Analysis of self-excited stick-slip vibrations in a model for creep groan using a combined Finite-Difference/Harmonic Balance approximation method

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Abstract. This contribution presents simulation results of stick-slip vibrations in a multi-degree-of-freedom model for disk brake creep groan. These self-excited periodic oscillations are approximated by a combined Finite-Difference/Harmonic Balance method (FD/HB). The method shows an increased efficiency compared to a pure FD or HB approach, especially for large-scale systems with localised non-linearities.

Introduction

Disc brake creep groan is caused by a negative slope of the friction coefficient as a function of the relative velocity within the brake pad/brake disk contact. The occurring non-linear limit cycles consist of sticking and sliding phases and are transmitted through the car chassis potentially leading to undesirable acoustic and structural vibrations. In the automotive industry, these creep groan vibrations thus cause high amounts of warranty cost and a subjective decrease in the level of quality perceived by the costumer. Various analysis strategies can make a valuable contribution in avoiding these unwanted vibrations. In addition to measurements, a calculation-based detection of these limit cycles early in the development process of a brake system is therefore desirable.

Mechanical systems and approximation method

The mechanical/mathematical description of these systems is usually realised via finite element (FE) models. The non-linearities relevant here (non-linear bearing support and frictional contact forces) are limited to local areas. Therefore, a combined FD/HB method for approximating the periodic oscillations is proposed, which exploits the mathematical equation structure with the goal of reducing numerical cost.

Basically, this method separates the degrees of freedom (DoF) subjected to non-linearities – the so-called non-linear DoF – from those that have purely linear viscoelastic kinetic properties – the linear DoF. Then, the periodic motion of the linear DoF is expressed as a FOURIER series and approximated by Harmonic Balance, respectively. Due to the linearity of their equations of motion, an analytical expression of the linear DoF's motion in frequency domain results – being solely a function of the FOURIER coefficients of the non-linear DoF. The motion of these non-linear master DoF's is approximated by the Finite Difference method for boundary value problems. In summary, the resulting algebraic equation system is solely depending on the approximated values of the non-linear DoF and can be numerically solved by NEWTON-like schemes.

Discussion

As a test case for this approach to the analysis of brake creep groan, a mechanical model is investigated that exhibits essential properties of FE models. It comprises the brake pad-disc contact, essential chassis control arms and is motivated by experimental testing. The friction force is modelled by an exponentially decaying and regularised STRIBECK friction characteristic which causes self-excited vibrations. The resulting stick-slip limit cycles are approximated by the proposed FD/HB method for a variable resolution of the chassis control arms. This shows the increased efficiency of the method for a growing number of linear DoF in comparison to pure FD or HB methods. In addition, the vibrations are analysed regarding brake pressure and rotational speed. For this purpose, a predictor-corrector path continuation is utilized.

References

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