American Journal of Mechanical and Materials Engineering
2017; 1(2): 26-30
http://www.sciencepublishinggroup.com/j/ajmme
doi: 10.11648/j.ajmme.20170102.11

Quenching Media Based Thermal Explorations over Spindle in High Speed CNC Machining Centres

Kuldeep Verma, Rajendra M. Belokar

Department of Production and Industrial Engineering, PEC University of Technology, Chandigarh, India

Email address:

K83v27883@gmail.com (K. Verma)

To cite this article:

Kuldeep Verma, Rajendra M. Belokar. Quenching Media Based Thermal Explorations over Spindle in High Speed CNC Machining Centres. *American Journal of Mechanical and Materials Engineering.* Vol. 1, No. 2, 2017, pp. 26-30. doi: 10.11648/j.ajmme.20170102.11

Received: March 9, 2017; **Accepted**: March 30, 2017; **Published**: May 15, 2017

Abstract: Thermal growth in spindles acting as a barrier in high speed machining technology. As speed of spindle increases, simultaneously heat generated at the tool-work-piece contact tends to elongate the spindle. This elongation effects accuracy and repeatability of high-speed machines. In this paper thermal growth of spindle neutralized upto maximum extent so as to enhance the performance of machines at higher speeds. This paper aims at studying the behavior of CNC machine tools spindle by utilizing different cooling medias like air, water, coolant, hydraulic oils of different grade and different refrigerants. Here, we have studied the behaviour of CNC machine tools spindle by utilizing different cooling medias like air, water, coolant, hydraulic oils of different grade and different refrigerants to reduce thermal growth. First, spindle rotated at various speed cooled by forced air. Second, spindle cooled with water Third, spindle cooled with coolant. Fourth, rotating spindle cooled with hydraulic oils having different viscosity *i.e.* 23 nos. and 68 nos. Fifth, spindle cooled with different refrigerants *i.e.* R-134 a and R-717. Finally, an analytical study along with experimental investigations carried out to prove out the validity of the proposed model.

Keywords: Spindle, Quenching Medias, CNC Machines

1. Introduction

In the recent years lots of research activities has been completed & others are in-line for high speed machining. These studies reported for enhancement in the performance of machining centers. The studies reported so far proved that three fourth of total thermal changes in the machines, generated from the thermal changes during tool-work-piece interface [1]. The impact of the interface relies on the rigidity of spindle. Minor deflections and small variations in spindle can affect the performance of the machine. Spindles are the source of maximum heat generation. It affects the accuracy of machines. The operations those are strongly impacted by the thermal behaviour are milling and drilling. Spindle cooling should be the basic need in modern high speed automatic CNC machines to enhance life of machine. The studies have been done so far for computing coefficient of convection heat transfer by air. Using FEM temperature field and thermal errors has been simulated under dynamic conditions. Heat flow has been analysed for simulated results. Thermal key points selection done for designing of spindle [2]. Heat generation in the spindles induces thermal expansion, which disturb accuracy of machines and deteriorate life of machine. So, it is of utmost requirement to control heat generated during machining. There are different ways of controlling heat generated namely: (i) To remove heat generated by cooling of spindles, (ii) To reduce speed during machining so that lesser of heat will be generated. The modern technologies lead towards high speed machining with reducing cycle time and improving productivity of machine. So in this paper studies will be done on how heat generated during machining can be reduced with different cooling medias. It has been studied that most of heat generated in the spindles are of different forms like heat generated by bearings (which further effected by speed, pre-load and lubrication), heat produced by motor and heat generation due to viscosity shear of air by rotating spindle. Reference [3] presented an analysis of the dynamic characteristics of machine tool spindle bearing system subjected to harmonic excitation at the spindle nose including the influence coefficient. The dynamic characteristics have been studied earlier by using FEA. The coefficient of heat transfer has been calculated with different flow rates [4 & 5]. Mayer et al. studied effect of thermal changes on the performance of milling machines. He presented work done in the past and current with respect to temperature changes [6]. A parametric study on oil/air lubrication of a high-speed spindle referenced in [8]. Wu presented his work to optimize the lubrication conditions. The Taguchi methods applied on spindle to study the effect of design parameter on the lubrication efficiency [9]. Investigational analysis over the CNC marching centers over performance parameters has been reported in references [10-11].

