Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird
Annals of DAAAM International

ON THE TORSION GEAR TOOTH STIFFNESS AT HELICAL GEARS

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Abstract: *The paper approaches a very interesting problem: the determination of a complex quantity being the static torsion gear tooth stiffness in the case of helical gears. In the introduction section, the paper statement, the state of the art, and the new aim are mentioned (a new lower dense model is studied by FEA in its processes). The results are compared with one with high density on length developed in previous papers by authors.*
Key words: *static torsion gear tooth stiffness; overlap contact ratio; line of action; FEA*

1. INTRODUCTION

The problem approached by the present paper is the determination of the gear tooth stiffness in helical gears using gear technique in a particular case of an overlap contact ratio equal to a natural number (ε_β=1). The justifications of this task are: a) the decisive effect of the variation in time of the gear tooth stiffness on gear vibration and noise behavior; b) the possibility to use modern techniques of FEA in the complicated analysis of displacement specific for helical gears.

A short description of the state of the art in this problem is carried out below. Pioneering studies pertaining to the decisive effect of the variation in time of the gear tooth stiffness on gear vibration and noise behavior carried out, for example, Rettig (1957); Schlaf (1962), Bosch (1965). Previous research regarding the effect of contact ratio on the dynamic behavior of cylindrical gears achieved Rettig (1956), Baethge (1969), Ziegler (1971), Geiser (2002). The team of authors developed a careful and profound use of FEA techniques in the mentioned subject, some of their papers being Dobre, Mirică, Sorohan. (2006) and Dobre, Mirică, Gabroveanu (2008).

The present paper explores aspects of FEA studies (model, analysis, post-processing) of the static torsion gear tooth stiffness along the line of action for the geometrical case of ε_β =1, for a model with a lower density on wheel length: 8 elements. This results in a new diagram of variation respecting the accuracy requirements related to the interference and a comparison with previous results (model with 25 elements/wheel length) given by Dobre, Mirică, Sorohan. (2006) and Dobre, Mirică, Gabroveanu (2008).

The future research will be aimed to estimating the accuracy of the results by convergence analysis that takes both work and time. Validation experiments are in progress.

2. FEA OF GEAR PAIR

The three known steps of FEA are described succinctly below.

1. The step of pre-processing or modeling the structure. a) The MATHEMATICA software was used to generate the profile of the tooth in the transverse section using procedures of gear generation (see, for example, Dobre, 1986). b) Based on experience, the twenty-node hexahedral BRICK element was chosen, because of its three degrees of freedom per node and the better mesh close the curve surfaces specific to gear wheels. c) The transverse tooth section is discretized, more dense elements being placed close by tooth profile (including tooth tip and root). d) The section is roto-translated (sweeping process) along the gear pitch helix till the last transverse plan. e) based on experience, five teeth at pinion and gear wheel are considered sufficient in the final model (not-given here) for a proper analysis. f) The constraints' (boundary conditions) definition, model of loading and mechanical properties definitions finalize the pre-process step.

This paper studies a model having a density of 8 elements/wheel length having 142908 nodes and 32424 hexahedral elements. The smaller number of elements on wheel length means, in our opinion, a lower density of the model in contact zones. Another studied model in previous papers have 25 elements/wheel length, this means that the contact calculation is more accurate.

2. Analysis. Matrix equations for each element (considering the geometry, the limit conditions, loading and the mechanical properties) are assembled into the global matrix equation:

$$\{F\} = [K]\{u\}, \tag{1}$$

in which: $\{F\}$ is the external force matrix; $[K]$ - global stiffness vector; $\{u\}$ - displacement matrix. The equation (1) solved by specific software (ANSYS) returns displacement values permitting the calculation of the static torsion gear tooth stiffness (procedure is given by: Dobre, Mirica, Sorohan, 2006; Dobre, Mirica, Gabroveanu, 2008):

$$k_{t\,m} = \frac{T_1}{\varphi_{12\,m}}, \tag{2}$$

The stiffness is determined along the gear line of action in some meshing points placed in the first transverse plan.

An important observation at this moment: the first obtained results given that the interference was not correct as values. As a result, the accuracy of the position angles of the wheels was increased to ensure interference fit values.

3. Post-processing. The first sub-step is the representation of the static torsion tooth stiffness variation along the line of action. For the two models mentioned in step 1 with different densities of elements, the variation diagrams are given in the fig. 1.

Another sub-step is the interpretation of the two diagrams, which is carried out below.

a) The variation of the static torsion gear tooth stiffness along the line of action is similar for the two models of structure mesh, in the idea that the style of gear tooth stiffness variation is alike along the line of action.

b) The differences are following: a) the values are different, the more dense structure on the wheel length resulting in higher values of the static torsion stiffness; b) the stiffness values of the high density model are closer for different loading in contrast with the case of lower density model. The explanation of these differences is a better description of the material behavior as a continuous structure in the case of dense model, thus the calculation accuracy is higher.

c) The variation of the static torsion tooth stiffness is sufficient uniform in time (along the line of action). Thus the parametrical excitation of the gear pair is more diminished.

