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Machinery Influence on the Production Accuracy of Precision-forged Parts

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Precision forging is an innovative manufacturing process for the flashless, near-net-shape production of high performance components. Outstanding material characteristics as well as a reduced process chain and a high material efficiency are the essential advantages of precision forging. Subsequent to the forming process only a final hard-finishing of specific functional surfaces with minimum cutting volumes is necessary. The high accuracy of precision forging demands a specific process and tool design. In this regard a detailed knowledge about fundamental material properties and the forming procedures predefined by the applied machine kinematic is essential.

Keywords: MASSIVE FORMING, PRECISION FORGING, SHRINKING BEHAVIOR, MACHINE KINEMATIC

The growing worldwide competition in the manufacturing industries leads to a constant increase in cost pressure. Research and developments in manufacturing technologies are the basic prerequisites to meet cost and quality requirements to maintain a favorable market position. Forging parts have outstanding material and component characteristics. They feature a high mechanical and dynamical strength due to the process-related freedom from cavities and grain refinement as well as the unbroken and shape-adapted grain flow [1]. This results in an increased strength of forged components which contributes to the trend of downsizing and light weight construction. Precision forging, a sub-discipline of die forging technology, is carried out using closed dies without a flash. By means of precision forging near-net-shape high performance parts with production accuracies of up to IT 7 (according to DIN EN 10243-1) can be obtained [1]. Due to the substitution of several soft machining processes by one forging process the reduction of production steps and times is achievable. Particularly in times of diminishing energy and raw material resources the high efficiency of forging processes is gaining more and more importance. Thanks to the high geometric accuracy, increasingly more functional elements can be produced as near-net-shape components by this forming technology. For this reason, the precision forging process is often regarded as a competitor for entire production sequences and competes no longer with only individual production processes [2]. Current research works deal with the realization of precision forging of spur and especially helical gearings. **Figure 1** shows a selection of parts which were precision-forged at the Institute of Metal Forming and Metal-Forming Machines of the Leibniz Universitaet Hannover (IFUM).

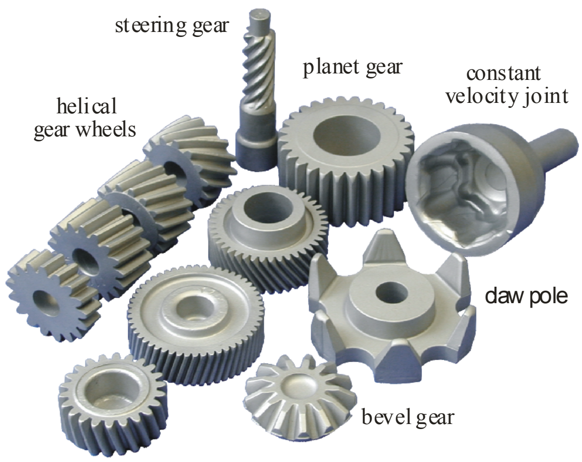

Figure 1. Selection of precision-forged parts (IFUM)

Within the Collaborative Research Centre 489 "Process Chain for Production of Precision-Forged High Performance Components" the studies are focused on the development and qualification of innovative technological, logistical and economical methods in precision forging. In this context the near-net-shape production of crankshafts and geared components by die forging is being studied. Other than the fundamental theoretical and practical process design the investigations also include the tool making, the integrated heat treatment, the hard fine machining and the component testings. Each production step is accompanied by a comprehensive technological, logistical and economical evaluation. The current researches of sub project B1 "Process design" are based on developments in the precision forging of a pinion shaft geometry which has an elongated shape and features an axially distinct mass distribution. The component with its essential tooth characteristics is shown in **Figure 2.**

The shaping is performed in a two-step forging process. In the first step the mass distribution including shank, shaft section and pinion preform is realized by a solid forward extrusion. The final shaping of the toothing is carried out by a precision die forging process in a closed die. The process operations are depicted in **Figure 3**.

Due to the high process temperature of 1200°C in hot forging there is a subsequent shrinkage of the shaped parts. By comparing the die geometry with the hot-forged and cooled-down part a shrinkage of nearly 1 mm in the gearing area was detected. Detailed contour measurements show that the shrinkage factor varies over the component outline. This behavior can be traced back to the fundamental geometrical component proportions on the one hand and the inhomogeneous cooldown and the resulting forming temperatures on the other hand. Due to the locally heightened contact pressures and the adverse surface-volume ratio in the area of the shaping teeth there is an increased heat loss so that the forming temperature as well as the local subsequent shrinking are reduced. By a numerical process simulation this cooldown behavior can be imaged and evaluated. In **Figure 4** the process simulation of the precision-forged pinion shaft is depicted for the final forging step.

