Influence of Machining Data on Developed Cutting Forces in Gear Hobbing

Abstract: In every manufacturing process the prior knowledge of the developed cutting forces is crucial in order to increase the cutting performance and make the optimal selection of cutting conditions. In gear hobbing the complexity of the process as well as the diversity of the produced chips makes it difficult to create and use empirical charts that predict cutting forces according to the process parameters. The simulation model Hob3D was developed in an effort to create an accurate model for gear hobbing that can produce reliable results for the cutting forces. The effect of the various parameters of the gear hobbing on the developed cutting forces by the aid of Hob3D is presented in this paper.

Keywords: Gear hobbing, Cutting Forces, CAD Based Simulation, Cutting conditions

1. Introduction

With the cutting process of gear hobbing the production of high precision external gears is possible. The complex kinematics of the process and the shape of the cutter are two of the reasons why it has not been thoroughly investigated. The cutting process creates a collection of chips whose geometries are complex and cannot be described by analytical equations. This is one of the main reasons why the effect of the parameters on the developed cutting forces has not been examined. The effect of the main parameters including tool, gear and cutting process parameters is hereby examined.

Research in the field of gear hobbing can be divided into three categories, according to the different approaches followed by the researchers. In the first of these categories researchers focus on the development of simulation models of the cutting process either by means of analytical, mathematical equations or by means of numerical methods. The first model for gear hobbing simulation was created by Sulzer (1973). In this model, in order to produce the non deformed chip geometry, the discretization of both the cutting tool and the work gear are used. Later, additions have been made in this model including cutting forces and wear calculation (Bouzakis and König, 1981; Bouzakis, 1980; Gutmann, 1988; Joppa, 1977). Another simulation code introduced by Michalski (Michalski, 2009; Michalski and Skoczylas, 2008a; Michalski and Skoczylas, 2008b) used a CAD environment in order to produce the geometry of flanks which were machined by means of gear hobbing. A mathematical modeling of the process, where chip characteristics as well as the flank geometry are calculated, was also presented by Vedmar (Vedmar, 2010; Vedmar, Andersson and Stahl, 2009).

The second category includes research on the development of finite element models of the manufacturing process, in order to calculate the cutting stresses or temperatures on the cutting tool or on the workpiece. The research in this field was done either with the use of the non deformed chip geometry in order to acquire the developed stresses on the cutting tool (Antoniadis, 1989; Antoniadis, Vidakis and Bilalis, 2002a, 2002b), or with the use of simulation programs that calculate the deformation during the machining process in order to acquire the temperatures and stresses in both the workpiece and the cutting tool (Bouzakis, Friderikos and Tsiafas, 2008; Bouzakis et al., 2008; Friderikos, 2008).

The third category includes experimental work to observe and model the development of the wear distribution during gear hobbing. In this research area the studies aim to find the
best combination of substrate and coating, the effect of edge preparation in wear development, the rapid characterization of the coating wear resistance and the study of the wear mechanisms (Claudin and Rech, 2009; Gerth et al., 2009a; Gerth et al., 2009b; Rech, 2006; Rech, Djouadi and Picot, 2001).

2. Simulation code Hob3D

The Gear hobbing kinematic chain consists of three independent movements, the correct coordination of which is crucial in the production of a gear of specific characteristics. The first of these movements is the rotation of the hob around its axis, which is the primary cut movement. The second one is the rotation of the gear around its own axis, whose rate is defined as a fraction of the hob’s rotation speed. Finally, the third movement is the transition of the hob parallel to the axis of the gear, movement which is the primary axial feed of the process. The three movements are graphically represented in the top left side of Fig. 1.

In order to simulate the cutting process a simulation model has been created. This simulation model was embedded in a CAD environment thus exploiting its capabilities of representing complex geometry solids. In order to simulate the process, the three movements, as described above, are moved into the cutting tooth and are composed into one 3D surface that is used to split the volume of the workgear into two parts: the workgear after a specific generating position and the non-deformed chip geometry that is produced. This is described in the lower left part of Fig. 1. Kienzle Victor’s equations (1957) are used in order to acquire the cutting forces from the non-deformed chip geometry. Their equations describe the cutting forces in relation to the width and the thickness of the chip geometry in the turning process. By segmenting the cross section of every revolving position into elementary areas, we can use these equations to predict the cutting force components in that specific elementary area. The process described above is repeated for all elementary area of every revolving position. This way we can acquire the total cutting force components for every generating position.

