Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 55 ISSUE 2 December 2012

Machining of near-net shape forged pinions

D. Kramar, J. Kopac*
Faculty of Mechanical Engineering, University of Ljubljana,
Aškerčeva 6 1000, Ljubljana, Slovenia
* Corresponding e-mail address: janez.kopac@fs.uni-lj.si

Received 11.10.2012; published in revised form 01.12.2012

Manufacturing and processing

ABSTRACT

The paper presents a machining of near-net shape (NNS) pinions with forged chamfer in automotive industry and compares it with an older procedure of turning pinions without forged chamfer as well as production of pinions in a classic mechanical way from steel bars. It contains a description, which focuses on a technological procedure, utilization of different types of tools, and machine tools. The last part of the paper deals with an economic analysis considering sub-assembly of car starter motors production, their treatment and pinion production in a classic mechanical way from steel bars and with NNS process. The calculations are presented for different batch sizes from prototype to mass production.

Keywords: Automotive industry; Cold forging; Turning; Cost evaluation; Batch size

Reference to this paper should be given in the following way:
D. Kramar, J. Kopac, Machining of near-net shape forged pinions, Journal of Achievements in Materials and Manufacturing Engineering 55/2 (2012) 716-720.

1. Introduction

Minimizing the price in automotive industry for each part is pushing technologists to reduce costs along the production chain. Near net shape (NNS) is an innovative concept in industrial manufacturing. The main focus of this technology is to produce parts, as near as possible close to their final shape and contour, implementing nonchipping techniques. Over the last few years, the precision forging of steel components has gained a much greater importance and recognition. This is predominantly due to the fact that there is an increasing demand for precision parts with high volumes. In this way the manufacturing gives the possibility of a finished product with minimal machining. NNS technology also generates the opportunity to reduce the production steps for a given process chain. Both the above-mentioned characteristics have the same main goal: achieving cost reduction [1-3]. This fundamental target incorporates several other advantages, such as: reduction of process variability, quality improvement in the finished product, and the possibility to focus the design of mechanical devices on functional features, eliminating technical constraints imposed by the process. Based on these factors and in cooperation with the ISKRA Avtoelektrika Company [4], the authors conducted a research regarding the manufacturing of innovative pinions as a part of automotive engine starter, produced by applying NNS processes. The goal of this study is to evaluate whether it is more convenient to produce the part implementing a traditional production chain or an innovative one, based on NNS process. The first step was to locate the available technologies in order to produce the selected part. There are two alternatives: a traditional machining performed with a NC-turning machine and a NNS process, characterized only by deformation processes. Successful cold forging requires appropriate material preparation which is reflected in low flow stress, tool loads and high ductility values. All these pre-conditions demand the proper heat treatment. When steel components are cold forged, soft annealing is the most recommended heat treatment. During annealing, the lamellar pearlite is transformed into a spheroidised microstructure. Such a structure offers less resistance to ferrite slipping, and the flow stresses are lowered as well; see Figure 1 [5].

The next step is to detect the main differential costs between the two opportunities. Comparing technical data, the authors detected the main differences of cost: raw material, amortization, manpower, and direct setup. In order to make the study more reliable, the authors assumed an actual industrial environment featured by an annual demand of 700,000 pieces and a product lifetime cycle of 10 yr. The evaluation led to the conclusion that the innovative manufacturing chain is more convenient.