The rest of the paper is organized in the following sections. Section 2 reported computation of heat generated and coefficient of convection heat transfer during machining. Section 3 presented the problem solution for our research work. Experimentation and Analytical investigations are presented and discussed in Section 4. Finally, conclusions are made in Section 5.

2. Analysis of Spindle Temperature

The temperature of spindle has been analysed by heat generated at tool work-piece interface during running of machine. The heats generated are as in [7].

Heat generated by angular contact bearings ($Q_{a/c}$):

$$Q_{\frac{a}{c}} = 1.047 \times 10^{-5} nM \tag{1}$$

where $M = 0.5\mu PD$ and $P = 0.1C$ and C represents dynamic load in kgf, μ coefficient of friction, D mean diameter of spindle

The coefficient of heat transfer for spindle is computed in equation (2)

$$h = 0.664\, k \left(\frac{n}{60v}\right) Pr^{\frac{1}{3}}, Re = \frac{ul}{v}, u = \pi dn/60 \tag{2}$$

where h = coefficient of convection heat transfer, k = thermal conductivity (w/m-deg) n = rpm, v = kinematic viscosity (m^2/s), Pr = Prandtl number.

The values computed for the Prandtl no and Reynolds no. for different cooling medias, at different rpm are as shown in table 1.

Table 1. *Cooling media values.*

	Prandtl No.	Reynolds No.
Air	0.710	4.16×10^{11}
Water	4.456	1.01×10^{13}
ISO VG 32	397.24	2.08×10^{11}
ISO VG 68	847.77	9.8×10^{10}
R-134	3.268	4.62×10^{13}
R-717	1.344	3.17×10^{13}

The coefficient of convection heat transfer for different quenching medias are as computed in table 2.

Table 2. *Quenching media values.*

RPM	h_{air} (w/m^{2}k)	h_{water} (w/m^{2}k)	$h_{vg\,32}$ (w/m^{2}k)	$h_{vg\,68}$ (w/m^{2}k)	$h_{r\text{-}134}$ (w/m^{2}k)	$h_{r\text{-}717}$ (w/m^{2}k)
500	10.262	2347.63	338.064	298.5243	567.2414	2060.5415
1000	14.512	3320.05	478.1264	422.1771	802.2	2914.045
1500	17.774	4066.225	582.582	517.093	982.49	3568.962
2000	20.524	4695.273	676.172	597.048	1134.482	4121.08
2500	22.948	5249.474	755.984	667.52	1268.39	4607.511
3000	25.137	5750.511	828.1392	731.2322	1389.452	5047.275
3500	27.151	6211.26	894.492	789.8211	1500.779	5451.68
4000	29.025	6640.11	956.2528	844.3542	1604.4	5828.0917
4500	30.786	7042.909	1014.259	895.572	1701.724	6181.624
5000	32.451	7423.878	1069.123	944.0167	1793.774	6516.004

Next, the values have been computed experimentally with respect to different boundary conditions.

3. Problem Solution

When the speed of rotation approached high level the bearing of spindle tends tp heat up and affecting the performance of spindle of high speed machines. The run-out of the componenet also getting deviated with the heating of spindle. Therefore, it seems mandatory to overcome the problem of heating in machines. The heat generated at tool work-piece interface has been controlled upto maximum extent but now we have to maximize the effect of cooling media in order to enhance the performance of CNC machines. This problem leads to investigate the study of thermal effects of spindle.

4. Experimental Investigations

This section enables us to implement and evaluate the coefficient of convection heat transfer with different quenching medias for enhancement of spindle performance of high speed machines The analysis work starts with idle running of machine for half hours at 1000 rpm. Afterwards, gradually increasing the rpm from 1000 to 1500, 1500 to 2000 and so on. Finally, running machine upto maximum rpm to achieve thermal stabilisation.