Tooth characteristics	
real pitch module	2
number of teeth	30
helix angle	20°
addendum modification coefficient	0
normal pressure angle	20°
pitch circle diameter	63.85 mm
tip diameter	67.85 mm
root diameter	58.85 mm
base diameter	59.54 mm
grinding allowance	150 µm

Figure 2. Precision-forged pinion shaft

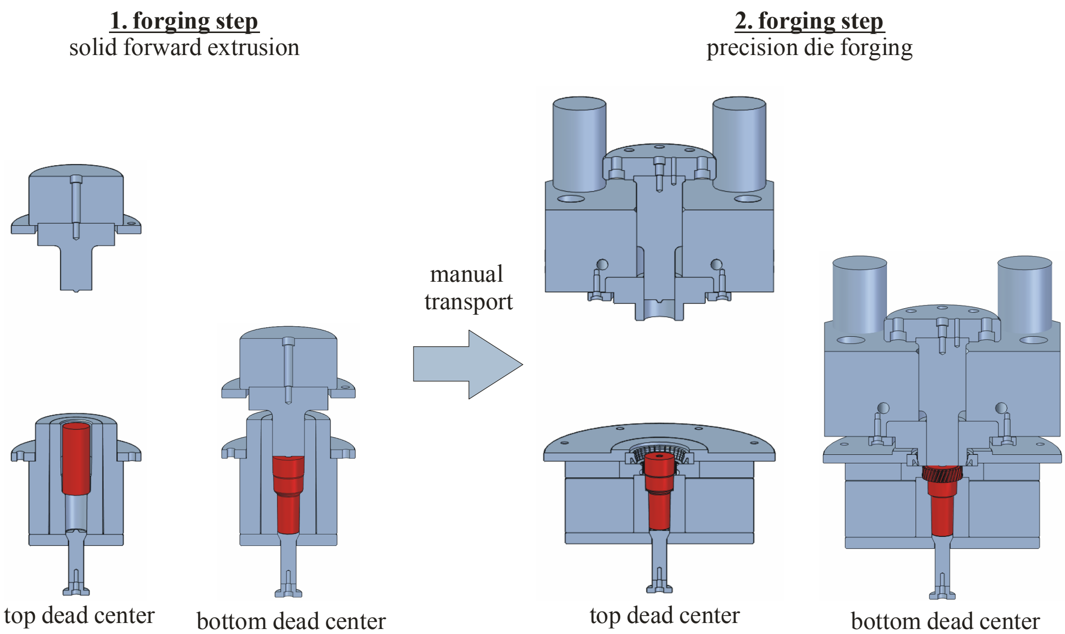

Figure 3. Two-step forging process

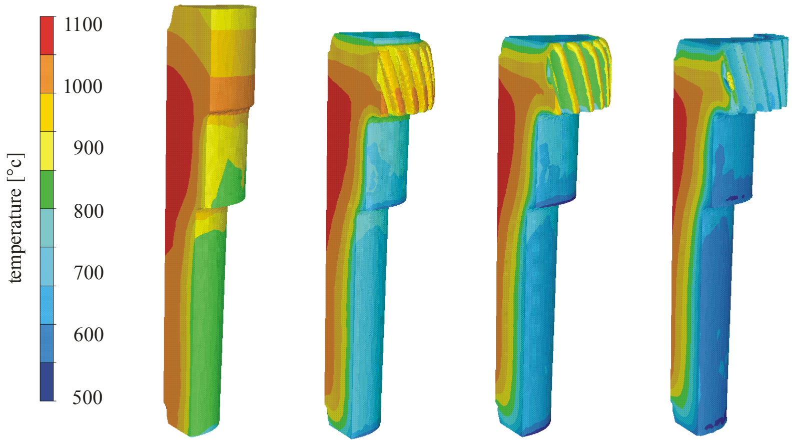

Figure 4. Numerical process simulation of temperature distribution during forging

