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Finite Element Analysis of Magneto-Rheological Fluid (MRF) Boring Bar

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Abstract: Chatter is a concern in boring process, due to the low dynamic stiffness of long cantilever boring bars. Chatter suppression in machining permits higher productivity and better surface finishes. In order to improve the performance of boring operations, several researchers have investigated electro- and magneto-rheological fluids and piezoelectric and electromagnetic actuators as vibration absorbers. The MR fluid, which changes stiffness and undergoes a phase transformation when subjected to an external magnetic field, is applied to adjust the stiffness of the boring bar and suppress chatter. The stiffness and energy dissipation properties of the MR fluid boring bar can be adjusted by varying the strength of the applied magnetic field. In this study, a finite element model of a MR fluid boring bar is established to investigate the strength of magnetic field at various locations of the boring bar for different current inputs.

Index words: Chatter, MR Fluid, Boring bar, Magnetic Flux Density, Finite Element Model.

I. INTRODUCTION

The vibration of tools used in machining operations plays a key role in hindering the productivity of those processes. Excessive vibrations accelerate tool wear, cause poor surface finish, and may damage spindle bearings. Chatter is a self-excited vibration phenomenon common in machining. In deep hole boring, the long, cantilevered boring bars have inherently low stiffness. This makes them prone to chatter, even at very small cutting depths. Chatter during the boring process directly influences the dimensional accuracy, surface quality, and material removal rate. Suppressing the chatter effectively in deep hole boring is important. Research in boring chatter suppression has been conducted during the past several decades. Tewani et al. [1995] used an active dynamic absorber to suppress machine tool chatter in a boring bar, the vibrations of the system are reduced by moving an absorber mass using an active device such as an piezoelectric actuator. Tanaka and Obata [1994] suppressed the chatter of slender boring bar using piezoelectric actuators, chatter vibration signals detected by a pickup are fed to a computer. Marra et al. [1995] designed a $H\infty$ controller to eliminate the vibrations in cutting operations with a active piezoelectric actuators. Li et al. [2006] investigated the effects of varying spindle speed. Pratt and Nayfeh [2001] suppressed chatter with a magnetostrictive actuator, and Pan et al. [1996] proposed actively controlling such an actuator. Wong et al. [1995] applied actively controlled electromagnetic dynamic absorbers. Rivin and Kang [1992] described a systemic approach to the development of cantilever boring bar tooling structures. Finally, Wang and Fei [1999] developed an on-line chatter detection and control system utilizing electro-rheological (ER) fluid. Based on the mode of chatter suppression employed, suppression methods can be classified into three types: passive, active, and semi-active. Passive chatter suppression is simple in structure, but the dynamic parameters of the damper used cannot be adjusted, leading to poor performance when the working condition changes. Rivin and Kang [1992] developed a cantilever boring bar tooling structures, belong to the passive chatter suppression method. Active chatter suppression allows for continuously adjustable dynamic parameters based on the feedback signals. The chatter suppression methods based on the effects of varying spindle speed Li et al., [2006], piezoelectric actuator Tewani et al., [1995], magnetostrictive actuator Pratt and Nayfeh, [2001] and actively controlled electromagnetic dynamic absorber Wong et al., [1995] belong to active chatter suppression method. This type is more effective than passive methods, but it requires high power and is expensive. Finally, semi-active chatter suppression can improve stability by changing the inherent stiffness and dynamic damping parameters of a system Wang and Fei, [1999]. Semi-active chatter suppression not only has better damping effectiveness than the passive mode, but also has lower power and cost requirements than active suppression Lam and Liao, [2001]. A semi-active chatter suppression method employing the MR fluid is investigated in this study. MR fluid exhibits some advantages over typical ER materials. Compared to ER fluids Wang and Fei, [1999], which have high working voltages (2–5 kV) and narrow working temperatures (10–70 ◦C), the power (1–2A or 50W) and voltage (12–24 V) requirements for MR fluid activation are relatively small, and the working temperatures (−40 to 150 ◦C) of MR fluid are relatively broadened. So MR fluids are more practical and suitable for machine tool applications. In addition, ER fluids are sensitive to impurities, which is not a problem for MR fluids Srinivasan and McFarland,[2001]. In this study, a MR fluid-controlled chatter suppressing boring bar is proposed. The mechanics of chatter suppression using an MR fluid-controlled boring bar is first introduced along with the design and fabrication of a MR fluid-controlled boring bar. Next, Finite element analysis (FEA) of the magnetic system is detailed.

