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Technical Paper

Dependence of tooth flank finishing on powertrain gear noise

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ABSTRACT

Finishing processes can be used in order to reduce manufacturing errors on teeth flank surfaces. These surfaces are at the heart of the gear meshing mechanics and thus should have an impact on gear noise. This paper addresses the issue of the impact tooth flank finishing on noise and vibration. The topographic and vibratory performances of two finishing processes, grinding and powerhoning, were compared. Multiscale analysis through continuous wavelet decomposition was used in order to characterize the teeth surfaces as well as the vibration spectra of a powertrain transmission tested on an industrial bench in a wide range of rotational speeds and frequencies. Results show that flank finishing processes leave their signature on the teeth surfaces which impact the vibratory behavior of the gear. Moreover, multiscale analysis approach allows the separation of vibration sources (meshing, environment, etc), and permits to quantify the impact of the choice of the finishing process.

1. Introduction

By their very nature, gears produce vibrations, the constantly varying load on the teeth generating excitations. They are then transmitted to the other pieces of the transmission and thus create noise. These vibrations inherent to gears are amplified by assembly and geometry defects [1–4]. Manufacturing errors, for example, can be reduced using finishing operations. However, such processes can sometimes introduce micro-geometry deviations on the surfaces of the flanks which are at the heart of the meshing mechanics.

Two such processes are mostly used after heat treatment: grinding and powerhoning. They are both abrasive processes which use the meshing mechanics to machine the flanks. Grinding (Fig. 1a), is very often used as a worming gear in order to generate friction between the abrasive surface and the piece. It is a process which has high cutting speed and thus induces high temperatures, which can lead to “grinding burns” on the flanks. The powerhoning process (Fig. 1b), uses an internal gear with shafts that are not parallel in order to generate the required friction. Due to this, the forces on the flanks are important, but more balanced on the flank, and it leaves high residual compression stress. The temperatures are lower than for the grinding process [5,6].

In this paper, the influence of the tooth finishing process on gear noise has been studied using multiscale analysis of: (1) the vibratory response of the gears and (2) the topographic signature of the considered finishing process on the teeth surface. Then the relationship between the multiscale topographic signature and the vibratory response was analyzed.

2. Experimental procedure and method

The studied system is an automotive powertrain transmission with two primary gear workpieces. The first gear train has 23×51 teeth while the second has 14×59. Note that the two separate gear trains have the same geometric and dimensional properties, though the numerical values of each characteristic are not disclosed. Only the concerned wheels were changed during the tests; the environment remained the same. The two tested configurations are illustrated in Fig. 2. The pieces were manufactured with the optimal production process parameters.

Negative surface replicas made of a silicon rubber material (Struers, Repliset F1) were used to assess the 3D texture of teeth surfaces finished respectively by grinding and power-honing finishing process. Topographical features of replica surfaces were measured in three locations by a three-dimensional white light interferometer, WYKO 3300 NT (WLI) (Fig. 3). The surface was sampled at 515×515 points with the same step scale of 3.88 μm in the x and y directions. Form component is removed from acquired 3D data using least square method based on cubic Spline function. The

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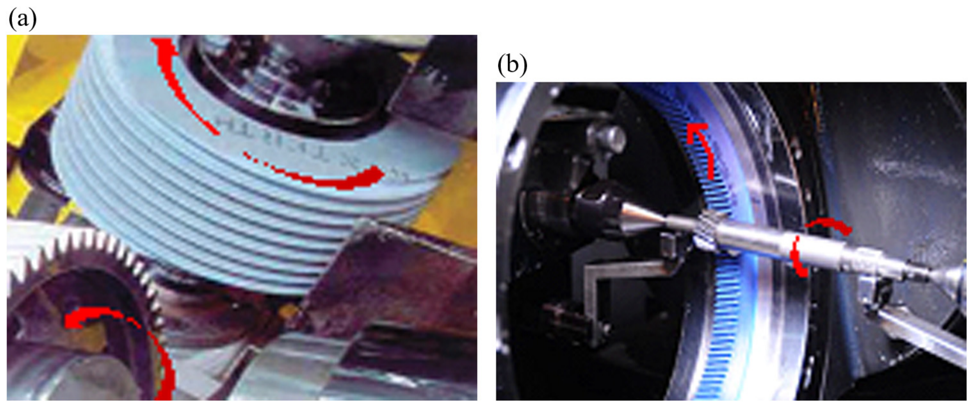

Fig. 1. Tooth flank finishing processes. (a) Grinding with worm meshing and (b) powerhoning with internal meshing.

