Doctoral Dissertation
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High Fidelity Model of Ball Screws to Support Model-based Health Monitoring

By

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Abstract

Born from environmental and cost saving concerns, the recent trend toward "more electric" aircraft has touched most of the more important on-board systems and equipment. For flight control devices, this tendency translated into several and still concurring efforts to replace the traditional electro–hydraulic configuration (EHSAs) with electro–mechanical actuators (EMAs) for primary and secondary aerodynamic surfaces, a technology already widely spread in several fields, such as the manufacturing industry.

EMAs theoretically provide several advantages over the hydraulic solution in terms of envelope, weight, environment pollution and so forth. Their widespread use is however hindered by a relatively higher jamming probability, which is beyond the imposed/required limit for manned and civil aircraft. To overcome this issue, several solutions have been proposed, mostly implying architectures with several redundancy levels of different actuator's components. These "jam-tolerant" solutions lead to the increase of the number of components and, consequently, to the increase of the overall weight and a significant reduction of the overall reliability, hence increasing the probability of fault occurrence during service.

An innovative solution is to employ a simple architecture with the minimum number of needed components, coupled with a prognostic and health monitoring system. This would allow to move from a preventive to a condition-based maintenance and potentially to predict the development of a jam-causing degradation, hence removing the need of encumbering mechanical redundancies. The awareness of fault modes is paramount to develop an effective PHM system: each fault occurrence has to be associated with one or multiple feature, indicative of the fault progression and actuator's health status. Monitoring these features in time it is possible to estimate the residual life of the components and to avoid the occurrence of a failure.

To do so, it is of primary importance to have a high–fidelity detailed dynamic model of the various EMA subcomponents, to be used as a virtual test bench on which to inject artificial defects, identify the appropriate feature and verify the PHM approach feasibility. Among all the components of an EMA, the ball screw is the most jam–critical.

Therefore, this thesis focuses on the development of a high–fidelity non–linear dynamic model of such component, with the ambition of accurately represent the physics of the system and the dynamics of the faults evolution in time as a direct consequence of the operative conditions. After an in-depth analysis of the current state of the art of ball screw modelling, the thesis describes the successive steps taken to prepare a multibody three–dimensional dynamic model of the system, complete with lubrication and degradation models. Several analysis are presented to prove the model capabilities and results are compared to the most advanced models available in literature. A number of selected degradations are hence simulated and the results discussed. To further test the model validity and support further analyses, a dedicated test bench has been designed and is currently under construction; both the model–based design and the final architecture of such test-bench are described in the thesis.

The proposed model puts the bases for the application of PHM strategies to ball screw mechanisms, allowing the effect of several kinds of defects to be investigated in a short time and a cost–effective way. This thesis is oriented mainly to aeronautical applications, since this is the field in which the introduction of the electromechanical technology is more challenging. Nevertheless, the content and applicability of this research is not only limited to this field, since ball screws are key components for actuation systems in several fields, in particular in machines for industrial applications.