Séminaire PIMM

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Arts et Métiers ParisTech, 151 bd de l'hopital, 75013 Paris

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Design oriented Time/frequency analysis of contact-friction instabilities in application to automotive brake squeal

Automotive brake design is nowadays oriented towards an optimized weight/performance ratio which tends to generate noisy systems. High friction coupling happening at the pad/disc interface is responsible for self- sustained instabilities in the auditive frequency range. The noise can attain 120dB in the brake vicinity and is known as squeal between 1 and 16 kHz or moan under 1kHz. Unlike low frequency vibrations the brake performance is not altered by squeal which happens mostly in low pressure, low speed conditions. The perceived quality is however altered, as the driver's feeling is disturbed and as the environmental nuisance is not welcome. Silent brake design methods are mainly empirical and difficult to control, would it be due to modeling issues (e.g. contact complexity) or due to implementation difficulties.

Classical design methods for brake vibrations are set in the frequency domain, following experimental results on unstable mode lock-in patterns as function of global parameters such as the friction coefficient or the braking pressure. The system is then linearized around a working point to apply Lyapounov theorem, in which the system stability is related to its complex modes damping ratio. This method shows great limitations and is not sufficient as only potentially unstable modes computed for a fixed contact state are output.

Working in the time domain allows to simulate the system with its full non linearities and should then give a clear view of the brake stability. Such implementation raises many issues - a direct simulation on a full industrial model would require prohibitive computational costs. Contact handling requires relatively small time steps around 10e-7s which makes long (20ms) simulations difficult to handle. Using a non linear implicit Newmark scheme on a 600,000

DOF system would actually generate over 1TB of data in over 700 hours. These issues are dealt with model reduction techniques and an adaptation of the Newmark scheme to non linear penalized contact vibrations. The simulation cost becomes then affordable yielding from 500MB to 5GB of data in 12 hours. Initial states are eventually optimized to obtain limit cycles quicker which is critical for a design phase.

From the design point of view, time simulation results must be exploited in a way allowing to close the loop with classical design parameters. It is then necessary to consider components and system characteristics, mostly known in the frequency domain. The presentation will suggest a panel of post treatment tools linking time and frequency domains. A space-time decomposition is proposed through the singular value decomposition (SVD) of the limit cycle, showing the principal deformation shapes of the solution, to be compared to the real and complex modes computed at the static state.

The space-time decomposition itself does not allow to understand the transient phase however critical for the assessment of squeal triggering mechanisms. The computation of modal mechanical energy contribution of the real modes (no friction nor damping) allows to follow the transient energy distribution in the system and the thresholds characterizing the apparition of a limit cycle. The notion of dynamic stability diagrams is introduced to highlight a significant evolution of the system complex modes during the time simulation. Energy transfers between stable and unstable modes as function of the vibration levels is then presented as a way of understanding limit cycle patterns.

In conjunction with time simulation, new design reanalysis methods have been developed in the frequency domain. In the scope of quality control at the early stages of the design cycle, relevant links between the detailed component design phase and the global assembled system validation phase are made. Reduced models with exact real modes and explicit component-wise degrees of freedom are then proposed. Sensitivity analyses of the system to specific component design can then be evaluated efficiently. Perspectives are also opened regarding detailed studies of large global parameters variations.