DEFINING INSTANTANEOUS CONTACT TRACK OF AERONAUTICAL BEVEL GEAR APPLYING FINITE ELEMENTS METHOD AND RAPID PROTOTYPING METHOD

Jacek Pacana, Bogdan Kozik, Grzegorz Budzik

Rzeszow University of Technology
Department of Mechanical Engineering
Powstańców Warszawy Av., 35-959 Rzeszów, Poland
tel.: +48 17 8651642
e-mail: pacanaj@prz.edu.pl, bogkozik@prz.edu.pl

Abstract

An instantaneous contact track is one of the parameters determining correct work of wheels in gears. It is the surface on the side of the tooth on which a contact is made with the cooperating surface of the other wheel in a given moment. The correctness of cooperation of wheels and kinematic accuracy of the gear depends on the shape and the size of an instantaneous contact track and its changes during rotation of wheels. Both the area of contact track and its position also depend on the greatness of load being in operation. Therefore it is important to carry out calculations for conditions of work which are the closest to real working conditions of aeronautical bevels gear. At the designing stage an instantaneous contact track can be determined by means of finite elements method (FEM). The article presents a methodology of defining contact track for loaded bevel gear by means of numerical finite elements method. The paper also presents information about creating virtual models of wheels, generating network of finite elements, defining edge conditions as well as carrying out calculations and processing the received results. Finally, it also presents the received solutions concerning the distribution of reduced stresses and an instantaneous contact track as well as the summary track of wheel teeth cooperation in a loaded bevel gear. However the results received by means of simulation of virtual models cooperation require verifying by other methods, favourably experimental ones. The received numerical solutions made using finite elements method were therefore compared to proper results recorded during examining real models of the same wheels. The examination was carried out on a special stand which had been designed end created for this purpose. The used wheels had been made by means of rapid prototyping method.

Keywords*: contact track, FEM, bevel gear*

1. Introduction

An instantaneous contact track is the surface on the side of the tooth on which a contact is made with the cooperating surface of the other tooth [6, 11]. The correct work of gears depends on the shape and the size of an instantaneous contact track and its changes during cooperation of subsequent teeth of both wheels. Both the area of contact track and its position also depend on the greatness of load being in operation. Therefore it is important to carry out calculations for conditions of work which are the closest to real working conditions of gear. The article presents a methodology of Loaded Tooth Contact Analysis (LTCA) for bevel gear by means of numerical finite elements method and by means of an experiment on a test stand.

As a result of numerical calculations one can get a solution concerning the distribution of reduced stresses and an instantaneous contact track of teeth in a loaded bevel gear. However the results received by means of simulation of virtual models cooperation require verifying by other methods, favourably experimental ones. The received numerical solutions were therefore compared to proper results recorded during examining real models of the same wheels. The examination was carried out on a special stand which had been designed end created for this purpose. The used wheels had been made by means of rapid prototyping method. In case of bevel wheels verifying

FEM calculations concerning the instantaneous contact track was carried out by comparing the size and location of characteristic areas on virtual models to the same features on real models.

2. Analytical model

Numerical analysis concerning determining contact track for bevel gears must be carried out applying spatial solids because of the gear's advanced construction and kinematic pattern. Therefore preparing and carrying out FEM calculations for analytical models of toothed wheels is a complicated task and requires substantial resources of computer memory. However a simplification is possible by applying given restrains in the wheel's geometry which do not influence the outcome of analysis in an examined area and do not cause changes to, for example, work character or stiffness of construction in relation to the original solution [3, 7].

Virtual models of wheels for bevel gear were prepared by AutoCAD Mechanical 2010 [4, 6, 7] for the needs of the contact track analysis. They were generated in a process of machining simulation. Then full wheels' models were simplified to fragments including only five teeth each. It is sufficient for examining the cooperation of wheel teeth alongside the whole path of contact. Only the three middle teeth cooperation of the virtual models was analyzed. It allowed for eliminating the influence of edge conditions in the cooperation of teeth of both wheels. Decreasing the number of teeth on analytical models allows for substantial limitation of the number of finite elements necessary for digitizing the network models used for FEM calculations [5, 10].

