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THERMAL MANAGEMENT SYSTEM OF CNC MACHINE TOOL SPINDLE FOR CONSISTENT MACHINING ACCURACY

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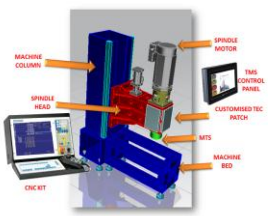
Graphical abstract



Abstract

This paper describes the research on the management of energy efficiency in controlling the machining accuracy of CNC machining centre. The focus is manipulating temperature distributions over the spindle head of CNC machining center without existing external cooling system and replacing with indigenous thermal management system. A proposed system configuration is presented by adapting a customized spindle head cover consists of several thermal electric coolers (TEC) acts as cooling pad to reach optimized temperature distributions and at the same time maintaining the accuracy of machining operation. It is anticipated the preliminary result of such configuration shall be obtained once the simplified prototype ready to be tested.

Keywords: Thermal management system, CNC machine tool spindle, machining accuracy

1.0 INTRODUCTION

Machine Tool System (MTS) is rotating component that is used to hold and drive cutting tool or work piece on lathes, milling machines and other machine tools [1].It is a major operational component in any machine tools for completing any machining jobs. The spindle is a key mechanical part of machine tools as motion errors will have significant impact on machined part quality. A variety of bearing types are normally used for MTS that includes air, angular contact, ceramic hybrid, hydrostatic, magnetic, roller and tapered roller bearings. MTS with encoders or resolvers provide feedback on the position and/or speed [1].

The higher rotational speeds of the MTS influences heat transfer especially conduction and forced convection. For machining accuracy, it is important to explore and identify heat generation, reduce shaft deflections, and eliminate the spindle thermal effects in supporting the development of micro manufacturing machines. The research on MTS had been explored by many previous authors mainly focusing on the thermally induced MTS on the design configurations and during cutting processes; method of reducing the thermal deformations; method of calibration and the speeds of the spindle. The literatures were reviewed on wide perspectives in order to further improve the machining accuracy of machined parts using CNC machining centre. The quest of such endeavour demonstrated some interesting findings in which research on this particular area is primarily crucial whereby a novel method of reducing the thermal deformation on MTS will be explored.

It has been reported that a comprehensive method developed and experimented for prediction of behaviour of spindle bearing using the principle of a developed finite element model and experimental set-up for its validation [2]. The author has proposed a general methodology used in the research as a platform for thermal model of motorized spindles. Particularly, prediction of bearing failures caused by excessive thermally induced preload is one of key issues in the design of high-speed MTS. There is a need for optimization of spindle bearing system and of its surroundings, which could be enabled by a general coupled thermo-mechanical model.

Temperature rise of ball bearings is the limiting factor to increase rotating speeds [3]. Ball bearings with ceramic balls have been gradually used on many high speed rotating systems due to low material density, low thermal expansion, high Young's modulus and hardness. Because of high cooling efficiency and low equipment cost, oil-mist lubricating systems have been widely used on various ball bearing systems.

In order to reduce thermally-induced errors of machine tools through temperature stabilization with compressed air, Donmez used inexpensive, specially-shaped, silicon tubing with small slits [4]. Compressed air forced through such tubing increased heat dissipation from the surface through Coanda-effect cooling (the tendency of a fluid jet to be attracted to a nearby surface). The research done described a simulated heat source as well as a turning center to evaluate and improve the effectiveness of the method. The results showed that this system, which can easily be applied to existing machines, could significantly reduce thermal drift and may be a viable alternative to other methods to reduce thermally-induced errors.

Furthermore, other research has also demonstrated that forced circulation of liquid lubricant or coolant can minimize spindle head thermal deformation [5]. Overcooled or thermally unstable coolant can cause unacceptable temperature distribution of the spindle head. The author has implemented two layer cooling jacket around the spindle head of bench type lathe by controlling the heat exchanging of overcooled oil in the inner jacket with constant temperature before flowing through the outer jacket. Experimentally the dual cooling jacket is practically effective in decreasing the thermal deformation of the spindle head.

2.0 RESEARCH OBJECTIVES

The research focuses on the investigation of the thermal effects on Computer Numerical Control (CNC) MTS to machine individual precision parts for precision industries with the accuracy tolerance of ±15µm. For that purpose, a TMS on MTS is to be proposed. Investigations of the MTS shaft deflections due to heat generation with the implementation of Thermal management System (TMS) to ensure the accuracy of machining will be conducted. It is anticipated towards the end of the research some substantial contributions can be realised in the perspectives of machining accuracy pertaining to thermal effects inside the MTS.

3.0 RESEARCH METHODOLOGY

The research shall be conducted based on the proposed methodology shown in Figure 1. The MTS shall be modeled using 3D CAD tool namely UG NX7.5 environment. The same 3D model is used for the purposes of virtual simulation to cater for FEA and CFD analyses. Once the mesh quality is accepted, the boundary conditions and the material properties are assigned to the FE model in order to solve the equations using engineering solvers. The simulation results would be able to assist the investigation of the temperature distributions, the structural deflections and the flow behaviour of the critical components of MTS. The outcomes of the analysis are then compared with the measurement of the MTS in terms of temperature readings using thermocouples and error motion for further analysis.