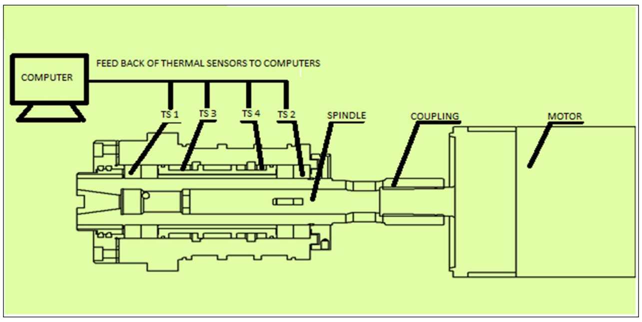

Figure 1. *Schematic diagram of spindle.*

Figure 1 shows the schematic diagram of the spindle along with the thermal sensors for measuring the temperature t various points. A spindle with BT-50 taper has been taken for the experimentation. At the tail of the spindle motor has been coupled with the spindle. The maximum rpm taken in our case is 5000 rpm. The thermo-physical properties of various quenching medias are as shown in table 3. All the properties of cooling medias are taken at 40°C.

Table 3. *Quenching media parameters.*

	Air	Water	ISO VG32	ISO VG68	R-134	R-717
D	1.06	992.22	857	862	1147	579.4
T	0.024	0.6	0.136	0.136	0.0757	0.4464
K	$16*10^{-6}$	$0.65*10^{-6}$	$32*10^{-6}$	$68*10^{-6}$	$0.14*10^{-6}$	$0.21*10^{-6}$
H	1005	4178.5	1970	1967	1498	4932

where D shows density in (kg / m^3), T reflect conductivity in (w/m-deg), K presents viscosity in (m^2/sec) and H denotes specific heat in (kj/kgk). The table shown above reflects that as speed goes on increasing, correspondingly coefficient of convection heat transfer changes. The aim of the work in this paper is to neutralise maximum heat generated to further enhance speed of the machine.

4.1. Analysis of Heat Transfer Coefficient upto 1500 rpm

Initially, we made an investigation analysis for convection coefficient with taking into the consideration all of the cooling medias. x

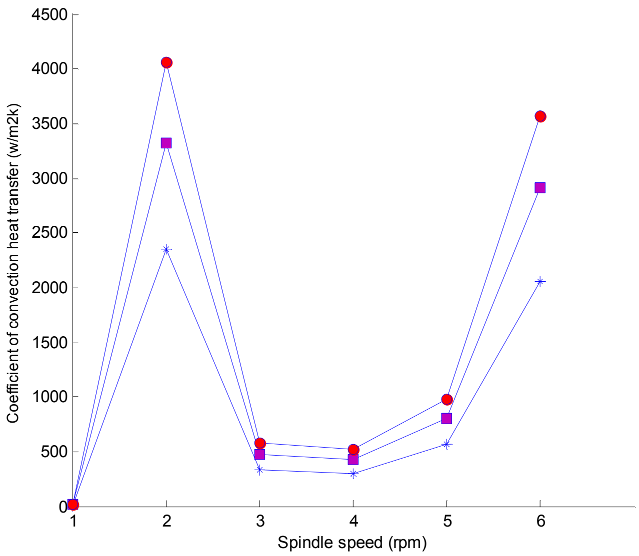

Figure 2. *Convection heat transfer vs speed 1500 rpm.*

Analysis started with 500 rpm, after that the speed gradually increased from 500 to 1000 and from 1000 to 1500 rpm. The results of investigations are as shown in figure 2. We computed the theoretical values and actual value for our proposed model. We observed that heat transfer coefficient is exhibiting linear incremental behaviour at the start i.e. for increasing for air showing diminishing trend for water and the liquid refrigerants and comparatively stable behaviour for the servo spins 32 and 68 nos. It has been analysed that upto 1500 rpm the maximum heat removed is 4066 w/m^2k.

4.2. Analysis of Heat Transfer Coefficient upto 3000 rpm

Next, we made an investigation analysis for convection coefficient with taking into the consideration all of the cooling medias. Analysis started with 2000 rpm, after that the speed gradually increased from 2000 to 2500 and from 2500 to 3000 rpm. The results of investigations are as shown in figure 3. We computed the theoretical values and actual value for our proposed model.

