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Gear skiving—CAD simulation approach

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ABSTRACT

Gear skiving is used as a gear finishing process to reduce distortion errors which occurred on the gears due to the heat treatment. This process is similar to gear hobbing but the difference is that the cutting tool has a negative rake angle and tooth rake offset. The present study simulates the kinematics of the cutting process with the aid of commercial CAD software and allows the precise determination of the non-deformed chips and the developing cutting forces. The simulation model is verified based on the theoretical shape of the produced gear gap and the comparison between measured and calculated cutting forces.

1. Introduction

Most mechanical equipment require power transmission and motion which is achieved with great accuracy by gears. However, the efficient operation of a gear pair depends mainly on the shape, geometrical accuracy and the quality of the gear teeth profiles. These characteristics are often related to errors during the gear production process. At the same time, machined gears need to acquire better resistance to wear, scuffing and pitting, which is achieved with quenching. Eventually, the possible deformations which are resulted can be corrected with grinding, honing, shaving or gear skiving where the workgear is re-hobbed by special hob with negative rake angle and tooth rake offset [1–3].

Nowadays, gear skiving is an economically competitive method in comparison to traditional grinding, especially for large modules where highest accuracy is not required, while it is also possible on fine pitch gears where grinding may not be feasible. Gear skiving research followed the corresponding gear hobbing research, which today has been fully studied [4–6]. The kinematics of gear hobbing processes, the produced undeformed chips and developed cutting forces have been overall simulated [7–9]. Michalski [10] made an analysis of three-dimensional surface topography of side and side out in tooth space flanks of cylindrical gear which are machined after hobbing. Some related software such as FRS, FRSDYN and FRSFEM have been developed in previous studies while the most recent simulations are based on CAD system's simulating solid chips and gear gaps with great accuracy [11–14]. Especially for gear skiving, the related computations have been made in the past using numerical methods with satisfactory accuracy which was further improved by CAD-based simulation as manifested in the present paper [15]. Finally, Sugimoto et al. [16] studied the wear behavior of gear skiving cutting tools and reached the tool life conclusions in relation to their coatings.

In gear skiving, just like in gear hobbing, the process follows the rolling principle. The skiving cutting tool and the work gear rotate while the cutting tool moves simultaneously with a specific axial feed. In the left part of Fig. 1, the basic kinematics of the cutting process is illustrated. The dashed area in this figure corresponds to the active part of the skiving profile. As expected the active parts of the skiving tooth profile are onto its flanks. In the right part of Fig. 1, the successive profile positions (revolving positions) of a skiving hob tooth while entering the pre-cut gap are illustrated.

2. Determination of the protuberanz and skiving hob profiles

Gear skiving is materialized on a pre-cut workgear which has been produced by gear hobbing with a special cutting tool (protuberanz). With this tool, the gear bottom land is fully cut and some material remains on the gear flanks at a desired thickness which will be consequently cut by gear skiving. Therefore, gear skiving simulation requires initially the pre-cut process simulation. For these two simulations, the cutting profiles of the two cutting tools, that is protuberanz hob and skiving hob, must be determined.

The protuberanz hob profile determination is based on the Petri's [17] analytical equations, part of which is illustrated in the left part of Fig. 2 (frame a). The protuberanz profile is determined with the aid of dp distance on the flank related to the desired thickness on the gear flank which will be removed by gear skiving