Once the parameters obtained after thorough analysis, the parameters such as the temperature difference between the spindle head and the TECs, the temperature distributions around the spindle head, the amount of circulating coolant needed and how critical the thermal deformation affecting the spindle head, then an algorithm of the control system has to be designed, tested and verified before assembling TMS component and eventually installed on CNC machining centre. A validation process will be undertaken by machining sample of machined parts as a measurement of the research output. The machine parts will be verified by using Coordinate Measuring Machine (CMM) to check the dimensional accuracies as per part drawings and surface roughness tester to check the accuracy of surface topology.

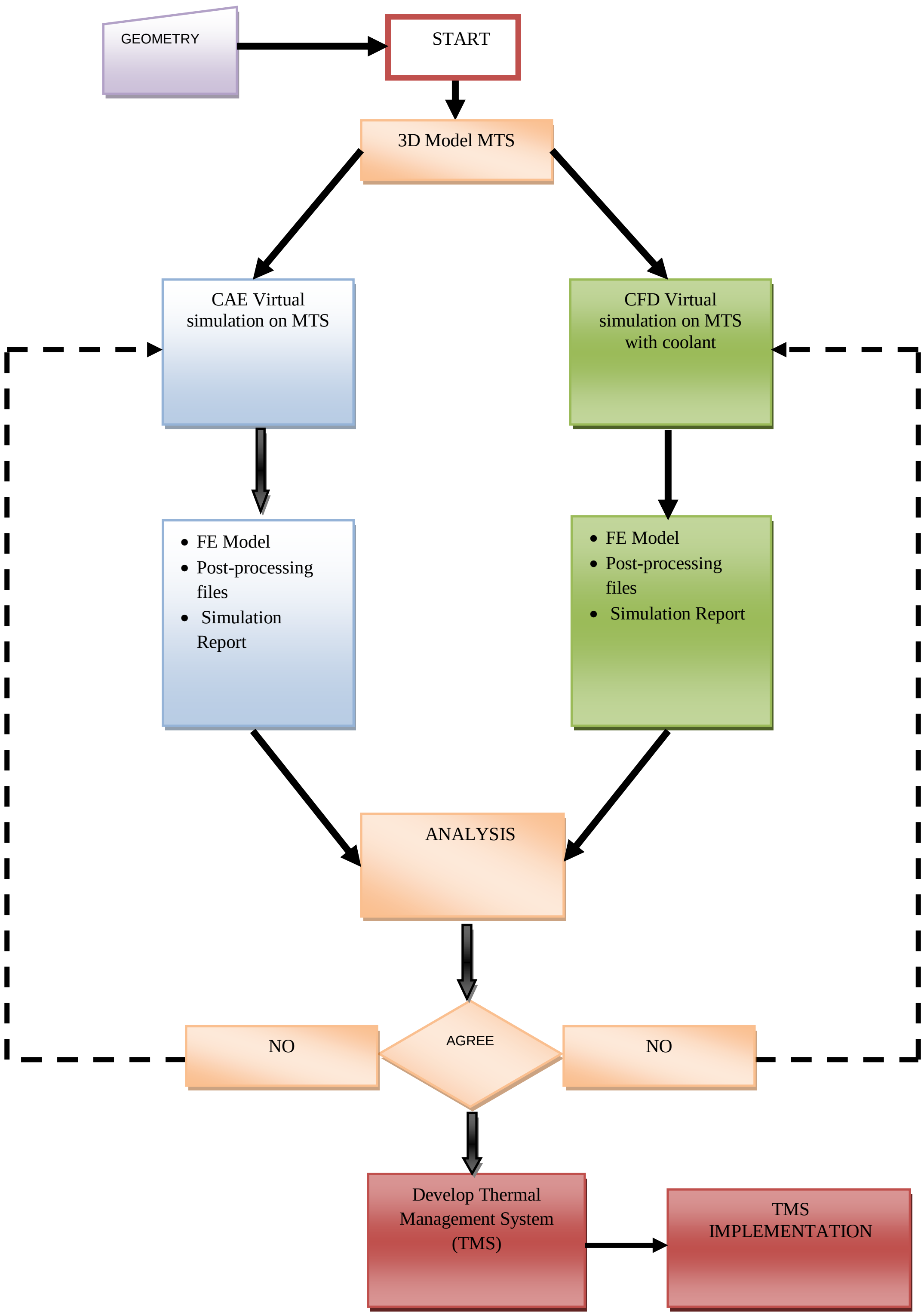


Figure 1 Overall research methodology

4.0 PROPOSED THERMAL MANAGEMENT SYSTEM (TMS)

It is therefore research on a novel method in managing and controlling the temperature distributions of MTS is important and significant in order to reduce the thermally induced errors while machining. It can be concluded that the quest on this topic is converging towards inconsistent machining accuracy due to thermal deformation of MTS, difficulty to calculate transient state of temperature rise during higher rotational speed of MTS and higher energy consumption to operate CNC machine tool in any precision machining job. The research gap has been identified as a thermal management model by using Peltier technology with a customised Thermal Management System (TMS).

