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High speed precise machine tools spindle units improving

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Abstract: A hybrid high-speed precise machining centre headstock model based on two computation methods: the finite element method and the finite difference method is presented. The model allows one to calculate precisely the headstock's indices on the basis of which its optimal operating characteristics can be determined. The presented modelling methods allow one to evaluate a design from thermal, stiffness and durability points of view. The bearing units and cooling system influence on machine tool preciseness has been described.

Keywords: Machine tool, Modelling, Spindle

1. INTRODUCTION

The development of modern machining centres proceeds towards very high machining speeds and precision. At the same time the static, dynamic and heat loads of machining centres become increasingly complex. Consequently, the creation of an accurate computational model is a very difficult task. Precise modelling is the basis for design improvement through the analysis and optimisation of the machining centre's operational properties and the minimization of its prototyping time and cost [1], [2], [3].

Hence the creation of machine tool models becomes highly important. Effective models are holistic hybrid models which accurately represent all the involved phenomena and their effects. The thermal phenomena which occur in such complex machine tools as machining centres are particularly difficult to model. It is necessary to search for accurate functions and procedures to describe the energy losses, the geometry, the heat exchange and the dynamics and nonlinearity of the involved phenomena. In this paper an idea of a holistic hybrid high-speed machining centre headstock model is presented and illustrated using as examples machining centre headstocks.

2. IDEA OF HYBRID MODEL

The thermal state of high-speed precision machining centres is affected by a whole range of factors, such as machine tool operating conditions, energy losses in kinematic system elements, temperature distributions and thermal displacements of machining centre elements and assemblies, and the interrelationships between them. Power losses are a function of the machine tool operating conditions and depend on the design features, the geometrical structure and the material properties of the particular components and assemblies, the lubricating media and methods, the cooling, etc. Power losses result in time-variable temperature distributions which in turn affect, among others, the running clearance in the bearings, the viscosity of the lubricating medium and the surface film conductance. Consequently, the power losses change. The interactions between the factors result in a complex, dynamic and nonlinear state of thermal equilibrium characterized by continuous changes in power losses, temperatures and displacements. The hybrid model of the high-speed headstock takes into account the above interactions (Figure 1) and makes possible a highly precise partial and full analysis.

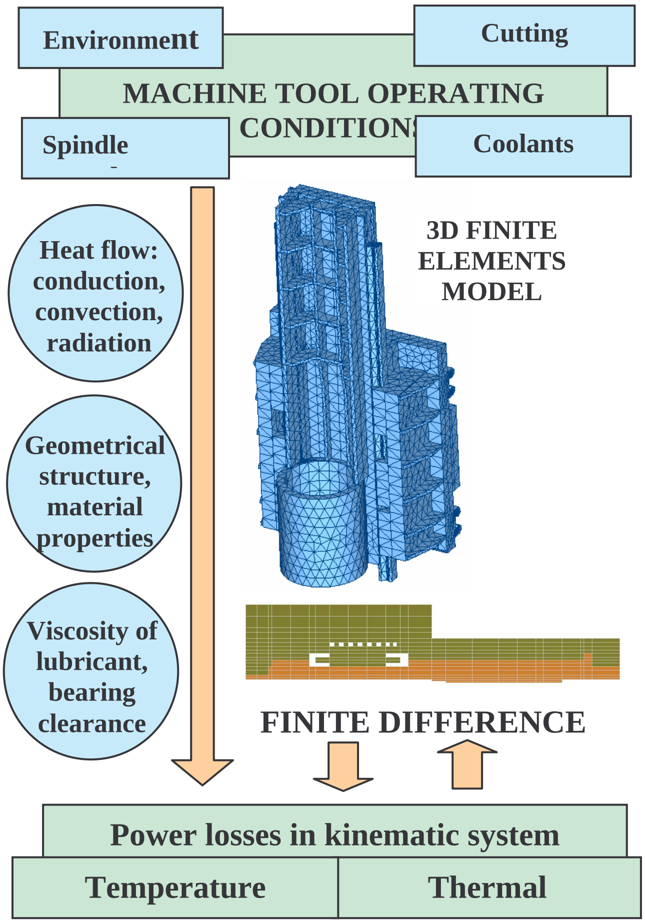

Figure 1. Schematic of hybrid model of machining centre headstock

The model is based on two computation methods: the finite element method (FEM) and the finite difference method (FDM). The components of the headstock's body are modelled by FEM using tetrahedral elements. The axially symmetric headstock assemblies are modelled by FDM using ring elements. The two computational submodels are integrated into one holistic model whereby it is possible to model very precisely the thermal phenomena in the axially symmetric kinematic system components. In this approach spindle assemblies are treated as modules which can be modelled separately and integrated into the headstock body whose geometry does not change. The hybrid model owes its high accuracy to the precise modelling of the heat sources and flows and to the fact that all the complex interactions are taken into account, e.g. when modelling rolling bearings their design, the rotational speed, the load, the lubrication conditions, the elastic and thermal properties of the bearing sets' components, the forced cooling and the bearings' lifetime can all be taken into account.

