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ANALYSIS OF THE DEFORMATION ON THE WORM GEAR WITH HELP OF FEM FOR THE ACCURATE DRIVED C AXIS OF THE TURNING CENTER

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Summary: *Main spindle where is C-axis realized is for turning operation drive with spindle motor with power 71kW. For milling and drilling operation is this main motor uncoupled through neutral position in this gear box and spindle is hydraulic coupled with worm gears, where are geared with two synchronous servomotors controlled in mode Master – slave. This mode assures to change the parameters of electrical preloading between both servomotors from the machine control. Important step for better specify of the mathematical model C axis is determine the torsion deformation and stiffness on the worm gear in relationship on the torque load. For this analysis will be create simplified 3D model ZA type of the worm gear for the calculation in FEM (Finite Element Methods). 3D model of worm and worm wheel is created in the program ProEngineer. Complete model is transferred to the program FEM concretely Ansys as volume assemble. Accuracy of the results from 3D model is compared with existing simplified 2D model. The value of the torsion deformation by more states of the loading on the worm gear is used to the calculated model of the drived C axis.*

1. Introduction

Within framework of better precision by the calculated model for C axis drive on the multifunction turning center developed the task, verified the accuracy of the value for torsion stiffness on the worm gear. Present state of the calculated value of the torsion stiffness proceed from simplified 2D model, witch is created in the plane of the section created of the plumb role on the angle of climb on the worm wheel teeth and straight line of take. It speaks about of type of the worm gear ZA, which is characterized by straight line profile of a worm tooth in the axis section. If isn´t time for measuring and verification of calculated model for real worm gear on the machine, it is necessary to create better accuracy model with help of comparing 2D model with 3D more complicated model, which is more testified about the real situation of the contact area by worm gear. Problematic of torsion stiffness by worm gear is solved on the Nottingham Trent University. Important knowledge their research is, that by different size of loading torque moment incoming to increasing of contact areas, but coming to increasing of the Hertz pressure on the contact areas (Yang, 2001; Su, 2003). But next folder of deformation, which has the influence on the whole stiffness for tooth on the stroke,

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is elastic deformation caused with tooth bend. On this folder has the influence the size of the loading of torque moment.

Calculated 3D model proceed from 3D model of designed assembly of the C axis (Fig. 1.). For the accuracies geometry of the worm gear was used first further software for calculation of gear with creating of 3D geometry TDS Technik. Unfortunately from generated 3D model from this software isn´t possible to use for the calculated volume model in Finite elements methods for reason of the great inaccuracy in the contact and form of tooth. But it is possible to proceed from calculated dimension from this program. On the basis of these dimensions is necessary to make exact 3D geometry direct in the program Proengineer.

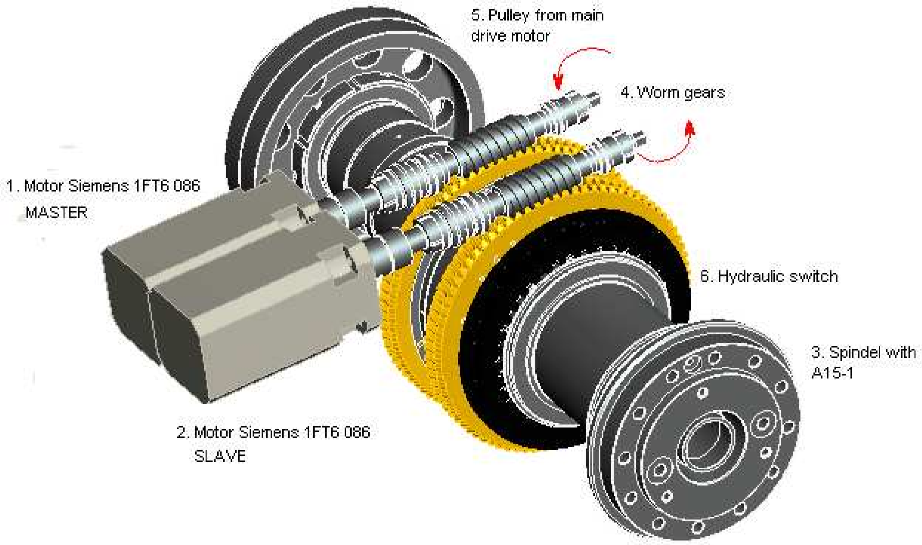

Fig. 1.: Development of the worm gear model (Křepela, 2007)

For reason of calculated capacity is calculated model created with consideration on the count of needed volume elements. Worm wheel is simplified solely on the sector of circle, which includes the teeth of the worm wheel in the stroke and needed surroundings (Fig. 3).