TMS shall be able to manage and control several Thermal Electric Coolers (TECs) patched around the MTS head. TEC uses Peltier technology that produces temperature gradient when current is applied. The thermocouples which are positioned around customized spindle head acting as boundary sensors to activate TMS. The control unit of TMS uses an algorithm of measuring the temperature difference between the spindle head and the TECs. The outcome of analysis will be used as a baseline to control the maximum temperature difference of TECs. Its closed loop system will ensure optimal temperature distributions around the CNC MTS are always maintained during the machining process. This in effect will eventually reducing and/or maintaining tolerable thermal deformation on CNC MTS by ensuring that optimal thermal loading is controlled during machining operation.

In order to verify the proposed system, this research shall build a simplified prototype model that houses CNC MTS with the installation of TMS. The error motion equipment shall be used to monitor any spindle deflection when MTS is rotating at least up to 10000 rpm with TMS and no external cooling system or chillers hooked up to the MTS. The graphical illustration is depicted in Figure 2.

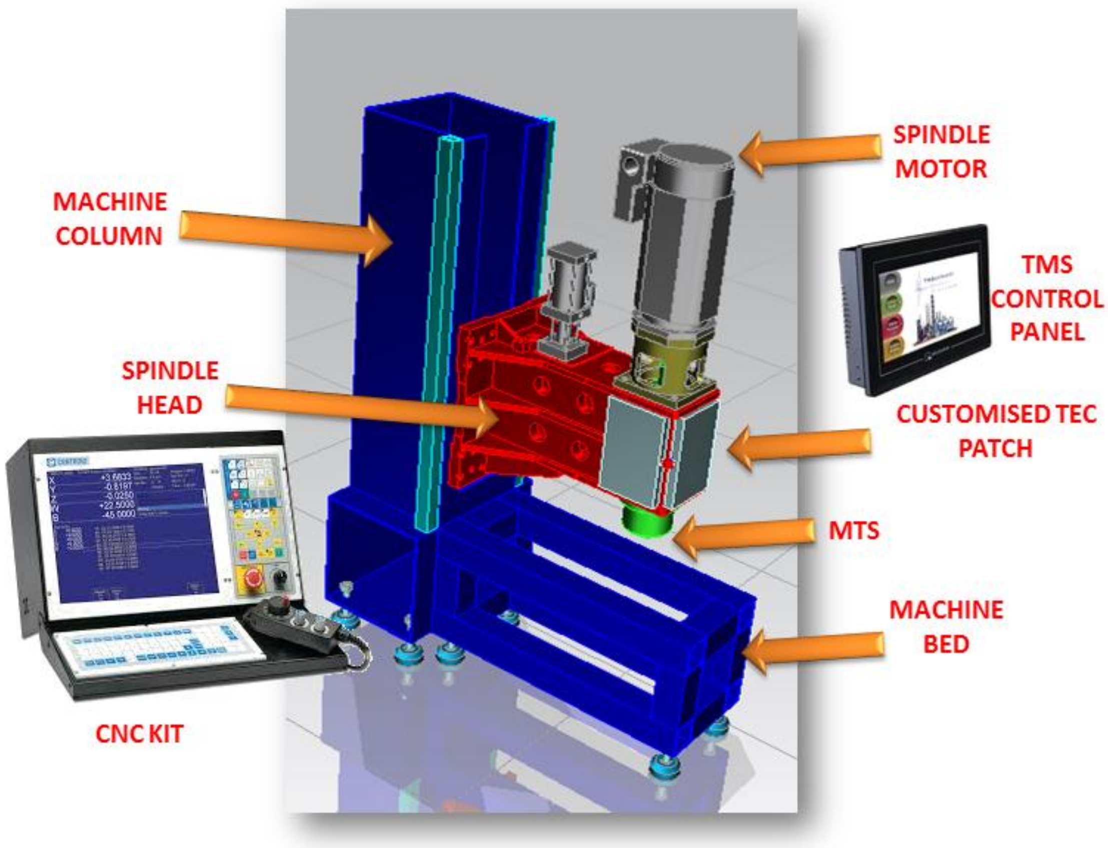


Figure 2 Graphical illustration of proposed TMS

5.0 CONCLUSION

The overall research concentrates on the requirements of achieving better accuracy in terms of spindle error motions using rolling element bearing of MTS for machining operation. The main concern of temperature rise occurs inside the MTS leads to this investigation to meet the set objectives. The planned activities commensurate to the set objectives that is able to produce a pre-determined TMS by analysing several outputs from the simulation processes. The output of the research will be a tremendous effort in minimising thermal deformation on CNC MTS with a simple and economical technique, yet be able to produce accurate machined parts. The primary aim is to eliminate or reduce dependency using the external chillers or cooler which is currently being used in order to provide good coolant circulation around the MTS. It is obviously an extra investment on top of investing the CNC machine tools. By virtue of the proposed TMS, the energy saving through its implementation is envisaged to be tremendous as compared with the use of the chillers or cooler.

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