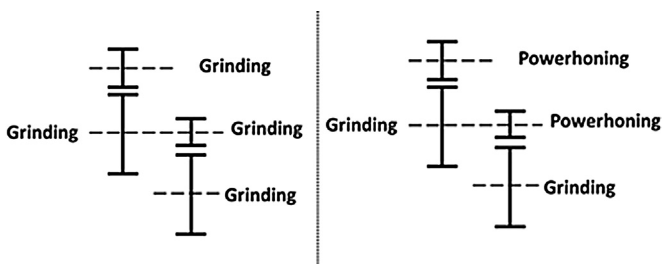

Fig. 2. The two tested configurations of processes. Grinding on the left and powerhoning on the right.

surface parameters were calculated according to the ISO standard 25178 [7].

The vibrations emissions performances of the two different gears samples were tested on an industrial vibratory test rig. The Fourier spectra of the radial acceleration signal were calculated at a rotational speed ranging from 500 to 6850 rpm with a 40 Nm load.

Fourier analysis permits to extract the periodic elements of a signal in function of their movement frequency. However when a structure is complex, the Fourier spectrum can become hard to interpret, as can be seen in Fig. 4. It shows the vibration spectra resulting from each process. The meshing frequencies as well as their first harmonics are represented. This two spectrum are globally very similar and do not allow to discriminate the finishing process effect. Similarly, Cepstral analysis is also often used to study gear vibrations. Indeed, the meshing and the associated defects introduce in the signal periodic patterns, which can be considered as a system with multiple echoes. Due to its definition it is used to separate the sources in a signal. Again, a system with multiple elements can surcharge the cepstrum.

Like Fourier and Cepstral analysis, Multiscale decomposition by continuous wavelet transform in the frequency-scale plan permitted to separate the sources of the vibrations measured on the testing rig. However, the main difference resides in the fact that, with a signal measured on a complex structure, it is clear how to separate the contributions of each source. This method allowed a finer analysis of the periodic phenomena in the spectrum such as the meshing of the teeth. It permitted to clearly separate the frequency scales of the meshing and the others, while highlighting their contributions. In order to do that, the Fourier spectrum was decomposed and the VMq parameter was calculated. It is the root mean square (RMS) of the amplitude in dB calculated at each frequency scale.

3. Results and discussion

Vibrations and surface topography signatures of the two finishing processes (grinding and powerhoning) were compared.

Fig. 5 gives the results from the ISO standard 25178 [7] for the flank surfaces finished by grinding and powerhoning. The arithmetic average roughness (Sa) is very close between the two processes, with their standard deviations overlapping. Three functional parameters obtained from the bearing curve were considered. The core roughness depth (Sk) is a measure of the surface

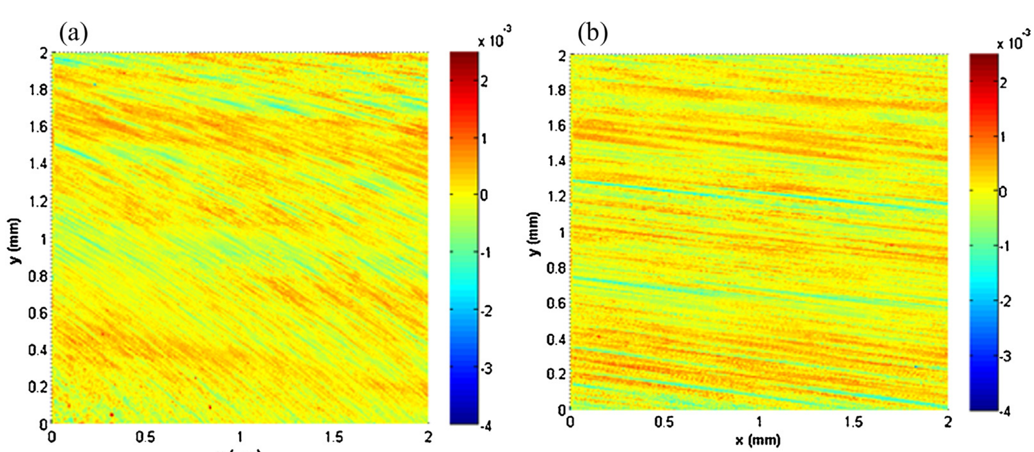

Fig. 3. 3D micro-topographies (2 mm × 2 mm) of tooth surfaces generated respectively (a) by powerhoning and (b) by grinding. The color scale is in mm. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)