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Geometric error monitoring of the machine tools using feed motor torque

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Abstract

This study introduces a self-diagnosis system developed to detect geometric error changes in the machine tools. The leveling of machine tools is very important factor because the accuracy of the machine tools depends largely on its proper leveling on installation. The accuracy of the machine tools must also be maintained for a long time. Over the long term, subtle shifts in the leveling of the machine tools can occur, potentially altering the machine tools' posture and tilt, often after a year or more, which also aligns with the average period when customers begin reporting such issues. These changes directly affect feed motor torque during feed drive operations, which in turn impacts the accuracy of the machine tools, particularly in maintaining critical parameters such as squareness between spindle and table.
The proposed monitoring system tracks variation in feed motor torque and correlates them with changes in the accuracy, such as squareness or inclination. By analyzing this relationship, it can accurately predict any deviations in geometric error. Additionally, the system can also be extended to a self-diagnosis system that periodically evaluates the accuracy of the machine tools. This self-diagnosis process allows the machine tools to track long-term trends in accuracy and detect gradual degradation before it reaches critical limitation of the accuracy. When variations exceed predefined tolerance of accuracy, the system automatically generates an alarm to alert operators, enabling timely intervention to restore accuracy.
In conclusion, this system offers a proactive solution for maintaining the accuracy and performance of the machine tools, especially in environments that need to maintain long-term accuracy.

Geometric error, Accuracy, Feed motor torque, Leveling, Monitoring system

1. Introductions

Accuracy of the machine tools is a critical factor in modern precision manufacturing, directly impacting product quality and productivity. A key factor in maintaining this accuracy is proper leveling during installation and throughout the machine's whole operational cycle. However, the subtle shifts in leveling can occur over time, leading to changes in the machine tool's posture and tilt. These changes can significantly affect the geometric accuracy of the machine tool, particularly in critical parameters such as squareness between the spindle and table.

Geometric errors, primarily resulting from imperfect geometry and dimensions of machine components, are one of the major sources of inaccuracy in machine tools. These errors can manifest in various forms, including linearity, angularity, straightness, and squareness deviations. Traditional methods of detecting and correcting these errors often involve time-consuming and costly calibration processes, which can lead to significant downtime and reduced productivity.

To address these challenges, a novel self-diagnosis system has been developed to detect changes in geometric errors of machine tools. This system leverages the relationship between machine leveling and feed motor torque during feed drive operations. By monitoring variations in feed motor torque and correlating them with changes in accuracy parameters such as squareness or inclination, the system can predict deviations in geometric errors with high precision.

The proposed monitoring system offers several advantages over traditional calibration methods. Firstly, it provides a non-intrusive means of continuously assessing machine tool accuracy without the need for extensive downtime. Secondly, it enables the tracking of long-term trends in accuracy, allowing for the detection of gradual degradation before it reaches critical levels. This proactive approach to maintenance can significantly extend the operational life of machine tools and reduce the frequency of major calibration events.

Furthermore, the system incorporates an automatic alarm feature that alerts operators when variations in accuracy exceed predefined tolerances. This timely notification enables prompt intervention to restore machine accuracy, minimizing the production of out-of-specification parts and reducing overall manufacturing costs.

In conclusion, this self-diagnosis system represents a significant advancement in the field of machine tool maintenance and accuracy assurance. By providing a continuous, real-time assessment of geometric errors, it offers a proactive solution for maintaining the long-term accuracy and performance of machine tools. This approach is particularly valuable in high-precision manufacturing environments where maintaining consistent accuracy over extended periods is critical to product quality and operational efficiency.

2. Relationship between machine tool posture and driving Torque

During the installation of machine tools, geometric errors arise due to mechanical assembly inaccuracies. To compensate for these errors, level adjustments are performed to ensure the horizontal alignment and precision of the table. In a well-leveled machine, the driving torque of the feed axis motor, corresponding to the reciprocating motion along the X-axis or Y-axis, forms a symmetrical Stribeck curve in both the forward and backward directions. However, over long-term operation, changes in leveling may lead to variations in the machine's posture or alterations in the inclination of the guideway. As a result, a difference in driving torque between the forward and backward directions occurs, corresponding to $Mg\sin\theta$ in Equation (1). The greater the inclination, the larger the fluctuation in driving torque.

