

# Hot Flashless Precision Forging of Long Pieces

## - Development, Realisation, Benefits -

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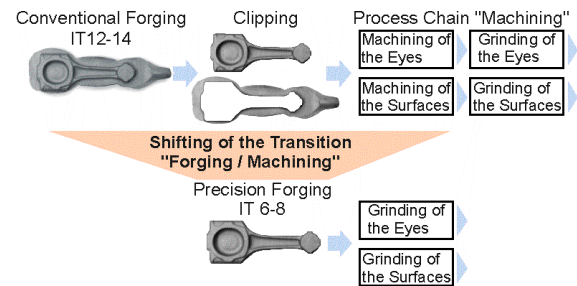
### Abstract

*Within the net-shape and near-net shape technology hot flashless precision forging leads to high forging accuracy of the workpiece with regard to dimensional and surface finish tolerances. The main advantages are shortened production cycles by eliminating machining operations and the saving on raw material lost during machining. By producing ready-to-mount forgings high economical and ecological processes can be designed. In Europe the transfer of the flashless precision forging technology into industry has just begun for rotational forgings, e.g. bevel gears. In case of long workpieces, e.g. connecting rods some important aspects must be taken into consideration to meet the special requirements by designing the process. This article points out the requirements and describes the procedure how to design the process supported by CAD and FEM, the used process technology as well as the benefits.*

**Keywords:** Precision forging, Connecting rod, Process chain, Closed die forging

### 1 Introduction

As a result of global competition as well as competitive processes and materials future manufacturing processes have to be highly innovative. Customer demands for higher quality, shorter time for delivery, higher range of variety and reduced lot sizes have to be fulfilled for lower costs. In the area of hot forging efforts have been made to shorten the entire process chain 'forging and machining' by adaptation, substitution and integration of single forming and machining operations (Figure 1). The precision forging is a suitable solution to design high economical and ecological processes.



**Figure 1.** Shortening of the Process Chain.

In Europe the industrial application of flashless precision forging technology of rotational symmetric forgings [1] (e.g. bevel gear) is established. In case of flat long forgings [2] it is much more complicated to meet the conditions of this technology due to a multistage forming process in contrast to the single-stage forming of rotational symmetric parts.

For this reason different research projects are carried out at IPH which prove the applicability of this technology for flat long pieces. Tested geometry are symmetrical and asymmetrical connecting rods in a range of weight between 186g and 825g as well as hand tools. Based on these results transfer projects into industry have just begun to realise the entire process chain.

Using a connecting rod (Figure 2) as a representative of flat long pieces a suitable tool concept for flashless precision forging, developed at IPH [3], will be described. Additionally detailed information about the design of this precision forging process will be given in order to highlight the peculiarities.



**Figure 2.** Connecting rod forged at IPH.

## 2 Prerequisites of Precision Forging

The implementation of precision forging requires increased efforts regarding the process control at every single step not only of the manufacturing process itself but also of the process design by means of CAD [4,5] (tool design) and FEM (material flow simulation). Therefore the factors discussed below must be taken into consideration:

### Tooling

Precise forging requires a precise tool! Because various factors have an important influence on the forging tolerance, this tolerance is typically poorer than the tooling tolerance. Therefore the tolerance bands must be set at a small fraction of the desired forging tolerances.

### Preform

Precision forging of rotational symmetric parts is normally done by only one stroke. The preform is simply a slug of raw material sheared or cut from a bar. In case of forging flat long pieces a multistage forming operation is required in order to achieve a proper material flow guaranteed by an exact mass distribution. In both cases, the quality of the preform, e.g. the surface of the preform as well as the sheared or cut surface, the entire weight of the preform, the microstructure and composition of raw material affects the precision of the finished forging. Also the position of the preform in the die sinking is very important for the material flow and formfilling.

### Lubrication

The lubricant has a very important influence on the forging load, the material flow and therefore the formfilling of the die, the uniformity of the metallurgical microstructure, and the surface quality of the forging. This requires constant properties of the lubricant achieved by controlling the composition even during production and by using automatic devices for applying the lubricant.