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II. MECHANICS OF CHATTER SUPPRESSION

Most chatter is what is termed regenerative chatter, which is usually caused by instability of the cutting process in combination with the mechanical structure of machining system. The frequency of regenerative chatter is close to the natural frequency of the machine tool. The tool tip displacement *Y* is generated by the dynamic cutting force *F* applied at the tool tip. The dynamic behavior of the mechanical structures is expressed by the dynamic flexibility *R*. The transient variation of chip thickness *h* is the difference between *Y* and the wavy surface *X* generated in the previous cutting pass. In an unstable cutting process, *F* will increase gradually. In boring, *T* is the period of spindle revolution, K_d is the cutting force coefficient (relating the cutting force to chip area), and *b* is the cutting width.

The mechanical structure of a boring system can be simplified to a single degree of freedom system modeled by a combination of equivalent mass (*m*), spring (*k*), and damping (*c*) elements. The chatter frequency of the cutting process ω_c isYang and Tang, [1983]

$$\omega_c = \sqrt{\omega_n^2 + \frac{K_d b(1-\cos\emptyset)}{m}} \qquad (1)$$

where ω_n is the natural frequency of the mechanical structure of the boring system.

When chatter occurs, the vibration frequency ω is equal to ω_c, and the cutting process is located in the unstable region. At this moment, if ω_n is changed by adjusting structural stiffness, ω will remain equal to ω_c for a short period of time. The cutting process will shift to the stable region because the vibration frequency is not equal to the resonant frequency of the system. Once in the stable region, the amplitude of vibration decays rapidly, and chatter is suppressed. However, the vibration frequency may shift to a new unstable resonant frequency during cutting, meaning the chatter could occur again.

If ω_n is changed continuously using MR fluid control, chatter can be suppressed. This concept is similar to changing spindle speed to suppress chatter. When chatter occurs, the cutting process will be in the unstable region. At this moment, if ω_n can be increased by increasing the stiffness of the MR fluid-controlled boring bar, according to Eq. (1), the chatter frequency ω_c will increase and shift to the stable region. The cutting process is then in the stable region, and chatter is suppressed.

As the cutting process continues, it may again shift into the unstable region. When that happens, ω_n can be reduced by decreasing the stiffness of the MR fluid-controlled boring bar. Just as when ω_n is increased, the cutting process is then back within the stable region. Thus, conditions promoting regenerative chatter can be dealt with by either increasing or decreasingω_n.

According to above theoretical analysis, as long as an innovative stiffness-tunable boring bar based on MR fluid can be developed, the chatter can be suppressed in boring process.

For the innovative chatter suppression method proposed in this paper, we just need to input a 1–5 Hz periodical square wave current to MR fluid controlled boring bar, so the response time of MR fluid is quick enough for the natural frequency adjustment and control in this research.