The models obtained in CAD program were recorded in universal *.IGS format and imported to ADINA 8.4.2 [1] and here the further stages of preparing the models were carried out. In the same program the calculations were made and the received results were processed. Also in ADINA the dimentional correctness was checked and mutual placement of the recorded models and their setting in relation to the axis of the main coordinate system.

Subsequently the wheels' models of bevel gear went under digitizing process by four-wall finite elements. The digitized models with the created network of finite elements are shown in Fig. 1a. To carry out calculations concerning the wheels' cooperation, two groups of elements (3D) were defined corresponding to each wheel's model (Fig. 1b). These groups were differentiated in ADINA by colours and also in the presented figures; light grey – the first group concerning the wheel and dark grey – the second group concerning the pinion.

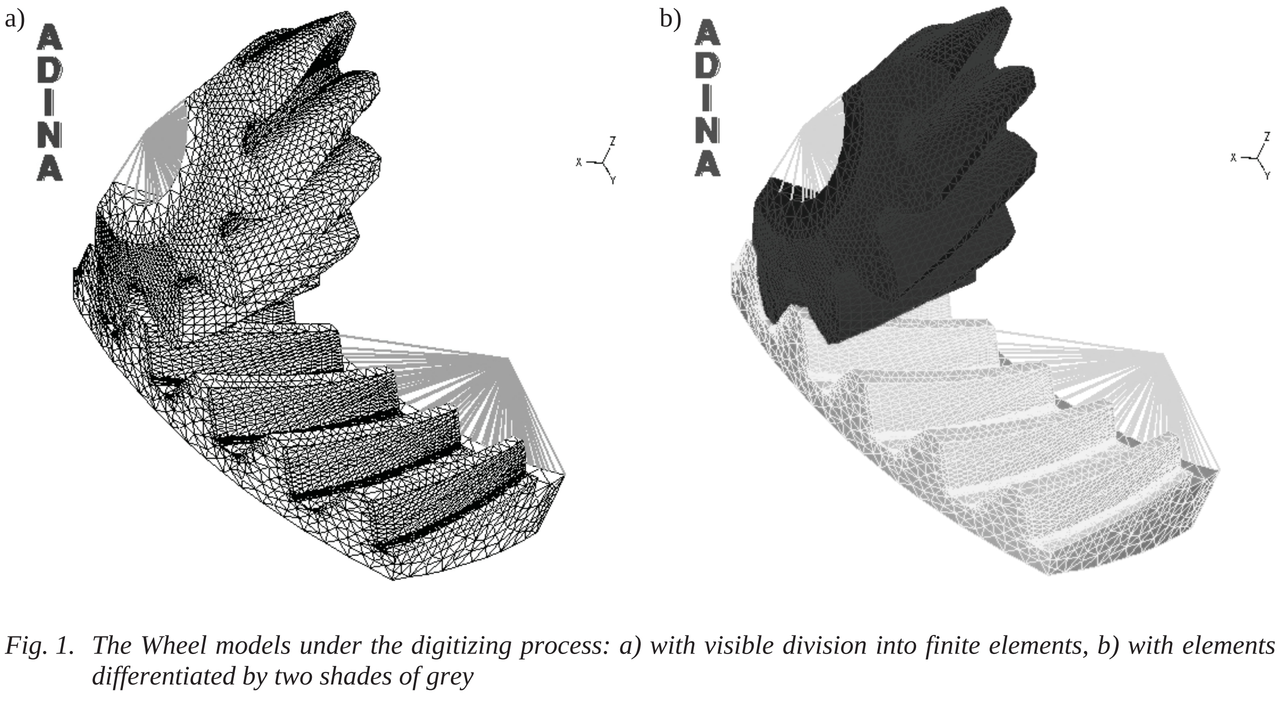

Fig. 1. The Wheel models under the digitizing process: a) with visible division into finite elements, b) with elements differentiated by two shades of grey

As a result of carried out division 278717 four-wall finite elements were obtained in which 140295 elements were for the pinion and 138422 elements for the wheel. The total number of knots was 56616 in both models.

