Expert spindle design system

Osamu Maeda, Yuzhong Cao, Yusuf Altintas*
Manufacturing Automation Laboratory, Department of Mechanical Engineering, University of British Columbia,
2324 Main Mall, Vancouver, BC, Canada V6T 1Z4
Received 27 July 2004; accepted 24 August 2004
Available online 5 October 2004

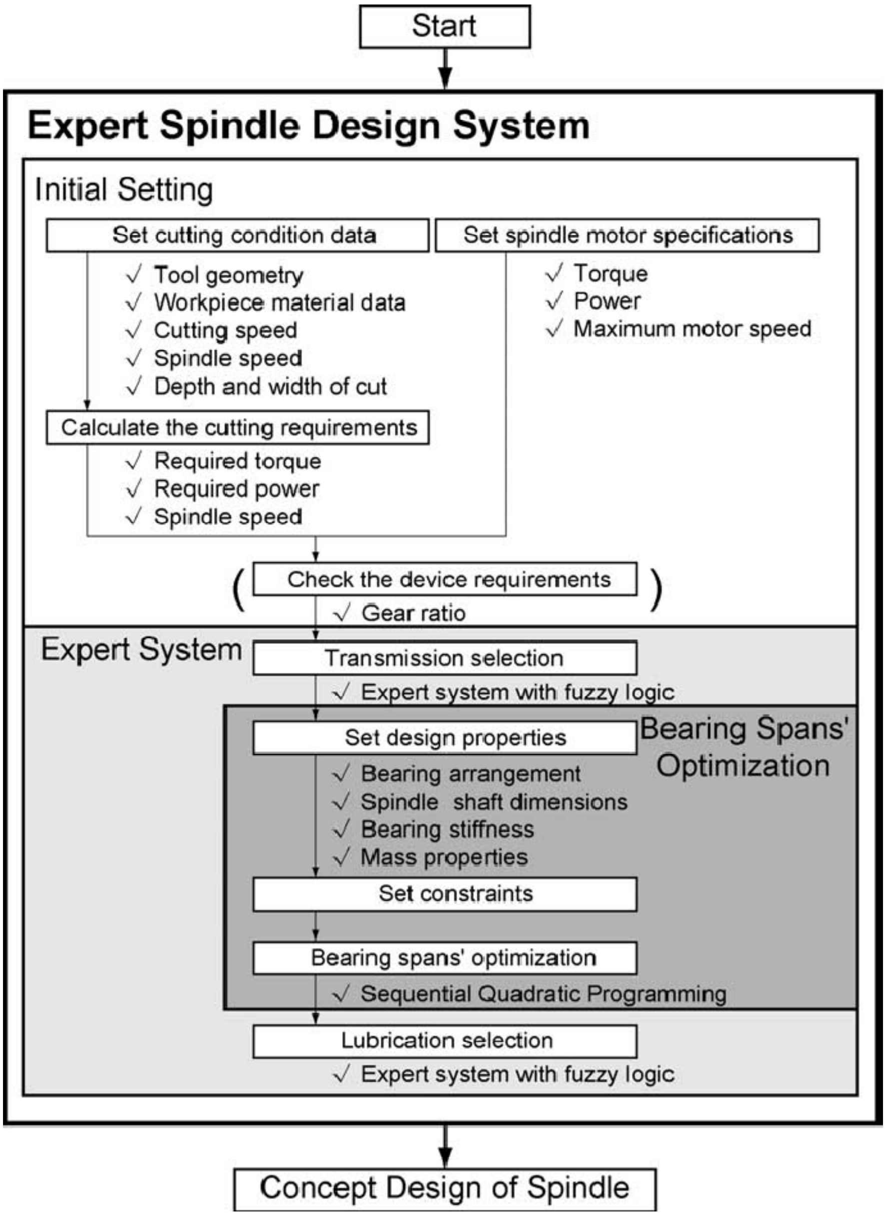
1. Introduction

The spindle is the main mechanical component in machining centers. The spindle shaft rotates at different speeds and holds a cutter, which machines a material attached to the machine tool table. The static and dynamic stiffness of the spindle directly affect the machining productivity and finish quality of the workpieces. The structural properties of the spindle depend on the dimensions of the shaft, motor, tool holder, bearings, and the design configuration of the overall spindle assembly. This research considers spindle component selection and configuration using the proposed expert system based on the digital knowledge base. The expert system with fuzzy logic is implemented as the selection system. Eskicioglu et al. [1] developed a rule-based algorithm for the selection of spindle bearing arrangement using PRO-LOG, which is a programming language for expert systems. The bearing arrangements are determined by the cutting operation type, and the required cutting force and life of bearings. Wong and Atkinson [2] demonstrated a knowledge cell approach for diverse designs. They divided the knowledge cell into four parts; the Function, Selection, Graphics, and Logic cells.
For design optimization of spindles, Yang [3] conducted static stiffness to optimize a bearing span using two bearings, and described the methods used to solve the multi-bearing spans' optimization method. Taylor et al. [4] developed a program which optimizes the spindle shaft diameters to minimize the static deflection with a constrained shaft mass. The Downhill Simplex Method is used to find the optimum value. Lee and Choi [5] conducted an optimization design in which they minimized the weight of the rotor-bearing system with the augmented Lagrange multiplier method. Chen et al. [6] and Nataraj and Ashrafiuon [7] demonstrated the optimization results to minimize the forces transmitted by the bearings to the supports. Wang and Chang [8] simulated a spindle-bearing system with a finite element model and 0890-6955/$ - see front matter q 2004 Published by Elsevier Ltd.
compared it to the experimental results. They concluded that the optimum bearing spacing for static stiffness does not guarantee an optimum system dynamic stiffness of the spindle. Hagiu and Gafiranu [9] demonstrated a system in which the bearing preload of the grinding machine is optimized. Kang et al. [10] conducted static and dynamic spindle analysis by using an off the shelve FE system with an added rigid disk and non-linear bearing model. The previous research used only two support bearings, although practical spindles may use more bearings depending on the machining application. In addition, most of them optimize design parameters, such as shaft diameter, bearing span, and bearing preload, to minimize the static deflection. This paper considers more than two bearings in the spindle model and takes into account the
