Analysis of complex manufacturing processes scheduling in different advanced informatics environments

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Abstract. In the case of the cost management itself, you can also indicate the existence of a similar dependency system. Their exact determination is connected with the establishment of similarity parameters, which will allow estimating the costs of new production orders based on previous experience. It must also refer to the existing machinery park. For example, if medium-sized elements have been implemented so far, the new order includes elements with large dimensions, then you need to have indicators to estimate the possible increase in costs related to the change in dimensions. Accurate estimation of this type is possible only on the basis of indicators obtained experimentally and determining the appropriate way to extrapolate them. The present study presents only the technological part of this process related to the determination of technological parameters, as a comparison for a narrow, but very specialized technological group, which are gears. The comparison of basic technological processes was taken into account. The purpose of these preliminary, basic studies was to obtain information on the estimation of gear machining costs, for new types of tools and new machining positions, which in some situations can be treated as an alternative. Application of the proper project management methodology leads to increasing the likelihood of success and achieving significantly better results at a lower cost, less effort and in shorter time.

1. Introduction

The actual tooth shape and its dimensions are the decisive result of the treatment process. Knowledge in the field of machining of gears, selection of parameters and the shape of the tool enables the theoretical determination of the actual dimensions of the teeth. The basic methods of machining of gears and the influence of machining and parameters on teeth are presented below.

In the envelope method, the tool, apart from the main movement (for example: straightforward for slotting, rotary for milling) performs a feed movement, rolling away from the gear being executed. The rolling motion is identical to the movement of a possible mating toothed wheel. During machining, the circle cut with the tool forms the so-called the technological transmission, and the teeth of the tools must have a contour in line with the forming outline. The flanks are formed as envelopes of subsequent tool tooth positions. The advantage of the hobbing method is the possibility of using one tool for machining the same module with different number of teeth or different profile shift ratio. It allows obtaining higher manufacturing efficiency [1].
In the contour method, the tool assumes the shape of the rebate and carries out the main motion along the whole width of the tooth, in contact with the produced wheel on its entire active length of the cutting edge. There are two methodical methods: the method with the division - the tool performs one bore, and after the division the next bend. The accuracy of this method depends mainly on the accuracy of the machine, in this case, the dividing device. The disadvantage of this method is that usually one tool corresponds to a particular gear wheel. The second method is the complete method - in this case, the tool for chiselling or drawing shapes all the outlines of the teeth in one moment. The advantage of this method is the mass production of smaller gears and internal teeth in a relatively simple way. The disadvantage - a separate tool is required for each type of wheel [2].

2. Theory of teeth manufacturing modelling
Conveying milling is one of the most commonly used methods for cutting external cylindrical teeth. The envelope milling cutter is a cylindrical tool where along the helix (one or several depending on the number of times the tool winding) the cutting teeth are made, which are formed on the body by the process of staggering and grinding (applies only to monolithic milling cutters). Modern technologies of producing monolithic envelope milling cutters allow to mill teeth up to the 6th grade of accuracy in accordance with the PN standard. The condition of the machine affects the accuracy to a large extent. The hobbling can be done either with straight or bevelled teeth (at the moment when the wheel has a groove between the teeth).

More and more production plants in the resources of production means have 4 or 5 axial machining centres. There are already available CAM environments [3, 4] that allow machine tools to be used for making involute teeth without the use of special tools, which was impossible several years ago, or possible using tools whose shape reproduced the shape of the root (involute notched on the tool profile).

The integration of CAD software with CAM software allows you to define the teeth in accordance with the constructor guidelines, and then determine the optimal path of teeth milling using a 4 or 5 axis machine tool. The difference between milling teeth with standard methods (envelope milling, contour milling) and milling with the use of machining centres is based on the number of tools used to produce one wheel (figure 1).

Figure 1. Rough milling simulation.
The standard methods use only one tool, while in the method using CAM software, several tools are used to make the gap between the teeth (figures 2 - 3).

