup is the same as the experiment described in the previous study [11], only forming tool was changed at this research when designing the new forming process.

4. Process and die design

A 4-stage operation was chosen to examine the performance of the handling system. The first stage designed for feeding while the finished forged part exit the forming zone at the last stage. In total four stations work together to complete the production line. The forming stages consisted of a forward extrusion and an upsetting process. The billets are cylindrical parts with diameter and height of 2.0 and 5.0 mm respectively. At the second stage the specimen is extruded with 50% reduction in area. At this stage the billet also is squeezed to remove the defects caused by billet preparation process. With upsetting at the third stage with an expansion of 25% in area, the diameter of 2mm of the billet increases to 2.65 mm. This expansion in diameter was designed in order to examine the effectiveness of the transport device to transfer the parts with diameter higher and lower than the initial value. Fig. 3 shows the geometry of specimens at different forming operations. The testing material is annealed Al 99.5.

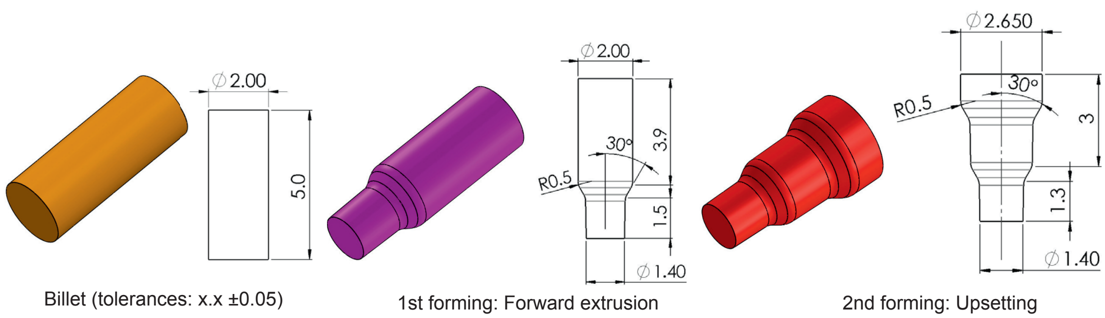
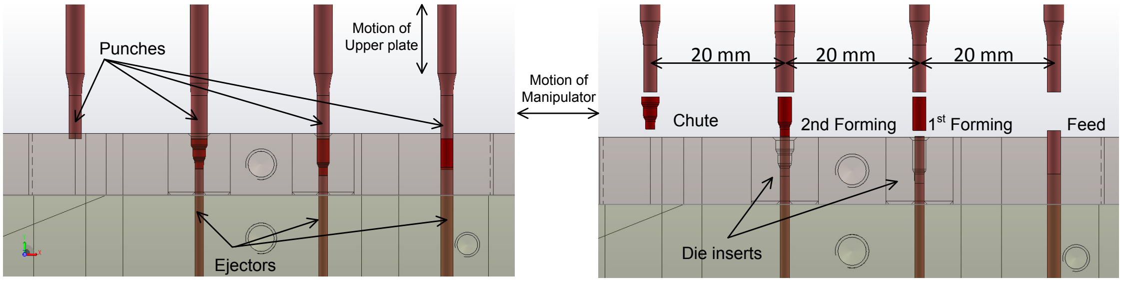


Fig. 3. Dimensions of specimens at different stages.

The two movements executed by gripper unit are performed in longitudinal forward direction to transfer the workpieces from one forming stage to the next, in transverse direction where punches are at bottom dead center position to align the grippers with die inserts. The longitudinal movement of the gripper unit is actuated directly from the linear servo actuator (positioning unit), as shown in Fig. 4.

In traditional multi-step forming presses intermediate gears and cams convert the rotational motion of electrical motors to linear motion of gripper unit. The part transfer and ejection are synchronized with the press drive via the servos controllers and solenoid valve respectively. The synchronization must be precisely reproducible. The movement of workpieces in feeder is perpendicular to the transport motion. Less mass and plays in construction and mechanism of gripper unit permit higher production rate and more reliability.



(a) Upper plate at BDC (b) Upper plate at TDC, transfer device at final placement

Fig. 4. The layout of tooling used in the experimental setup.