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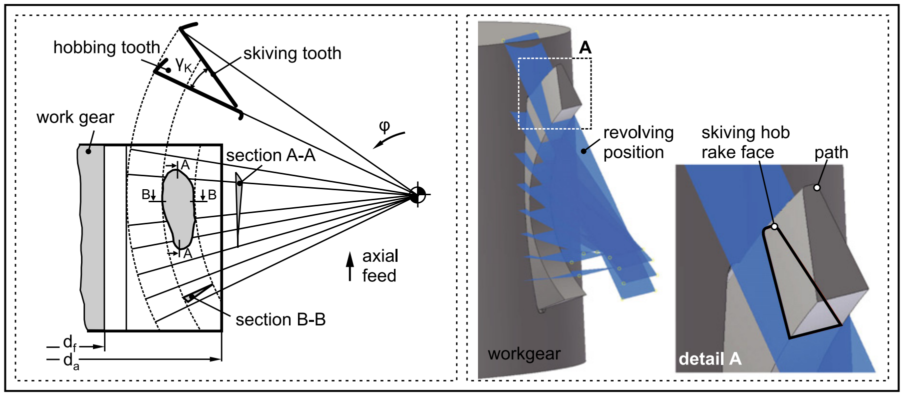

Fig. 1. The principle of the cutting process in gear skiving.

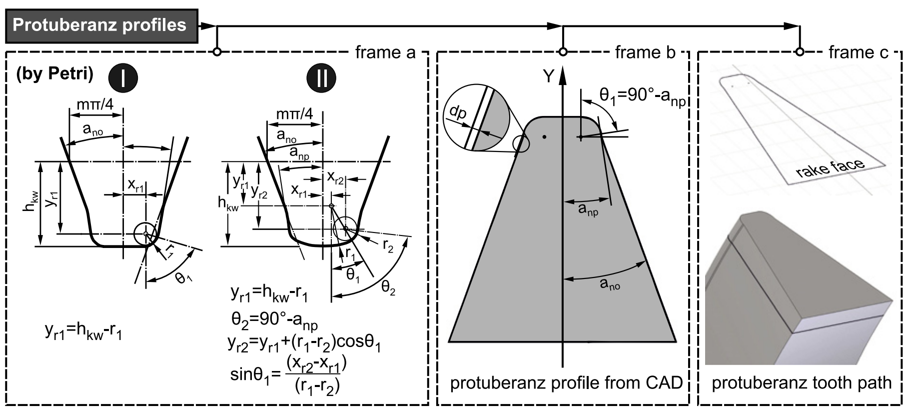

Fig. 2. Analytical and CAD based determination of the protuberanz hob profile.

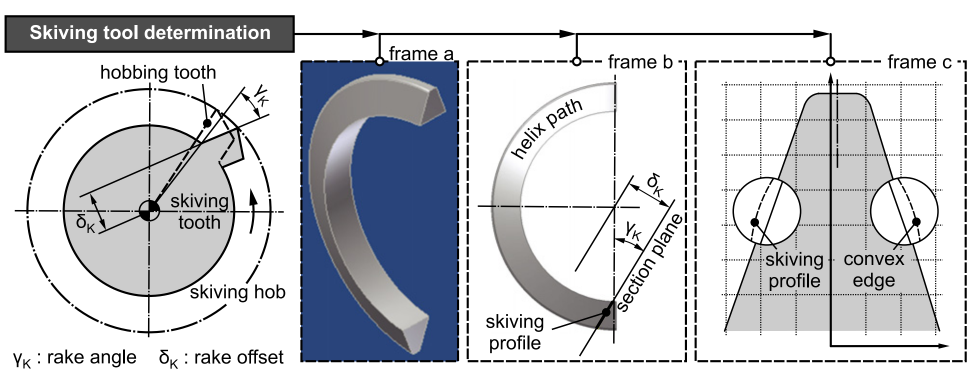

Fig. 3. CAD-based determination of the skiving hob profile.

(frame b). The protuberanz tool profile can be seen in the right part of Fig. 2 (frame c).

As already mentioned, the basic difference between hob and skiving tool is the rake angle γ_κ and the tooth rake offset $\delta\kappa$, as seen in Fig. 3. This negative rake angle protects the carbide cutting tool from instantaneous overloadings and shocks. The same figure presents the determination process of the skiving cutting profile with the aid of process kinematics. The skiving tooth makes the same 3D path as the corresponding hob tooth in gear hobbing (frame a). This behavior helps define the skiving tooth profile through the corresponding hobbing one, taking into account the rake angle γ_κ as well as the tooth rake offset δ_κ. Therefore, as can be seen in frame b, the skiving tooth profile is determined as the section of the helix which is produced by the movement of the hob profile with a plane. This plane has a dihedral angle γ_κ with the plane of the hob profile and its distance from the rotation axis is δ_κ.