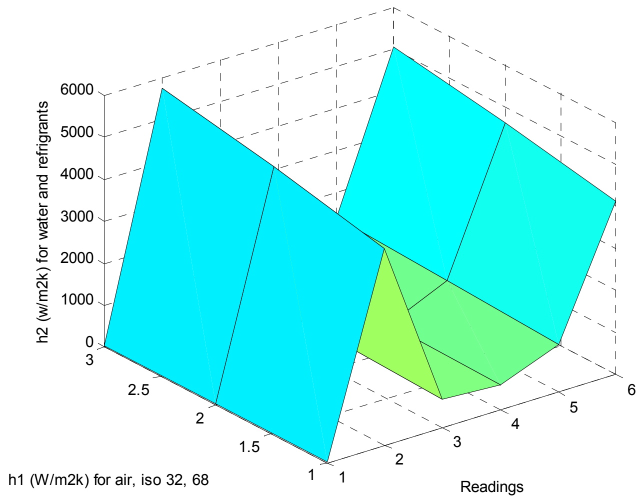

Figure 3. *Convection heat transfer versus speed 3000 rpm.*

We observed that heat transfer coefficient *i.e.* h (w/m^2k) is exhibiting mixed behaviour with respect to different media. In the beginning, it shows increasing, decreasing afterwards, remains stable in middle and again increasing for liquid refrigerants. It has been analysed that upto 3000 rpm the maximum heat removed is 5750 w/m^2k.

4.3. Analysis of Heat Transfer Coefficient upto 5000 rpm

Finally, we made an investigation analysis for convection coefficient with taking into the consideration all of the cooling medias. Analysis started with 3500 rpm, after that the speed gradually increased from 3500 to 5000. The results of investigations are as shown in figure 4. We computed the values both analytically and experimentally.

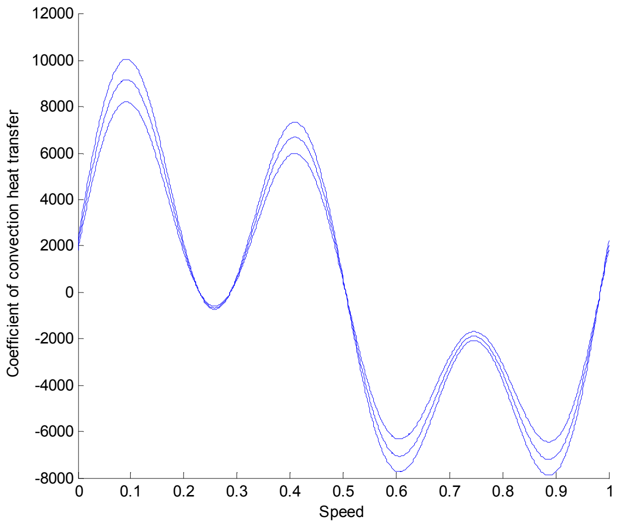

Figure 4. *Convection heat transfer versus speed 5000 rpm.*

We observed that heat transfer coefficient *i.e.* h (w/m^2k) is exhibiting mixed behaviour with respect to different media. In the beginning, it shows increasing behaviour, decreasing afterwards, remains stable in middle and again increasing for liquid refrigerants. It has been analysed that upto 5000 rpm the maximum heat removed is 7423 w/m^2k.

5. Conclusion

This paper proposed an evolutionary methodology to compute and analyse the heat removal capacity in spindle of high speed machining centers. In this paper we design and developed spindle housing, along with the study of effect of different quenching media. The analysis performed with different quenching medias to find the best quenching medias among others. We performed analytical investigation for computation of coefficient of convection heat transfer. We observed that the estimations in our study are more practical in nature. The results from our proposed methodology reveal that there always remains a considerable separation among theoretical and practical aspects in machining and manufacturing areas. We stressed on four major directions. (i) Firstly, we evaluated the heat transfer coefficient upto 1500 rpm (ii) Secondly, we investigated the heat transfer coefficient upto 3000 rpm (iii) Finally, the same model is evaluated upto 5000 rpm. Among the others it has been observed that water serves as the best cooling media for the cooling of spindle of high speed machines. The major drawback with water is corrosion. To overcome the drawback the spindle housing developed is of corrosion resistant material for successful implementation of proposed model. In the future, we would like to investigate the spindle with some other methodologies for enhancement in the performance of high speed machines. This proposed media significantly enhanced the performance of machine i.e. accuracy, repeatability, speed, and quality of the component produced. Finally, this work allows us to analytically formulate the investigation strategies under the spindle driven system and therefore provides insight for directing the designated model for CNC machining.