The results of the model include, as mentioned before, the 3D chip geometry of the non-deformed chip as well as the gear gap. In addition, text files that include data about the chip thickness and the chip cross section area in all the revolving positions and the cutting forces in every tooth of the entire hob are exported. In the left part of Fig. 2 the geometries of 22 solid chips are presented. In the lower right part of the same figure the chip cross section area of all the revolving positions, of all the generating positions are presented as well. As it can be seen, the cutting process begins from the leading flank of the cutting tool for the first few generating positions. At this stage the chip cross section area is rising slowly as the chips grow in size but not in thickness. As the head of the cutter gradually enters the cutting process, starting from generating position -29, the chip cross section raises rapidly, especially in the last revolving positions of every generating position. This is because the chips grow both in size and thickness. The maximum cross section area moves from the first revolving positions to the last. At the same time the trailing flank enters the cutting process and the chip cross section area gets to a maximum at generating position -15. From that point on, the chip gradually becomes thinner until the leading flank stops machining and the slope of the descent of the chip cross section area decreases.

Finally, the cutting process ends with the generating position 17. In the top right part of Fig. 2 the development of the maximum chip thickness and the chip cross section area in
the generating position -15 are presented. Generally, the maximum chip thickness follows the variation of the cross section area except for the mid part of the plot where the maximum chip thickness is maxed at 0.13mm and stays in that region for 12 degrees of hob rotation, whereas the chip cross section area rises. This is due to the fact that the chip grows in width while its thickness does not change.

The simulation model is equipped with a fully functional user interface, with which the user can submit simulations, view the results and run queries on the results in respect to chip dimensions and cutting forces. The cutting force viewer form is presented in Fig. 3. The cutting forces are plotted for all three components on the main part of the form. On the right part of the form, the three coordinate systems in which the cutting forces can be seen as well as the data of the simulation are illustrated. Finally, the controls of the viewer are located on the bottom right part of the form.

The verification of the force calculation algorithm was conducted using experiments carried out by Gutmann (1988). The comparison between the calculated and the measured cutting force components is described in Fig. 4. As it can be seen, both simulated and measured cutting forces have the same magnitude and follow the same pattern. As it can also be observed, the maximum and minimum values of the cutting force components are accurately predicted, especially in the case of the highest, in magnitude, cutting force component.

3. Effect of process parameters in resultant cutting forces

Having verified the simulation code as well as the cutting force component calculation code, this model can be used to predict the influence of six parameters on the extreme values of cutting forces. The parameters that were selected were the ones that have the greatest influence on the developing of cutting forces and are related with the geometry of the produced gear and the hob as well as the cutting conditions.

First, the parameters that influence the gear geometry are examined. These parameters include the module of the produced gear, its helix angle and the number of its teeth. The first parameter that was examined was the module of the produced gear. In order to be able to study the influence of the module on the resulting cutting forces, the hob helix angle was kept stable and the diameter of the hob was modified as for the cutting forces to be comparable. As can be seen in Fig. 5, all three components of the cutting forces increase with the growth of the module.

Moreover, the values of all three components increase in magnitude linearly as the module increases. This is due to the fact that, as the module increases the chips become progressively larger. In this behavior, the more affected dimension is the width of the chip compared to chip thickness. This can explain the fact that there is a linear relation between the module of the produced gear and the resulting cutting forces. The slope of this relation is different between the three force components with the Z component having the steepest slope and the Y component having the mildest slope. This is explained by the fact that Fz is less influenced by the mutual cancelation of the cutting force components produced by the opposite flanks of the hob, whereas the Fy is more affected by this cancelation.
The next parameter of the gear geometry that was examined was the number of teeth of the resultant gear. As it can be observed in the left part of Fig. 6, the variation of the number of teeth has a small effect on the resulting cutting force components. More specifically, the X component of the cutting forces is increased, whereas the Y component is slightly decreased by the increase in the number of teeth of the produced gear. This behavior is due to the fact that more generating positions are needed to produce a gap, due to the larger diameter of the gear. This leads to minor changes in the geometry of the chips and the cutting forces.