![Figure 2. Finish milling simulation.](image)

![Figure 3. Simulation of finish milling of the involute.](image)

The last stage is a key one, because the required involute on the teeth is obtained there. In contour milling, this is achieved by the process of coiling and synchronizing movements of the workpiece with the tool, in this case the complicated CAM software algorithm generates the appropriate tool movement path, synchronizing all axes of the machine in such a way that the milling cutter involute on the flank. This is not possible with the standard CAM software.

3. General aspects of CAM simulation
Machining process simulation is a complex task, which depends on the attributes of the applied CAM environment. In figures 4 – 6 are presented different stages of gear toothing using different milling
cutters types. The first two diagrams present stages of operation of a slotting cutter. The last one presents the operation of an interlocking cutter.

Figure 4. Beginning of milling of a tooth space.

Figure 5. Finishing of milling of a bottom land of a gear.

Figure 6. Finishing milling of a side wall of a tooth.
The aim of the study is to compare the time of envelope milling, using a screw milling cutter for sintered carbide exchange plates, with milling using commercial milling cutters on a 4-axis machining centre.

4. Tests of the CAM approach
Milling of the investigated gear (33 teeth) was conducted using a commercial working milling centre. The process itself was complex because it was a contour milling and not the hobbing one which is the most effective method of gears milling but it requires a special milling machine. The process parameters are presented in table 1.

| No | Tool     | Revolution 1/min (1/min) | Rolling velocity m/min (m/min) | Travel mm/rev (mm/rev) | Travel by tooth mm (mm) | Cut depth mm (mm) |
|----|----------|--------------------------|-------------------------------|------------------------|------------------------|-------------------|
| 1  | Cutter 35 | 2000                     | 219,91                       | 1998                   | 0,333                  | 1,5               |
| 2  | Cutter 20 | 1980                     | 124,41                       | 750                    | 0,095                  | 2                 |
| 3  | Cutter 16 | 3200                     | 160,85                       | 950                    | 0,074                  | 0,8               |
| 4  | Cutter 12 | 6630                     | 249,95                       | 2984                   | 0,15                   | 0,75              |
| 5  | Disc cutter | 830                      | 286,83                       | 1145,4                 | 0,138                  | 4                 |

Figure 7 shows the milling times on the envelope milling machine compared to milling at the machining centre. The parameters for particular operation and technological actions have been determined according to proper milling standards.

Figure 7. Milling times [min] of a gear Z=33 depending on the method being used composite hobbing cutter, hobbing cutter, milling centre.

According to the above results, the method of milling using CAM software is the slowest and requires the most tools, but the time is comparable with cutting the teeth with a conventional cutter. One should point that apart from time the other product parameters are also important. Among other there are problems with proper material characteristics [5,6]

5. Conclusions
Analysing the above study it can be concluded that milling with the use of CAM methods is unprofitable due to the use of a large number of tools, while obtaining machining times corresponding to the milling times with conventional milling cutters. However, the advantage of this solution is the ability to perform various gears with any module, angle of inclination, angle of tooth inclination; different tooth width without the need to buy expensive tools dedicated to machining gears, which in the production of a small series generates huge costs. Another advantage of using CAM in machining of gears is the ability to make prototype gears, and very easy edition and the ability to manoeuvre the gear wheel parameters directly in the CAM software enables rapid production of prototypes for many
devices or machines and allows cooperating with CAD solutions [7]. The important factors that should be considered at the plantings the quality level of obtained products. One should take into consideration complex method of quality assurance [8,9].

The other factor that should be taken into consideration is the production organization. It is related with such elements like resources flexibility, unpredictability and uncertainty as well as supervising [10,11]. One of possible adding approaches is the application of CCPM [12]. This method combines the most important features of good project management. It is a reliable technology for project management. One of the most important aspects of CCPM is the reasonable analysis of the project realization process.

6. References
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