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Dynamic behaviour of gearbox with backlash nonlinearity - hammering and rattle noises

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Abstract:

LTDS and VIBRATEC founded the Labcom LADAGE (gears dynamics joint laboratory). One of its goals is to develop numerical methods and simulation tools for predicting gears dynamics, in order to take account of multiphysics couplings between internal and external excitations and to follow the evolution of industrial demand towards more and more complex systems.

The operation of a combustion engine is such that it generates a cyclic disturbance of the circular motion of the gearbox primary shaft. Coupled with internal excitations, this disturbance can generate losses of contact at the loaded gear pair. Corresponding vibroimpacts regimes are responsible of the gearbox hammering noise. The irregular rotation of the motor is also sufficient for generating loss of contact of unloaded gears, such as idler gears of an automotive gearbox. Corresponding vibroimpacts regimes are responsible of the gearbox rattle noise.

Two different approaches can be retained to describe the nonlinear dynamic behaviour of mechanisms with contact and backlash nonlinearities, depending on the intensity of the vibroimpact pulses and contact duration.

Hammering noise

For high level pulses, the contact duration of successive vibroimpacts is long. A nonlinear dynamic model is introduced, taking into account both the gear backlash and the contact stiffness nonlinearities. Solving the equations of motion requires the implementation of specific methods dedicated to nonlinear problems. For example, the finite difference method is used in order to obtain the periodic solutions. They are followed up according to a parameter control, thanks to a pseudoarc length continuation method. Indeed, this approach has proven very efficient for studying multifrequency excitations. A direct integration time method is also used in order to compare obtained results. Eigenvalues of the monodromy matrix inform us about their loss of local stability and about the nature of the bifurcations that occur.

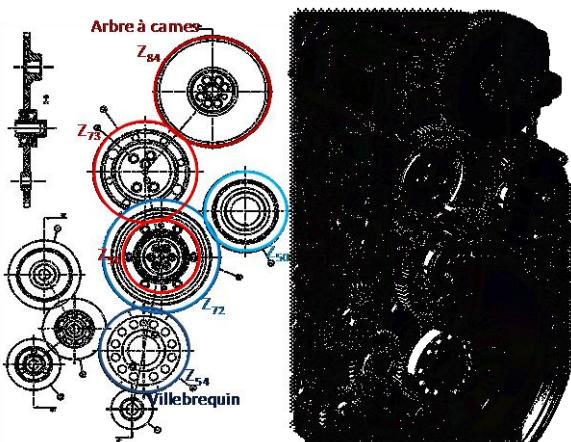
This first approach is well suited to characterize the hammering noise of a truck timing multistage gear. A large variety of dynamic behaviours have been identified. In addition to periodic responses, pseudoperiodic and chaotic ones are highlighted. Multiple impacts per period of excitation are observed. These nonlinear responses occur at resonances and instability regions. Then, the adding effect of the engine torque fluctuation is considered. The dynamic behaviour of the two-stage gear train becomes more complex. Vibroimpact regimes are observed over a wide range of operating conditions.

Rattle noise

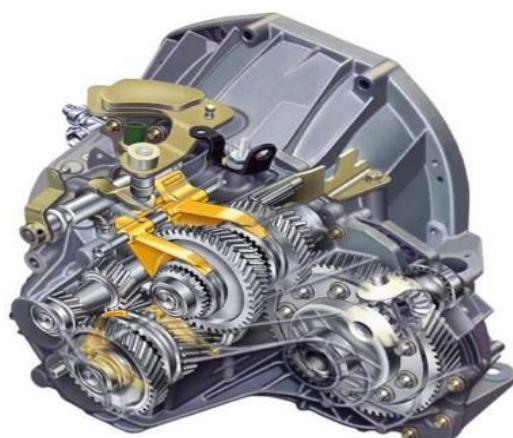
A second approach is retained for low level pulses. The contact duration of successive vibroimpacts is very short. They are described in a more simple way, using a coefficient of restitution. The dynamic

response of the system is built piecewisely by solving the equations of motion for the free flight periods. New initial conditions are introduced after each impact, derived from the dynamic response just before impact. This second approach is particularly well suited to characterize the rattle noise due to nonlinear dynamic behaviour of idle gears of an automotive gearbox.

In addition to the gearbox design parameters and the engine operating conditions, the dynamic response of idle gears depends on the drag torque applied to the idle gear and the coefficient of restitution. They are identified experimentally through implementation of optical encoders in an actual automotive gearbox and the operation of a specific test bench which replicates the automotive power train. Models of the different drag torque sources are validated from analysis of the free damped response of the drivelines. The coefficient of restitution and its probability density function are measured from further experiments under stationary operating conditions. A nonlinear model of the dynamic response of idle gears is built. The key parameters are the dimensionless backlash, the coefficient of restitution and a dimensionless parameter proposed to describe the rattle excitation level. Periodic, pseudoperiodic and chaotic responses including impacts between active flanks and reverse flanks are observed. Experiments under controlled excitation are performed to validate the assumptions, to confirm the ability of the proposed parameter to describe the rattle noise threshold, and to characterize the dynamic behaviour of the idle gear. Predictions are fitted with the drag torque and coefficient of restitution previously identified. Comparisons with measurements demonstrate the ability of the model to predict gear rattle for any idle gear, any gearbox and any operating condition.



Truck timing multistage gear studied for hammering noise characterization.



Automotive gearbox studied for rattle noise characterization.

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