3. HYBRID MODEL OF ELECTROSPINDLE

3.1. Model of electrospindle

The electrospindle model is based on the FEM and FDM. The hybrid model is particularly useful when the temperature distributions resulting from the heat generated in the assemblies are to be calculated and it allows one to:

- freely shape the geometry of the headstock's housing,
- avoid the computation of body deformations when calculating temperature distributions – owing to the analytical models for determining power losses in the bearing sets,
- avoid excessive mesh density within bearings when determining running clearance,
- store models of typical bearing set designs in the system's database.

3.2. Bearing set and running clearances

Spindle bearing set modelling requires special attention since accurate evaluation of power losses is not possible unless the influence of the set's temperature and deformations is precisely known. Power losses are determined from temperature relations while bearing losses are computed from a simplified model consisting of a body wall fragment, the spindle and the bearings. Bearing set deformations are needed to determine running clearance which in turn is needed to calculate the power losses and the bearing wear-out time. The final clearance value for a given design depends on the fit between the bearing set's components, the bearing preload and the bearing set thermal deformation.

Running clearance in the bearings depends on changes in the dimensions of all the bearing set components caused by the distribution of temperature. From the conditions of the equilibrium of forces in the bearing set, taking the forces generated by the radial and axial changes in the dimensions of the bearing set components into account, the running clearance in each of the bearings could be determined. Changes in running clearance in the particular bearings for different spacer lengths are shown in Figure 2.

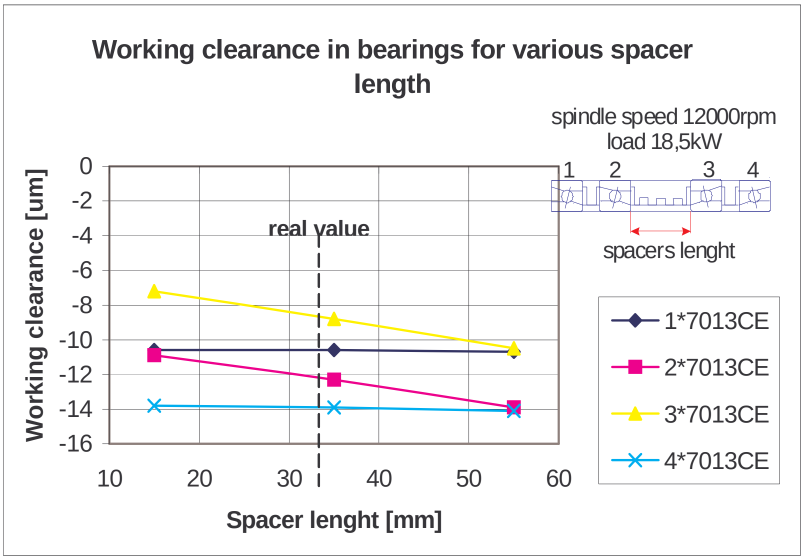

Figure 2. Running clearance in bearings versus spacer length

4. HYBRID MODEL OF MACHINING CENTRE HEADSTOCK

A precise machining centre headstock with the spindle rotating at a very high speed of 50000 rpm was modelled. An electrospindle with an asynchronous motor and aerostatic bearings was used. The electrospindle motor stator is intensively cooled. The hybrid model was used for analysing the effect of motor stator cooling on the thermal behaviour of the machining centre electrospindle. An example of this analysis is shown in Figure 3 where the temperature of the electrospindle is compared for three cases: no stator cooling, stator cooling with oil and stator cooling with water. The analysis showed a very strong effect of cooling on electrospindle temperature, particularly for intensive cooling with water. The spindle thermal displacements, precisely simulated using the hybrid model assuming water cooling, was decreased in the Y axis from 100 μm to 20 μm and in the Z axis from 110 μm to near 0 μm.

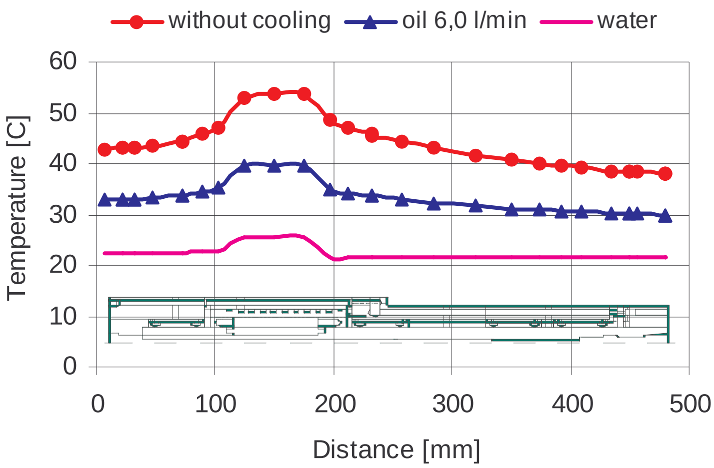

Figure 3. Effect of stator cooling conditions on temperature of the electrospindle

5. CONCLUSION

Precise modelling of the thermal behaviour of high-speed machining centre headstocks is a complex and time-consuming problem. Owing to its high accuracy, ensured by the precise modelling of the main heat sources, the presented hybrid model can be successfully employed in the design of high-precision machine tool headstocks and spindle assemblies. The model has been repeatedly verified in the design of machining centres.

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