The Application of Fault Simulation to Machine Diagnostics and Prognostics

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The early development of machine diagnostics and condition monitoring was based on measurements from actual failures, but these cannot be predicted or arranged to occur when and where desired. In recent years it has become possible to make simulation models of a machine, such as a gearbox or engine, including the simulation of various faults of different types, severity, and location. There are a number of benefits from doing this, the first being to be able to produce sufficient representative signals to train automated fault recognition algorithms, such as artificial neural networks, as it is not economically viable to experience the number of actual failures required. Being able to produce signals from faults of different sizes and locations can be useful in the development of diagnostic and prognostic procedures — the latter, for example, by being able to develop appropriate trend parameters. Finally, the effects of faults in complex machines are often based on nonlinear interactions, which are difficult to foresee, and the simulation modelling of the whole machine can be very useful to obtain a physical understanding of these complex interactions. This paper illustrates these principles using examples of rolling element bearings, gears, geared systems (including bearings), and internal combustion engines, with favourable results in all aspects.

1. INTRODUCTION

There are three main areas where fault simulation is valuable in machine diagnostics. The first has to do with the training of artificial neural networks (ANN) and similar classifiers to perform diagnostics and prognostics of faults in machines. Many authors have proposed using ANN to perform automated machine diagnostics, by learning the features that characterize various types of faults. However, neural networks must be trained using a considerable amount of data to characterize each condition to be detected and classified, with a certain amount of random variation typical of the variations in operating conditions experienced by a machine in a given condition. Virtually, the only condition which would provide sufficient data to achieve this goal is the normal condition, and, so, ANN can be used to detect this, as well as departures from it. On the other hand, it would not be economical to actually experience the number of faults and failures of each type required to train ANN for all fault conditions.

Moreover, real faults cannot be made to appear at will; one usually has to wait until they occur, which may be very infrequent. Another problem with some of the papers that describe the use of ANN for diagnostics is that the data on which they are trained comes from a particular machine (often a laboratory test machine with seeded faults). Though the training process may be successful in this situation, it is not at all clear how the results could be extended to even a very similar machine, let alone the wide range of machines in operation, where it is impossible to experience the full gamut of faults for which the machine must be protected.

Therefore, the only way to viably use ANN for machine diagnostics and prognostics is to use simulated signals to train them. The level of sophistication of the simulation required depends on the application, but this paper describes a range of applications with different levels of sophistication. In general, it is desirable for the simulations to cover as wide a range of situations as possible, but there are cases with very valuable machines (e.g., turbogenerator sets) where it is worth making a detailed simulation model specific to a particular machine, (e.g.,[1,2]).

Simulation models can also be used to provide signals to test new diagnostic methods and to compare different methods, rather than being forced to rely on randomly captured case histories, or data generated by laboratory test rigs, — often with seeded faults.

A final application of simulation of machine faults is to give a better understanding of signal characteristics that have been experienced in practice, where, for example, nonlinearities can give interactions which are difficult to predict, and this can be used to help explain anomalies.

This paper illustrates a number of these applications, using as examples the simulation of rolling element bearings, gears, and geared systems, as well as the interactions between gears and bearings. The simulation of signals from reciprocating machines (such as diesel and spark ignition engines) is also covered, mainly by simulation of their torsional vibrations, but a project is also underway to simulate cylinder head and block vibrations.

The examples that are illustrated are of increasing complexity. As an example, local faults in rolling element bearings give very distinctive patterns in the spectra of envelope signals obtained by demodulating frequency bands dominated by the faults,[3] and such spectra can be simulated directly, without having to go via the time signals. This type of modelling, while general, would only indicate whether a particular type of fault were present, and it would be difficult for it to indicate degree of severity, although this is a goal of future development. The type of simulation ranges in complexity up to the modelling of a particular machine, showing how the small amount of actual measurement data available (for good and faulty condition) can be used to update and calibrate the model, and give confidence