The finite elements were spread out unevenly on models because of the expected different accuracy of the results in individual areas of the models. The most important analytical task was defining the contact track on side surfaces of wheels and that is why in these areas much more dense network was defined than in the remaining parts of the models. Such density of finite elements network considerably improved the accuracy of the received result and at the same time did not increase the size of the final file of calculations.

The contact elements (contact surfaces) were defined on the side surfaces and tops of cooperating teeth of the wheel and the pinion. Rotation and loading of wheels were both executed in ADINA preprocessor using Rigid Links combining their centres to inside diameters. Rotation of the pinion around X axis of the main coordinate system having value of 2 [rad] was defined on the pinion's axis. Load of the gear T_2 = 400 [Nm] was defined on Z axis which was at the same time the main rotation axis of the toothed wheel. The whole calculation was divided into 100 analytical steps and the results of each step were automatically recorded to be used in later analysis.

3. FEM calculation results

The distribution of reduced stresses on models of the analysed wheels are shown in Fig. 2. They are the outcome of carried out calculations.

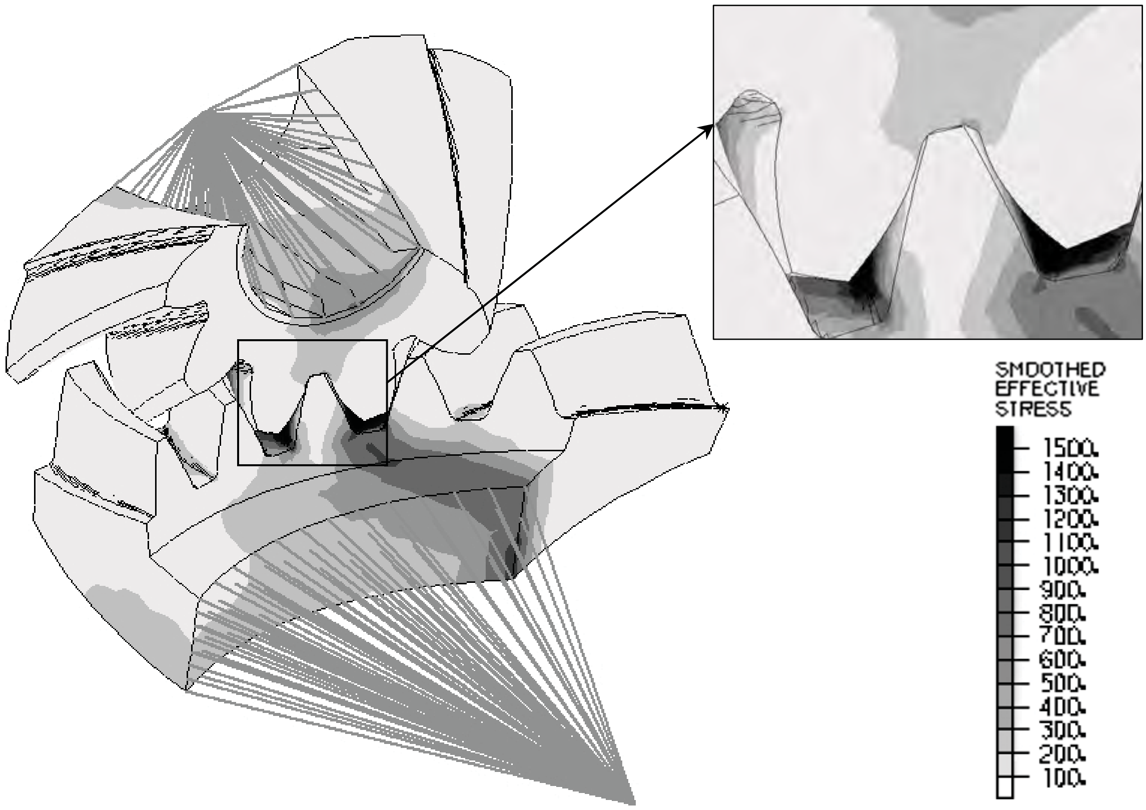

Fig. 2. The reduced stresses (according to Misses) in overall sight and on a detail of wheel model and pinion model

The outcome presented in this form does not make it possible to unequivocally read the stresses in a chosen wheel. That is why for further analysis a mode of separate projection of each model was selected in ADINA postprocessor. Fig. 3 and 4 present the distribution of stresses in a toothed wheel and a pinion corresponding to the same time step of calculations.