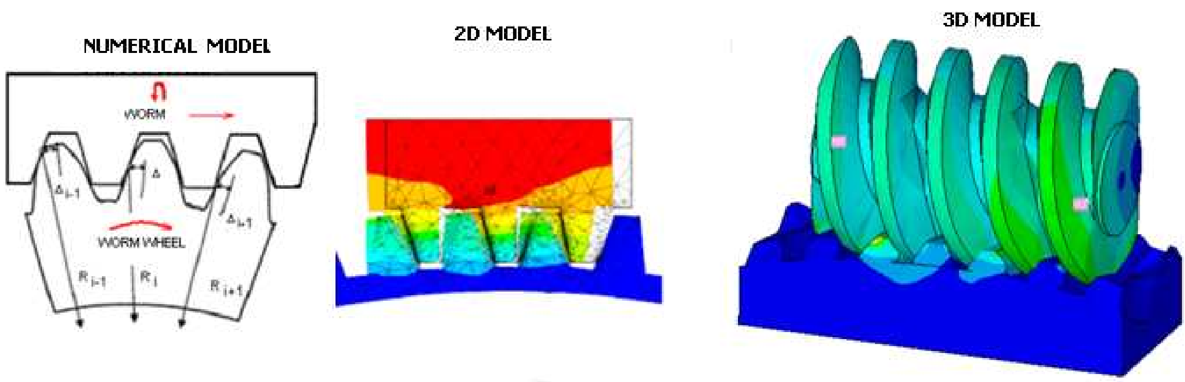

Fig. 2: Development of the worm gear model

2. Creating of the calculated 3D model of worm

Worm is created with help of tool "Helical sweep cut" in Proengineeru, by witch is necessary to define pitch diameter, pitch of worm and created profile of teeth gap. Worm wheel is created with help of the tool "Sweep", bat the direct trajectory is solely the median line of gap between the both teeth. Thereafter is this gap with help of axis pattern multiplicated on the defined count of tooth gaps. The model of worm wheel has already modulated in the Finite elements methods (next FEM) is cut solely segment of circle, which includes teeth in the stroke and surroundings of these teeth.

To the FEM is transferred the coupling assembly worm- segment of circle of worm wheel with help of the format IGES. In the FEM is this format opened as assembly. Definition of the material constants is initiated separate on the worm and separate on the segment of circle of worm wheel. Materials characteristic are showed in the table 1. The meshing of the volume elements is created so, that the areas with dense meshing are on the contact areas and profiles of teeth in the stroke on the worm wheel (Fig.4). Greatens slides and consequently deformation are expected in the teeth of the bronze worm wheel.

Used material characteristics:

Tab.1: Material characteristics

Material	Density ($kg.m^3$)	Modulus of Elasticity ($x\ 10^3$ MPa)	Poison number
steel	7870	206	0,3
bronze	8800	88,3	0,35

Next importent step is the definition of contact areas. As "target" areas are indicated the lateral areas of the tooth gaps of worm, by witch is assumed contact. As "contact" areas are indicated the flank of teeth by worm wheel. The value of the friction is taken from literatur, as the value by static friction between steel and bronze.

By definition of the border conditions is necessary to respect the real assembly. In reality is the shaft of worm put in the radial- axial bearings. Torsion and bended stiffness of the shaft of worm in this model isn't included and is this problematic simulates extra. Axial stiffness is initiated on the frontal area of worm.

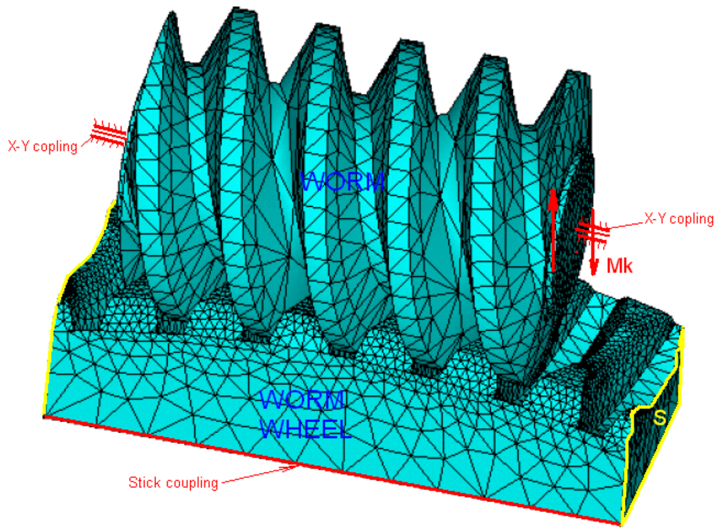

Fig. 3: Development of the worm gear FEM model

Segment of the worm wheel is coupled subsequently:

- bottom area of the segment of worm wheel is stick
- head areas are symmetrical
- worm is coupled rotary in the axis of worm
- front is axial coupled with definite stiffness of bearings

The torque of the loading is established on the input head of worm, where is subsequently studied the angle of torsion on the worm head versus blokated segment of worm wheel.