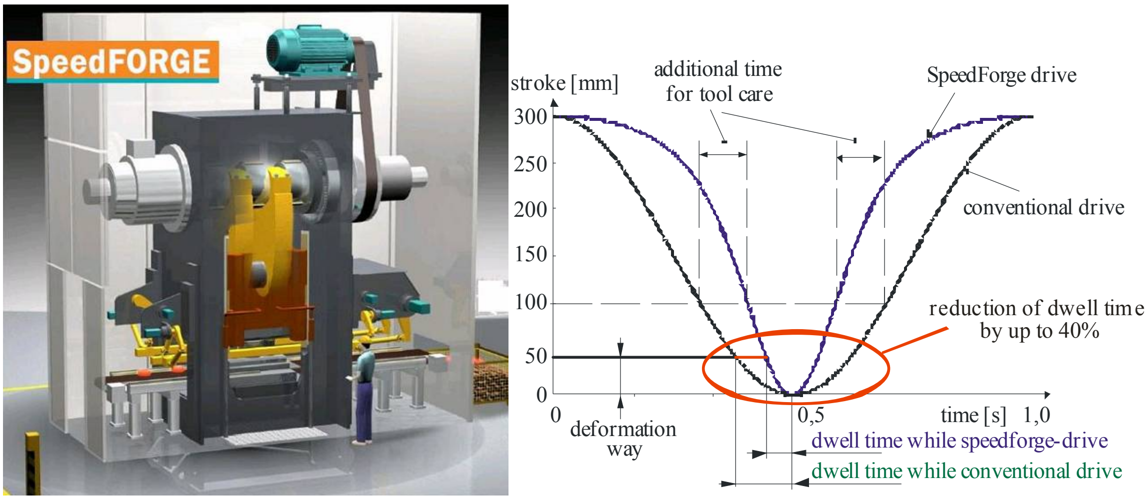

Figure 5. Innovative drive concept "SpeedForge" (MüllerWeingarten/Schuler)

The resulting temperature distribution has considerable effects on the forming and shrinking behavior and ultimately on the attainable component dimension. To still ensure the high production accuracies in precision forging this geometry-specific behavior has to be compensated in advance by an adapted die design. Based on the given part dimensions and empirically elaborated correction factors the required die contour is designed [3, 4]. The proportion of the shaping die contour and the resulting component shape after cooldown are shown in **Figure 7**. In a number of forging tests a material influence on the final part dimensions was noticed which was investigated in detail. The results showed an interrelation between the alloy composition and the thermo-physical material behavior. Especially in the high temperature range of hot forging a significant material influence was detected [3-5].

Beside these material-specific parameters the heat balance and the resulting heat transfer are time-dependent and thus fundamentally determined by the chronological process flow. Here the choice of machinery is decisive for a suitable process design. The mechanically defined ram kinematic and thus the high reproducibility and good automation capacity predestine crank presses for hot precision forging. The dwell time and thus the time of increased heat loss is determined by the given ram motion. The innovative drive concept "SpeedForge", developed and marketed by MüllerWeingarten/Schuler, accelerates the ram movement and enables a reduction of the dwell time by up to 40% in the automated production process. By using two parallel operating drives coupled via a planetary gearing with a hydraulic clutch-brake combination and a free-wheel, the motion profile of the ram can be adapted to the requirements of hot forging. A frequency-controlled auxiliary drive determines the "flexible" ram motion. The performance required for forging is supplied by a conventional main drive with flywheel. A sketch of the dual drive concept and the resulting ram kinematic are presented in **Figure 5** [1].

The accelerated downward movement of the ram reduces the times of heat-impact. The saved time can be used for an extensive tool care by cooling and lubricating. By this reduction of the thermal load a longer tool life can be achieved. The changed heat transfer also suggested an altered cooldown and shrinking behavior. For this reason the influence of the ram speed on the component dimension of precision forged parts was analyzed by comparative forging tests. For these investigations the final forging step of the pinion shaft geometry was analyzed. The experimental settings and parameters are listed in **Table 1**.

For the evaluation of the overall and local shrinking behavior of differently deformed parts the tip and root diameters as well as several tooth contours were measured tactile by a coordinate measuring machine and compared. A selection of measuring results is summarized and depicted in **Figures 6** and **7**.

Table 1. Experimental settings and parameters

component:	pinion shaft	
workpiece material:	42CrMo4	
raw part temperature:	1200°C	
number of forging steps:	2	
deformation way:		
preform (measured)	33.65 mm	
final form (measured)	16 mm	
driving mode:	conventional (c1-c3)	SpeedForge (SF1-SF3)
cycle time:	30 min^{-1}	60 min^{-1}
dwell time:		
preform (measured)	0.294 sec.	0.133 sec.
final form (measured)	0.156 sec.	0.078 sec.