References

[1] D. A Kruelwich, Temperature integration model and measurement point selection for thermally induced machine tools errors, Mechatronics 8 (1998) 395-412.

[2] Zhao haito et al. Simulation of thermal behaviour of a CNC machine tool spindle, International journal of machine tool and manufacturer (2007) 1003-1070.

[3] Brandon J. A, on the effects of variations in the design parameters on the dynamic performance of machine tool spindle bearing system, International journal of machine tool and manufacturer, 30, (1990) pp. 31-445.

[4] Choi J. K and Lee D. G, Thermal characteristics of the spindle bearing system with a gear located on the bearing span, International journal of machine tool and manufacturer, 38, (1998) pp.1017-1030.

[5] Chi-wei Liu, Jay F. Tu, Model based design of motorised spindle systems to improve dynamic performance at high speeds, Journal of manufacturing process, 9, (2007), pp.94-108.

[6] Mayr et al. (2012), Thermal issues in machine tools, CIRP Annals - Manufacturing Technology 61 (2012) 771–791.

[7] T. A Harris, Rolling bearing analysis, Wiley New York, 1991, pp.540-560.

[8] Cheng-Hsien Wu et al. (2005), A parametric study on oil/air lubrication of a high-speed spindle, Precision Engineering 29 (2005) 162–167.

[9] Y. Altintas et al (2010), Machine tool spindle units, CIRP Annals - Manufacturing Technology 59 (2010) 781–802.

[10] Kuldeep Verma, R. M. Belokar."Optimized Investigations over Diameter and Distance Based Factor towards Rigidity and Accuracy of Spindle in CNC Machining Centers". Journal for Manufacturing Science and Production. Volume 16, Issue 2, Pages 115–121, ISSN (Online) 2191-0375, ISSN (Print) 2191-4184, DOI: 10.1515/jmsp-2015-0026, June 2016.

[11] Kuldeep Verma, R. M. Belokar. "Pervasive Investigations of Critical Speed over Weight and Deflection Factors of Shaft Assembly in CNC Ball Screw System" Hindawi Publishing Corporation International Journal of Manufacturing Engineering Volume 2016, Article ID 6198278, 6 pages http://dx.doi.org/ 10.1155/2016/6198278.

Biography

Kuldeep Verma born in Kalka (Haryana), India. He is a Deputy Manager in the Section of Computer Numerical Control Machines at HMT Machine Tools Limited, Pinjore, India. He earned his BE degree in Mechanical Engineering from M. D. University, Rohtak, his MS degree in Manufacturing from BITS, Pilani and pursuing PhD degree in Production Engineering from PEC university of Technology, Chandigarh, India He has published papers in Journal for Manufacturing Science and Production and Journal of Manufacturing Engineering. He has rich work experience for over eleven years in product development, CNC machine assembly, design and development of CNC machines, GPM, machine assembly. His current research interests include CNC manufacturing, design and development, structure assembly and evaluation.

Dr. Rajender M. Belokar is working as an Associate Professor in the department of Production and Industrial engineering at PEC university of Technology, Chandigarh, India. He earned his PhD Engineering and Technology from Punjab University, Chandigarh India. Dr. Belokar has many publications in reputed International / National journals and conferences. He served various international and national level bodies in different capacities as Sr. Member SME, USA, Member APICS, USA, Life Member of ISTE, Member IE (India), Member INVEST. He has rich teaching and research experience for over twenty years. His current research interests include Manufacturing System Design, Value Engineering, Production and Operations management, TPM, and TQM.