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Hob3D: A Novel Gear Hobbing Simulation Software

Nikolaos Tapoglou, Aristomenis Antoniadis

***Abstract*— Gear hobbing is a common method of manufacturing high precision involute gears. The thorough knowledge of the developing cutting forces and the wear of the cutting tool are of great importance in order to produce helical and spur gears as they influence the cost of the manufacturing process and the quality of the produced gear. HOB3D is a simulation code that enables users to simulate the process of gear hobbing through a commercial CAD program. This paper illustrates the graphical user interface with which the user interacts with HOB3D and the cutting force module of the program as well.**

***Index Terms* - cutting forces, gear manufacturing, gear hobbing, simulation**

I. Introduction

EVERY high performance gear transmission module is composed of involute gears. External involute gears can be manufactured with a series of methods of which gear hobbing is the most widely applied. A novel simulation code was developed aiming at the simulation of the gear hobbing process. This code, called HOB3D, can simulate the cutting process in a commercial CAD environment, thus producing results determined with the optimal precision.

II. State of the Art

Gear hobbing process, as opposed to turning and milling, is a sophisticated metal removal technology owing to the complexity of hobbing cutters geometry and the advanced kinematics of the process. The process is based on three relative motions between the workpiece and the hob tool. Due to the generating rolling principle, complex tool geometry, different chip flow mechanisms and complex kinematics, the simulation of gear hobbing process is quite difficult. A great number of experimental-analytical methods have been established in order to calculate the developing cutting forces and tool wear progress aiming to the process optimization [1].

As in any cutting process, the predictability of machining parameters, such as cutting tool wear, cutting forces, etc., are of immense research and industrial importance in gear hobbing. For this reason, experimental and sophisticated numerical models [2], [3] are used to simulate the cutting process in order to determine the non-deformed chip geometry. In the 1970s, the FRS code was built, calculating chip dimensions and cutting force components [4], [5]. This approximation model is proposed for the determination of the hobbing process results, but the main characteristic of its method is the reduction of the actual three-dimensional process to planar model, primarily for simplification reasons. The application of this former approximation is leading to planar results, without to represent the exact solid geometry of the real chips and gears, with accuracy directly dependent from various input parameters such as the number of the calculation planes [6]. Furthermore, any post-processing of the extracted chip and gear planar geometries, e.g., finite element analysis, requires additional data processing which leads to supplementary interpolations of the two-dimensional results. Nowadays, FEM and CAD software packages support chip removal calculation and analysis, while others have been developed to assist with the determination of data such as chip geometry, cutting force components, mechanical stresses and wear performance [7], [8].

III. Hob3D Simulation code

The simulation code Hob3D [9]-[12] consists of the simulation code and the Graphical User Interface. The interface enables the user to submit cases for calculation in the Hob3D code and analyze the simulation results as well.

The geometry of a gear can be defined based on six parameters: modul (m), number of teeth (z_2), outside diameter (d_g), helix angle (h_a), gear width and pressure angle (a_n). In order to fully define the kinematic chain of gear hobbing, a series of other parameters must be established. These parameters are hob diameter (d_h), number of columns (n_i), number of hob origins (z_1), depth of cut (t), axial feed (f_a) and cutting speed (v). Finally, there are more parameters such are the helix angle of the hob (γ) and the axial pitch (ε) which already exist or can be calculated. Fig. 1 presents the form which is used for data input for the gear geometry parameters.

In order to simulate the process of gear hobbing, Hob3d software has been developed. The proposed simulation model has been embedded in a commercial CAD program, thus taking advantage of its accuracy, also resulting in more accurate calculations. The model is capable of calculating the non-deformed chip geometry, the 3D gap geometry and the cutting forces involved in the production of spur as well as in helical involute gears. The new simulation code uses

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three coordinate systems in order to calculate the required results. The first (1) is positioned on the examined cutting edge and has the x axis parallel to the hob's axis, the y axis perpendicular to x axis and finally z axis perpendicular to the prior two. Coordinate systems (2) and (3) have axis z running through the workgear's axis. In coordinate system (2), x axis is always rotating towards the direction of the gap center while the axes of coordinate system (3) are fixed.

