Whining Noise: From the Transmission Error Computation and Minimization to the Dynamic Behavior of Gear Systems

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1. Introduction

The Static Transmission Error (STE) fluctuations and the consequent mesh stiffness fluctuations are the dominant excitations mechanisms in geared systems [1]. These excitations result from tooth deflection and tooth micro-geometries (voluntary profile modifications and manufacturing errors).

The aim of this work is to present a method to handle the (TE) and its dynamic effects on a complete industrial system (with the shafts, bearings and housing).

2. Studied systems

The STE optimization has been performed on a truck geared timing chain. Indeed, considering the high applied torques in a truck, the timing function is done by a geared system. The truck timing studied gears are circled in color in Figure 1

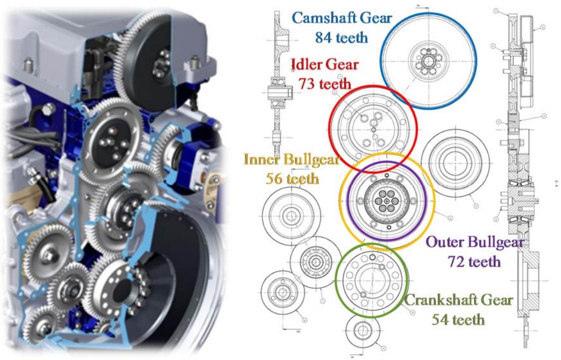

Figure 1: Truck geared timing chain for STE optimization studied system

For the dynamic computations, studied gearbox is presented in Figure 2, where a part of the housing has been removed. The gearbox is composed of four gears, three shafts and 2 meshes. The number of teeth Z of each meshing gear is indicated. Accelerometers and optical encoders were used to measure static and dynamic errors of transmission and the vibration response of the casings.

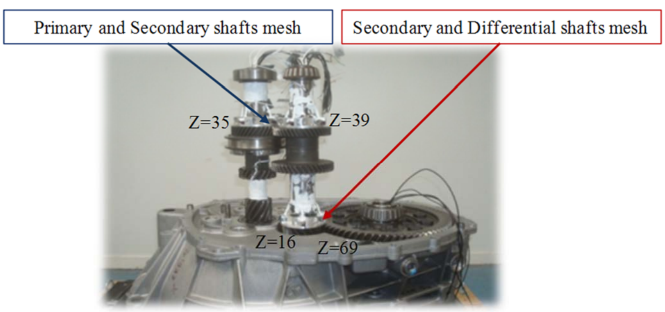

Figure 2: Picture of the studied gearbox with the two considered meshes and the instrumentation

3. Transmission Error Optimization

To reduce the radiated noise, STE fluctuations need to be minimized by introducing voluntary tooth micro-geometrical modifications. A complete robust computation scheme has been developed as presented Figure 3.

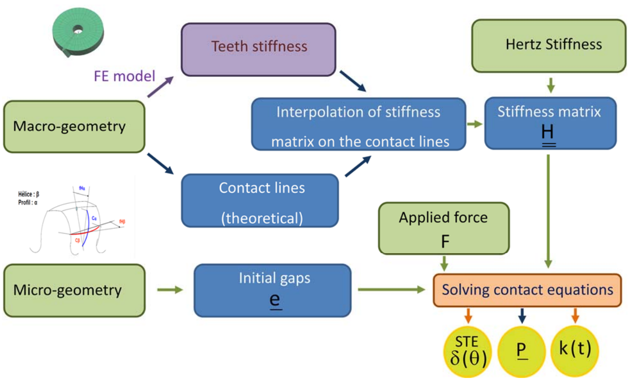

Figure 3: Complete transmission error computation procedure

Figure 4 shows an example of probability density functions for different possible solutions. It illustrates how an optimized solution is selected. The solution S2 has a smaller mean value, but it is associated with a large dispersion. The solution S1 appears to be the best compromise between the mean value and the deterioration capability of the solution.

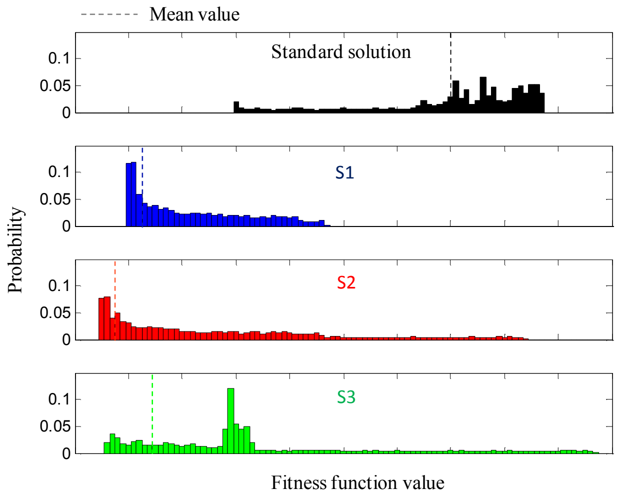

Figure 4: Probability density functions for the standard solution and three selected optimized solutions for the three-gears-cascade

After considering the STE_{pp} and its robustness, optimized solutions have been retained for the first three-gears-cascade and for the second two-gears mesh. The evolution of the STE_{pp} is calculated as a function of the applied torque for the standard and the optimized sets of gears. Some measurements have been done to determine the actual teeth topologies, allowing the confrontation of the recommendations made and the tooth modifications get.