The helix angle of the produced gear was the last parameter of the gear to be analyzed. In the right part of Fig. 6, the cutting forces of helical gear cutting are presented. As can be seen, in all cases, the cutting force components are larger than the ones observed in the spur gear. This happens because the chips produced by the gear hobbing process of helical gears are longer and the teeth of the cutter that are simultaneously engaged in the helical gear are more than the ones of the spur gear case. Another thing that can be observed from the plots of the cutting force components is the fact that for the X and Y components of the cutting forces, the extreme values acquired are symmetrical with respect to the spur case, whereas the ones for the Z component are not. This happens because hobbing gears with a positive helix angle correspond to Equi-directional hobbing, whereas hobbing gears with a negative helix angle correspond to Counter-directional hobbing. These two processes produce different chip geometries. As an example, in the case of Equi-directional hobbing of the 30° gear, the generating positions required to generate a full gap range from -48 to 16, whereas in the -30° case they range from -17 to 47.

Apart from gear parameters, the hob geometry parameters are examined. The parameters that were selected were the number of hobs columns and the number of hobs origins. Their influence on the resulting cutting force components is presented on Fig. 7. In general, the cutting force components in all three axes decrease as the number of hobs columns increases. More specifically, the maximum values of cutting force components on the X and Z axis decrease in magnitude as the number of columns increases, in contrast to the minimum value of them. This happens because the increase in the number of hobs columns corresponds to thinner chips, which is the main reason behind the non-linear reduction of the cutting forces. In the case of a six and eight fluted hob, the minimum value of the forces in the X and Z axis are zero, due to the fact that the hob cuts the gear blank one column at a time. As the number of columns increases the distance between the hobs columns becomes smaller and more than one column machining simultaneously, leading to the increase of the minimum values of the cutting forces. It can also be seen on the same figure that the hobs with more origins generate higher cutting forces as they cut the gear blank. This is a logical result since more hob origins results in fewer generating positions required in order to fully cut the gear gap. Taking this into account, the produced chips are thicker and the cutting forces are bigger as the number of origins of the hob increases.

Finally, the last set of parameters to be analyzed was the cutting conditions. The examined parameters were the axial feed and the cutting strategy. Fig. 8 sums up the results of the simulations made for different axial feeds in both conventional and climb hobbing. It can be easily observed that climb hobbing produces higher forces in the X axis in all axial feeds, whereas the Z component of the cutting forces is always higher in the conventional hobbing strategy.
The influence of the axial feed on the resulting cutting forces is illustrated in the same figure. The cutting force components increase rapidly in X and Z axis whereas in the Y axis they tend to be stable. The reason behind this behavior in the cutting forces on the X and Z axis is the fact that as the feed increases the chips produced become longer and thicker, increasing their cross section area and the cutting forces.

In order to examine the combined influence on the resulting cutting force components of the change of the module and the teeth of the produced gear, a set of simulations was executed. The results into three surface plots are presented in Fig. 9. In general, on the X axis the forces tend to become bigger as the number of teeth increases in all the cases examined, whereas this behavior is reversed in the Z and Y axes.

4. Conclusions

Cutting force component prediction is crucial for the correct planning of every machining process. Gear hobbing is the most common method of manufacturing high precision involute gears. In this paper a CAD based simulation code was used in order to calculate the penetrations of the cutting tool as well as the resultant cutting forces. The results of the model were verified by experiments performed by Gutmann. The thorough knowledge of the developed cutting forces and the influence of gear and hob geometry as well as of cutting conditions on them, are of great importance as they influence the cost of the manufacturing process and the quality of the produced gear. So, the influence of the parameters of the cutting process on the resultant cutting force components was studied.

References


Author


Title

Figures

Figure 1: HOB3D simulation process.
Figure 2: Chip solid geometry characteristics.

Figure 3: HOB3D global cutting force viewer form.
**Title**

**Figure 4:** HOB3D Verification.

**Figure 5:** Influence of the module in the resultant cutting force components.
Figure 6: Influence of the number of gear teeth and gear helix angle in the resultant cutting force components.

Figure 7: Influence of the number of hob columns and hob origins in the resultant cutting force components.
Figure 8: Influence of axial feed in the resultant cutting force components.

Figure 9: Influence of the module and the number of gear teeth in the resultant cutting force components.