The produced skiving tool profile is illustrated in the frame c of the figure. The determined profile does not have linear edges, as the initial DIN3972 profile, but curves while it is not symmetric and the corresponding maximum distances from the linearity are not equal on two flanks [18]. These flanks of the skiving profile are determined with curves edges, which as a matter of fact are convex.

3. CAD-based gear skiving simulation

The basic kinematics of the gear hobbing as well as the gear skiving process, are described with individual tool and workgear

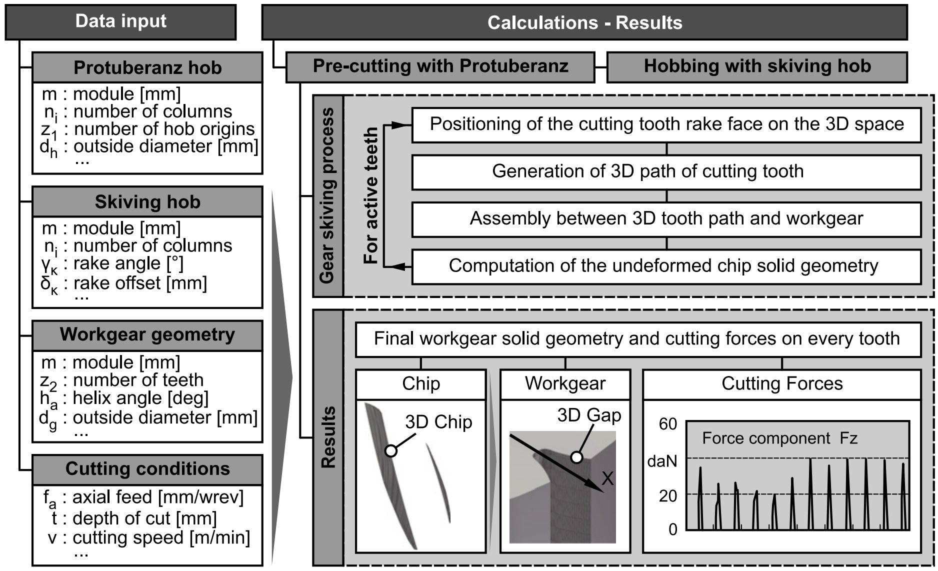

Fig. 4. The flow-chart of the gear skiving simulation process.

movements. The corresponding data is presented in the left part of Fig. 4. The basic idea for the simulation of any of the above mentioned gear cutting processes is the usage of a suitable CAD environment for the design of the workgear and the cutting tool rake face positions and subsequently the creation of the path which is made by the cutting tool taking into account all the relevant movements. Every individual cutting tooth path, called generating position, along with the current workgear, pre-cut or not, can form an assembly. The intersection of those two solids which constitutes the chip for this particular generating position can be calculated by means of a Boolean operation. When this process is completed for every cutting tooth, the final shape of the gear gap is produced as can be seen in the right bottom part of Fig. 4. Respectively, after each such simulation, the undeformed chip cross sections are determined and the developing cutting forces are calculated with Kienzle–Victor equations [19].

A more descriptive analysis of the gear skiving process with the consecutive calculation steps in CAD system is illustrated in Fig. 5. After the initial definition of the profile sketch in accordance with DIN3972 (a), the protuberanz profile is determined (b) and the pre-cutting is concluded thus creating the pre-cut workgear (c) which is entered as a workpiece for the following gear skiving process. After gear skiving profile is determined (d) it is positioned on 3D space (e) and the successive revolving positions are determined taking into account the relative hob and workgear movements (f). These profiles are then combined resulting in a 3D surface that describes the movement of a specific tooth of the skiving hob in the 3D space (g). The 3D surface path splits the volume of the workgear in two parts (h). The volume which is in the inner side of the surface is the non deformed chip (i), and the other is the 3D gap (j) after that pass. At the end of the simulation, the final geometry of the 3D gap and all the undeformed chips in every step of the process constitute the results. These chips can be analyzed and data obtained as regards the maximum chip thickness, chip cross section area and cutting forces (k).