### Workpiece Temperature

The workpiece temperature affects the precision of the forging through the thermal contraction of the

forging, the varying flow stress of the material and elastic compliance of the tool and the lubricant performance. With regard to e.g. metallurgical phase transformation processes, which determine metallurgical microstructure after cooling, it is absolutely necessary to keep the workpiece temperature in close tolerances. Finally, the cooling of the forging under controlled conditions may be necessary to avoid the distortion and to control the metallurgical microstructure.

### Tool Temperature

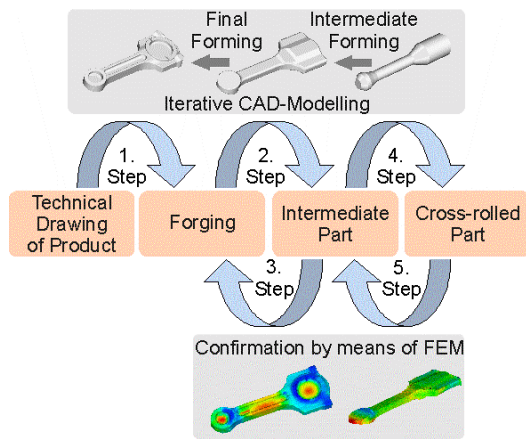
The reasons for controlling the tool temperature are similar to the reasons for controlling the workpiece temperature. The temperature of the tool on the one hand affects the temperature of the workpiece through the heat transfer caused by the temperature differential between tool and workpiece, on the other hand affects the behaviour of the lubricant. Another important influence is the thermal expansion of the tool on the final dimensions on the forging. In consequence the dies should be temperature controlled, in order to keep the temperature during the production run relatively constant. This temperature has to be predetermined by means of FEM in order to define the thermal expansion of the die cavity and finally to compensate this amount by tooling the dies.

### Protective Atmosphere

In order to reduce wear of the tool caused by scale and to achieve a good workpiece surface, it is necessary to heat the initial part under protective atmosphere. Special applications may require the additional consideration of specific factors (e.g. isothermal forging of aluminium alloys). In any case the successful application of the precision forging technology depends on the exact adjustment and reproducibility of all parameters with tolerances as low as possible. This application has to be done by an automated forging line in order to exploit the advantages of the flashless precision forging completely [6].

## 3 Development of the Forging Process

For the technology of flashless precision forging a method was developed to define each step and to verify the forging process. This process development is done backwards starting from the geometry of the finished forging product. After designing the final forming tool the next step is to create an intermediate part which can be inserted into the final forming die. The succeeding step is the creation of the intermediate forming tool and of a rotational symmetric preform, which can be inserted into the intermediate forging die (Figure 3).



**Figure 3.** Defining of the Forging Sequence.

The design of the different parts and tools is done by CAD in an iterative process. Furthermore the entire sequence planning has to be supported by FEM in order to optimise the preform and the intermediate part based on the evaluation of the material flow and the formfilling.

IPH uses the CAD-tool ProEngineer and the FEM-tools MSCSuperforge and MSCAutoforge.

### 3.1 Development of the Final Forming Process

The CAD-model of the finished product and specifications such as material and properties are the starting point for developing a new manufacturing process. The geometry of the CAD-model of the finished product has to be redesigned according to the common recommendation to get a forgeable product (e.g. no sharp corners, undercuts). Surfaces which have to be machined need overmeasures, inner flashes have to be considered and the die parting surface has to be determined. Additionally certain sections of force admission have to be determined where the material can be formed with punches. This are the fundamentals of the flashless precision forging with ‘closed die’, where the die-closing process is separated from the forming process (see chapter 4.5).

The finished CAD-model consists of net-shape areas which do not have to be machined any more, areas with functional surfaces where at least final grinding is necessary and areas of force admission, where the forming is caused by movable punches. In order to achieve a complete formfilling, these force admission areas have to be distributed equally. In addition the minimised flow way leads to a reduced wear of the die. Based on the CAD-model of the forging the parting surface, respectively the two parts of the die are defined and the punches are integrated.

During the closing of the upper and lower die the inserted intermediate part should not touch the upper die sinking. The intermediate part must have the same volume as the finished forging. Furthermore the mass distribution along the main axis of the two parts should be similar in order to minimise the flow way and achieve a complete formfilling. A slug cannot fulfil these requirements of the intermediate part. Therefore long workpieces cannot be precision forged in a single step as it is possible with rotational symmetric parts.