chatter stability that is totally related to the dynamic properties of the spindle.
The overall expert spindle design system is outlined in Fig. 1. The design of the spindle with optimized bearing spacing is automated using the requirements set by the

machining application, expert spindle design rules, cutting mechanics, structural dynamics and chatter stability of
milling process.

References

[1] H.Eskicioglu,M.Akkok, O.H. Yildiz,Computer aided selection ofmachine tool spindle bearing arrangements, American Society of Mechanical Engineers, Petroleum Division (Publication) PD 64 (8-1) (1994) 181–187.
[2] W.L.D. Wong, J. Atkinson, A knowledge cell approach to processing design information, Journal of Materials Processing Technology 107 (1–3) (2000) 44–52.
[3] S. Yang, A study of the static stiffness of machine tool spindles, International Journal of Machine Tool Design & Research 21 (1) (1981) 23–40.
[4] S. Taylor, B.T. Khoo, D. Walton, Microcomputer optimization of machine tool spindle stiffnesses, International Journal of Machine Tools and Manufacture 30 (1) (1990) 151–159.
[5] D. Lee, D. Choi, Reduced weight design of a flexible rotor with ball bearing stiffness characteristics varying with rotational speed and load, Journal of Vibration and Acoustics, Transactions of the ASME 122 (3) (2000) 203–208.
[6] W.J. Chen, M. Rajan, S.D. Rajan, H.D. Nelson, Optimal design of squeeze film dampers for flexible rotor systems, Journal of Mechanisms, Transmissions, and Automation in Design 110 (2) (1988) 166–174.
[7] C. Nataraj, H. Ashrafiuon, Optimal design of centered squeeze film dampers, Journal of Vibration, Acoustics, Stress, and Reliability in Design 115 (2) (1993) 210–214.
[8] W.R. Wang, C.N. Chang, Dynamic analysis and design of a machine tool spindle-bearing system, Journal of Vibration and Acoustics, Transactions of the ASME 116 (3) (1994) 280–285.
[9] G. Hagiu, M.D. Gafiranu, Preload optimization: a high efficiency design solution for grinding machines main spindles, ASTM Special Technical Publication, No. 1247, 1995


Start
Expert Spindle Design System
Initial Setting
Set cutting condition data
√ Tool geometry
√ Workpiece material data
√ Cutting speed
√ Spindle speed
√ Depth and width of cut
Set spindle motor specifications
√ Torque
√ Power
√ Maximum motor speed
Calculate the cutting requirements
√ Required torque
√ Required power
√ Spindle speed
(Check the device requirements)
√ Gear ratio
Expert System
Transmission selection
√ Expert system with fuzzy logic
Bearing Spans' Optimization
Set design properties
√ Bearing arrangement
√ Spindle shaft dimensions
√ Bearing stiffness
√ Mass properties
Set constraints
Bearing spans' optimization
√ Sequential Quadratic Programming
Lubrication selection
√ Expert system with fuzzy logic
Concept Design of Spindle