4. Determination of chip formation in gear skiving

In pre-cutting, apart from the two cutting tool flanks, that is the leading and the trailing flank, chips are also obviously produced by the head of the cutting tooth. When a protuberanz tool is used in pre-cutting, the bottom land area of the gear is fully cut and therefore the skiving tool does not cut with its head. Solid chips produced during the CAD simulation of pre-cutting with a protuberanz tool are illustrated in Fig. 6 where the cutting process data is mentioned.

After the pre-cutting simulation for all generating positions the final gear gap is produced as presented in the same figure along with a comparison of its theoretical one for two gear flanks, the leading and the trailing flank. This comparison shows that the deviation DIF between the simulated profiles and the nominal ones corresponds to a remaining thickness on the gear teeth, as a result of the pre-cutting process, equal to 0.1 mm, as provisioned by the input data.

Relative solid chips produced by the CAD simulation of the gear skiving are illustrated in Fig. 7, while the process data can be seen in the right part of the figure. The solid geometry of the chip of generating position 0 divided into 9 slices, the maximum thicknesses of each cross section and the chip cross section area are presented in the same figure.

The gear gap produced by gear skiving and the theoretical one are compared and the obtained results for the down and up-cut skiving are illustrated in Fig. 8. The difference between theoretical and simulated gear gap is very low and is less than 16 μm which is expected due to computational errors. This difference resulted from the arc length between theoretical and simulated gear flank, as can be seen in the left bottom part of figure.

5. Cutting force components determination and comparison between analytical and experimental results

In gear skiving the produced chips are very thin as shown in Fig. 7. Thus, the resulting cutting force components are much smaller than the corresponding gear hobbing forces. The computation of those cutting force components is based on Kienzle–Victor equations with the aid of the undeformed 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, where the outline of the chip is obtained for each one of them. The section is divided and for each elementary area the cutting force components are calculated. The first step of this calculation is the identification of the elementary chip equivalent width and thickness. Next, the Kienzle–Victor's equations are implemented