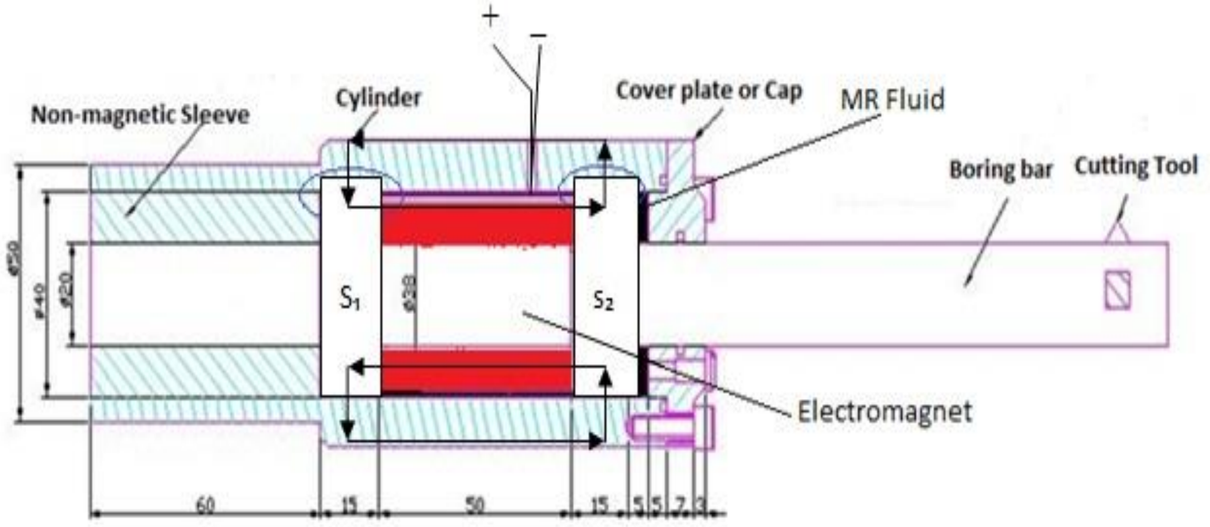
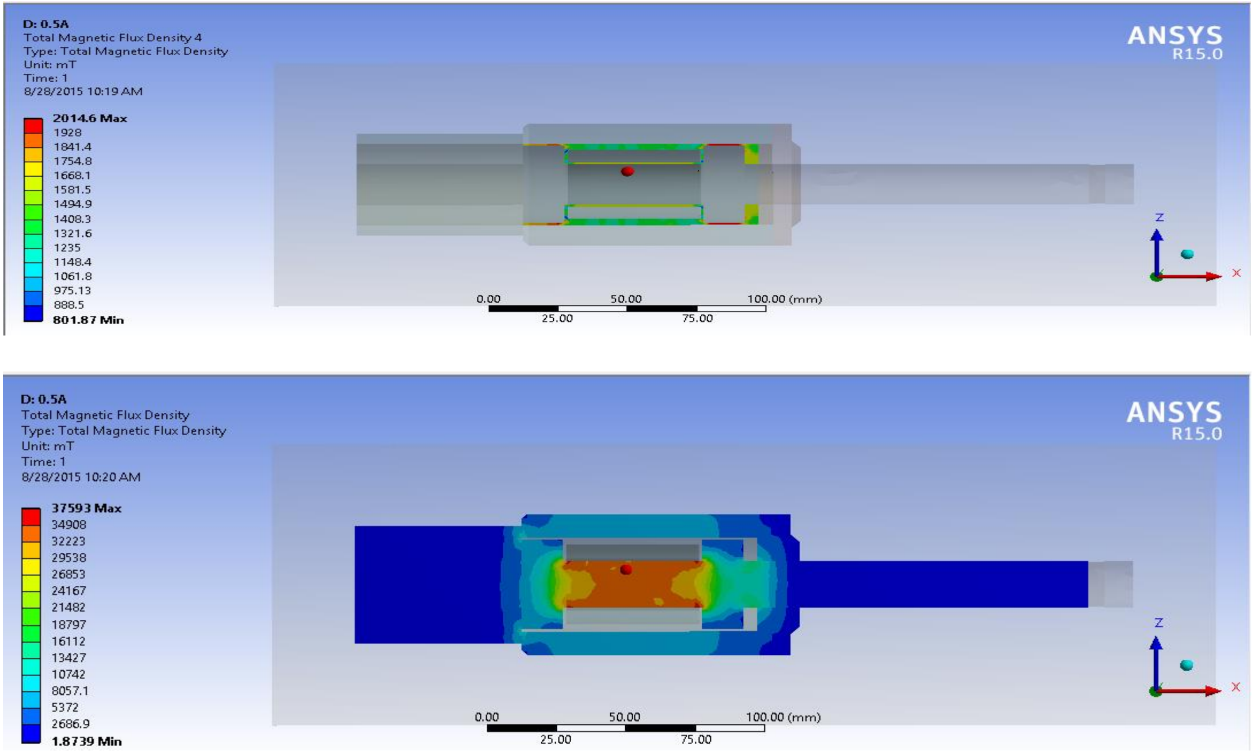