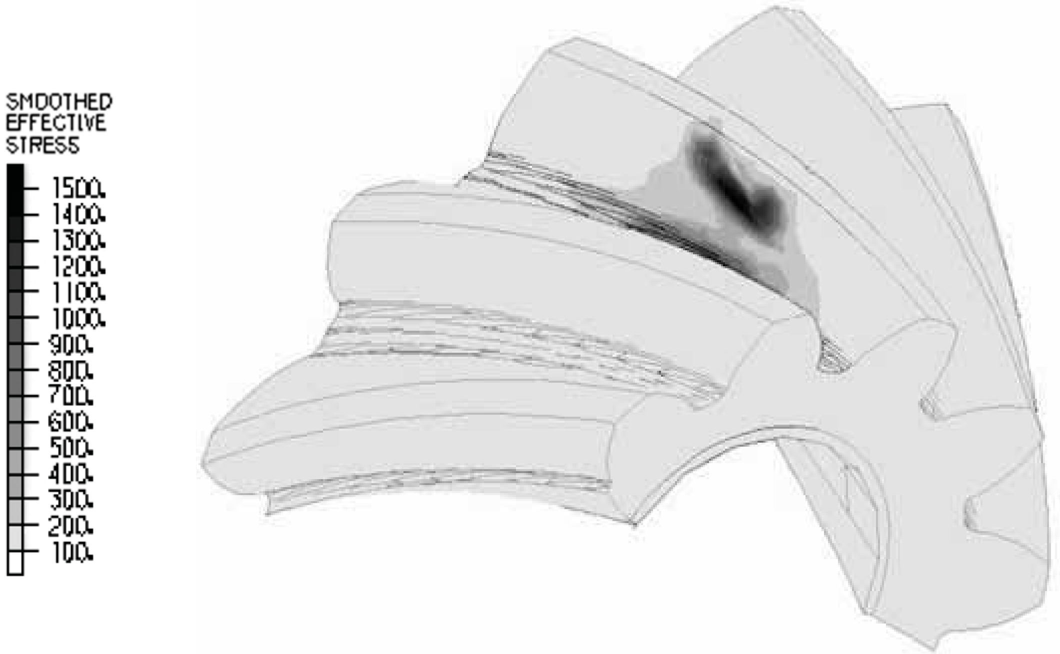

Fig. 3. The distribution of reduced stresses in a selected analytical step for the pinion