The analysis of the interference and penetration values was another sub-step. The first model with lower density led to non-valid interference; as a result, the stiffness values incorrectly decreased with the load. A new correction of the position angle values of the wheels brought the interference within acceptable values; also the penetration values are in good limits (table 1) considering the case of grinded teeth.

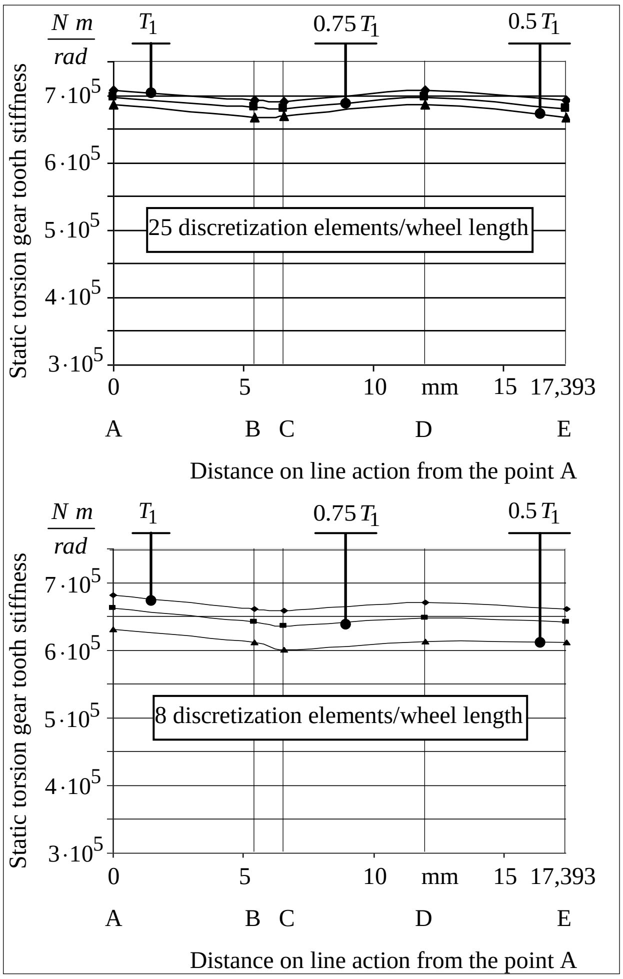

Fig. 1. Variations of the static torsion gear tooth stiffness along the line of action. Data: gear center distance, a_w =125 mm; normal module, m_n =4 mm; helix angle, β =10^{o}; numbers of teeth for pinion and gear wheel, z_1 =15; z_2 =46; normal addendum modification coefficients for pinion and gear wheel, x_{n1}=0.427; x_{n2} =-0.138; face width, b =72.367 mm; transverse contact ratio, ε_α =1.45318; overlap contact ratio, ε_β =1; nominal torsion torque for pinion, T_1 =392.466 Nm; A, B, C, D, E – main points on line of action (pinion root to pinion tip).

3. CONCLUSIONS

The following conclusions could be outlined.

1. The study of the complex problem of the gear tooth stiffness determination using FEA techniques is decisively influenced by the accuracy of the model.

2. A model with lower density on the wheel length led to non-accurate results of the static torsion gear tooth stiffness.

Point on the line of action for the teeth pair 1	Loading in [%] from the nominal one	Pairs of teeth being simultaneously in gear action					
		2		1		0	
		Interference (for null loading) or penetration (for non-null loading) [μm]					
		Number of elements/wheel length					
		25	8	25	8	25	8
A	0	-		0.71	0.30	0.47	0.26
	50%	-		0.83	1.92	1.68	1.77
	75%	-		1.22	2.78	2.28	2.62
	100%	-		1.62	3.61	2.75	3.42
B	0	0.51	0.15	0.07	0.23	-	-
	50%	0.72	1.49	1.16	2.67	2.17	1.38
	75%	0.95	2.11	1.50	3.82	3.33	3.11
	100%	1.24	2.73	1.95	4.93	4.18	4.81
C	0	0.05	0.14	0.07	0.39	-	-
	50%	0.71	1.47	1.14	2.37	-	-
	75%	1.03	2.13	1.68	3.57	-	-
	100%	1.33	2.81	2.19	4.60	-	-
D	0	0.07	0.00	-	0.00	-	-
	50%	0.83	1.91	1.69	1.78	-	-
	75%	1.22	2.77	2.28	2.63	-	-
	100%	1.62	3.59	2.75	3.42	-	-

Tab. 1. Penetrations and interference along the line of action

4. ACKNOWLEDGEMENTS

The authors thank the company COMOTI of Bucharest for its support in sustaining the publication of the paper.

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