PRECISION FORGING, ECONOMICAL ADVANTAGES IN THE PRODUCTION OF STRAIGHT BEVEL GEAR

Iulian TURCILĂ[1]

This paper aims at analyzing the results of the economic calculation for producing straight bevel gears in two ways, precision forging and machining. The costs for straight bevel gear production are presented in two ways. Moreover, the limits of precision forging process are presented, with respect to the fact that it begins to be more economical than machining and influences a lot the size to costs, thresholds at which the production costs are not substantially changed.

Keywords: Precision forging, straight bevel gear, costs.

1. Introduction

Forging answers to the needs of producing more durable parts, with cheaper and faster methods. Other processes for producing metal parts have certain disadvantages, which are not present in the forging process. For example, the pieces that are made by machining bring high material consumption, high consumption of time, micro cracks on the processed surfaces, briefly - high production costs. The casting process can only be used for some materials and brings porosities in the material of the parts. Pieces achieved by powder metallurgy don't have the same density throughout the mass of material [1]. The forging process has its limitations, but a wide range of pieces can be achieved by this process, using various materials, and having varied and complex shapes. Precision forging brings near-net surfaces or surfaces that do not require additional processing. In case of straight bevel gears, the active surface of the teeth is realized in net form from forging. The pieces realized by forging have a continuous grain-flow, who follows the part profile during deformation. Due to continuous grain-flow and microstructure obtained by the forging process, the durability of such parts is increased by approximately 27% in the case of straight bevel gear.

Meanwhile, forging companies together with software companies have done modeling and simulation of forging process to help improve the design of parts and removal or modification of the factors that hinder the forging process, resulting in premature wear of the tool. Finite element (FE) simulations of tool

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[1] Technical manager, S.C. T.P.S.COM SRL., Romania, PhD student University POLITEHNICA of Bucharest, Romania, e-mail: iulian_turcila@yahoo.com

failure in hot forging processes, a process design which uses thermodynamics and microstructure modeling, and also modeling of the friction between piece and tools have been studied [2].

The purpose of this paper is to show the benefits of precision forging process, both technical and economical.

2. Calculation of costs needed for producing straight bevel gear in two ways, precision forging and machining

Precision forging of straight bevel gears is done on electro-hydraulic press. The press tools are installed with two workstations. In the first stage, the first job is made as an intermediate deformation and results in a very similar shape as the final one of the part. After the first phase, in which the die with teeth profile is located in the upper side, the piece is placed with the teeth down on the second workstation and the final forging is performed (Fig. 1). The result is a straight bevel gear, Ø107 mm external diameter, that will be machined to Ø96.50 mm, having a 6.5 module and 15 teeth, and which doesn't need other machining on the teeth surfaces (Fig. 2).
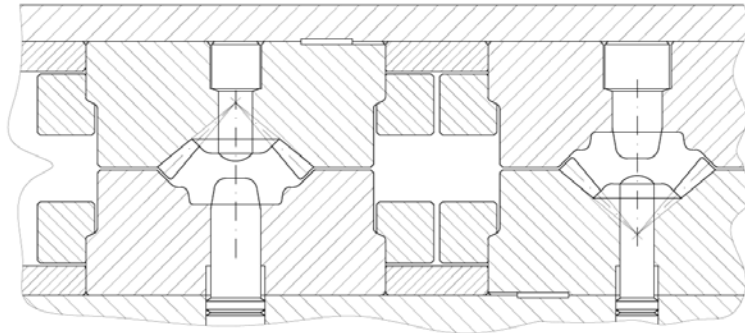

Fig. 1. Precision forging of straight bevel gear, two workstations with one piercer, two dies and one extractor for each [4]

Fig. 2. Precision forged straight bevel gear [3]

Comparing the results obtained after calculating the production costs, it can be observed that the parts made by precision forging are much cheaper than those made by mechanical processing.

Money economy (E_{money}) in case of forged parts is 20.98 euro/piece, established by equation (1). Money economy is calculated by subtracting the costs for production of the forged piece (C_{fp}) from the costs for production of the machined pieces (C_{mp}).

$$E_{money} = C_{mp} - C_{fp} = 51.43 - 30.45 = 20.98 \text{ euro/piece} \tag{1}$$

Equation (2) shows that the costs of producing straight bevel gear by machining are 69% higher than those obtained by precision forging.

$$R_{m/f} = \frac{C_{mp}}{C_{fp}} = \frac{51.43}{30.45} = 1.69 \tag{2}$$

Results from equations (1, 2) are presented for a lot of 2000 pieces, the durability of forging tools being between 2000 and 3000 pieces. This is the maximum ratio between the costs of production. Due to the high cost of producing the forging tools, reducing the number of parts / lot ratio $R_{m/f}$ decreases, reaching 1 for a lot of approximately 800 pieces. Below this threshold, the cost of production is smaller for parts made by machining.

The material costs are taken into account in the above calculations. If the material is more expensive, then, the forging process is more economical due to the small volume of material which is consumed in the plastic deformation, compared to the necessary volume for mechanical processing [4].