Fig.1: Magneto-Rheological Fluid Boring Bar

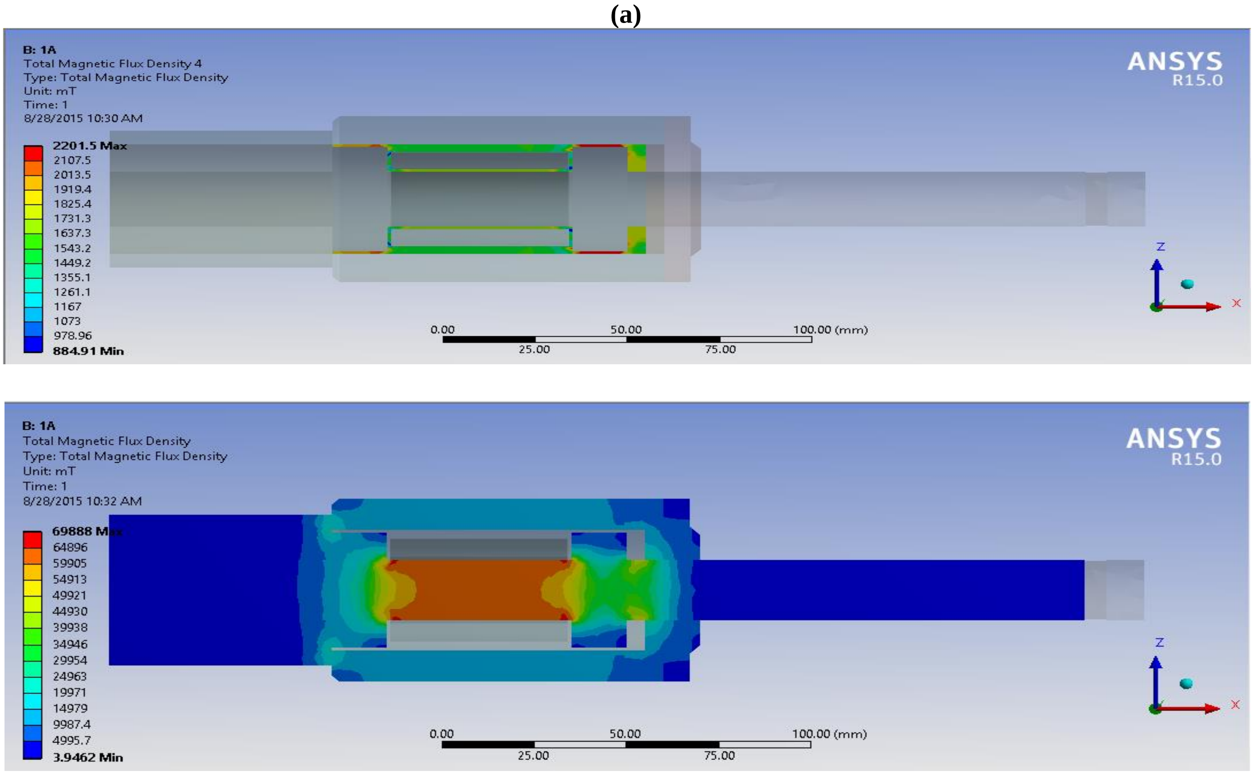
By surrounding the base of the boring bar with MR fluid, as shown in Fig.1, the stiffness and natural frequency of the boring bar can be continuously varied by changing the intensity of the magnetic field passing through the MR fluid. The boring bar assembly in Fig.1 consists of the MR fluid, a cylinder, a non-magnetic sleeve, an electromagnet, and a boring bar with two shoulders, marked as S_1 and S_2. To fabricate this boring bar assembly, the electromagnet is first embedded between the two shoulders of the boring bar and coated with ethoxyline resin. The non-magnetic sleeve and cylinder are then assembled. The MR fluid is poured into the annular cavity and then sealed in by a cap and O-rings. The thickness of the MR fluid layer in the annular cavity is about 1.0mm. The diameter of the boring bar is 20mm, the ratio of length and diameter is 6, and the length of the fixed portion is 160mm.