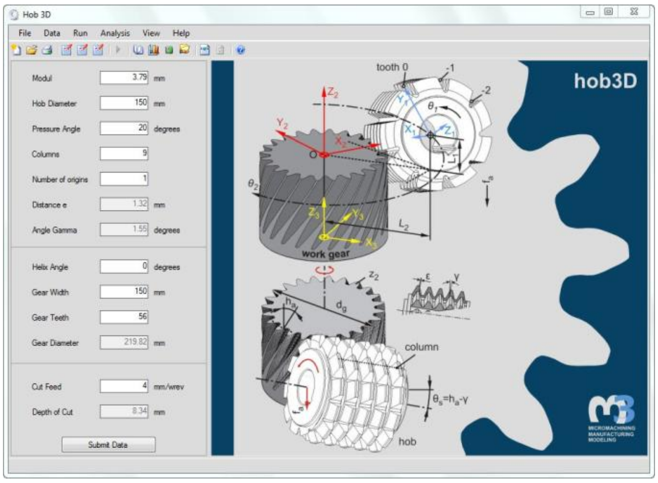

Fig. 1. Hob3D geometric parameter input form.

The simulation process of HOB3D is initialised after the input of valid data. Due to the fact that the gear is axisymetric, the simulation can be executed in one 3D gap thus reducing the simulation time.

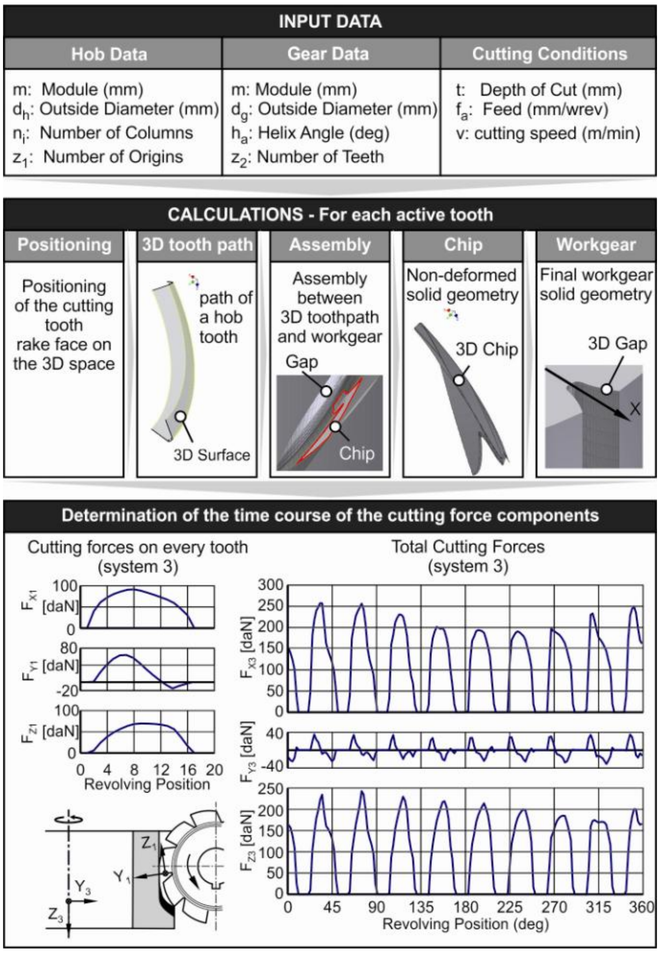

Fig. 2. Hob3D Flowchart.

The first step of the calculation process is the calculation of the effective cutting hob teeth (N) for which the simulation is executed, as illustrated in Fig. 2. The concept of the simulation is the creation of a 3D surface for each of the active teeth. This surface is developed by the hob's rake edge paths in the 3D space including all movements required in order to simulate the process. This surface defines the intrusion of the specific cutting tooth on the 3D gap. In the next simulation step, the workgear and the 3D surface are assembled and the volume of the gear is split by the surface, thus defining the 3D chip and gap. The final step of the simulation is the determination of the time course of the cutting force components, which is performed with the use of Kienzle-Victor's equations.

