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COMPARISON OF MODELS, APPLIED IN MULTIOBJECTIVE OPTIMIZATION OF MACHINE TOOLS' SPINDLE-BEARING SYSTEMS*

S. Tompa, K. Jármai

1. INTRODUCTION

To increase the accuracy of the machine-tools' spindle-bearing system has a great importance, because if we analyse the static, dynamic and thermal stiffness of the total machine, usually this is the weakest parameter. One can decrease the effect against the accuracy, if the rigidities are increased and the troublesome effects are decreased as well.

The optimization of spindle-bearing system can be performed on the following two stages according to [4]:

1. during the design,
2. during operation.

At the design stage 1. one should have the following considerations:

- functional,
- static,
- dynamic,
- thermal,
- tribological,
- economical, requirements.

At the operational stage 2. one can control the accuracy with the following parameters:

- measurements, control and/or regulation of the static and dynamic characteristics;
- thermal behaviour, measurements of displacement and compensation by cooling and heating;
- control the bearing, mass of lubricant, lubricant system and bearing function.

The aim of this research to choose mechanical models at the design stage for the optimization and to compare two possible models.

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2. DETERMINATION OF OPTIMAL PARAMETERS OF SPINDLE-BEARING SYSTEMS

The main task of a machine-tool design is to find the main parameters of the spindle-bearing system, considering the different requiring. Using computers, one can make a number of computations, taking into account the different effects, to describe the best parameter values. There are also some analytical solutions exist.

These works are started from the "optimal distance" between bearings (optimal distance: the distance between the middle line of front and back bearings, where the stiffness of the spindle is maximal) The described solution in [1,3,4,6] are in the category of multiobjective optimization, because they try to determine the optimal parameters of the spindle-bearing system in such a way, that consider more expectations, or objective functions to be minimized or maximized simultaneously.

3. DETERMINATION OF OPTIMAL PARAMETERS OF SPINDLE-BEARING SYSTEMS WITH ROLLER AND BALL BEARINGS

During the development of machine-tools a great knowledge is accumulated in the designers. To built the spindle-bearing system which is fulfil the complicated requirements the solution needs a number of difficult computations and a range of decisions of designer. Our aim is to form these procedures into structure, to decrease the number of those decisions where the information is not enough, to give a tool to the hand of the designer, forming a good (fulfil the requirements) and an economical construction. The design and decision maker computer code which computes the optimal dimensions of the spindle-bearing system is founding on principles describe in [1].

3.1 THE OBJECTIVE FUNCTIONS

The machine tools, which are able to solve complex and different technological problems are very different and the objective functions can be different, or opposite [3,4].

They are as follows:

1./ blow of spindle end (δ_{r1}) should be minimal [4]

2.a/ the bending stiffness of the spindle end (s_h) should be maximal;

b/ the torsional stiffness of the spindle (s_t) should be maximal;

3.a/ the first eigenfrequency at flexural vibration of the spindle-bearing system should be maximal, or be above a give value;

b/ the first eigenfrequency at torsional vibration of the spindle-bearing system should be maximal, or be above a give value;

4./ mass of the spindle-bearing system should be minimal;

5./ cost of the spindle-bearing system should be minimal;

The components of the cost are:
- manufacturing cost of the spindle;
- cost of the bearings;
- maintenance, setting costs.

3.2 SOME POSSIBLE MODELS

The first step at the design we've chosen possible bearings from the catalogue of bearing production companies for the machine-tools' spindle system. We've summarised the typical bearing possibilities in [1].

3.2.1 SIMPLIFIED MODEL

The spindle-bearing system is modelled as variable cross-sectional beam with two elastic supports (Fig. 1.) It is neglected, that the bearing is usually contains more real bearings (roller or ball bearings or the combination of them). At this model the elastic supports are placed both at front and back bearings at the influence line of the bearing block. At this simplified model the number of sections is limited so the real shape is much simple as can be seen in Fig. 1.

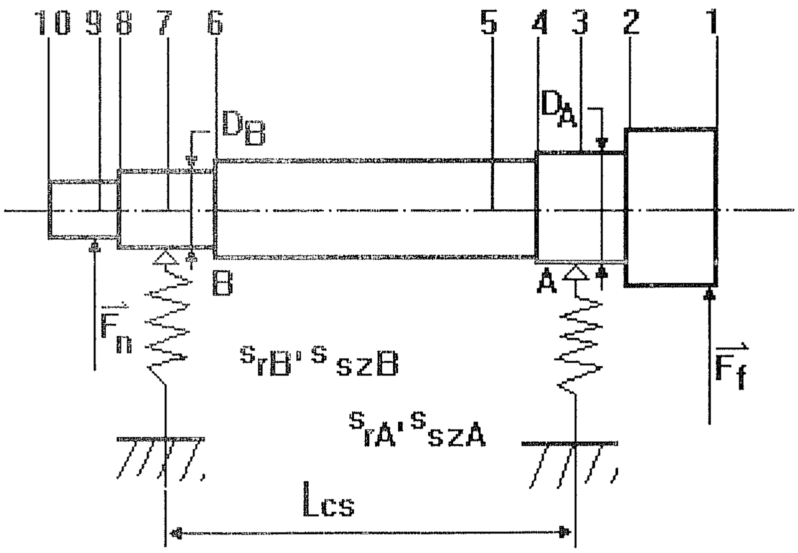

Fig. 1.