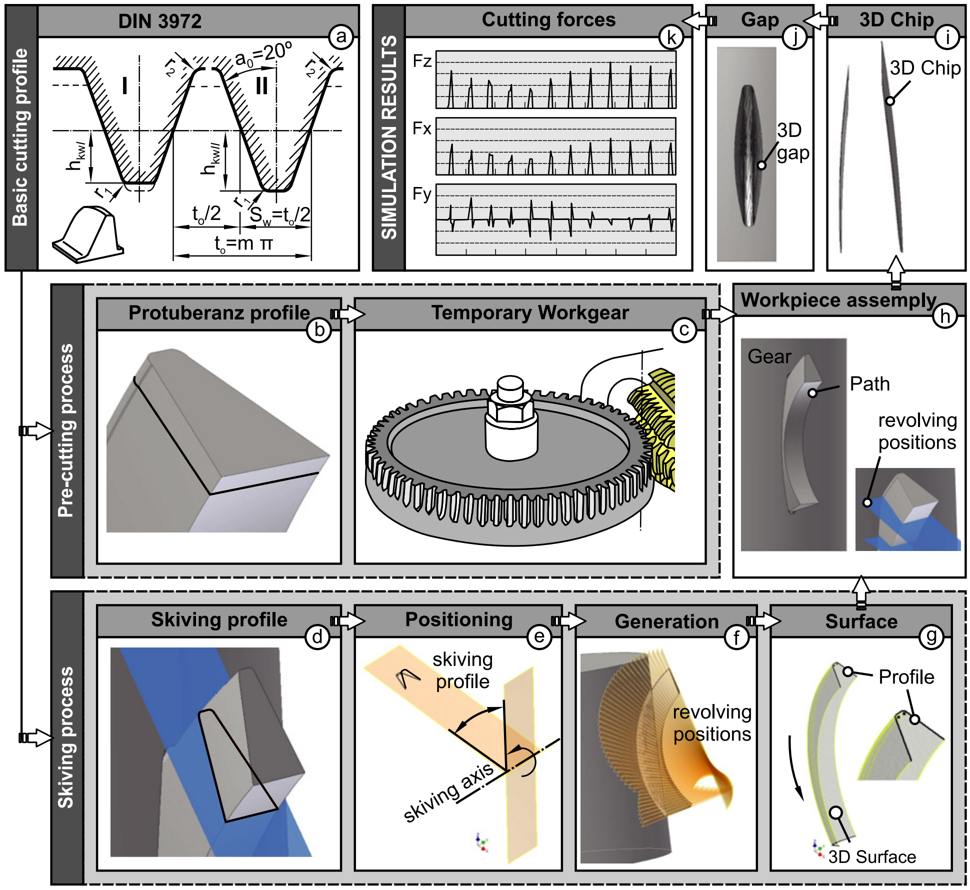

Fig. 5. Sequential steps on CAD environment for gear skiving simulation.

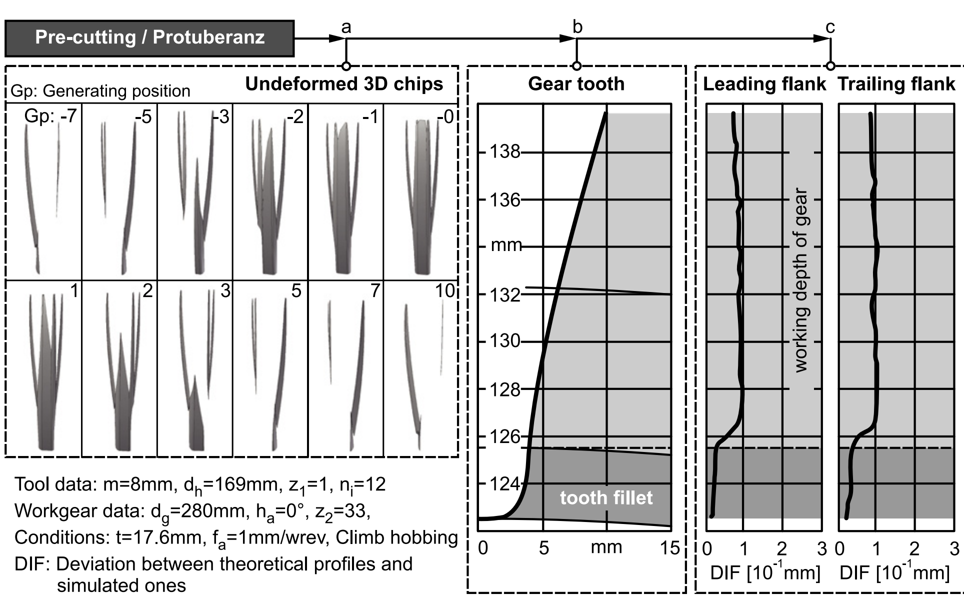

Fig. 6. Pre-cutting hobbing with protuberanz tool.

to produce the magnitude of the cutting force components on the cutting edge. Three force components are calculated according to Kienzle–Victor Fr, Fs and Fv. The first is parallel to the cutting edge, the second parallel to the cutting speed vector and the last perpendicular to the prior two. The three force components are rotated in order to match the local coordinate system and then added up in order to produce the total cutting forces on every cross section.