IV. Hob3D Results

Hob3D was used in order to simulate a series of gear hobbing cases by varying parameters of the hob, workgear or the cutting conditions. It was found that in all cases the produced gear was geometrically correct. More specifically the gear profile was compared to the theoretical one as already presented [13]. The results of any simulation include the non-deformed chip geometry as well as statistics of the chip, such as chip cross-section area and chip maximum thickness. The results of one chip are presented in Fig. 3.

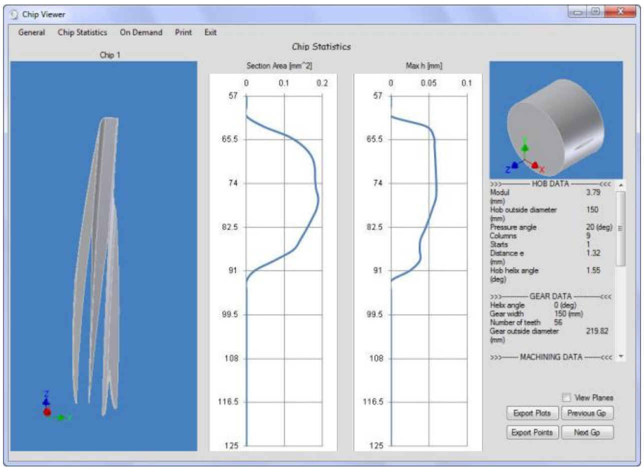

Fig. 3. Hob3D chip analysis form.

The solid 3D non-deformed chip geometry of generating position 1 is presented in the left side of Fig. 3. The chip can be rotated freely in the environment. In the same manner the gear gap after generating position 1 is presented on the right top area of the figure. On the centre the graphs are presenting the cross-section area and the maximum chip thickness development in the current chip. These graphs as well as their data can be exported in jpg and txt form respectively. All the chips of this case are presented in Fig.4.

V. Cutting Force Calculation

The prediction of the cutting force components is a crucial parameter in gear hobbing. HOB3D uses the equations of Kienzle-Victor so as to calculate the 3D components of the cutting forces based on the non-deformed chip geometry. In order to calculate the cutting forces, a series of cross-sections are made on the 3D chip on the plane of the cutting edge, see Fig. 5, where the outline of the chip is obtained for

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each one of them. The section is discritised as seen in detail A. The discritisation is made with lines vertical to the cutting edge. For each elementary area, like the one highlighted in red in the middle line of Fig. 5, the cutting force components must be calculated.

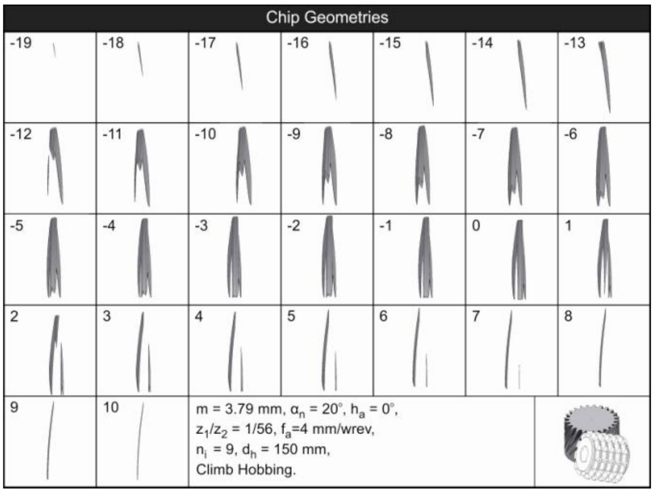

Fig. 4. Hob3D solid chips.

The first step of the calculation is the identification of the elementary chip equivalent width and thickness, marked as b and h. The calculation is simple on the linear parts of the chip whereas it becomes more complex on the head of the cutter, where the elementary chip takes an odd shape. This shape consists of one arc, two non parallel lines and one B-Spline and is simplified to a rectangular one with the use of geometric equations and integrals.