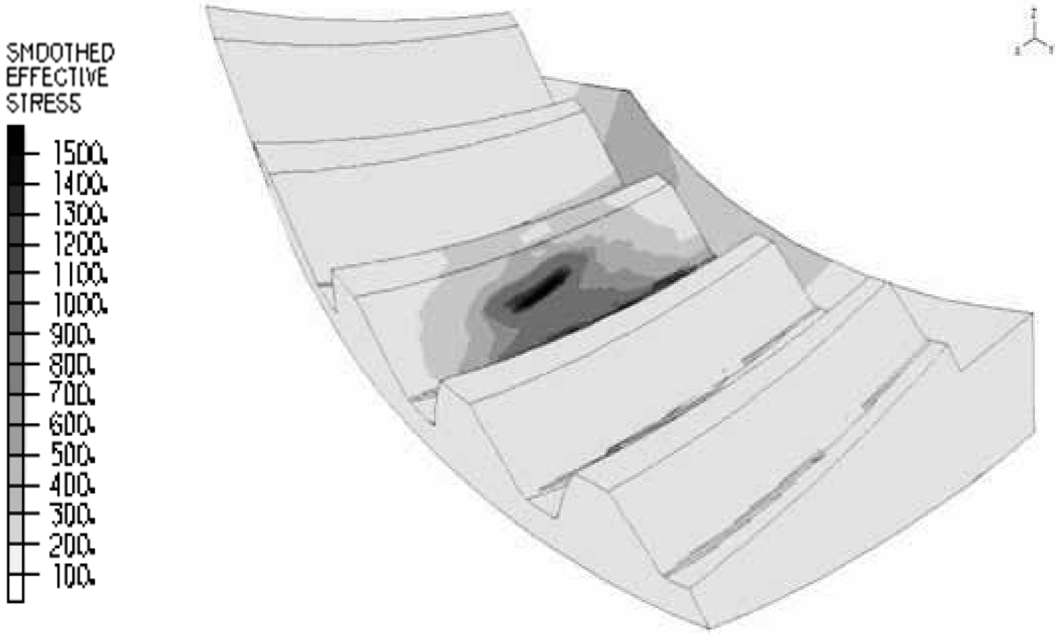

Fig. 4. The distribution of reduced stresses in a selected analytical step for the wheel

A graphic presentation of the distribution of reduced stresses is not sufficient for determining the contact track. In that case it is necessary to mark out the size and location of the area of high contact stresses for both wheels of loaded bevel gear. Figure 5 and 6 present contact tracks on the side surfaces of the gear’s teeth and of the pinion’s teeth which are the outcome of cooperation of these models. The presented outcomes concern the same time step where a single-pair cooperation of bevel gear occurs.

The instantaneous contact tracks on the side surfaces of the gear’s teeth and of the pinion’s teeth have a different width and shape. However the outcome should be considered as correct and the unsmooth contour of the contact track on the pinion is a result of the way of making the models by means of processing simulation. The received outcomes are confirmed by the outcomes of other experimental methods [2, 8, 9].

