Development of a vibration monitoring strategy based on cyclostationary analysis for the predictive maintenance of helicopter gearbox bearings

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Extended abstract

The scope of this paper is the development of a fault detection and diagnosis method aimed to helicopter gearbox bearings vibration monitoring in an operational context. Bearings are critical components in the gearbox, and their monitoring allows for failure anticipation capabilities, leading to increased safety and improved maintenance planning. Deploying a monitoring strategy for helicopter gearboxes necessitates the development of a methodology which can provide reliable information under varying operating conditions, dealing with a noisy vibration environment and simultaneously considering acquisition system constraints, such as limited acquisitions and sampling frequency, and operational needs, such as low rate of false alarms and minimal workload for the analyst. The approach proposed in this paper is based on the cyclostationary signals theory and relies on a two-steps procedure of detection and diagnosis. First, bearing fault detection indicators are devised on a statistical basis, leveraging on the theoretical properties of the envelope method. Different indicators based on the squared envelope spectrum and on the recently proposed logarithmic envelope spectrum are obtained, with the aim of providing early warning to impending bearing faults, while keeping a low, predictable false alarm rate. Interfering signals from other rotating equipment within the gearbox are considered, as well as different noise statistics. Mitigation measures based on deterministic-random separation methods are considered. A detailed, original analysis of the effects of angular resampling on the statistics of envelope-based indicators is also carried out. In the second, diagnostic stage of the proposed approach, the averaged cyclic periodogram is computed to assess the damage in the eventuality of an alarm. The fault signal is then filtered out, allowing the analyst to take an informed decision on whether validating or rejecting the alarm. This allows minimizing the risks of a wrong maintenance decision. The developed methodology is validated on real helicopter data collected over about twenty thousand flight hours, including four

bearings from different machines for which in-service spalling initiation occurred. Where a consistent amount of literature is available concerning the analysis of vibration detection methods on experimental rigs, there is a lack of comprehensive analyses based on operational helicopters data. A first contribution of the paper is in addressing this gap by investigating different envelope-based indicators in an industrial set-up, taking into account the associated complexities and uncertainties in a rigorous manner. The effect of interfering, periodic gear signals on the computed statistical indicators is considered, as well as that of the computed order tracking for angular resampling, and of deviations from the white noise assumption. Further, the variability of the operating conditions across different acquisitions is taken into account, with considerations on the effect of rotating speed and torque level. It is shown that a proper statistical treatment allows obtaining predictable false alarm rates in the detection phase across all the encountered flight conditions, maintaining the capability of providing early warning in case of fault development. On a second level, the proposed combined detection and diagnosis strategy is demonstrated on a variety of cases, proving the robustness of the approach and validating its applicability within an operational framework. The detection performance is assessed on the basis of the achieved false alarm rates and the improvement in fault anticipation with respect to chip detectors, whereas the capabilities of isolating the fault-related signals using cyclostationary signal separation methods is shown for the diagnosis stage.

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