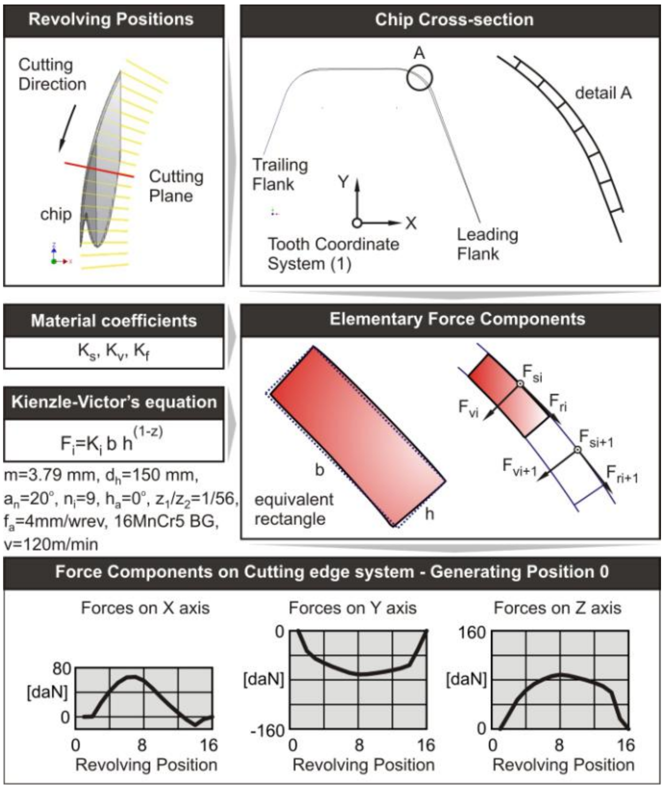

Fig. 5. Cutting force components calculation algorithm.

Next, the Kienzle-Victor's equations are implemented to produce the magnitude of the cutting force components on the cutting edge. The force's point of application is in the middle of the elementary chip's side which belongs to the cutting edge. The three force components are rotated in order to match the local coordinate system (1) and then added up in order to produce the total cutting forces on every cross-section. After all the sections are calculated, the total forces on the tooth are obtained, as presented on the bottom of Fig. 5. After the calculation of the cutting forces on the coordinate system (1) the cutting forces are rotated with the aid of rotation matrices and the cutting forces on systems (2) and (3) are calculated.

The data for the force calculation module are inputted in a special form, presented in Fig. 6.

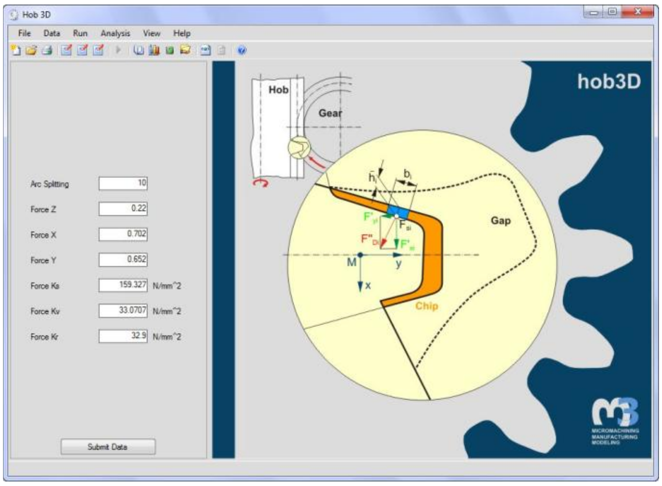

Fig. 6. Hob3D cutting force data input form.

After the calculation of the cutting forces the user can visualize them through the appropriate form. The cutting forces of generating position 0 are presented in Fig. 7. On the three graphs the x, y, z components of the cutting forces in all 3 coordinate systems can be plotted. The total cutting forces for all generating positions as viewed by the user of the program is presented on Fig. 8.