$$F_t = F_{friction} \pm Mg\sin\theta \qquad (1)$$

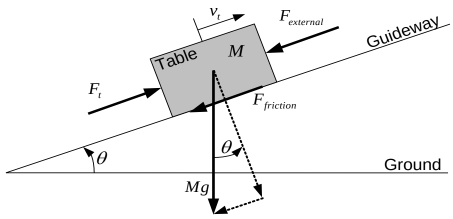

Figure 1. Drag force according to the inclination angle of the guideway

3. Measurement of driving torque variation due to level adjustment

Figure 2 shows a machine tool (DVF5000 of DN Solutions) with six leveling points. To alter the machine's posture from its precisely leveled initial installation state, the installation height of Leveling Point 1 was increased by 500 μm. As a result, the inclination of the X-axis and Y-axis on the table changed. This change in posture can be indirectly verified through perpendicularity measurements. The measured XZ squareness of the machine increased by approximately 8 μm compared to the initial installation state. The machine tool manufacturer's allowable tolerance for squareness is within 5 μm, and the torque change correlated to this value is the threshold of alarm. However, the threshold is different for each machine tool.

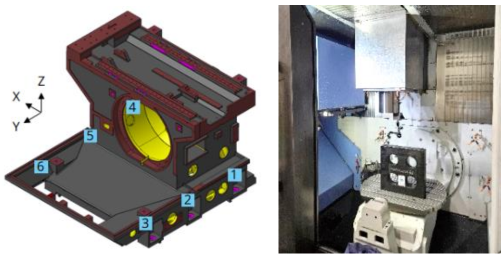

Figure 2. Level position of machine tool and measuring the squareness

Table 1 Squareness error (ΔXZ) due to level adjustment

Level adjustment	Squareness error (μm)
Initial	0
500 μm	8

Furthermore, when measuring the driving torque during X-axis feed motion before and after level adjustment, an increase in driving torque was observed in Figure 3. Additionally, the difference in torque between the forward and backward directions approximately doubled.

4. Effect on machining quality

The level condition of a machine tool not only affects its posture and static errors but also influences its dynamic characteristics. In particular, an unstable leveling state can lead to a decrease in the machine's first natural frequency. A reduction in the first natural frequency makes the system more susceptible to inertial effects caused by acceleration during feed motion, leading to an increase in residual vibration.

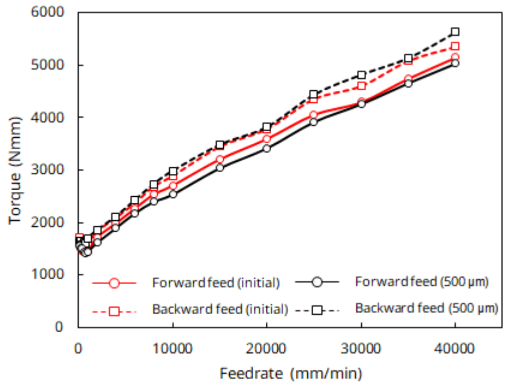

Figure 3. Driving torque variation due to level adjustment

Consequently, in precision surface finishing, poor leveling can result in degraded surface roughness, especially in acceleration and deceleration phases of the feed motion. The changes in natural frequency and machining results due to level adjustment in this study are summarized in the table below.

Table 2 Effect on natural frequency and machining roughness

Level adjustment	The 1st frequency	Machining result
Initial	X 13 Hz / Y 16 Hz	Good
500 μm	X 10 Hz / Y 12 Hz	Fail

5. Monitoring system for the machine tools

During the initial installation of the machine, the driving torque corresponding to the X-axis and Y-axis feed motion is measured and stored as reference data in the NC system. Through periodic self-diagnosis, if the measured driving torque deviates beyond a predefined threshold from the reference data, changes in machine posture and precision can be predicted. This allows the system to alert the user and prompt a re-leveling adjustment to maintain optimal machine performance.

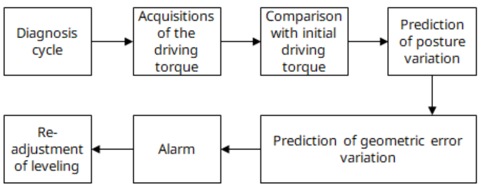

Figure 4. Geometric error monitoring system

6. Conclusion

This study demonstrated that changes in the geometric error of a machine tool can be identified by measuring the driving torque of the X and Y feed axes. Furthermore, it was analyzed that level changes not only induce geometric errors but also alter the machine's natural frequency, thereby affecting surface roughness in machining. Ultimately, since changes in machine posture impact both mechanical performance and machining accuracy, a continuous monitoring system was proposed to detect these variations in real time. This system is expected to be commercialized in the future.

References

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