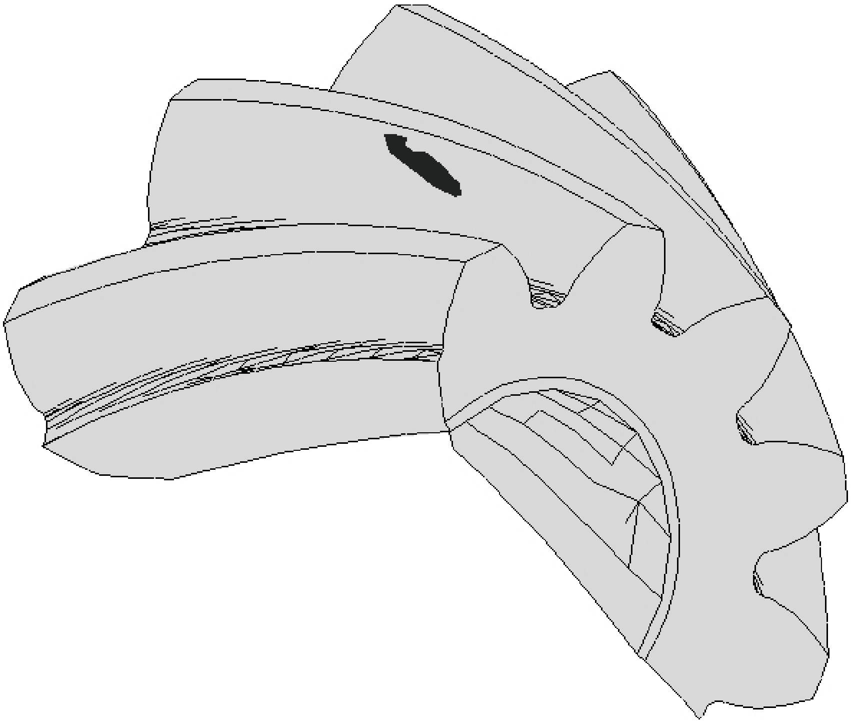

Fig. 5. Instantaneous contact track on the side surface of the pinion's tooth

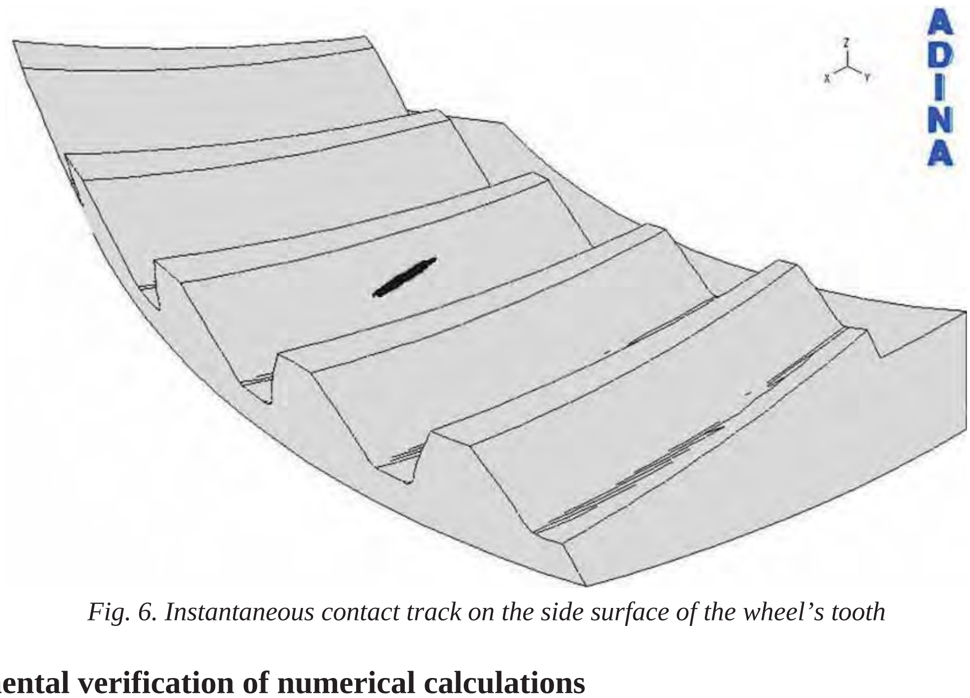

Fig. 6. Instantaneous contact track on the side surface of the wheel's tooth

4. Experimental verification of numerical calculations

A verification of the results received using FEM was carried out as a part of that analysis. An evaluation of the results' correctness was made directly by visual comparison, measuring the field and the location of contact track of the bevel gear wheels. A verification of numerical calculations was carried out on a test stand (Fig. 7) applying actual models.

The tested wheels were made of a SL 5170 resin by means of stereolitography on SLA 250/50 machine by 3D Systems. The physical models were cleaned and some of the working and constructional surfaces were polished. Then the models were fixed to an earlier prepared stand in a way that they really work. The test stand was equipped with an engine with rotation control and a break which imposed load to the tested gear.