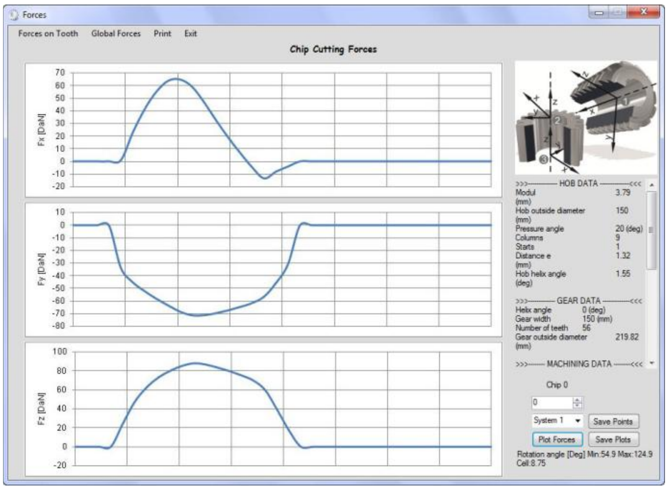

Fig. 7. Hob3D cutting force viewer form.

VI. Verification of Cutting Force Calculation

The verification of the force calculation module was conducted using experiments carried out by [4]. The case of climb hobbing of a spur gear was examined and the cutting forces simulated on specific teeth were compared to the ones measured.

In Fig. 9 the results of the climb hobbing case is presented. As it can be seen, each column of the figure illustrates the measured and calculated cutting forces on one generating position. These cutting forces are measured on the coordinate system of the 3D gap (2). In most of the cases, the simulation code predicts not only the form but also the magnitude of the cutting forces. Especially in generating positions -6, and 2 the simulation results are almost identical to the ones measured.

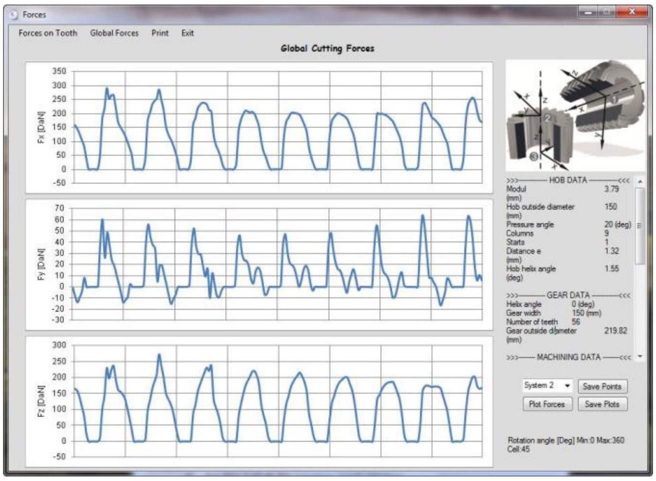

Fig. 8. Hob3D total cutting force viewer form.

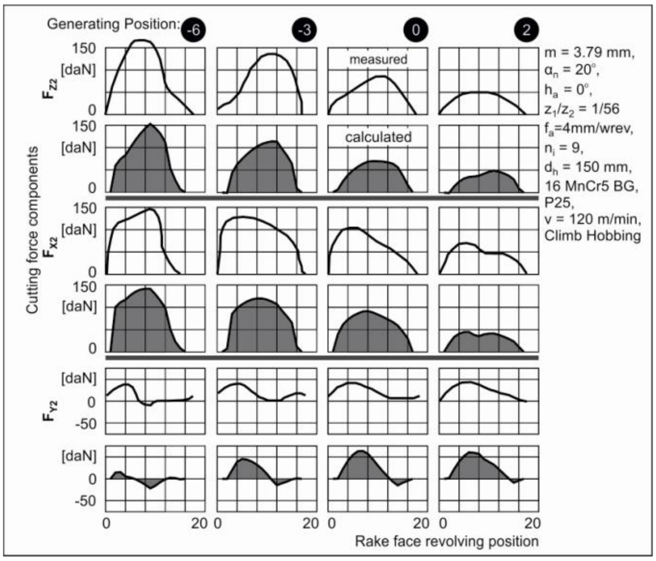

Fig. 9. Comparison between calculated and measured cutting forces in climb hobbing

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