The determined cutting force components at the machine tool coordinate system Fx, Fy and Fz, are presented in Fig. 9 and the corresponding data can be seen in the left part of the figure. In the same figure the measured cutting force components

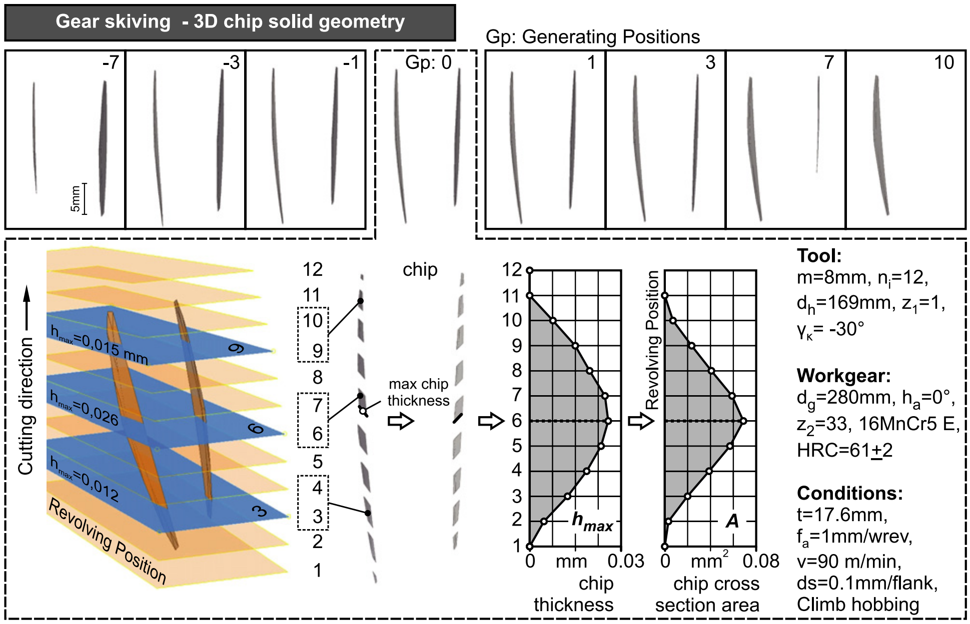

Fig. 7. Undeformed chips on gear skiving.

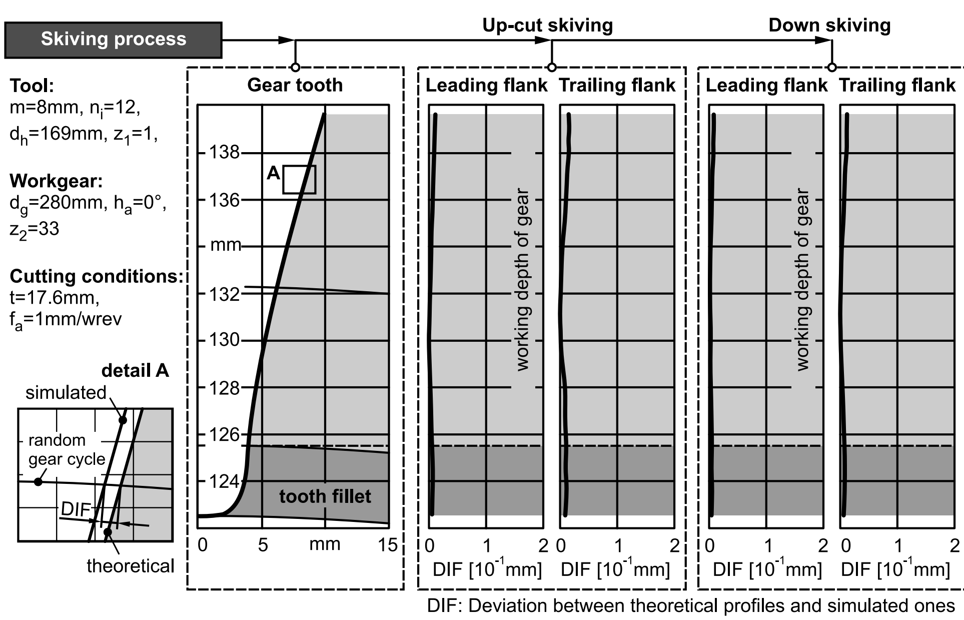

Fig. 8. Verification of the simulated gear gap and the theoretical one.

