Surface texture measurements of gear tooth

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Abstract

This work presents a study of the surface texture of gear teeth with different surface finish. Surface data have been analyzed by means of traditional roughness parameters and by the harmonic decomposition with FT transform. A method for selecting the significant frequencies of the roughness profile is presented. A comparison of results on gear teeth made by hobbing, grinding and lapping techniques is shown to point out the main effects of each texture finishing on the harmonic analysis.

Keywords: gear, tooth, surface texture, roughness

1. Introduction

The roughness of gear tooth surface plays an essential role in gear performance among all other gear parameters. As reported by several studies, the surface texture is a main source of vibration generation and wearing during normal gear operation. Among others, the relation between roughness and micropitting [1], the correct selection of roughness parameters for the evaluation of gear performance [2,3] and the prediction of gear noise from roughness analysis [4] have been investigated. Moreover, there is an increasing demand for gears with high transmission power and long lifetime [5,6]. An example is given by gears for wind generators.

This work presents a study of the surface texture of gear teeth with different surface finish. The aim is to go beyond the traditional surface roughness parameters by a richer description of texture in terms of harmonic content and by a quantitative threshold of power spectrum density (PSD) level. For this purpose, the harmonic decomposition with Fourier Transform (FT) is a good choice. In particular, the FT representation as PSD allows to evaluate how the mechanical energy is associated to the frequencies of the gear tooth profile.

The next section gives the details of texture measurements. Then section 3 explains the extraction of roughness data from the raw 2D profiles. Section 4 shows the PSD graphs of tooth texture.

2. Gear data

A set of gear data was obtained by 2D tooth profiles taken from three helical gears of different surface finish: a hobbed gear, a ground gear and a lapped or super-finished gear. One tooth from each gear was measured with a stylus profilometer, producing profiles data with a dense sampling interval of 0.25 µm. Several parallel and equispaced profiles along the involute and helix directions were taken (fig. 1). The evaluation length spans from 5mm to 25 mm. The tooth surface was oriented to be almost leveled with the tip scan path in order to match the vertical extent of the tooth profile with the measuring range of the profilometer.

Figure 1. Scan paths along the gear tooth: involute direction (red); helix direction (blue).

3. Roughness data

The roughness profile is extracted from the raw texture (unfiltered profile) according to IS0 4288 [7] and to ISO 16610-21 [8]. A cutoff length (Lc) of 0.8 mm was used to calculate the roughness profile over the full evaluation length. The Gaussian filter was truncated at one cutoff length from the middle point, as suggested in ISO 16610-21 for reference software. The noise filtration wavelength (Ls) is set to 2.5 µm. At the beginning and at the end of the 2D profile for an extent of data equal to a cutoff length, the Gaussian filter is not completely filled by the data, in this case, filter output is considered invalid and discarded.

4. Harmonic analysis

The roughness profiles were analyzed by FT and the modulus squared of the FT coefficients divided by the FT bandwidth was taken as PSD. The PSD is computed applying the Hann window, suitable for noisy signals like roughness profiles.

4.1. Power Spectral Density

Figures 2 and 3 show the PSD graphs calculated from the 2D profiles taken on teeth of different surface finish. The graphs make use of axis with logarithmic scale to better cope with data range. The graphs are truncated at the cutoff frequency (1/Lc) on the X-axes and at 10^{-6} amplitude on the Y-axes. Each plot is the mean of the PSDs of roughness profiles from parallel scan paths spaced to each other by 0,5 mm, along the involute and helix sections of the tooth.

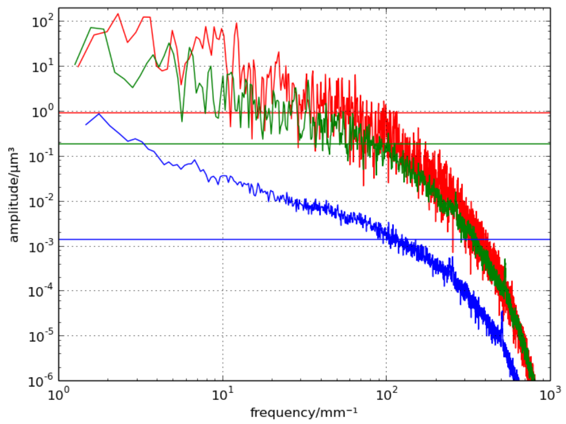

Figure 2. Mean of the PSDs calculated from 20 profiles taken on parallel scan paths of 5 mm length along the involute direction of three teeth: (red) hobbed, (green) ground, and (blue) lapped.

When compared, the lapped tooth exhibits the lowest amplitude PSD with a small noise (blue plot), while the hobbed tooth exhibits the highest amplitude PSD with a great noise (red plot). The ground tooth is just below the hobbed one.

As expected, PSD value decreases as frequency increases. The slope of this variation depends on the curvature of the involute profile with respect to the measuring path of the profilometer tip.

4.2. Effective PSD

Looking at fig. 2, it is clear that the most part of the energy described by PSD (area below the PSD) is concentrated into a frequency (inverse wavelength) band of the whole range. Only these frequencies contribute significantly to vibrations and wearing. Let us choose an empirical threshold level of energy, 95% of the whole area below the PSD. If the values of PSD are sorted into decreasing order and the result is integrated, when the integral reaches the 95% of energy, the corresponding PSD amplitude can be taken as threshold dividing non effective frequencies, below the threshold, from the effective ones, above the threshold.

The horizontal lines in figures 2 and 3 show the thresholds levels, as calculated for the hobbed (red), the ground (green) and the lapped (blue) teeth. Following the above principle, only frequencies on the left side with respect to the crossing of the PSD plot with the threshold line are effective to qualify the surface texture. It follows that the shape and frequency bandwidth of the PSD plot above the threshold level give a better insight of the surface texture in terms of wavelength and amplitude of the effective components.

It is to be noted that the PSD red plot of profiles along the helix (hobbed tooth) is not monotonic, with a relative maximum at a frequency of about 12 mm^{-1} . The hobbed tooth surface performs better than ground tooth at frequencies below 10 mm^{-1}.

4.3. PSD and rms roughness

PSD data can be related directly to the roughness parameter *Rq*, the root mean square of the roughness profile, by applying the Parseval theorem: the integral of PSD is equal to the squared *Rq* multiplied by the evaluation length.

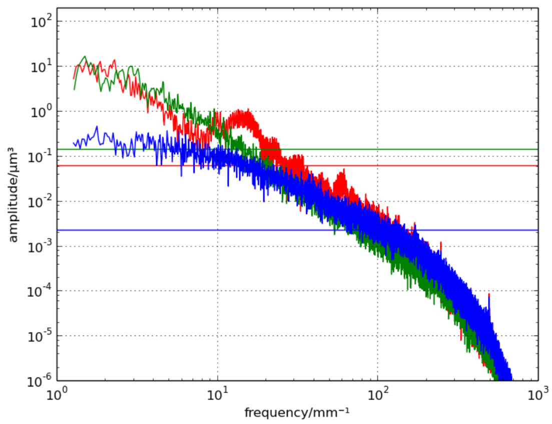

Figure 3. Mean of the PSDs calculated from 10 profiles taken on parallel scan paths of 25 mm length along the helix direction of three teeth: (red) hobbed, (green) ground, and (blue) lapped.

5. Conclusions

A simple method to select significant frequencies of the roughness of a gear tooth surface is presented. The method is applied to three gears with different surface finish. Shape and frequency bandwidth of the effective PSD plots of the surface texture of the teeth are compared. It is also shown that the roughness parameter *Rq* can be related to the PSD.

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