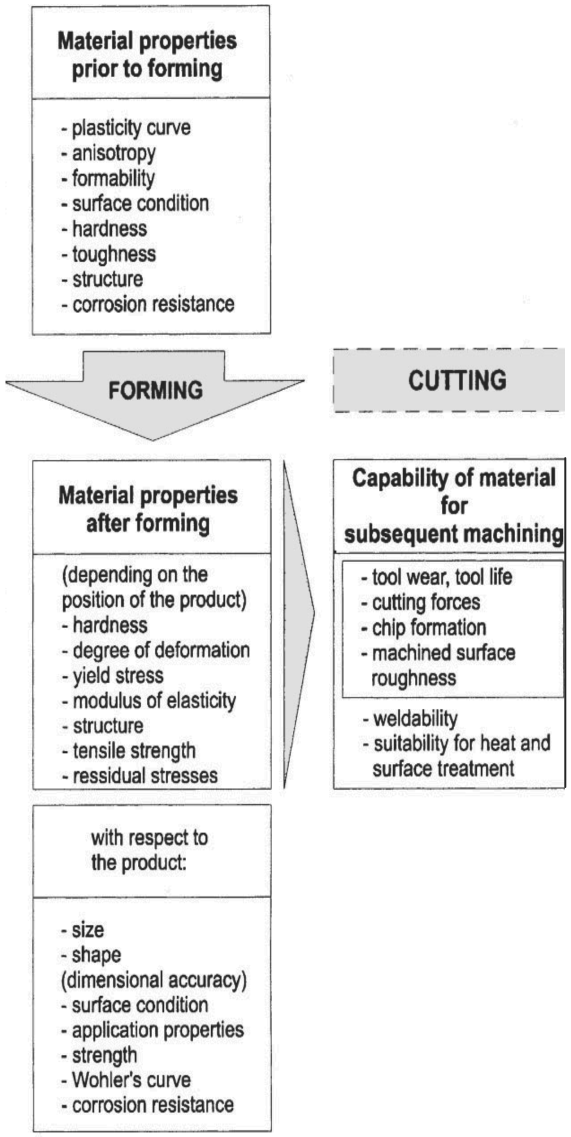

Fig. 1. Material properties prior to and after cold deformation as the basic element of machining with cutting

2. Pinion as a part of motor starter

Figure 2 illustrates a cross-section of a component which is assemble-ready. This motor starter pinion is utilized in a different vehicle for a major German automotive manufacturer. The material grade for this component is 16MnCr5.

2.1. Original manufacturing process

Originally, this part was designed to be produced solely by machining processes. As there is a minimum allowable part length because of functional reasons, this method requires an increased length in the part which in turn requires more weight in the part by the added extra material.

The machining process consists of the following steps (Reference: cross-section in Fig. 2):

1. Part sawing,
2. Rough machining: face and centering, and turning operations,
3. Finish turning,
4. Gear hobbing and deburring,
5. Milling of the chamfer.

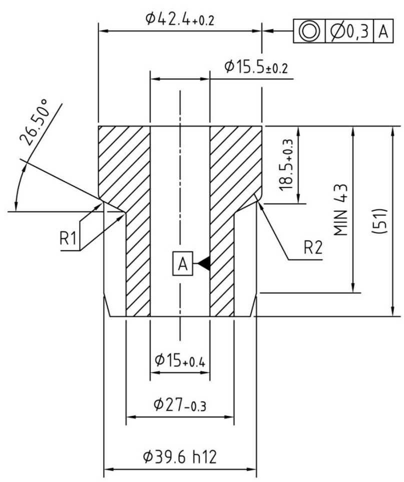

Fig. 2. Cross-section of the pinion

2.2. Today's manufacturing process

Today's design for this component is produced by cold forging. This process entails a three stage cold forging operation. Pinion is formed in the final stage of this operation and the overall dimension for this part is to print specification meaning no further machining is required for this dimension except finish turning. Milling operation of the chamfer at the end of outer gear is also needed to complete the part functional requirements. One significant advantage of formed pinions versus machined one is also the enhanced mechanical strength obtained from the forming process itself. This can be measured by increased strength in the root of the pinion tooth by as much as 25-30%, depending on the heat treatment process [5]. This increase can be attributed to the grain flow orientation created by the forming process, which is favorable for achieving higher oscillating loads. Table 1 illustrates the comparison of the previous and the current design and production steps. The reduction of material for this component is 26% less weight. The cost saving to produce workpiece for final machining is 28% and sawing is replaced with three staged cold forging, and the final cost for this part with the new design amounts to 51.1% in comparison to the previous part using the old design methods of manufacturing.

Table 1.
Comparison of the original and today's manufacturing process costs (€/part)

	Original machining	NNS	NNS optimized
Material / weight (g)	0.71 / (552)	0.43 / (407)	0.38 / (355)
Saw/forging	0.40	0.37	0.60
Σ Workpiece	1.11	0.80	0.98
Turning	0.56	0.42	0.44
Hobbing + deburring	1.19	-	-
Milling	0.35	0.35	-
Σ Machining	2.1	0.77	0.44
Total cost	3.21	1.57	1.42

2.3. Optimized manufacturing process

As this component had been originally designed solely for machining, the forming process replaced and improved previous machining requirements. Design changes are now locked into current production requirements, yet further improvements are still possible as defined below. Another significant advantage of forming the pinion gear versus machining is the cost savings gained by the forming process. The costs involved to machine gears are considerably higher than it is to form them. In addition to this advantage the gear chamfer, which is required for the functional reason and is produced by machining, may be involved in the forming process. Forging tool is more complicated, but cost per finished part is even lower when comparing formed or machined chamfer. Forging with such tool is almost 40% more expensive as forging without chamfering, but one machining operation, namely milling is eliminated. This leads to less material requirements which now decrease the overall weight of the raw material. This also means less material scrap overall.