5. Production

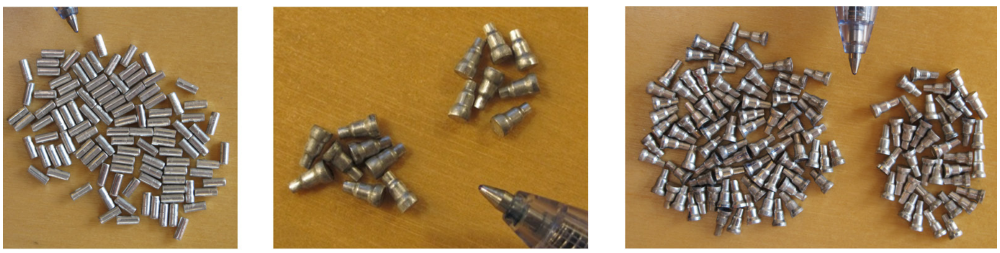
The testing procedure consisted of running the press associated with characteristic values listed in Table 1, while the specimens were transferred with the new handling device and die set as discussed in previous section. An example of the parts at the first forming stage and the final forged part is shown in Fig. 5. While not shown, several tests were examined to verify the reliability of the machine in mass production. The maximum number of the components at each run is 150 ppm when the feeding mechanism has limited capacity at this research. In the entire tests, collision never detected and the whole mechanism worked as smooth as intended. No scratch or any defect was found in the surface of the parts as can be seen from the samples in Fig. 5.

Table 1. Characteristic values of test.

	Servo motor (Main Slide)	Servo motor (Transport)
Displacement (mm)	19.4	20
Half cycle time (ms)	100	150
Max. Velocity (mm/s)	333	323
Acceleration (m/s^2)	11.1	10.7
Dwell time (ms)	10	60
Moving mass (kg)	App. 17	App. 0.3

Fig. 5. Specimen at different forming stages.

The representative forged parts of the tests, when deformed while applying the conditions associated with parameters in Table 1, are shown in Fig. 6. When interpreting the images, the bottom dead center at no load condition and the bottom dead center at loaded condition correspond to Fig. 6(b) and (c) respectively. When comparing the deformed shape of the specimens, while inspecting the upper part of the parts, not complete filled insert is observed for (b) associated with bottom dead center value at no load test.



(a) Billets (b) Not completely formed (c) completely formed

Fig. 6. Production of the parts with automated machine.

To avoid this problem, the absolute value of bottom dead center increased until the die insert was filled completely with the material as can be seen in Fig. 5 and 6(c). In examining the two forged parts, it is apparent that the elastic deflection exists at the machine tool influencing the geometrical accuracy of the forged parts. The concept of uncompensated changing force of the tooling device in respect with elastic deflection is illustrated in Fig. 7. In order to minimize the effect of elastic deflection, the stiffness of the machine tool must be found and compensated when programming the controller.

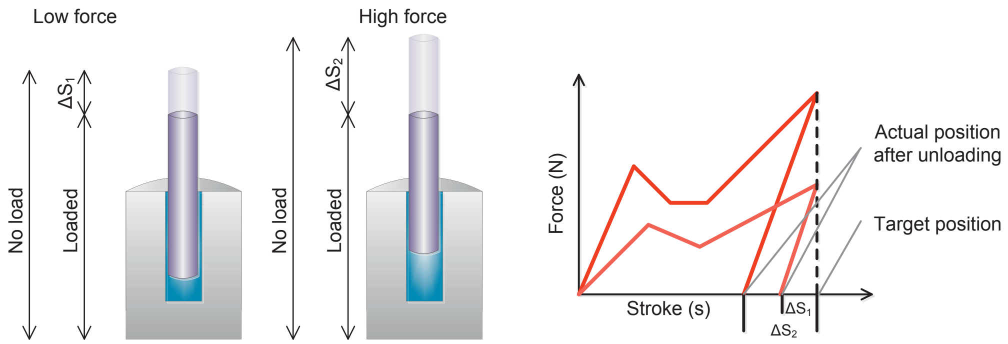


Fig. 7. Concept of elastic deflection due to changing force (Schmidt Servo Press).

6. Conclusion

This paper introduced a methodology for selection of the linear servo motors for a multi stage former with two axis movement. The proposed method includes the precision of the part, die design as well as FE simulation of the process. As was shown, the transfer press proved to be successful in production of the forged parts. The accuracy of the forged part was altered to a great extent by the elastic deflection of the machine.

Acknowledgements

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