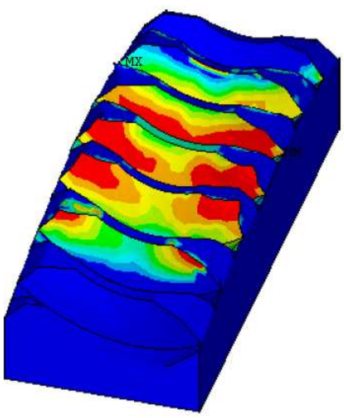

Fig. 4: Results for analyse of the contour line of the contact areas on the worm and worm wheel

3. Possibility for the evaluation of results 3D simulation

1. From the angle of torsion on the head of worm, witch is loaded wit torque
2. From the bended deformation of the tooth on the worm wheel and subsequently calculated angle of torsion on the worm wheel.

3.1 Calculation in this method has two conditions:

How is possible to show on the Fig. 5, by the measuring of the deformation section in the direction of the loading with torque is possible to calculate the angle of torsion. Is necessary to asses the value of the moving in the place, where cause the force from the torque in the horizontal plane, which is near the stroke with the blocated worm wheel.

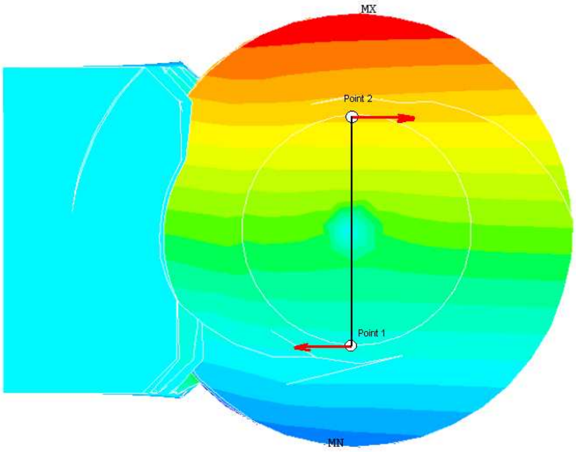

Fig. 5.: Results of the torsion angle analyses on the head area of worm

3.2 Calculation z průhybu zubu šnekového kola:

This metod was used by the evaluation of the 2D model.

Conditions of the calculation:

1. Deformation of the tooth is elastic.
2. Center of the contact ellipse isn´t move from elastic deformation.

Elastic deformation both teeth consist of the deformation of worm U_1 and deformation of tooth from worm wheel U_2. By calculation on the individual tooth is separated the elastic deformation to a two sections. First section is flexural part and second section is from contact. Flexural part of deformation is defined as displacement along the normal of contact area towards to the tooth profil, where is initialized force loading. Section of contact is defined on the basis Hertz pressure. Size of deformation U_i (δ) in the center of contact ellipse for the worm U_1 and tooth of worm wheel U_2 is deformation for position particular elements. Stiffness for particular element of the tooth is possible to calculate with help of equation 1 (Yang, 2001).

$$K_i(\delta) = \frac{F_\delta}{U_i(\delta)} \qquad (1)$$

Immediate contact stiffness in the point of tooth in stroke [Yang, 2001]:

$$K_\delta = \frac{K_1(\delta) \cdot K_2(\delta)}{K_1(\delta) + K_2(\delta)} \qquad (2)$$

Because in the reality isn´t only once tooth in the stroke, is necessary to respect deformation more teeth. For these teeth in the stroke refer the equation 3 [Yang, 2001].

$$U_i = \frac{\Delta_{i-1}}{R_{i-1}} = \frac{\Delta_i}{R_i} = \frac{\Delta_{i+1}}{R_{i+1}} \qquad (3)$$

4. Conclusions

After the evaluation both models was calculated the different by the same loading approximately 60%. Unfortunately in this time isn´t possible to compare the values of torsion stiffness of both models with measured values. In the different of the values for torsion stiffness between the 2D model and 3D model are included inaccuracy of both models. It is possible to assume, that 2D model isn´t so accuracy as 3D for reason great simplification of the situation. In the 2D model isn´t included the torsion of worm, direct of moving areas and form of the contact areas. The different 60% in the results of the torsion stiffness haven´t so great influence on the behavior of the C axis dynamic system. By using these both values of torsion stiffness for worm gear into the whole calculation model for C axis drive is possible to compare results for both values of stiffness. The result is, that is only the different in the process of regulation during the oscillated section. It causes the different in the eigen frequencies for both models.

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References

Yang, F. Su, D. Gentle, R. C. (2001) Finite element modeling and load share analysis for involute worm gears with localized tooth contact. The Nottingham Trent University. IMechE.Vol.215. Part C.

Su, D. Qin, D. (2003) Integration of numerical analysis, virtual simulation and finite element analysis for the optimum design of worm gearing. Journal of Processing Technology. pp.429-435.

Garcia, E. Gonzales de Santos, P, Canudas de Wit, C. (2002) Velocity Dependence in the viscous friction Arising with Gears. The International Journal of Robotics Research. Vol. 21. No. 9. Sage Publications. pp 805-815.

Křepela, J. Singule, V. (2007) Dynamic behaviors of the C axis with the worm gear on the turning center. Simulation Modelling of Mechatronic System III. Brno University of Technology.

Křepela, J. Singule, V. (2007) Mathematic model of C-axis drive for identification of dynamic behaviour of the horizontal multifunction turning center. Engineering Mechanics 2007 Svratka.