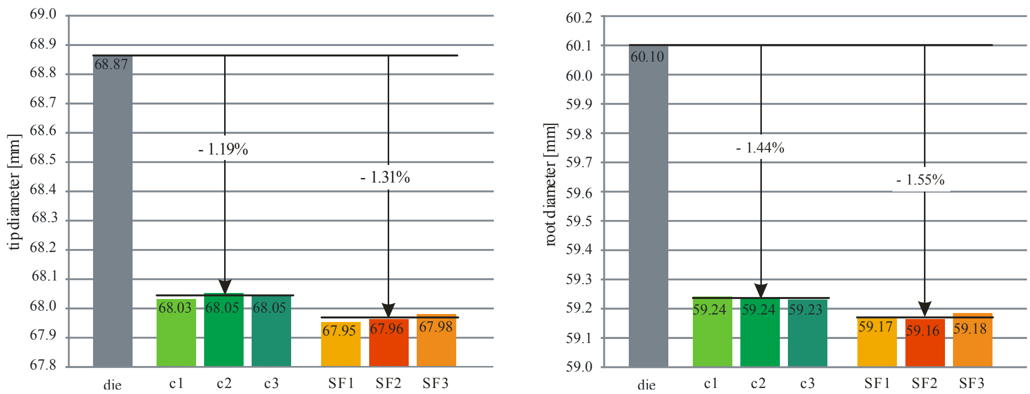

Figure 6. Resulting tip and root diameters of conventional and high-speed-forged gearings

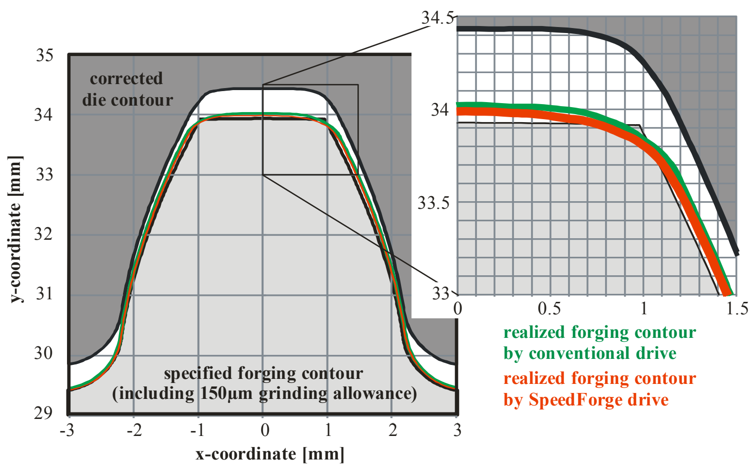

Figure 7. Resulting forging contour of conventional and high-speed-forged gearings

The measuring results show the high reproduceability of the designed precision forging process. In both test series (c1-c3; SF1-SF3) nearly constant part dimensions were reached. The comparison of conventional and high-speed-forged parts reveals a correlation between ram speed, resulting dwell time and the final component size. The final tip and root diameters fluctuate each by ~70 μm depending on the machine settings and resulting forging conditions. The comparison between the shaping die contour and the tip diameter revealed a shrinkage of 1.19% in conventional and 1.31% in high speed forging. Similar investigations for the root diameter show an increase in shrinkage from 1.44% to 1.55% due to high speed forging. This varying process behavior can be traced back to a changed heat balance. The reduced dwell times lead to a decreased heat loss during forming. The hereby increased residual heat in the part leads in turn to a higher subsequent shrinking and finally to a smaller component size.

The contour measurement reveals the suitability of the performed die correction. Despite shrinkage all forged gearings feature a sufficient grinding allowance of 150 μm for the final machining of the tooth flanks. Only the uppermost area of the tooth crest exhibits small deviations from the specified forging contour. However, the final tooth contour after hard fine machining is not affected by this minor undersize. The comparison of the different contours confirms the different process-related shrinking behaviors of conventional and high-speed-forged parts. The analysis of the local shrinking behavior of teeth indicates no appreciable effect of the forming velocity. All parts show a tooth height of 4.4 mm. Thus, the local shrinking in teeth is comparable and independent of the applied forming velocity. For the tested settings the influences of the ram speed on the cool-down and shrinking behavior is not remarkable. In the range of these already high forming velocities and short dwell times of just a few tenths of a second the material-specific heat conductivities of the contact partners are the determining and limiting factors. The results show that a further reduction of dwell times affects the heat loss only slightly. For precision-forged parts with a given grinding allowance of 150 μm the speed-dependent radial fluctuations of just a few μm in component dimensions merely have a slight influence on the production accuracy.

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Влияние оборудования на точность производства деталей точной объемной штамповки

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Высокоточная штамповка является инновационным процессом производства, позволяющим производить детали без заусенцев с высокими эксплуатационными характеристиками. Основными преимуществами процесса высокоточной штамповки являются небольшое количество технологических операций и низкое значение коэффициента расхода металла. После процесса штамповки необходима только окончательная отделка конкретных функциональных поверхностей с минимальным расходом металла. Процесс высокоточной штамповки имеет ряд особенностей, в частности проводится с использованием инструмента специальной конфигурации. В связи с этим изучение фундаментальных свойств металла и процесса штамповки с использованием специального оборудования имеет особое значение.