# 論文 / 著書情報
# Article / Book Information

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| Title(English) | Characteristic investigation and robust active stabilization methods for friction-induced vibrations - Special study for disc brake squeal |
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# 論 文 要 旨

THESIS SUMMARY

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| 専攻： Department of | Mechanical and control Engineering 専攻 | 申請学位（専攻分野）： Academic Degree Requested | 博士 Doctor of Philosophy |
| 学生氏名： Student's Name | 梁　瑶 Yao Liang | 指導教員（主）： Academic Advisor(main) | Prof. Hiroshi Yamaura |
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）


Friction-induced vibrations (FIVs) widely exist in engineering systems. Those systems containing friction-induced vibrations are prone to dynamic instability. It is because that the friction violates the symmetry of the damping or stiffness matrices or both of them, and thus the resultant asymmetric system leads to eigenvalues on the right half of the complex plane. When instability occurs, along with large amplitude vibrations, annoying noises always generate simultaneously.

Brake squeal, induced by the friction between brake pads and a disc rotor, is a typical example of the noises generated along with the FIVs. Characterized by higher frequencies (above 1 kHz), it is the most irritating type of brake noises. Therefore, it causes significant warranty costs to car manufacturers. Due to rising customer expectations of the Noise, Vibration and Harshness (NVH) of vehicles, brake squeal has attracted active research attention for several decades. Researchers and engineers of vehicle manufactures have tried to solve this conundrum using analytic, computational and experimental methods.

In this research, mode-coupling and negative-damping mechanisms for explaining the instability of FIVs are illustrated and verified through performing finite element analyses (the complex eigenvalue analysis and the dynamic transient analysis) to a disc brake model. In addition, normal modes of key disc brake components are extracted.

Later in the third chapter, an impact test, an experimental modal test and a squeal experiment are performed. In the impact test, natural frequencies of the disc in three-directions are obtained. To further confirm natural frequencies of the disc and to get the corresponding mode shapes, the experimental modal test is conducted using the roving impact hammer test. In the experimental modal test, natural frequencies and out-of-plane mode shapes of the disc are obtained. Furthermore, in order to offer more detailed information of squeal phenomena, the squeal experiment is carried out to measure sound pressure level of the squeal and accelerations of brake components (the disc, caliper and pad) simultaneously. Thus, measured squeal signals can be analysed using different signal processing methods.

For sake of variability in manufacturing and operational conditions (such as friction and contact), FIVs are complex and fugitive. Although the computational analysis can demonstrate the property of the instability caused by varying material and structures, detailed information of those instabilities should be extracted from the experimental signals. This research investigates the characteristics of brake squeal signals using several signal processing methods. Especially, a versatile signal processing method named as Ensemble empirical mode decomposition (EEMD) that is developed for nonlinear and non-stable signals is utilized for processing squeal signals. Moreover, an improved EEMD is suggested to alleviate the mode mixing problem in EEMD for processing squeal signals.

Passive structural modifications are considered to lack competence to stabilize FIVs under various uncertain conditions. Consequently, it is preferable to propose robust methods that can stabilize unstable FIVs under various conditions with uncertainty. This research proposes robust active control methods for stabilizing the instability caused by the friction. First, based on the first-order system, 2 control strategies (an improved PID control and a robust linear quadratic regulation) are developed. The robustness of the traditional PID control is improved by using H-infinity tuning method. The suggested robust linear quadratic regulation can make the arrived closed-loop system insensitive to uncertainties in contact parameters. Second, using the second-order formulas, robust eigenvalue, eigen-sensitivity and partial eigenvalue assignment methods are proposed using state feedbacks (displacement and velocity feedbacks).

Taking advantage of the receptance method that requires no information of the mass, damping and stiffness matrices, control gains for assigning required eigenvalues are derived for asymmetric systems. Moreover, eigen-sensitivities of asymmetric systems with respect to uncertain contact parameters are derived. The robust full eigenvalue assignment is then arrived by solving overdetermined least squares optimizing problem in which both required eigenvalues and eigen-sensitivities are assigned. Furthermore, since it is expensive and unnecessary to assign all the eigenvalues of a system, a partial eigenvalue assignment method is developed for asymmetric systems which are easy to be unstable. Using both uncontrollability and unobservability condition, the partial eigenvalue assignment, which assigns only a few undesirable eigenvalues while keeping the others unchanged, is realized. Again, the robustness of the partial eigenvalue assignment is enhanced by minimizing the Frobenious norm of the normalized eigen-sensitivity matrix. Therefore, using these proposed robust active control methods, asymmetric systems are stabilized since all of their eigenvalues are on the stable regions of the complex plane. Even with consideration of uncertainties in contact parameters, the robustness of those methods is validated through Monte Carlo simulations.

In summary, this research focuses on developing robust active stabilization methods for friction-induced asymmetric systems. Taking brake squeal as a special case of FIVs, finite analyses, signal analyses, experiment analyses are performed to identify the underlying mechanism of its instability. In the future, the realization of the proposed stabilization methods to real brake systems can be further explored.