Ain Shams University
Faculty of Engineering
Design and Production Engineering Department

Simulation approach to evaluate the performance of a milling machine based on the accuracy of the milling products

A Thesis Submitted in Partial Fulfilment for the Requirements of the Degree of PhD in Mechanical Engineering

by

Amr Ahmed Sayed Shaaban

Master of Science in Mechanical Engineering

Supervised by:

Prof. Dr. Monir Mohamed Farid Koura

Asst. Prof. Mohamed Lotfy Zamzam

Cairo-2015

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STATEMENT

This thesis is submitted as partial fulfillment of Ph.D. degree in mechanical engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or qualification at any other scientific entity

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EXAMINERS COMMITTEE

The undersigned certify that they have read and recommend to the Faculty of Engineering – Ain Shams University for acceptance a thesis entitled “Simulation approach to evaluate the performance of a milling machine based on the accuracy of the milling products” submitted by Amr Ahmed Sayed Shaaban, in partial fulfillment of requirements for the degree of Doctor of Philosophy in Mechanical Engineering.

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Abstract

This thesis presents a simulation system which is employed in order to evaluate the static, dynamic, and thermal performance of machine tools. Obtaining such a virtual model could replace many experimental tests that must otherwise be carried out each time the parameters affecting the machine performance are changed. The system is created based on well-defined design considerations, then, it is verified, and applied on some realistic cases. The system evaluates the machine tool performance based on several perspectives namely: static loop stiffness, mode shapes, frequency response function at tool center point, and thermal deformation. Mechanical modeling of mechanical structure and other subsystems of machine tool is achieved, cutting loads are analytically generated, and the heat generation at the hot spots is determined as well. Cutting conditions, cutter and work piece characteristics, category of mechanical structure, supporting webs, position of spindle head are all considered when evaluating the performance of the machine tool in order to provide designers with helpful recommendations in the early design stage. The obtained results from the designed simulation approach provide an evaluation of the behavior of the tool center point in relation to the work piece. Since that behavior will be reflected on the product, these results can be used as criteria for the product accuracy.

The designed evaluation system is proved to give a realistic simulation of the performance of machine tools that concerns the behavior of various machine tool elements and the parameters affecting the machining process.

Keywords:

Machine tools; Static loop stiffness; Natural frequencies; Dynamic performance; Finite element method (FE); Thermal deformation.

Thesis summary

Virtual prototyping is one of the most crucial research points in the field of machine tool design over the last decade. It provides the designers with a realistic simulation of the machine tool behavior without the need for experimental tests that consume cost and time. Obtaining such a realistic model facilitates investigations and modifications during the design stage. Among various modeling techniques, the FEM technique is proved to be a useful mathematical model for simulation.

In this thesis, a virtual system that employs the FEM technique is created to evaluate the static, dynamic, and thermal performance of machine tools. Modeling of the machine tool mechanical structure that includes machine bed and column is carried out together with the modeling of the mechanical and thermal behavior of various machine tool elements such as guide ways, feed drives, spindle unit, and bolted connections. On the other hand, in order to simulate the cutting process and integrate its contribution to the overall machine tool performance, analytical methods are used to obtain the cutting loads generated on both TCP and worktable during single tooth cutting interval. Based on the desired logic and the designed flow chart, the evaluation system is constructed so as to comprise five analysis modules created using FEM solving tool. The prerequisites of each module, the data connection among them, and the generated results from each are all clearly defined.

The system is applied to a case study where it is used to evaluate the static, dynamic, and thermal performance of a 3-axis open milling machine tool. All useful data related to the mechanical structure, various machine subsystems, and the cutting process is clearly defined and entered to the data sink of the evaluation system. The results generated by static analysis give an evaluation of the static performance of the machine tool in terms of

directional and total relative deformation between TCP and worktable and the static loop stiffness in various planes. The dynamic performance of the studied machine tool is evaluated based on the results generated by modal and harmonic analyses such as the fundamental frequency, the range of the first six mode shapes, and the TCP compliance along the exciting frequency range. In the same context, the time-varied deformation on both TCP and worktable in x and y-directions is generated by the transient response module along single tooth interval. Besides, the thermal performance is evaluated in terms of temperature distribution all over the milling machine and the thermal deformation at critical regions such as TCP guide ways and screws. The obtained results from the designed simulation approach provide an evaluation of the behavior of the tool center point in relation to the work piece. Since that behavior will be reflected on the product, these results can be used as criteria for the product accuracy.

The designed evaluation system is then employed to carry out some investigations that help the machine tool designers to achieve the desired performance during the early design stage. These investigations include the comparison of open and closed structures, the effect of supporting webs in columns, and the spindle head position effect, which are all carried out and the results are represented.

The designed system is proved to be capable of giving a total evaluation of the performance of machine tools concerning the major parameters that affect it.

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