Fig. 3. Three stages of forming for the pinion with chamfered gear

In summary the information pertaining to the pinion and the comparable methods of manufacturing are as follows:

- Cost reduction by replacing expensive processing methods such as gear chamfering.
- Enhanced mechanical properties.
- Weight and scrap reduction by optimum material utilization and process considerations.

Table 2 shows the advantages in terms of costs and weight when comparing the original design with today's and an optimized layout. The cost of the machined version is double than that of the formed variant. By realizing the optimized variant an additional cost advantage of almost 10% is achieved.

3. Differential cost analysis

In this section the authors present the core subject of this research: the comparison between traditional and optimized NNS processes under an economic point of view. To reach this scope, the differential costs between the two alternatives were considered.

As from economic literature, a differential cost is a future and avoidable cost. We will consider as differential a cost that is different in one of the selected production chains. This evaluation shows the total cost difference between two alternatives; it is not a total industrial cost, since some of costs are not included, i.e. space costs. The main differential cost voices are: raw material, amortization, manpower, and direct costs of setups. The evaluation is made considering a realistic industrial environment characterized by an annual demand of 700,000 pieces for 10 years. In order to make it easier to compare, the costs are always referred to a conformed finished product. The following sections will report one voice of cost each, for both the process chains.

3.1. Raw material

The basic cost of raw material was obtained by a producer of steel rods: the price of a commercial rode is about 1286 € per ton for both the alternatives. The cost of raw material was obtained by simply comparing the price per ton with the amount of the material used to produce a finished part. It is about 0.71 € per piece for the machining process including sawing, and 0.38 € per piece for the NNS process including rod chopping. This price considers the pay-off obtained selling the scrap material. Due to its low value compared to the raw material, the pay-off is not enough to cover the difference by its selling. In the machining process the incidence of raw material is considerably higher.

3.2. Amortization

The number of machinery used in each process chain is imposed by the annual demand. This is the first data needed to estimate the impact of amortization. To calculate amortization the annual demand was compared to lead time and effective working hours. This evaluation was conducted considering the same lifetime of 10 years both for the product and the machineries. The recovery value of the machineries is supposed to be zero. It is an estimation of the impact of the investments on the finished products; it is not a fiscal evaluation. The machining process requires two multi-spindle lathes with driven tools in parallel that cost about 500,000 € each. In total they weigh on the cost of each piece for about 0.7 €. NNS process needs three flow forming machines in parallel that cost about 750,000 € each. The total cost for forging process is about 0.22 € per piece, and then for finish machining the cost of amortization is 0.20 € per piece. So the total amortization costs in case of NNS process are 0.59 € per piece.

3.3. Manpower

The evaluation of the impact of manpower is calculated by the number of machines in use. All the equipment considered in this evaluation is suitable for operating continuously. To keep the manpower cost down, the production is supposed to be set on a three shifts basis. The evaluation is made considering the medium gross cost of manpower for Western Europe, that is about 21 € per hour. The total amount of productive hours per year was estimated to complete the calculation of the manpower cost. The traditional process is performed on two multi-spindle lathes. The operator of this machinery must only load and unload the pieces and oversee the production. Despite this consideration, one operator can take care of only one lathe, so the request is for two operators per shift for three shifts a day. The total cost for manpower in the machining process is about 1.33 € per piece. The NNS process is characterized by three forming machineries. The researcher conducted an evaluation to verify whether one operator can keep care of all machineries at the same time, basing himself on the distribution of up time and down time of these machineries. The result of this evaluation was positive, and so three operators for three shifts a day work on three deformation machineries. The impact of manpower for the NNS process is about 0.19 € for forming and 0.23 € for machining per piece, together the total costs for manpower for NNS process is 0.42 € per piece.