After the design of the intermediate part the final forging process is simulated by FEM. Important results are the formfilling and the stress and strain of the dies and the punches. Areas with a lack of formfilling have to be determined and the geometry of the intermediate part has to be optimised in an iterative process by modifying the outer line and profile of the part.

### 3.2 Development of the Intermediate Forming Process

The development of a suitable intermediate part starts with the analysis of the mass distribution of the forging. By means of the CAD-system the forging is cut into regular sheets which are orthogonal to the longitudinal axis (neutral axis). Based on the calculated volume of every single sheet the exact mass distribution of the forging can be determined. Starting with the outer line of the die sinking of the final forging an intermediate part with the same mass distribution is developed. Apart from the exact mass distribution and the closing of the dies without forming, this intermediate part must fulfil further requirements. One of the most important is an exact and reproducible positioning of the intermediate part in the final forging die sinking. Therefore a gap of 1 mm has to be ensured between the outer line of the intermediate part and the final forging die.

An upsetting process in a closed die is a suitable technology for producing the intermediate part. This intermediate forming process is also simulated by FEM in order to examine the formfilling behaviour as well as stresses and strains of the tool. Analogous to the design of the intermediate part the preform for simulating the intermediate forming process is designed with regard to the mass distribution of the intermediate part. This preform may be produced by the highly economical cross rolling process [7]. Considering this the preform geometry is rotational symmetric. Depending on different requirements on the preform process (e.g. produced piece number) naturally alternative technologies such as thermal cutting or forming in a closed die with different moving directions of the punches are conceivable. In this case the preform has a rectangular cross section.

## 4 Tool Technology

The process chain for precision forging of flat long pieces consists of the stages production of the slug, heating, mass distribution (preform), upsetting (intermediate part) and final forging (precision forged workpiece).

### 4.1 Slug

Mass deviations of the slug cannot be compensated by an outer flash as it is usual in case of traditional forging. In order to guarantee a precise volume of the slug either a shearing process with integrated weight control or a sawing process can be used. In comparison to sawing the process shearing is the more efficient slug preparation process without any loss of material. The allowed deviation of the required volume depends on the product geometry. The higher the ratio of punching areas to the entire projected surface of the forging the more material can be compensated by a varying thickness of the inner flashes based on the elastic compliance of the punches. In case of a tested automotive connecting rod with a weight of 825g the allowed mass deviation is about  $\pm 1\%$  (see chapter 5). With a slug diameter of 39 mm and a length of 88,5 mm the allowed deviation of the cutting length is about  $\pm 0,8$  mm. Due to the achievable mass precision of sawed slug the sawing process is very suitable for precision forging.

Because of the reduced final machining of the forging the surface defects of the slug caused by the shearing or sawing process affects the quality of the final forging. The surface of the slug especially the sheared or sawed surfaces has to be without any defects such as hollows, burrs or cracks and should also be parallel and perpendicular to the axis of the bar.

### 4.2 Heating

A rapid heating of the slug decreases the tendency to scale, which is unacceptable according to the required surface quality of the final forging. Another possibility to avoid scale is the heating under protective atmosphere (e.g. nitrogen). To achieve a reproducible complete formfilling it is important to control the temperature. In case of the connecting rod the tolerances on temperature should be  $\pm 10$  °C for hot forging at 1250 °C. Also the temperature distribution within the slug should be homogeneous in order to prevent a variation of the material flow and forming load caused by different flow stresses.

The heating of the slugs can be done by induction-heating, resistance-heating and gas fired furnaces.

The controlling of the slug temperature can be done by different sensors (e.g. pyrometer) and incorrectly heated slugs are sorted out. The heat transmission of the part to the manipulator during the handling between the single operations has to be considered and needs a reproducible timing of the handling equipment.