III. FE ANALYSIS OF MAGNETIC SYSTEM

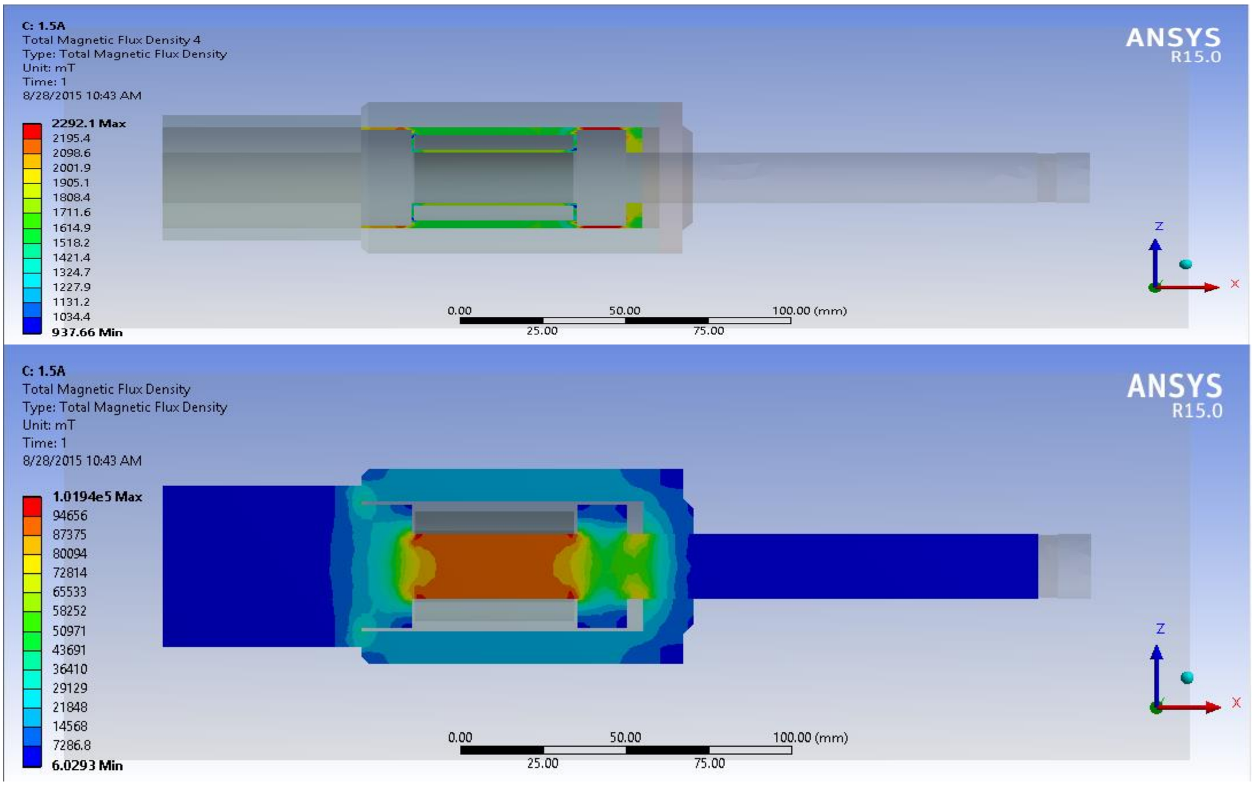
The magnetic system for the MR fluid boring bar is important for energy transformation efficiency, as well as the chatter suppression capability of the system. FE analysis was applied to analyze and design the magnetic field. The boring bar and cylinder are made of low-carbon steel with a magnetic conductivity of 1000 H/m. The MR fluid is MRF-132DG, produced by the LORD Corporation, USA. The magnetic conductivity of this MR fluid is 15 H/m. An ax symmetric FE model of the magnetic system was used to analyze the MR fluid boring bar shown in Fig.2.