3.4. Direct costs of the setup

Direct costs of setup include the purchasing of the equipment and tools that need to be replaced due to wear. The loss of productive time attributed to setups was already considered in the calculation of the actual productive time. The multi-spindle lathes are equipped with a set, composed of 13 cutting tools, that costs about 100 €. The life time of these tools is calculated considering the material worked on and the setting parameters. The result is that each tool can work about 340 to 560 pieces, depends on operation and cutting tool producer, before being replaced. In the traditional process, setup costs have an impact of about 0.47 € per piece. In the NNS process the only equipment that needs to be replaced is forging tool composed of three deformation inserts. The wear of this device causes the reduction of the external diameter and the roughness on the deformation surface. The tool costs about 18,000 €, and needs to be rebuild every 30,000 pieces produced. The costs of the setup in the NNS process together with cutting tools are about 0.2 € per piece. The price for new clamping device, which is required for new way of clamping, is also included.

4. Conclusions

Due to the ever increasing demand for precision parts with high volumes for the automotive industry, the precision forming of steel components will also in the future gain more significant importance. Because of this requirement, new manufacturing methods and practices have been and will need to be further developed utilizing cold, warm, hot and combination forging processes. With the increasing demand for assemble-ready components, formed parts with machining requirements will be in greater demand.

The sum of the four parts of cost analysed is superior in the traditional process. In fact the total differential cost amounts is 3.21 €, whereas the total cost of the NNS process is 1.57 € for today's and 1.42 € for optimized NNS process. Supposing an annual demand of about 700,000 pieces, the difference in cost leads to an annual saving of about 1,148,000 € for today's process. Optimization of the NNS process leads to another saving of 105,000 €. The graphs in Figure 4 represent the percentage distribution of the differential voices of cost for both the alternatives. It is interesting to remark that the cost of direct setup has almost the same percentage in both cases. Actually real cost for direct setup is more than double in case of machining process. The manpower has the main incidence on the difference of costs. In fact the cost of the manpower used is about two times higher in the machining process. The fact is that the NNS process is more automated and one operator can handle more machines.

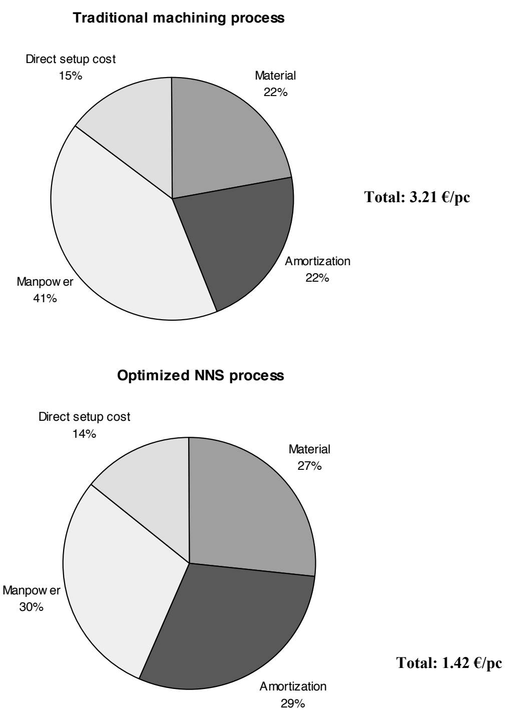

Fig. 4. Distribution of the differential costs in percents

The difference of the raw material costs also leads to another important economic consideration. The percentage in NNS process is higher, but actually the cost of material is reduced almost in half in case of NNS process. The company must support the financial costs of the material starting from the time of purchase to the selling of the finished product.

A smaller amount of raw material usage traduces into a limited environmental impact. Both the consumption of the natural resources and the need of energy used in supplying, manufacturing and transporting are reduced.

We can conclude that the traditional machining process is only reliable for prototype series or batches with less than 10,000 pieces. In case of larger batch size NNS process should be considered.

This report will direct us to focus on the future and the overall manufacturing processes involved to design, and to produce these components for the future. This means that an intelligent combination of individual manufacturing processes may lead to the reduction of individual processes and this leads to an increased cost effectiveness and competitiveness of the component.

References

[1] K. Lange, T. Herlan, Material and energy saving by metal forming processes, Advanced Technology of Plasticity 1 (1990) 285.

[2] R. Balendra, Net-shape forming: state of the art, Journal of Materials Processing Technology 115/2 (2001) 172–179.

[3] K. Lange, H.J. Keller, Some aspects of the economic production of complex steel components by cold forging and machining, Journal of Materials Processing Technology 46 (1994) 239-251.

[4] M. Gorjup, Turning pinions with forged chamfer, Diploma work, 2012 (in Slovene).

[5] J. Kopac, M. Sokovic, Dimensional accuracy and cost optimisation in the finish machining of cold formed parts, Journal of Materials Processing Technology 92-93 (1999) 335-343.