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Hypoid Gear Noise and Vibration Control in Automotive Rear Axle Systems

By

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Abstract:

Gear whine is a key issue for the vehicle powertrain system, and the design of a quiet, reliable driveline system is highly desirable for the automotive industry. From past studies, the main source of excitation for gear vibration and noise is the transmission error (TE), which generates the dynamic mesh force between the gear teeth. Then the vibration transmits through the flexible axle components and radiates off from the surface of the axle housing structure. The dynamic responses of the hypoid geared rotor system in the rear axle have a significant effect on the performance of noise, vibration, and harshness (NVH) for the vehicle design.

Hypoid gear noise and vibration reduction can be achieved by controlling the excitation source and the path transmissibility. However, the gear design optimization usually relies on the experience of gear engineers or trial-and-error approaches. Therefore, a robust method is needed to consider all the hypoid gear design parameters of both macro-geometry and micro-geometry, and to optimize the noise performance as well as meet the design criteria of strength and durability. Moreover, the goals of gear designers and NVH engineers are different. The design goal needs to compromise to have a win-win situation on the axle system. Accordingly, an end-to-end solution is also needed to bridge the gap between gear designers and NVH engineers. In this study, a rear axle system modeling methodology is proposed which considers from gear design parameters to vibro-acoustic analysis. The simulation models can be applied to optimize the gear TE and tune the axle system dynamic parameters to make the system less sensitive to the given TE.

Firstly, gear tooth profile modifications (TPM) and machine tool settings are optimized to reduce TE and dynamic responses. The loaded tooth contact analysis (LTCA) is performed with some combinations of TPM and machine tool settings. An artificial neural network model, namely the Feed-Forward Back Propagation (FFBP), combined with improved Particle Swarm Optimization (PSO) algorithm, is constructed to predict the TE. The results of LTCA are used to train the model. With the optimal hypoid gear TPM and machine tool settings, system-level analysis of the vehicle axle system is performed to verify the improvement of dynamic response.

Secondly, an ease-off hypoid tooth surface modification methodology is applied. The ease-off surface is the deviation of the real design pinion surface from the ideal conjugate of its mating gear surface. The ease-off topography can be modified by different TPM parameters and machine tool settings. The highly sensitive parameters for ease-off topography is used to construct the sensitivity matrix. The optimal design parameters can be calculated with the sensitivity matrix and the variation of ease-off topography between the target surface and the original surface.

Thirdly, a full axle system model is created to include the flexibility of axle shafts and bearings, manufactural and assembly errors, and axle housing geometry. The detailed finite element model and boundary element model of the axle housing is used to simulate the vibration response and noise radiation for the given work condition of the rear axle systems.

Finally, a case study is presented to validate the proposed method with experimental data of a hypoid gear rear axle system with specified design parameters and working conditions. The modal characteristics and dynamic response before and after the TPM are shown. The vibration and sound pressure measurements are compared with simulation results. The results conclude that the minimization of TE, the main excitation of vehicle axle gear whine noise and vibration, with optimal TPM parameters and tuning the system dynamics parameters can improve the overall NVH behavior. The proposed approach provides a better understanding of an optimal design hypoid gear set and axle components to efficiently control the noise and vibration of the automotive rear axle system.