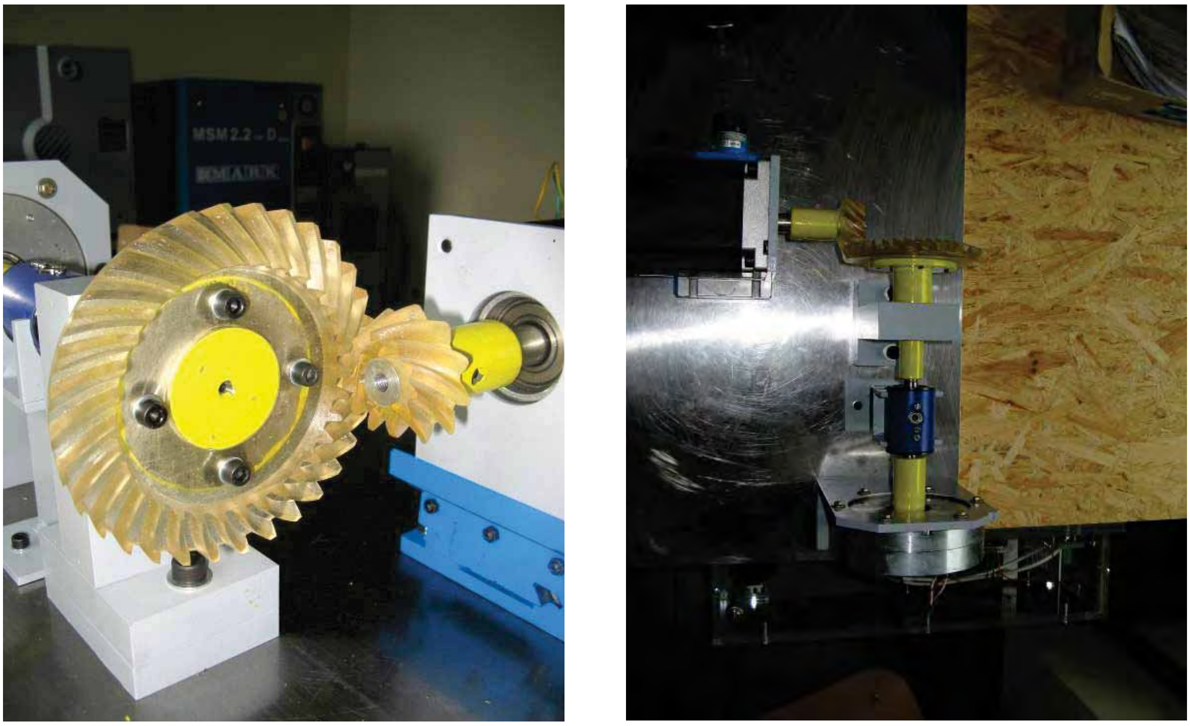

Fig. 7. A test stand for examining the contact track of bevel gear wheels

Observing the contact track on test sand was carried out while the gear was working under constant low speed. This way one could define the location of the contact track at individual stages of the teeth cooperation. Because of the dynamic character of the experiment the presentation of results was limited only to some selected elements shown in Fig. 8. Additionally, to improve the pictures' legibility the profile of tooth of the wheel was outline with a dotted line and the contact track with a solid line.

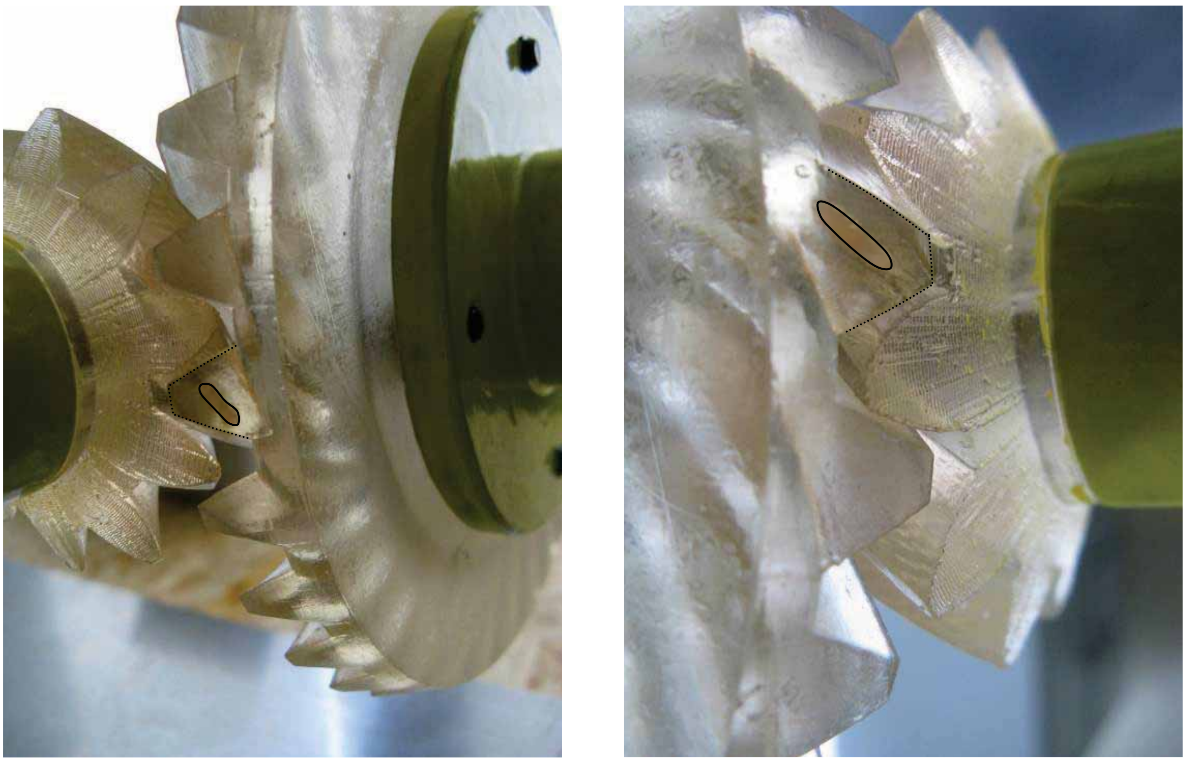

Fig. 8. An instantaneous contact track of bevel gear wheels marked on the test stand