Both standard and optimized gears sets have been mounted on a thermal engine and the corresponding radiated noise has been measured. Results are plotted in Figure 5. The benefit is less than expected but the operating torque in a little bit higher than T_{max} and the complete timing system had to be considered (e.g. the oil pump pinion is necessary for the engine oil supply). Nevertheless, the measurements show at least 1 dB of total power reduction, which is satisfying given that the levels (confidential) are initially not high.

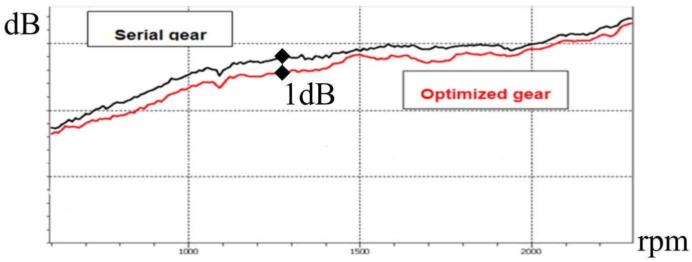

Figure 5: Total power in function of the engine rotation speed

4. Dynamic Response calculation

The prediction of whining noise requires models capable of accounting for both micro scale effects (the teeth geometry) and macro-scale behavior (the dynamics of the gear box and its response to the excitation).

All the computational scheme steps (see [2]) are summarized in **Figure 6**.

The analysis of Figure 7 leads to two main conclusions:

- Some discrepancies between measurements and computations are due only to a not accurate enough model tuning,
- The influence of the excitation dispersion can lead to huge differences on the dynamic response of some order (more than 20dB for the second order of the first mesh).

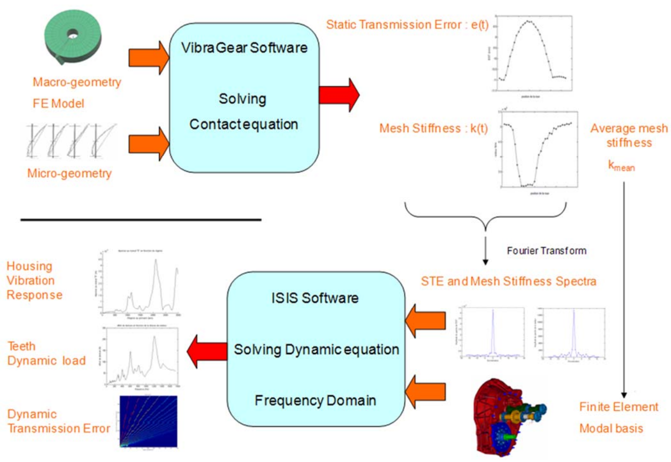

Figure 6: Overview of the computational scheme.

Figure 7 displays the quadratic mean value of the acceleration for some housing points for both measurements and simulations.

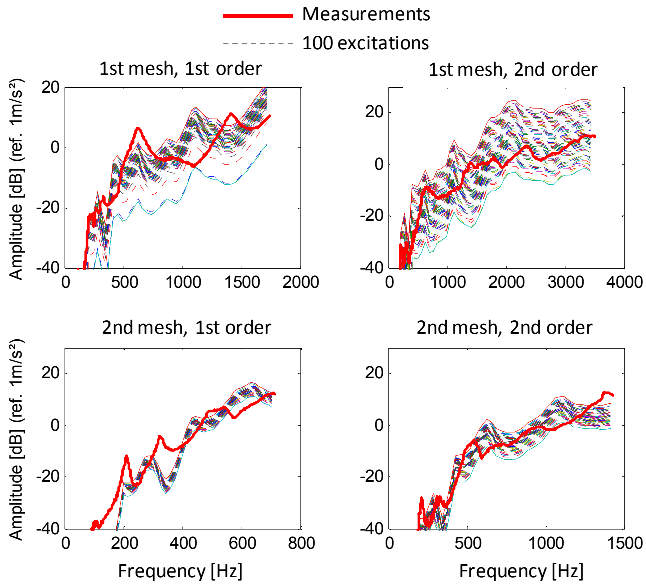

Figure 7: Quadratic mean value of the acceleration of housing points for both meshes and two first order.. Red: Measurements. Blue: dynamic response with an average teeth micro-geometry.

5. Summary/Conclusions

A robust optimization based on the swarm particle algorithm and coupled with a statistical approach of the robustness through Monte-Carlo simulation has been presented. Considering the severe dispersion associated with gears manufacturing errors, this method shows the benefits if this approach by reducing by at least 1 dB the total power level, which is precious considering the incoming noise norms.

The computation scheme presented in this paper is a complete method to predict whining noise severity, accounting for the scattering of the manufacturing data. The scheme is globally validated and can be used to optimize the current studied gearbox. The prediction remains satisfying despite some bad tuned model parameters.

6. References

[1] D. Remond, P. Velex, J. Sabot, et al., “Comportement dynamique et acoustique des transmissions par engrenages”, *Synthèse bibliographique*. 1993.

[2] A. Carbonelli, “Caractérisation vibro-acoustique d’un cascade de distribution poids lourd”, *Thèse de doctorat de l'Ecole Centrale de Lyon N°2012-34*”, 2008.