The main advantage of the straight bevel gears achieved by precision forging is high durability of these parts during engagement. Taking this factor into account when we calculate the profitability, it can be seen that the forging process is still more cost effective than the machining process. This can be assessed for lots of less than 250 parts as well, especially due to the fact that in lots of less than 250 parts, the costs of mechanical process start to increase [4].

Thus, the pieces realized by precision forging are cost effective for lots smaller than 250 pieces, even if the production cost is higher, due to greater durability, by approximately 27% higher than in the case of parts made by precision forging.

Once an estimated cost of production is realized for a lot of 250 pieces, taking into account the time needed for the preparation of the tools and machines, and the costs of forging process, it is observed that the ratio of the costs of parts made by machining and costs of forged parts is below unity, equation (3).

$$R_{m/f} = \frac{C_{mp}}{C_{fp}} = \frac{54.16}{62.75} = 0.86 \tag{3}$$

Thus, a piece produced by machining may bring an economy of 8.59 Euro. However, relating to the durability of parts too, the forging process is more efficient, even for a lot of 250 pieces.

In (Fig. 3.) the evolution of the costs can be observed for the two processes. The price of machined parts does not decreases significantly in the range of 250 – 2000 pieces, compared to the price of forged parts, which have a significant decrease until the lot reaches the durability of the forging tools.

For lots of less than 250 parts, the costs to produce the pieces increase considerably in case of forging process. The costs for the production of parts by machining have a significant growth, too, because the tool costs are much higher.

For lots greater than 2000 parts, the costs to produce the pieces by plastic deformation have a decrease to the level where they are equal to the tools durability. After this level, there are no longer significantly changes of costs. The costs for achievement by machining no longer change [4].
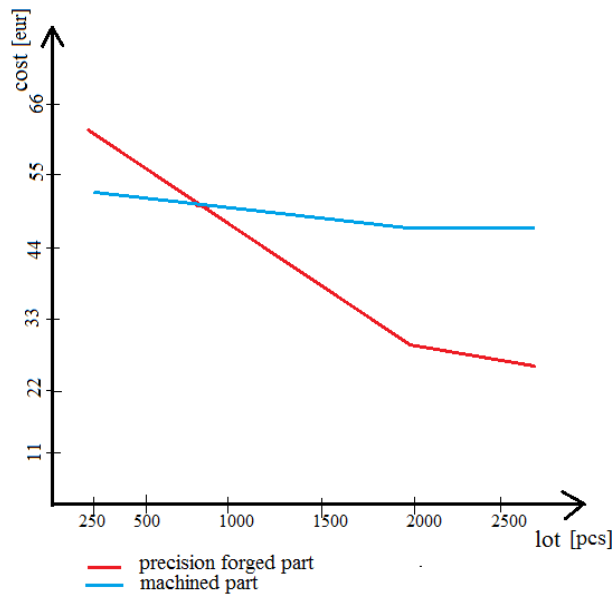
Fig. 3. The evolution of costs according to lot size

By means of calculating the necessary time to achieve a straight bevel gear, it is observed that the milling operation lasts longer, about 10 minutes, compared to the forging process which takes less than 1 minute [4]. This is an important factor in calculating the production costs, and therefore, the costs of achieving the pieces decrease a lot in the case of precision forging process. To reduce the time for producing a lot of parts, the forging process is far superior compared with the machining processes.

3. Conclusions

After forging, straight bevel gears in class 9 of precision were obtained. For higher accuracy, classes 8 - 6, should be performed a cold or a warm calibration. Durability tests revealed that forged straight bevel gears have a durability with approximately 27% higher compared to the machined straight bevel gears.

Pieces like straight bevel gears obtained by precision forging could be used at agricultural machines and industrial equipment.

Calculations can show where the precision forging process start to be more cost-effective compared to the machining processes. In this paper, results of calculations on the costs of fabrication of a straight bevel gear were detailed, taking into account the costs of materials, tools, man-power, utilities resulted from time and industrial machines necessary to produce the pieces.

For maximum efficiency of the plastic deformation processes, the number of pieces from a lot has to be close to the durability of the necessary tools to produce the pieces. These processes can be more economical than machining also for smaller lots than the value close to the durability of tools, due to the fact that these processes result in major savings of time, material, equipment, man-hours and personnel.

In the case of precision forging, where, after the plastic deformation of the material the finished surfaces or near-net shapes are obtained, the final cost to produce the pieces is significantly lower, usually up to 50% of the total cost of mechanical processing. To this factor, the increased durability of the parts due to plastic deformation resulting from grains flow is added also.

The hot or cold plastic deformation processes bring significant cost savings. When the shapes and dimensions of the forged parts are closer to the final part shapes, the costs needed for mechanical processing are lower. It would be ideal to obtain those pieces that require no further machining directly from the forging process. This is possible for parts that do not have very small tolerances and do not have too many surfaces with a functional role.

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