The contact track received as a result of the test was equivalent to an earlier marked track received by means of FEM. Both the location of an instantaneous area of adhesion and its size match exactly the received results of numerical calculations. A verification of results in a dynamic way was possible thanks to a function of ADINA which allowed for a dynamic presentation of results as a film composed of results of subsequent steps of calculations. The FEM results presentation and observing the experiment made it possible to compare not only the static results but also their changes in time.

5. Summary

Defining contact track of loaded bevel gear by means of FEM is fully justified. If the models are properly prepared and the character of work and limitations of each method are taken into account, one can get correct solutions. A legible graphic form of the received results and the possibility of automating the process of calculations make the FEM method a basic tool for a designer. However carrying out the numerical calculations properly and their later verification require a lot of experience. The results received by means of FEM should be checked by some other analytical or experimental method. As a part of the above analysis, verifying the results concerning the contact track of wheels in bevel gear was made experimentally. The experiment on the test stand confirms the results received earlier applying numerical calculation. The convergence of solutions received by means of both methods fully confirms the right assumptions made initially, carrying out the calculations and finally the correctness of received results.

Acknowledgements

Financial support of Structural Funds in the Operational Programme - Innovative Economy (IE OP) financed from the European Regional Development Fund - Project “Modern material technologies in aerospace industry”, No POIG.0101.02-00-015/08 is gratefully acknowledged.

References

[1] ADINA 8.4.2 - *Podręcznik użytkownika*.

[2] Budzik, G., Oleksy, M., Marciniec, A., Sobolak, M., *Określenie śladu styku kół zębatych z zastosowaniem tiksotropowych kompozycji akrylowo-styrenowych*, Zeszyty Naukowe Politechniki Rzeszowskiej, Chemia, z. 20, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2009.

[3] Budzik, G., Markowski, T., Sobolak, M., *Tooth contact analysis of hypoid gear transmission prototypes manufacturing with Vacuum Casting method*, Journal of KONES Powertrain and Transport, Vol. 16, No. 3, 2009.

[4] Jaśkiewicz, Z., Wąsiewski, A., *Przekładnie walcowe, Tom I. Geometria, wytrzymałość, dokładność wykonania*, WKŁ, Warszawa 1992.

[5] Kleiber, M., *Komputerowe metody mechaniki ciał stałych*, PWN, Warszawa 1995.

[6] Marciniec, A., *Analiza zazębienia i śladu współpracy przekładni stożkowych o kołowo-łukowej linii zęba*, Zeszyty Naukowe Politechniki Rzeszowskiej, Nr 188, Mechanika z. 57, 2001.

[7] Matuszek, J., Hernia, S., *Ewolwentowe przekładnie zębate ogólnego przeznaczenia. Część 1. Podstawy projektowania*, Wydawnictwo Akademii Techniczno-Humanistycznej, Bielsko-Biała 2002.

[8] Skawiński, P., Siemiński, P., *Badanie śladu współpracy i generowanie wykresów ruchowych spiralnych przekładni stożkowych w środowisku programów CAD*, Zeszyty naukowe Politechniki Rzeszowskiej, Nr 259, Mechanika z. 75, 2008.

[9] Sobolak, M., Budzik, G., *Experimental Method of Tooth Contact Analysis (TCA) with Rapid Prototyping (RP) Use*, Rapid Prototyping Journal, Vol. 14, No. 4, 2008.

[10] Szmelter, J., Dacko, M., Dobrociński, S., Wieczorek, M., *Programy metody elementów skończonych*, Arkady, Warszawa 1973.
[11] Wójcik, Z., *Przekładnie stożkowe systemu Gleason, konstrukcja i technologia*, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2004.