Detection sensitivity study of local faults in spur gears based on realistic simulations

Lior Bachar, Ido Dadon, Renata Klein, Jacob Bortman

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Abstract:

The dynamic response of gear transmissions holds essential information for the recognition of an incipient fault and its propagation. A realistic and validated dynamic model is used to predict the vibration regime of gear transmissions [1]-[2]. This model was validated experimentally for both healthy and damaged conditions [1]. A great virtue of a model is the ability to examine each phenomenon separately and to isolate its contribution to the dynamic response. The model considers the nonlinear behavior of the gear mesh stiffness, integrating the geometric profile errors of the gears. The scattering in the data, which is generated by the random factor of the simulated surface roughness, simulates the reality better than data of an ideal profile. The ability to determine what is possible to monitor for each surface roughness is not trivial and cannot be achieved experimentally, due to the immense span of cases to consider.

This work presents an analysis of spur gears transmissions that can be separated into two integral but still different studies. The first study examines the effect of the operating conditions, including speed load and surface roughness, on the vibration signature of a healthy gearbox. The two main evidences from this study are related to the levels of the gear mesh frequencies (GMF) and to the sidebands (SB's) in the spectra, which are caused by the frequency modulation (FM) of the rotational speed. It was found that there is a strong dependency of the energy at the gear mesh frequency on the applied load. Figure 1.a presents the total GMF's energy for different rotational speeds (R1 is the lowest speed, R3 is the highest speed) under different loads (L1 is the lowest load, L4 is the heaviest load). It is noticeable that under the same rotational speed, the total GMF's energy sharply rises as load increases. On the other hand, it was found that the total spectral energy of the FM sidebands sharply rises as speed increases, but is not affected by load. Figure 1.b shows the spectral energy of the FM SB's for different speeds under different loads around the first six harmonics of the GMF. As for the influence of the surface roughness [3], it was found that a coarser surface roughness tends to obscure the effects of load and speed on the signature due to the gears profile error. Furthermore, the energy level of the FM sidebands sharply rose as the surface roughness got coarser, while the energy level of the GMF's barely changed due to the surface roughness.

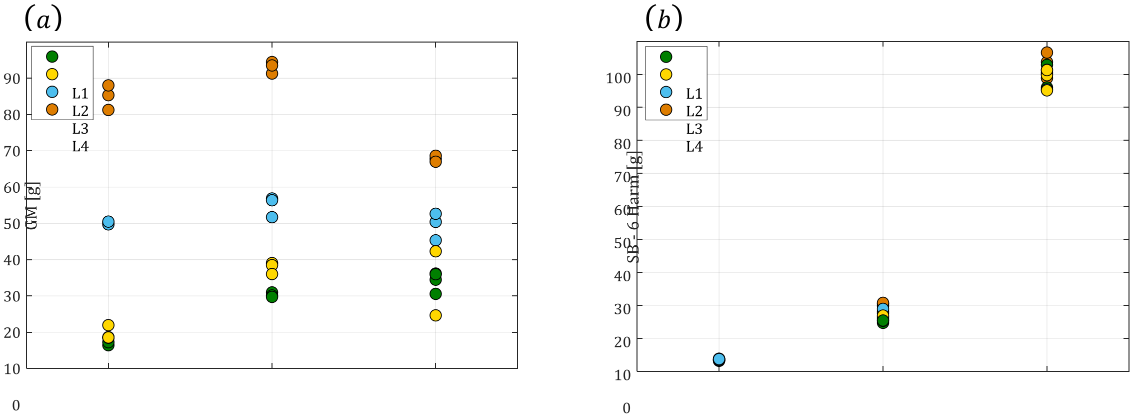

Figure 1: total energy against rotational speed and load of the (a) GMF's (b) FM sidebands around the first six GMF's

The second study examines the expression of local tooth faults in the vibrations signature. Load effects and other AM phenomena including eccentricity and misalignment may obscure the expression of local tooth faults. The comprehensive study of the effects of the operating conditions on the signature was necessary in order to fit a robust and sensitive monitoring process for the local faults detection capability. The optimal process should reflect the expression of the fault in the signature, while extinguishing the effects of the operating conditions, which are not related to the fault itself. The difference signal removes from the synchronized vibrations signal the GMF's components that are strongly affected by load, and components which are related to AM phenomena. Hence, the difference signal let us focus on the fault expression while diminishing the effects of the operating conditions. Figure 2.a shows the RMS level against kurtosis, both of the difference signal, for five different fault severities (where "Fault 1" is the least severe fault and "Fault 5" is the most severe fault). It can be seen that a separation of the faulty conditions from the healthy condition can be achieved for most faults severity levels, due to the significant differences in their locations on the graph. Besides the analysis of the difference signal, we can also utilize the total spectral energy of the FM sidebands. For each random signature, the total energy of the FM sidebands can be calculated and be compared to the healthy condition by statistical distances. The statistical distance may determine whether the examined signature can be attributed to the healthy population or not, meaning that a separation of the faulty condition from the healthy condition may be achieved. It was found that the detection capability is clearer when examining the spectral energy of the FM sidebands around the gear mesh frequencies overlapping the natural frequencies of the gearbox. Figure 2.b presents the Mahalanobis statistical distances (D) of the total FM sidebands energy around the GMF harmony which was found to be the most affected by the natural frequencies of the gearbox, against the level of the fault severity level. A Mahalanobis distance of $D = 10$ was determined to be the threshold for excluding a signature from the healthy population [4]. It can be seen that a separation of most of the local faults was achieved, as well as ranking of the three most severe faults.

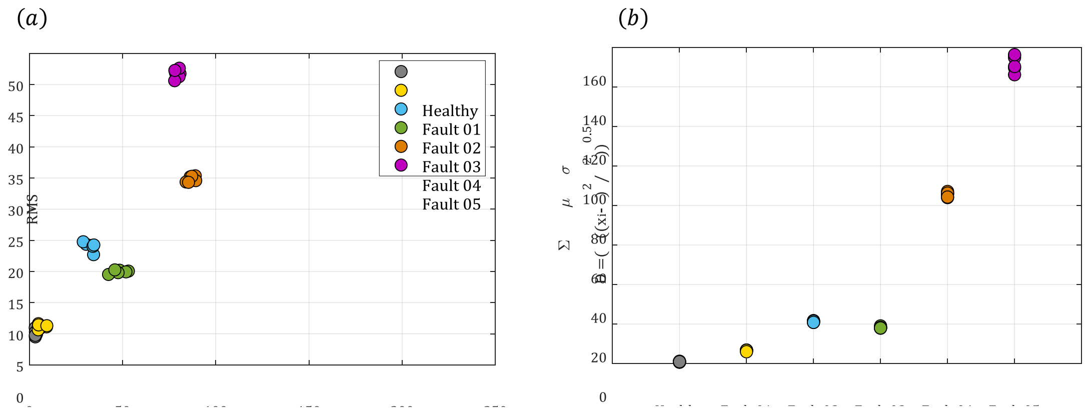

Figure 2: (a) RMS Vs. Kurtosis of the difference signal (b) Statistical distance of FM sidebands around the harmony of the GMF which was found to be the most affected by natural frequencies

References

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