are illustrated as have been taken from bibliography [20,21]. The comparison between measured and calculated cutting force components shows a good agreement and therefore the gear skiving simulation results satisfactory taking into account that in real machining processes many other phenomena were occur which have not been considered in this simulation approach. Those phenomena are the chattering, the tool wear influence, etc.

6. Conclusions

Nowadays, the gear skiving process is an attractive alternative solution for gear finishing. In the current research work, an advanced and validated simulation method for gear skiving process was presented. The novelty of the current research is that the algorithm has been developed and embedded in a commercial CAD environment, by exploiting its modeling and graphics capabilities. In contradistinction to former research attempts, in the present investigations, the kinematics of gear skiving is directly applied in one tooth three dimensional space by the construction of spatial surface paths, for every generating position. The kinematics involves the rotations and displacements of the two rolling parts (skiving tool and work gear) for every possible manufacturing case of gear skiving process. These 3-dimensional surface paths are used to divide the subjected volume and directly create the chip and the remaining work gear continuous solid geometries. The confirmation of the validity and accuracy of the proposed method has been accomplished by comparing the produced gear gap profile with theoretical ones. The final step of the gear skiving simulation was the determination of the time course of the cutting force components, which is performed with the use of Kienzle–Victor's equations. The cutting forces were also verified through experiments. The results of the present work hold significant industrial and research interest, including the accurate

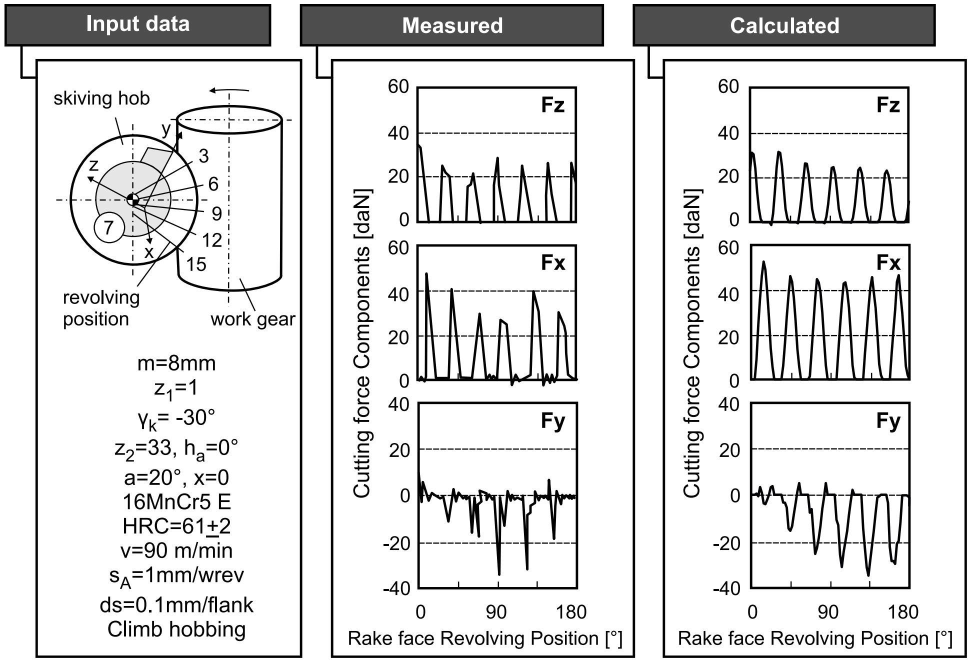

Fig. 9. Calculated and measured cutting force components at the machine tool coordinate system.

prediction of dynamic behavior and tool wear development in gear skiving procedure.