3.2.2 EXTENDED MODEL

At the spindle-bearing system, the number of bearings is equal to the real number of them, each of it is elastic support. The model is a variable cross-sectional beam (Fig. 2.). To increase the accuracy, we've applied unlimited number of sections at the spindle, to be closer to the real shape of it.

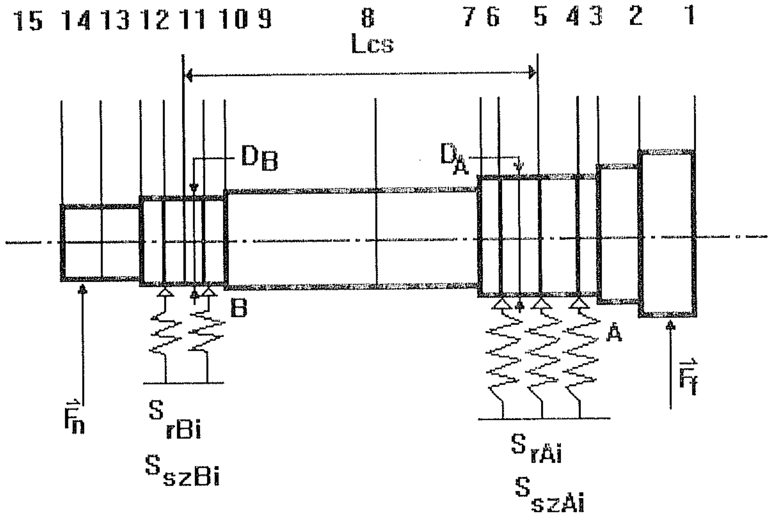

Fig. 2.

3.3 ANALYSIS

During the optimization the following dimensions are unknowns:

DA - diameter of the front bearing in [mm];

DB - diameter of the back bearing in [mm]; (there are geometric and maintenance relation between the two diameters!);

Lcs - distance between bearings in [mm];

sri, sszi - radial and tangential stiffness of bearings with the given diameters in [N/μm], [Nm/rad];

We considered the correlation linear between the stiffness and diameter of the bearings.

The loading of the spindle-bearing system, the coordinates of the loading points and the range of revolution per minute are input data.

3.4 DESIGN CONSTRAINTS

The constraints can be the operational, or technological requirements of the spindle, or some objective functions can be transferred to design constraints. They are as follows:

- one should design a spindle with given radial displacement;
- one should design a spindle with given radial and torsional stiffness;
- one should design a spindle which flexural and torsional eigenfrequencies should larger then a given value;

4. THE OPTIMIZATION ALGORITHM, THE FLEXIBLE TOLERANCE METHOD

The FT [2] algorithm improves the value of the objective function by using information provided by feasible points, as well as certain nonfeasible points termed near-feasible points. The near-feasibility limits are gradually made more restrictive as the search proceeds toward the solution, until in the limit only feasible x vectors are accepted.

With this strategy the original optimization problem can be replaced by a simpler problem, having the same solution:

$$\begin{aligned} &\text{minimize} \quad f(x), \\ &\text{subject to} \quad \Phi^k - T(x) \le 0 \end{aligned} \tag{1}$$

where Φ^k is the value of the flexible tolerance criterion for feasibility on the kth stage of the search, and T(x) is a positive functional of all the equality and/or inequality constraints, used as a measure of the extent of constraint violation. It is very important to choose a good size of initial polyhedron, which is difficult, when the difference between the values of unknowns is great.

5. EXAMPLE

We've used the two models shown in Fig. 1. and 2. There are two objective functions to determine the optimal dimensions of the spindle-bearing system. After getting these results, we could compare the results and the two models. There are 3 pieces of single-row ball bearings at the front, with slanted influence line (72th series), at the back 2 pieces of single-row ball bearings, with slanted influence line (72th series).

Bending moment is: 500 Nm.

Objective functions:

1. the realization cost of the spindle-bearing system should be minimal:
2. the displacement of the spindle at the end of first section should be minimal.

Unknowns:

1. DA
2. Lcs

Design constraints:

1. geometrical:

$$5 \le Lcs \le 100 \quad [mm]$$
$$60 \le DA \le 120 \quad [mm]$$

2. radial stiffness:

$$5 \le s_h \le 50 \quad [N/\mu m]$$

3. circular eigenfrequency due to bending:

$$4000 \le \alpha_h \le 15000 \quad [1/s];$$
$$4000 \le \alpha_h \le 15000 \quad [1/s].$$

6. RESULTS AND CONCLUSONS

The computations made by using the two models as in show in Fig. 1. and 2. The objective functions and design costraints forms are as we've described above.

1. We could find, that the results, the optimum sizes of DA and Lcs are nearly the same at both models.

2. It is possible to determinate the exact cost of the spindle-bearing system using the extended model, because it takes into account the real number of bearings (the cost of the high precision bearing can reach 80-90 % of the total realization cost).

3. For the technological and maintenance constraints is result construction is applicable it is not necessary to simplify it.

The further development of this research is to speedup the computer code and to connect database of bearing types.

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Dr. Sándor TOMPA, Senior Lecturer
Dr. Károly JÁRMAI, Ph.D., Associate Professor
University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
Tel./fax.: (36) (46) 365-111, (36) (46) 369-554