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主　論　文　の　要　旨

論文題目　**Self-identification methods of cutting-relevant information**
(加工関連情報の自己同定手法に関する研究)

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論　文　内　容　の　要　旨

Cutting is an essential process when manufacturing a tremendous number of parts. Its efficiency and accuracy significantly affect the productivity and the feasibility of the entire industry, therefore realizing lower downtime and higher productivity are major objectives in this field. However, the cutting process using CNC machine tools still has several issues that require manual operations and the decisions of experienced manufacturing engineers, and these issues impede efficient automation. For example, a precise alignment of the jigs, workpieces, and tools, and an observation/analysis of undesirable phenomena such as mechanical vibrations are challenging issues that require manual decision-making based on the knowledge of the cutting process.

To overcome such challenges and realize the high efficiency cutting process on machine tools, attempts to apply the concept of smart manufacturing to the machining process have been made. Specifically, the smart machine tool which refers to the integrated concept between conventional machine tools and smart technologies such as sensors, adaptive decision-making models, and data analytics has been suggested. In this manner, studies to resolve the problems addressed above are conducted relying on information achieved from the cutting process. For example, cutting-relevant information which can possibly contribute to the above challenging issues is collected and aggregated from the local machine tool, then analyzed for the data-driven monitoring/optimization systems.

Despite the fact that deep theoretical understandings of problematic issues of the machining process have been achieved, and a sufficient number of countermeasures have been proposed as outcomes of previous studies, the industrial application has been limited because the necessary cutting-relevant information is often complicated and cost-consuming to be achieved/analyzed. To overcome these limitations and realize practical smart solutions, research on self-identification methods of cutting-relevant information based on data that is practically achievable for machine tools is indispensable.

Particularly, the axial depth of cut (ADOC) and the radial depth of cut (RDOC) are the key cutting-relevant information when planning the vibration-free tool path with a high MMR. With the information on present ADOC and RDOC, precise predictions on the current stability margin become available, and adequate countermeasures can be determined. However, conventionally suggested methods for real-time identification of DOCs require expensive and hard-to-mount sensors and complicated calibration processes which impede the automation. Also, they are vulnerable to vibrations that occur in the cutting processes.

Meanwhile, the relative position between the tool and the workpiece is important cutting-relevant information for calibration/compensation of the process geometry which can exclude tool/workpiece-originated geometric errors. In the general turning process, solutions for attaining the tool-workpiece relative position such as in-situ touch probes, external devices mounted with air/electric micrometers, and cameras are adopted, however, they are either indirect or cost/space-consuming.

Therefore, to realize high efficiency cutting process on machine tools in the several perspectives mentioned earlier, the author carried out the following research on self-identification methods of cutting-relevant information.

1. Proposal of the DOCs and runout identification method based on easy-to-achieve information.
2. Proposal of the contact detection method based on the machine tool servo, and the rotational center self-identification method.

The main contributions and findings of this thesis are summarized as follows:

In Chapter 2, a novel integrated real-time monitoring method for the DOCs and the tool runout based on the frequency domain analysis of the cutting torque for the square end milling process is proposed. The notch frequency due to the helix of the tool is searched from the shape of the tooth passing frequency harmonics, and the ADOC is calculated from it first. For the next step, the RDOC is calculated using the monitored ADOC value from the ratio and phase difference between the tooth-passing frequency components of the cutting torque. With the monitored ADOC and RDOC values, the specific cutting force and the tool runout are calculated from the tool-runout-independent and tool-runout-dependent frequency components, respectively. Finally, an index for evaluating the reliability of the monitored outputs is calculated. Experiments are conducted to confirm the validity of the proposed method. The desired parameters, i.e., the DOCs and the tool runout, are monitored from the z-axial cutting force, which is proportional to the cutting torque. 3 types of the cutting conditions, i.e., tool paths with constant ADOC and constant RDOC, constant ADOC and changing RDOC, and changing ADOC and constant RDOC, are tested. As a result, the DOCs and the tool runout are monitored successfully even for the transient conditions where the tool enters/exits the workpiece. The computation time is below the machining operation time; therefore, the real-time monitoring system can be realized. In addition, the relationship between the suggested reliability index and the relative errors of the DOCs is investigated. The index is shown to be correlated with the monitoring error of the DOCs; therefore, it can be said that the introduced index indicates the reliability of the monitored parameters.

In Chapter 3, two methods for identification of the tool-workpiece relative position, specifically the rotational center, in the general CNC turning process are proposed: a novel direct tool-workpiece contact detection method and a rotational center self-identification strategy. The former method identifies the contact coordinates by utilizing the internal data of the machine tool servo. Especially, the servomechanism-originated-error is eliminated by comparing the data of non-contact and contact motion. In addition, the threshold-originated-error is excluded by processing the time-sequential internal data backwardly. The latter method makes multiple tool-workpiece contacts on the pre-machined surface with a redundant-axis movement. The rotational center is identified from those contacts by fitting a circle to the identified workpiece coordinates projected in the cross-sectional direction. Experiments have been carried out to confirm the validity of the proposed methods. The results showed that the proposed methods can realize good accuracy and repeatability, i.e., an error of 13.46 μm and repeatability of 1.18 μm for the contact detection and an error of 11 μm for the rotational center identification.

Based on the accomplishments of the research in the thesis, the real-time self-identification of the DOCs and runout for the square end milling process can be achieved by only relying on the practically achievable information. Also, the identification of tool-workpiece relative position while excluding tool/workpiece-originated geometric errors for the general turning process can be realized. Hence, this study is significantly advantageous for expanding the applicability of smart machining because of the verified practicality of the proposed techniques.