Identification of changes in noisy spectra – to detect incipient problems in rotating equipment

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Background / overview of problem context

Faraday Predictive is a small Cambridge-based technology company, specializing in the predictive maintenance of rotating industrial equipment such as pumps, fans, compressors, and conveyors. Issues associated with maintenance of this industrial equipment are estimated to cost $700 billion pa worldwide, with much of this money being wasted through inappropriate maintenance strategies. Faraday Predictive provides a means of remotely monitoring rotating equipment and diagnosing impending faults. This helps the customer (who might be a water company, for example) maintain their assets in a timely manner and avoid a catastrophic machine failure by scheduling preventative actions well in advance and conversely to avoid doing un-necessary maintenance on a time-schedule when it is not required.

Our technology uses the electric motor driving the equipment as a sensor, by measuring the voltage applied to, and current drawn by, the motor, and identifying subtle distortions in the shape of the current waveform relative to the voltage waveform. These relative distortions, identified by means of a mathematical modelling approach, are expressed as a residual current. The frequency components in this residual current correspond to the characteristic frequencies of the phenomena causing them, which are typically related to deterioration of the equipment, such as bearing wear, belt slippage, internal corrosion, rubbing, misalignment, etc. By matching the observed frequencies against known characteristic frequencies, we are able to identify the likely cause of the distortion, and the amplitude of the signal at this characteristic frequency indicates the severity of the problem.

The overall steps in this process are as shown in figure 1 below:

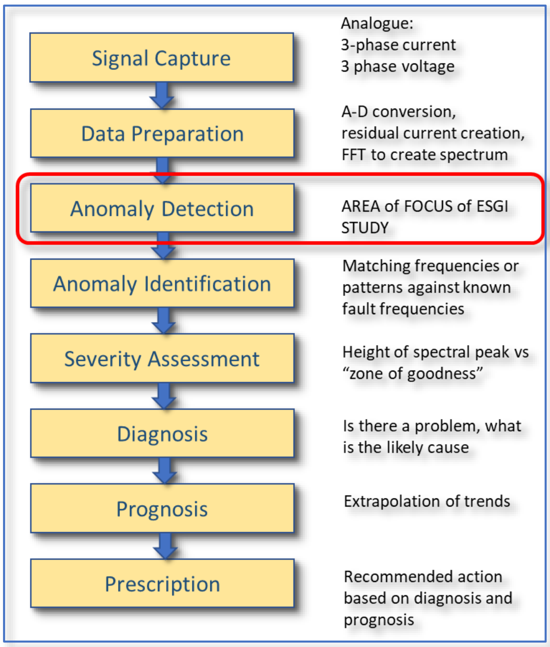

Figure 1 - overview of mathematical processes

Problem Briefing

A range of mathematical techniques are used in each step of this process, and we can describe them and explore limitations or alternatives to them if this is of interest, particularly if the initial “exam question” is solved early in the week. However, the “Exam Question” is a specific one in the area of Anomaly Detection:

- **How can we reliably detect changes of shape of our spectrum given a noisy signal?**

Once this step is firmly established, the subsequent steps in the process can be called into action, and whilst we can describe and discuss these other steps with the group, their effective deployment is all predicated on having detected the anomaly in the first place, so that is where we want the group to focus first.

For some failure modes, the problem manifests itself as a simple peak at a particular location on the spectrum, and this can be detected relatively easily. This is not the focus for ESGI.

However, some other phenomena show up as a broad “hump” of signals rather than at a single peak, and so far we do not have a good solution to identifying this sort of shape change. Examples of this issue are shown in figures 2 & 3 below:

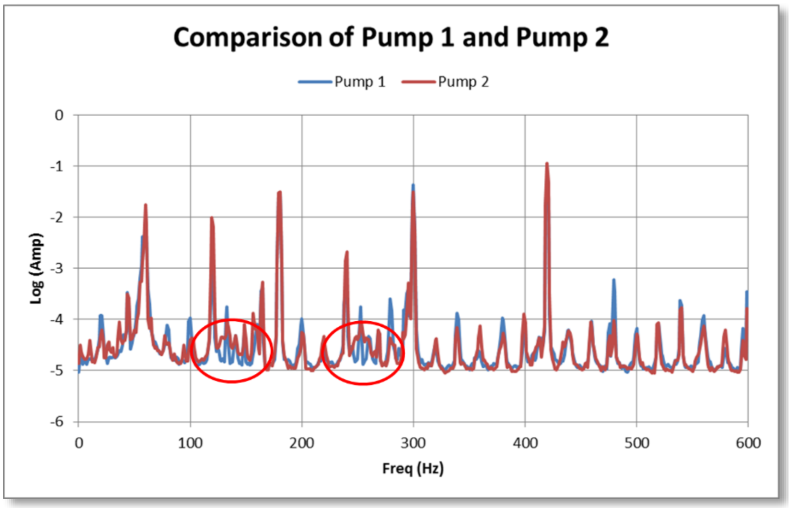

Figure 2 - shows the spectra for two identical pumps - with the red one showing two elevated areas

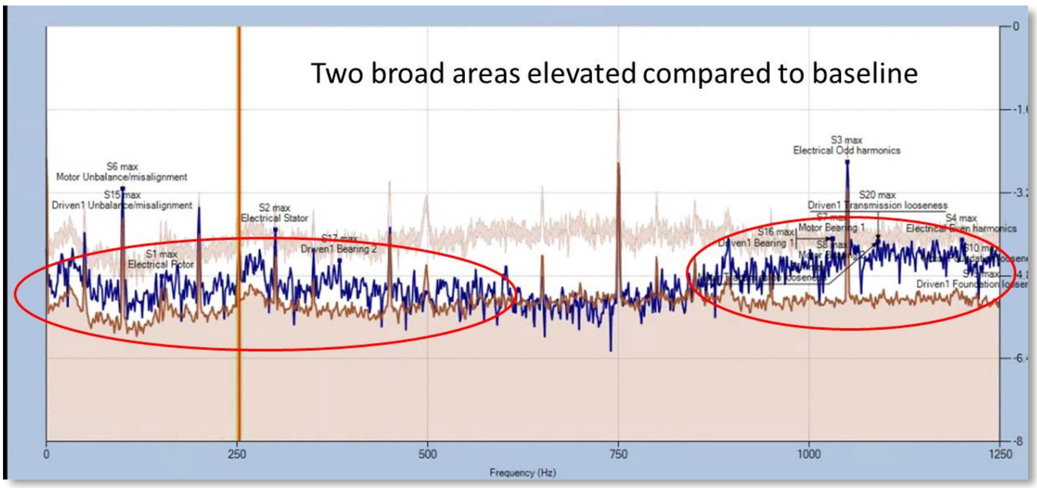

Figure 3 - Spectra for one item of equipment that has changed over time. Brown = baseline from October, Blue = single instant in December (note shape continues to display this elevated shape over extended period, eg right up to Feb 2019)

Figure 2 shows the spectra for two otherwise identical pumps. It can be seen how similar the shapes are, which indicates how similar the pumps are and what similar duties they are on. However, it is clearly visible to the eyeball that there are two distinct humps on the red trace that are not present on the blue trace. It is believed that these humps indicate the early stages of deposit build up inside the pump. What we seek is an automated method for spotting this sort of anomaly.

Figure 3 shows two spectral traces – the blue one is a single "instant" spectrum corresponding to a measurement made at a particular point in time. The brown trace is a baseline, created by combining and averaging a number of consecutive spectra at an earlier period. Two points to note from this figure are firstly, the instant spectrum is much noisier than the baseline, where noise has been averaged out; and secondly, the two broad areas where the more recent blue spectrum is elevated compared to the baseline, indicating something is going on, ie some deterioration is occurring in the rotating equipment. We seek a way of automatically alerting users to the presence of this change, without creating false alarms from random noise.

If the primary "exam question" were solved early on during the week, a number of other areas would also be of interest, including:

- What causes these humps, as opposed to peaks?
- What causes signals to show up as sidebands on higher harmonics as opposed to sidebands on the fundamental? In addition, is there a rational basis for weighting the significance of one of these higher harmonic peaks as compared to ones on the fundamental?
- Empirically, we see subharmonics (e.g. 1/3, 1/5, 1/7th and sometimes multiples of these, e.g. 2/7th, 3/7ths) of the rotational speed when rubbing friction is present. Can you explain why this should be the case, and why it shows up at the particular frequency in any particular case (e.g. why sometimes 1/5, and other times, 1/7th)?

Available Data and Tools for the study group

We can make available a number of data sets that are held in SQL databases, and tools that allow easy viewing of the spectra, trends, and in some cases the underlying source voltage and current waveforms.