### 4.3 Mass Distribution

For the majority of long parts the cross section along the longitudinal axis is characterised by large diameter variations. The cross-section of the big eye of a connecting rod is more than two times bigger than the cross section of the shaft. The rolling process is a suitable technology to produce mass distributed parts. Especially stretch rolling is an established process in industry because of its high productivity. But for precision forging the achievable geometry and dimensional tolerances are often not adequate. However, cross rolling meets in most cases the demanding requirements for precision forging. Based on the exchange of information with producer, researcher and user of the cross rolling technology the tolerances, which are achievable under standard operating conditions, are about  $\pm 0.3$  to 0.4 mm in diameter. If the conditions are optimal, tolerances close to  $\pm 0,2$  mm are conceivable, too. In any case the applicability of cross rolling for precision forging mainly depends on the function and geometry of the workpiece and the follow-on machining. In consequence the applicability has to be verified for each single workpiece. Further constraints for designing the cross rolled preform are the minimum (15 %) and maximum (58 %) reduction of the diameter of the slug in a single step in order to avoid material or surface defects.

### 4.4 Upsetting

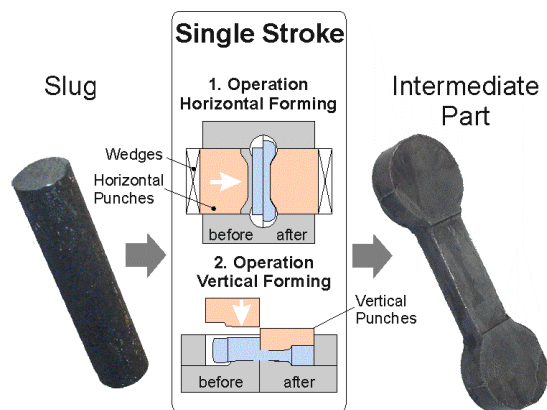
The rotational preform is formed in a first press stage into the intermediate part. This is done in an upsetting die by an upper and a lower upsetting punch. As the punch of the upsetting tool moves into the cup there has to be a gap between these two components. Based on this gap a microflash may occur which will cause some defects on the surface of the final forging. In order to avoid this microflash the reproducible and exact positioning of the preform in the cup must be guaranteed. Otherwise the nonuniform material flow causes premature formfilling in certain areas of the die sinking and a material flow into the gap during the further punch movement. Another measure to avoid this microflash is a not complete formfilling, which leads to intermediate parts with free-formed corners.

The forming load of this upsetting process is quite low compared to the final forging process. The ratio is approximately 1 : 30. In consequence the

intermediate forming and final forming process can be carried out simultaneously in a one-hit stroke. In order to prevent a bending of the intermediate part during the ejecting process the ejectors have to be distributed regularly. Due to the allowed narrow temperature tolerances during the entire process chain the tool temperature has to be controlled.

An alternative tool for substituting the mass distribution and upsetting processes is a tool with a closed die and movable punches coming from different directions (Figure 4). This tool will be integrated together with the final forging tool on a single side press. The horizontal movement of the punches is driven by wedges connected with the press slide. A decoupling of the horizontal and the vertical movement of the punches is done for example by disc or nitrogen springs to realise different moving directions under a single stroke.

This concept is currently investigated by IPH in order to determine the boundary conditions concerning its applicability for precision forging. In comparison to the achievable maximum

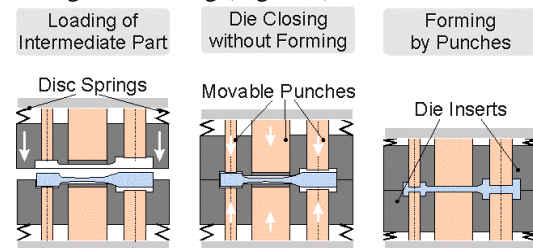


**Figure 4.** Principle of a Multidirectional Upsetting Tool.

reduction of the diameter by cross rolling the first experiments with this tool confirm the possibility to realise similar reductions of the cross section close to 55 %. Depending on the function and geometry of the forging as well as the economical conditions, for example lot size, piece number, range of variety, it is also conceivable to produce the initial part by laser or thermal cutting and proceed either with upsetting or final forming. These alternative forming sequences have been investigated in an industrial project.

#### 4.5 Final Forging

The tool concept for flashless precision forging is based on a separation of the two operations of die closing and forming (Figure 5).



