

Automatic Corrector of Forming Operations during Forging on High Speed Forging Machines

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Abstract: Currently, the wear of anvils on speed forging machines is mostly checked manually, using calibration gauges. In practice, an authorized worker, on the instructions of the machinist, measures the finished forging with a calibrated gauge and this dimension is compared with the final setting of the forging program. The problem is that the program information on the clamping of the anvils does not take their wear into account. During the forging of bars with diameters greater than 200 mm, excessive die wear frequently occurs. Worn dies subsequently measure the in process dimensions of the forged bars inaccurately. In response, a new measurement method has been proposed, utilising a laser camera to determine the intermediate dimensions of forged bars while accounting for die wear. This information is then used to correct the forging algorithm, thereby improving the accuracy of the final forging operations.

Keywords: Forging; laser; dies; measurement; correction.

1. Introduction

The main concept behind improving the accuracy of forging operations is the application of real time correction of the automatic forming program of high speed forging machines using laser based measurement. During the forging of shafts on high speed forging machines, the dies inevitably undergo wear over time. The forged material is most often made of low-alloy steels (S235 and S355), which have a cold yield strength in the range of 235 ÷ 355 MPa and a hardness of most often 20 ÷ 30 HRC. Already at a temperature of 600 °C, these mechanical properties decrease to less than half. The material of the anvils, on the other hand, is made of medium-alloy steel (tool steel), which has a declared cold hardness in the range of 55 - 65 HRC [7].

1.1 Materials used

When choosing tool steels for hot forging, it is necessary to consider the mechanical and plastic properties of the tool steel. The die steels used must have a sufficiently high yield strength at elevated temperatures during hot forging to avoid plastic deformation during operation. The yield strength at elevated temperatures and the tensile strength of tool steels depend on the chemical composition, heat treatment and working temperature during forging. The hardness of tools for hot die forging is selected according to the dynamic stress and the required yield strength in compression. For presses, where the stress is calm and the requirements are lower, the hardness is selected in the range from 50 to 55 HRC. For hammers, where the dynamic stress is increased, the hardness is reduced to 40 HRC. Due to the lower hardness, there is higher resistance to thermal fatigue and a lower tendency to cracking, but the tools have poorer wear resistance [1, 4].

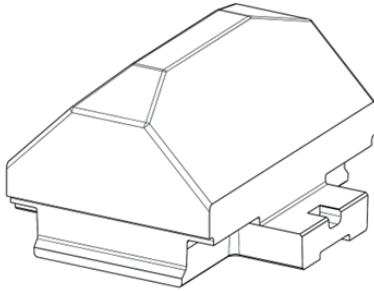


Figure 1: Drawing of anvil.

Required properties of anvils: 1. high strength and toughness over the entire range of forging temperatures, 2. good hardenability and the highest possible tempering temperature, 3. low thermal expansion and the highest possible thermal conductivity, 4. high abrasion resistance, 5. resistance to thermal fatigue cracks, 6. good machinability and favourable price of steel [7].

1.2 Measurement methods

Die measurement is a key process for checking the accuracy of forging cavities, including verification of dimensions, shapes and wear. Modern methods such as digital microscopes, 3D scanning and coordinate measuring machines are used. Limit deviations, offsets and cavity depth are checked, often with a view to the service life (approx. 4,000 pcs). Key aspects of die measurement:

- *Dimensional inspection: Measurement of cavity depth and width, draft angles and parting plane to ensure correct volume and material flow.*
- *Wear and shape: Monitoring cavity wear, which affects the forging strength and accuracy of the forging.*
- *Modern methods: Use of digital microscopes for detailed observation of the surface and defects, 3D scanning for complete shape check against the CAD model.*
- *Standards and tolerances: Limit deviations of dimensions and shapes (offset, burr) are usually governed by standards, e.g. ČSN 42 9030.*

In addition to the actual forming, the anvils themselves also serve to measure the current diameter of the forged shaft from their current position. As this die wear may reach several millimetres, the required measurement accuracy is no longer ensured after a certain period of operation. The proposed system uses input image data from a camera to control the dies and the movement of the forging press so that the resulting forging achieves the required geometry. The solution is limited to the forging of rotationally symmetric parts.

2. Description of the Improved Technology

For this purpose, a system for automatic measurement of the forged shaft using an NIR camera (a camera operating in the near infrared spectrum) was developed. The camera outputs a luminance image, which is transferred via Gigabit Ethernet in raw data format to the control computer, where it is further processed. Using specially developed computer vision algorithms, a 3D model of the forging is reconstructed (a rotationally symmetric body is assumed).