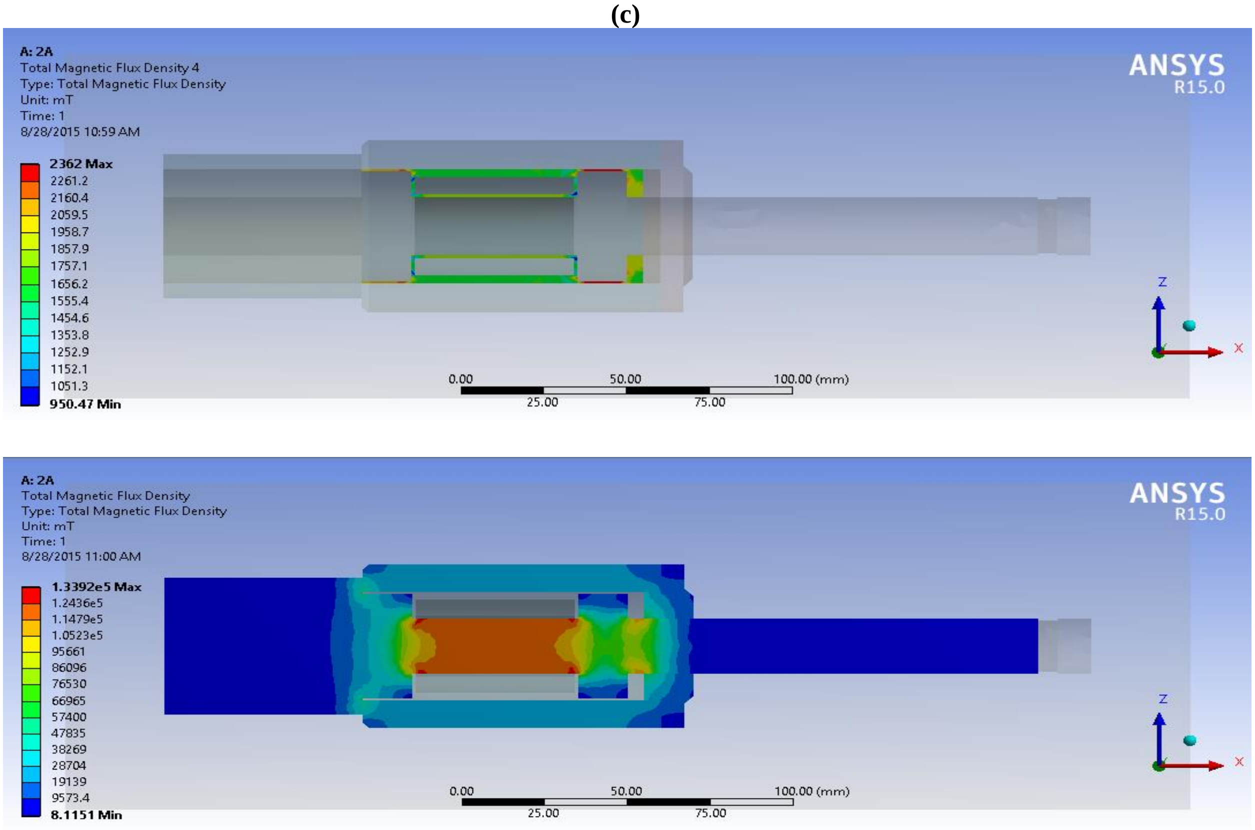
(a)



(b)



(c)



(d)

Fig.2: FE model and results of the magnetic system for a Magneto-rheological Fluid Boring Bar (a) Magnetic flux density at 0.5A input current (b) Magnetic flux density at 1.0A input current (c) Magnetic flux density at 1.5A input current (d) Magnetic flux density at 2.0A input current.