References

[1] Koenig W, Klocke F. Fertigungsverfahren — Drehen, Fraesen, Bohren. Berlin, Heidelberg: Springer Verlag; 1997.
[2] Schlarb G. New innovations and applications of hobs. SME technical paper MR99-268. 1999.
[3] Gimpert D. Fine pitch gear hobbing advances. SME technical paper MS91-246. 1991.
[4] Sulzer G. Leistungssteigerung bei der Zylinderradherstellung durch genaue Erfassung der Zerspankinematik. Dissertation. TH (Aachen); 1974.
[5] Gutman P. Zerspankraftberechnung beim Waelzfraesen. Dissertation. TH (Aachen); 1988.
[6] Michalski J, Skoczylas L. Modelling the tooth flanks of hobbed gears in the CAD environment. International Journal of Advanced Manufacturing Technology 2008;36(7–8):746–51.
[7] Antoniadis A. Determination of the impact tool stresses during gear hobbing and determination of cutting forces during hobbing of hardened gears. Dissertation. Aristoteles University of Thessaloniki, 1988.
[8] Antoniadis A, Vidakis N, Bilalis N. Fatique fracture investigation of cemented carbide tools in gear hobbing. Part 1: FEM modeling of fly hobbing and computational interpretation of experimental results. ASME Journal of Manufacturing Science and Engineering 2002;124(4):784–91.
[9] Antoniadis A, Vidakis N, Bilalis N. Fatique fracture investigation of cemented carbide tools in gear hobbing. Part 2: the effect of cutting parameters on the level of tool stresses—a quantitative parametric analysis. ASME Journal of Manufacturing Science and Engineering 2002;124(4):792–8.
[10] Michalski J. Surface topography of the cylindrical gear tooth flanks after machining. International Journal of Advanced Manufacturing Technology 2009;43(5–6):513–28.
[11] Dimitriou V, Vidakis N, Antoniadis A. Advanced computer aided design simulation of gear hobbing by means of 3-dimensional kinematics modeling. ASME Journal of Manufacturing Science and Engineering 2007;129(5): 911–8.
[12] Dimitriou V, Antoniadis A. CAD-based simulation of the hobbing process for the manufacturing of spur and helical gears. International Journal of Advanced Manufacturing Technology 2009;41(3–4):347–57.
[13] Tapoglou N, Antoniadis A. CAD-based calculation of cutting force components in gear hobbing. In: DTMM 2010 international conference design, technology and management in manufacturing. Iasi (Romania); 14–16 May, 2010.
[14] Tapoglou N, Antoniadis A. Hob3D: a novel gear hobbing simulation software. In: World congress on engineering 2011, July 6–8. London (UK); 2011.
[15] Antoniadis A, Vidakis N, Bilalis N. A simulation model of gear skiving. Journal of Materials Processing Technology 2004;146(2):213–20.
[16] Sugimoto T, Ishibashi A, Yonekura M. Performance of skiving hobs in finishing induction hardened and carburized gears. Gear Technology 2003;34–41. May/June.
[17] Petri H. Zahnhuß— Analyse bei außenverzahnten Evolventenstirnraedern: Teil III Berechnung. Antriebstechnik 1975;14(5):289–97.
[18] DIN 3972. Bezugsprofile von Verzahnwerkzeugen fuer Evolventen-Verzahnungen nach DIN 867. Taschenbuch, vol.106. Beuth Verlag; 1992.
[19] Kienzle O, Victor H. Spezifische Schnittkrafte bei der Metallbearbeitung. Werkstofftechnik und Machinenbau 1957;47(5):224–5.
[20] Ross V. Schaelwaelzfraesen als Feinbearbeitungsverfahren einsatzgehaerteter Zylinderraeder. Dissertation. TH (Aachen); 1983.
[21] Vuellers M. Hartfeinbearbeitung von Verzahnnungen mit beschichteten Hartmetallwerkzeugen. Dissertation. TH (Aachen); 1999.