AGMA Technical Paper

Complete Machining of Gear Blank and Gear Teeth

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Demands for increased throughput, with smaller lot sizes at lower cost have led to the development of an innovative approach to machining both: the gear blank and gear teeth on a single machine.

This paper will concentrate on the potentials and risks of combined process machines what are capable of turning, hobbing, drilling, milling, chamfering and deburring of cylindrical gears. The same machine concept can be used for singular operations of each manufacturing technology on the same design concept. This leads to reduced amounts of different spare parts, increases achievable workpiece quality and harmonizes on a common user friendliness. In the end the economical potential of combined process technology and a vision for integrated heat treatment is shown.

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Introduction

Over the past years a large number of different machine tool builders have shown a tendency for combination of different processes into one machine [1]. The benefit and the limitations of such a concept including gearing processes is characterized by technical, commercial and local impacts. Increased flexibility and shortening down of lead times are the main driving factors of such developments.

Productivity in soft gearing processes

Due to increased flexibility requests on industrial serial production today batch sizes are decreasing [2]. In parallel the part complexity and the requested workpiece quality is increasing. For meeting both requests the process chain has to be analyzed for shortening set up times (Figure 1).

In general the gear production of a forged or sawed blank part is characterized by subsequent manufacturing processes like turning, milling and/or drilling, hobbing and in most applications a rotary chamfering and deburring before heat treatment (Figure 2). Added by washing and marking operations as optional operations there are at least 5 different operations in the green stage for dry machining a geared workpiece [3,4]. Due to wet cutting, the demand on washing/cleaning and additional operations there are existing up to 12 different operations in gear manufacturing in today's green stage production. The focus of process optimization was in a first step the concentration on the 5 most important process technologies like turning, milling, drilling, hobbing and chamfering/deburring.

General market trends:

![General market trends diagram](image)

Figure 1. Why combination technology?
The so-called combination technology is based on a restructure of the existing process chain. In a first step a common machine platform for all this different manufacturing technologies had to be identified. This was realized by a L-formed mineral cast installation rack. Based on that a broad range of different subassembly components for continuous and interrupted cutting has to be added (Figure 3). In most cases the subassembly component has to meet divergent requests and with that come associated compromises. One example for that is the work piece drive. For turning a high torque capacity in combination of highest rpm-capability is state of the art. For gear operations, for example, hobbing or shaping a high level of continuous rotary movement is necessary. For meeting both characteristics the torque capacity of well known turning spindles had to be reduced by factor three. In parallel a universal interface for different subassembly groups on the machine platform and installation basis had to be identified and to be realized. This standardization will ensure in future that on the same platform additional manufacturing technologies will be implemented or can substitute different configurations, based on applications needed of technology enhancements.
As a result on that concept the total duration of a workpiece that is remaining in different machines is reduced by the red marked idle times (Figure 4). In daily production not all operations are optimized to one common time. In addition to that every operation shows a smaller or larger stock or queue of workpieces in front of any machine, so that a larger than necessary amount of workpiece material is stored in the production line. This is impacting logistic efforts and costs as well as the working capital by the amount of workpiece material that is stored semi finished in the production line. Along with workpiece materials in different stages of the production lines, quality of the process has to be considered. This is due to the different features and workpiece clamping features change from turning to gearing operations.

One additional aspect is the workpiece quality. In subsequent operations the turned bearing seat is not perfect adjusted to the gear due to a change in workpiece clamping between turning and hobbing operation.

As mentioned in Figure 1, a broad range of workpieces is capable for combination technology. In the shown example a first focus is related to shaft typed gear production (see Figure 5). Due to the limited no. of tool places on the turret a lengthening and centering operation is requested before loading the shaft typed workpiece to a machine that is capable for combination technology.

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**Figure 4. Benefits of multiple manufacturing in one clamping**

- Rough part forged or from bar.
- Workpiece weight < 30 kg

**Figure 5. Workpieces for combined process technologies**
Based on that, external part geometries and features can be manufactured.

Lengthening and centering of shaft typed workpieces. For disk typed workpieces a corresponding driven tailstock with a special solution of workholding equipment is necessary.

Combination technology combines different manufacturing technologies into one numerical control (Figure 6 and Figure 7). Due to the high number of operations and machine functions, the machinist has to have a high level of machine and process understanding. Turning is not hobbing, chamfering and deburring is not milling or drilling. This high request on experience and skill brings up the question of the level of skill and the area of market, where such a technology that will be successful installed.

![Output shaft: - Clamping between centers with face driver](image)

**Figure 6.** Process Analysis for shaft typed workpiece

![F40 Turning cell: OP 10](image)

**Figure 7.** Process Analysis for disc typed workpiece
Based on individual skills the combination technology is a high end request on a machinist’s experiences and skills. Based on local documented skills of production employees and an analysis of that shows that combination technology will ensure positive impacts to the higher salary areas of the world. In Asia-Pacific region the labor costs for human resources and footprint of a machine will show significant benefit for well known, old structured process chains (see Table 1).

### Table 1. Labor cost comparison

<table>
<thead>
<tr>
<th>Country</th>
<th>Labor cost per year</th>
<th>Labor cost per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>$1.70</td>
<td>$1.35</td>
</tr>
<tr>
<td>India</td>
<td>1.45</td>
<td>$1.15</td>
</tr>
<tr>
<td>West Europe</td>
<td>$70.00</td>
<td>$55.55</td>
</tr>
<tr>
<td>Americas</td>
<td>$65.00</td>
<td>$51.58</td>
</tr>
</tbody>
</table>

At the higher cost levels, like the situation in Europe and North America, the combination technology shows beneficial characteristics.

In future the inductive heat treatment of gears, bearing seats and other relevant items on a work piece will reorganize and reduce the manufacturing efforts of geared work pieces. Today the carburizing heat treatment process is subdividing the gear manufacturing process into two different sections. A first soft oriented part and afterwards a second, hard finish manufacturing sequence. The continuous flow of material of each, soft and hard, are interrupted by the carburizing process. By implementation of the inductive hardening process a change of the today used work piece materials will be necessary. In addition to that the soft manufacturing strategy will be impacted by longer cycle times and reduced life times to the used tools.

The great chance will be a in line heat treatment with competitive work piece behaviors in comparison to the carburizing process. First applications of gears show a well working performance on that, see Figure 8.

### Summary

Main manufacturing technologies in gearing are turning, hobbing, chamfering and deburring. In serial and mass production of gears the direct linked use of singular processes is state of the art.

In parallel to optimization of each process the integration of different processes shows a high potential for reduction of the lead time as well as an increased level of work piece quality. Reduction of production process complexity and peripheral investments for automation systems increase the economical aspect of such efforts.

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**Figure 8. Inductive hardened gear**
The discussion of local based human costs, the integration of heat treatment and in final the possibility for inline inspection of gears ensures a possibility for high level gear production.

Final the complete machining of gear blank and gear teeth will impact manufacturing strategies in future.

References

1. Statistisches Bundesamt/VDMA