The electromagnet of the magnetic system consists of 200 turns, 24AWG coil wire and was energized by 0.5-2.0A DC as shown in Fig.2. The direction of magnetic flux lines is shown in Fig.1 by the arrow lines. The geometry of the boring bar components was designed with the goals that the magnetic lines of flux are perpendicular to the thin layer of MR fluid in shaft shoulders S_1 and S_2, and most magnetic lines of flux can go through two shoulders, thus enabling better actuation of the MR fluid.

IV. CONCLUSIONS

A chatter suppression method based on a MR fluid boring bar was presented. The magnetic system inside the boring bar was designed using the FE analysis. Fig. 2(a) to (d) shows that the magnetic flux density is maximum at thin layer of MR fluid and the core of the electromagnet. So the FEM analysis of magnetic system for the MR fluid boring bar shows that the design of its magnetic system is reasonable. Thus, chatter could be suppressed by adjusting the damping and natural frequency of the system by varying the lateral stiffness of the boring bar. A MR fluid-controlled tool can be applied to other machining processes for chatter suppression and material removal rate enhancement.

REFERENCES

1. Tewani, S.G., Rouch, K.E., Walcatt, B.L., 1995. A study of cutting process stability of a boring bar with active dynamic absorber. International Journal of Machine Tools and Manufacture 35, 91–108.
2. Tanaka, H., Obata, F., 1994. Active chatter suppression of slender boring bar using piezoelectric actuators. JSME International Journal
3. Marra, M.A., Walcott, B.L., Rouch, K.E., Tewani, S.G., 1995. $H\infty$ vibration control for machining using active dynamic absorber technology. In: Proceedings of the American Control Conference, Seattle, Washington, pp. 739–743.
4. Li, C.J., Ulsoy, A.G., Endres, W.J., 2006. The effect of spindle speed variation on chatter suppression is rotating-tool machining. Materials Science Forum 505–507, 859–864.
5. Pratt, J.R., Nayfeh, A.H., 2001. Chatter control and stability analysis of a cantilever boring bar under regenerative cutting conditions. Philosophical Transactions: Mathematical, Physical and Engineering Science, Nonlinear Dynamics in Metal Cutting 359, 759–792.
6. Pan, G., Xu, H., Kwan, C.M., Liang, C., Haynes, L., Geng, Z., 1996. Modeling and intelligent chatter control strategies for a lathe machine. In: Proceedings of the 1996 IEEE International Conference on Control Applications, Dearborn, MI, pp. 235–239.
7. Wong, B.W., Walcott, B.L., Rouch, K.E., 1995. Active vibration control via electromagnetic dynamic absorbers. In: Proceedings of the Fourth IEEE International Conference on Control Applications, Albany, NY, pp. 868–874.
8. Rivin, E.I., Kang, H., 1992. Enhancement of dynamic stability of cantilever tooling structures. International Journal of Machine Tools and Manufacture 32 (4), 539–561.
9. Wang, M., Fei, R.Y., 1999. Chatter suppression based on nonlinear vibration characteristic of electrorheological fluids. International Journal of Machine Tools and Manufacture 39, 1925–1934.
10. Lam, H.F., Liao, W.H., 2001. Semi-active control of automotive suspension systems with magnetorheological dampers. Proceedings of SPIE 4327, 125–136.
11. Srinivasan, A.V., McFarland, D.M., 2001. Smart Structures: Analysis and Design. Cambridge University Press, Cambridge.
12. Yang, S., Tang, H.L., 1983. Machine Tool Dynamics. China Machine Press, Beijing

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