**Figure 5.** Concept of the Final Forging Tool.

As the precision forging process should be realised under a single side press with only one moving part, the separation of die closing and forming can only be achieved by using decoupled, movable punches. These movable punches effect the forming operation after the complete closing of the dies. This tool kinematics can be realised on single side presses by using for example disc springs or nitrogen springs. Springs allow a relative movement between the slide of the press and the dies. Besides they provide the required force to keep the dies closed and therefore this force has to be higher than the internal pressure during forming.

Depending on the geometry (e.g. symmetry) of the forging the punches are integrated only in one or in both sides of the tool. The die sinking is decoupled from the press by means of the springs while the punches are directly fixed with the press slide respectively the machine table. Analogous to the upsetting tool a temperature control (including preheating) has to be integrated in the final forging tool.

Summarised the tool for the final forging operation must respect the following aspects:

- Closing and locking of the dies
- Positioning and centring of the die inserts
- Conducting of the movable tool elements
- Mounting of the dies
- Admission of the forming force
- Ejection of the forging
- Temperature control

### 5 Benchmarking

In order to assess the flashless precision forging technology a comparison with the traditional forging process was carried out on an automotive connecting rod with a mass of the forging of 825 g. The forging product was designed concerning the different requirements of the two technologies and the corresponding tools were built.

In order to determine the influence of mass deviations of the preform on the final dimensions of the forging different experiments were carried out. Different parts with deviations concerning the mass distribution and the entire mass were examined. The entire mass of the preform varied in a range of  $\pm 1\%$  and the diameters varied in a range of  $\pm 0,2$  mm. Caused by these variations the thickness of the inner flashes of the precision forged part varied about  $\pm 0,3$  mm at the small eye and about  $\pm 0,25$  mm at the big eye of the connecting rod. The tolerance of the thickness of the inner flash of the shaft was  $\pm 0,18$  mm. The variation of the workpiece thickness out of the inner flashes is in the area of the big eye  $\pm 0,1$  mm, in the area of the shaft  $\pm 0,09$  mm and in the area of the small eye  $\pm 0,08$  mm. These variations cause an entire mass deviation of the forging of 7 g. The inner flash of the small and big eye are removed by punching. Whereas the deviation of the remaining inner flash of the shaft as well as the elastic compliance of the die sinking cannot be compensated and causes a remaining mass deviation of the punched forging, which is less than the a.m. deviation of 7g. In comparison the mass tolerance of a traditional forged connecting rod only caused by an inaccurate insertion of the preform is about 22 g. This corresponds to a variation of the thickness of the forging about  $\pm 0,35$  mm.

These experiments showed, that in case of a connecting rod the precision forging technology is suitable to shorten the process chain by eliminating certain operations such as machining, weighing, counterbalancing and classifying. This eliminating of certain finishing operations is only possible by realising a highly precise forging, which is more costly than a traditional forging. To realise the economical benefit the entire process chain including forging and machining has to be considered. An economics calculation done by IPH in co-operation with an automotive supplier for a representative product showed, that in spite of increased tool investments the cost of production, excluding the overhead, decreases close to 20%.

## 6 Conclusion

In order to produce forgings more economical it is necessary to shorten the process chain by eliminating process machining operations. This requires forgings with high precision regarding the surface quality and dimensions. One suitable solution is the flashless precision forging technology.

The presented precision forging technology consists of a multistage process including preform, intermediate part and final forging. Usually the preform is produced in a cross-rolling process, but

also alternative processes are conceivable. The intermediate part, which is produced by an upsetting process in a closed die, is inserted in the final forging tool. The principle concept of the final forming tool is the separation of the closing of the dies and the forming by movable punches.

Different requirements have to be fulfilled to implement this technology into industry. Important aspects are a precise tooling, lubrication, temperature control of tool and workpiece, workpiece handling as well as the process design supported by CAD for tool design and FEM for material flow simulation. The success of realising a process chain for precision forging depends on the function and the geometry of the forging as well as the economical conditions, e.g. lot size, piece number, range of variety. In consequence the applicability has to be verified for each single workpiece.

A benchmarking between a traditional and precision forged connecting rod showed the benefits which are a higher precision concerning the dimensions and the entire mass. This enables a shortening of the process chain by eliminating finishing operations.

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