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主 論 文 の 要 旨

論文題目　**High-Efficiency Cutting with Spindle Speed Variation**
(主軸回転速度変動法を用いた高能率切削加工)

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論 文 内 容 の 要 旨

For the suppression of regenerative chatter without sacrificing the machining efficiency, spindle speed variation (SSV) has been studied. This technique has been developed to utilize in production sites. However, since the stability of SSV varies greatly depending on the SSV parameters, it is quite a complicated problem to determine the parameters properly. Furthermore, the temporal growth of chatter occurs even if SSV is applied and its reason was not clarified. Moreover, there is no simple and logical methodology to determine the parameters properly for the suppression of chatter and the improvement of the machining efficiency. For this problem, despite the fact that SSV is an effective technique, the industrial application has been limited. To overcome these limitations and to expand the applications of SSV in the industry, research on high-efficiency cutting with spindle speed variation is carried out in this thesis. The aims of thesis are clarifying the characteristics of the chatter growth in SSV, proposing the chatter stability indices in SSV, proposing the novel spindle speed variation profile for improvement of chatter stability, and proposing new technology with speed variation for utilizing in the short-duration cutting process.

In Chapter 1, the various types of chatter vibrations and the chatter suppression techniques were introduced. The previous studies related to spindle speed variation were briefly overviewed. Subsequently, the motivation and objectives of this thesis were described.

In Chapter 2, the chatter growth characteristics in SSV were revealed, and the suppression effect of SSV was newly explained focusing on the fluctuation of the time chatter frequency. It was found that the regenerative chatter generally grows at a constant spatial frequency in SSV (the first chatter growth characteristic). Therefore, when chatter occurs, the time chatter frequency changes at the same ratio in which the spindle speed changes, meaning that the spatial frequency is kept constant, and it brings out change of the magnitude of the dynamic compliance. Due to the change of the magnitude, the chatter can be suppressed since the dynamic compliance usually reduces as the chatter frequency changes. It was found that the chatter is likely to grow during a period where the absolute acceleration rate is small in SSV (the second chatter growth characteristic). The average of the absolute acceleration rate in one period of SSV (the first stability index) and the number of revolutions in a unidirectional acceleration section (the second stability index) were proposed as novel indices to evaluate the chatter stability in SSV. Through the analytical investigations with time-domain simulation, it was proved that the revealed chatter growth characteristics are valid. In addition, the relations between the stability and the proposed stability indices were investigated, and the results denoted the effectiveness of proposed stability indices. Next, the influence of SSV parameters to stability were clarified. The chatter suppression effect of TSSV and SSSV decreases in high-speed region, and thus remarkable improvement of machining efficiency cannot be realized unfortunately. A series of experiments were carried out to verify the validity of the revealed chatter growth characteristics in SSV and to confirm the effectiveness of the proposed stability indices. The experimental results showed same tendency with the results in the time-domain simulations.

In Chapter 3, a new SSV profile, which was named CAR-SSV (SSV with constant acceleration rate), was proposed to overcome the limitation of the chatter stability improvement in conventional SSV. Since the absolute acceleration rate is maintained a constant, chatter suppression throughout the cutting could be achieved. Analytical investigations were carried out to reveal the potential of the proposed profile. Firstly, the relations between the stability limit and the proposed stability indices in SSSV, TSSV, and CAR-SSV were investigated. From the results, the higher stability was confirmed in CAR-SSV under the same conditions of the stability indices. Secondly, the relations between the parameters of CAR-SSV and the chatter stability were revealed. Thirdly, the machining efficiency against the thermal load of the spindle motor in CAR-SSV was compared to the conventional SSV profiles to verify the effectiveness of CAR-SSV considering its applicability to the actual industry. From the results, it was confirmed that the higher machining efficiency can be achieved by utilizing CAR-SSV when the thermal load of the spindle motor is the same. A series of experiments were carried out to confirm the relations between the parameters of CAR-SSV and the stability as well as to verify the effectiveness of CAR-SSV. The experimental results were consistent with the simulation results. Therefore, CAR-SSV is an effective solution to overcome the limitations of conventional SSV and it can realize the higher applicability to the industry.

In Chapter 4, the 'accelerative cutting' was proposed to improve the chatter stability in short-duration cutting process. Due to the nature of SSV, the transitions from acceleration to deceleration exists regardless of the type of SSV. In those sections, the chatter easily grows since the absolute acceleration rate decreases. In accelerative cutting, the spindle is accelerated/decelerated in a unidirectional manner, and hence the direction of acceleration does not change. Thus, there is always a sufficient speed difference between the present and previous revolutions. In addition, the spindle is accelerated/decelerated so that the absolute acceleration rate is kept constant. Particularly, the set acceleration rate is kept above the critical rate to achieve chatter suppression effect throughout the cutting. The time-domain simulations were conducted, and it was proved that the stability increases drastically by utilizing the accelerative cutting. Specifically, the increase of the set acceleration rate realized a great increase of the critical stability. Cutting experiments were carried out to verify the effectiveness of the accelerative cutting. It was validated that the stable cutting can be conducted at large widths of cut, e.g., 7 times larger than that of constant speed cutting. Therefore, it is expected that accelerative cutting can be utilized for short-duration plunge cutting and increase the stability drastically in practice.

In Chapter 5, the utilized data and the applied Real-World Data Circulation in this thesis were described. In addition, the imagined future RWDC of the research in thesis for wide application and greater contribution to the manufacturing site was introduced.

From the thesis, the chatter growth characteristics in SSV and the chatter stability indices were clarified for the first time. By proposing the new SSV profile and the accelerative cutting, the high-efficiency cutting without chatter in both long-duration and short-duration cutting can be achieved. Hence, this study is significantly contributed to expanding the applicability of cutting with speed variation techniques.