The control system of the high speed forging machine uses the data obtained from the described camera system to correct the actual dimensions of the forged shaft and subsequently adjusts the forging regime in real time based on the detected die wear and the current shape of the forging.



Figure 2: Shows images captured by the 3D laser camera.

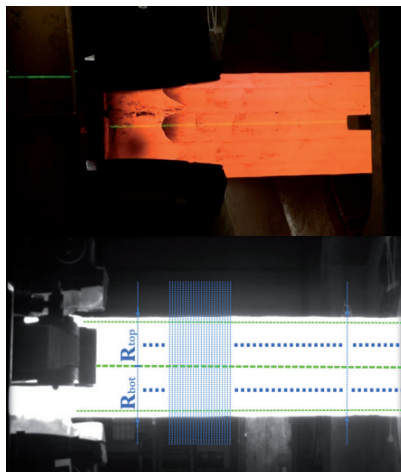


Figure 3: Shows the measurement process and the visualisation of the forging in the scene.

3. Practical Application

The final practical implementation of the measurement system for forging was carried out at the forging plant, where the measurement is performed using the method described above. The introduction of this correction system enabled automatic calibration of the die to die distance during the instantaneous forming process, and it also allows the operator to precisely control the dimensions and rough machining allowances in real time. The correction factor was implemented into the control system of the forging machine using a software application developed by the University of West Bohemia in Pilsen.



Figure 4: Shows a photograph of the forging machine and the enclosed camera equipped with a cooling system.

The camera itself is mounted on a special column and is automatically guided toward the moving forging. Data from the specially cooled camera are communicated in real time with the Siemens control system. This method of immediate

automatic correction of the forging machine control program using real time dimensional data of the forging (compensating for die wear) has not been used previously in the Czech Republic. For this reason, the Industrial Property Office of the Czech Republic granted this technology a Utility Model under number UV 32 227.

4. Measurement on the Industrial Forging Unit

The forging machine operates in a four shift regime. Its main production assortment consists of steel ingots for forging bars made of low alloy structural steels. Due to downtimes, material flow, and shift changes, the net forging time is also measured. Based on these values, it was possible to establish a time based prediction of die wear, both absolute (indentation in millimetres) and specific (related to the net forging time). The specific wear does not necessarily correlate with the absolute wear, as the variability of production may require different degrees of deformation, or ingots of different dimensions may cool at different rates, which can influence the instantaneous wear of the dies. Anvil wear measurements were carried out over a period of one week on a standard range of shaft forgings. Every day at 6 am the anvil thickness was measured, and the working time was recorded. This procedure measured the progressive plastic deformation of the anvils as a function of production. The measured parameters are listed in Table 1.

From the measured parameters, a graph was constructed illustrating the progression of die wear. The resulting values are consistent with the expected exhaustion of plastic deformation. After approximately 130 hours, the plastic deformation becomes exhausted, and stress begins to

Table 1. Measured input parameters.

Date	Original dimension	Working time	Procedure	Final dimension	Correction	Specific correction
d:m:y	mm	hrs	hrs	mm	mm	mm.hr ⁻¹
02.12.2024	117.2	21.0	21.0	116.5	0.7	0.033
03.12.2024	116.5	22.0	43.0	115.8	0.7	0.032
04.12.2024	115.8	14.0	57.0	115.3	0.5	0.033
05.12.2024	115.3	22.0	79.0	115.0	0.3	0.015
06.12.2024	115.0	18.0	97.0	114.7	0.3	0.017
07.12.2024	114.7	17.0	114.0	114.5	0.2	0.012
08.12.2024	114.5	23.0	137.0	114.3	0.2	0.009
Diameter	115.6	19.6	-	-	0.4	0.022

accumulate in the working part of the dies. The trend is shown in Figure 5.



Figure 5: Anvil wear over time.

5. Conclusion

The use of a laser camera will allow the operator of the high-speed forging machine to more effectively control the intermediate dimensions of the forging. Before the introduction of this technology, it was necessary to check the wear of anvils using gauges, now the operator has this information in real time. The measurement results are consistent with the predicted die wear of approximately 2 mm after about 100 ÷ 120 hours of forging. Further wear is minimal due to the exhaustion of plastic deformation; however, energy accumulates in the crystal lattice, which may lead to the formation of cracks.

Only one calibration measurement was required for communication between the Siemens control unit and the laser camera. The measurement was used only to set up syntactic communication between the anvil position and the control SW. The correction factor was developed in the form of a SW extension by a specialist at the University of West Bohemia in Pilsen and implemented directly into the Siemens control unit. The detailed specification of the SW extension is protected by the above-mentioned utility model.

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