MECH4305 Problem Set #4
Due Date: Friday 19th May 2017 at 5pm

QUESTION 1: Signal Processing.

Introduction and Background

Two B&K type 4332 accelerometers were attached to a machine via screw mount. The machine contains a small 7 bladed fan that operates at between 1450 and 1600 rpm. The motor of the machine operates at 2975 rpm. The conditioned accelerometer signals were fed to a 24 bit National Instruments NI USB-9234 data acquisition device and acquired at a sampling rate of 50 kHz for a sample time of 4 s. The sensitivities of accelerometer 1 and 2 are 60.2 and 59.9 mV/g, respectively.

The mat file *VelocityData.mat* contains the variables *Vdata_1* and *V_data2* which are vectors of the uncalibrated time series data from accelerometer 1 and 2, respectively (in V).

Provide a copy of your Matlab code with your assignment solutions. Ensure your Matlab code contains appropriate comments, figure axes are labelled correctly and legends are used where appropriate.

Tasks

1. Apply the sensitivities to the time series data to produce calibrated acceleration signals with units of m/s^2. Plot the first 0.1 s of the calibrated acceleration signals (on the same figure).

2. Calculate the mean, peak, peak-to-peak and RMS of the calibrated acceleration signals.

3. Calculate and plot (on the same figure) the autocorrelation sequences of the calibrated acceleration signals. Set the x-axis limits to a time lag range of -0.05 to 0.05 s.

4. Do the autocorrelation sequences plotted in part (3) suggest the signals of both accelerometer 1 and 2 contain a time repeating component? Why?

5. Calculate and plot (on the same figure) the power spectral density (PSD) of the calibrated acceleration signals using Welch’s method with window and FFT lengths of 2^{13} samples and overlap of 2^{11} samples. Plot with a loglog scale and set the x-axis limits to a frequency range of 200 Hz to 10 kHz.

6. Describe the acceleration spectra plotted in (5). What is the frequency resolution of the spectra? Which of either the fan or the motor is responsible for the peak components visible at frequencies between 800 and 1470 Hz and why?

7. Replot the PSD of the calibrated acceleration signals (on the same figure) with a frequency resolution of 25 Hz and using 25% overlap. How does changing the frequency resolution affect the spectra?

8. Calculate and plot (on the same figure) the magnitude-squared coherence of the calibrated acceleration signals. Use the window, FFT length and overlap parameters given in (5). Plot with a log scale on the x-axis only and set the x-axis limits to a frequency range of 200 Hz to 10 kHz.

9. At what frequencies are the accelerometer signals most coherent (i.e. have coherence > 0.5)?

QUESTION 2: Bearing Diagnostics.

Introduction and Background

The aim of this exercise is to introduce you to machine diagnostic techniques by providing hands-on experience in processing measured vibration signals. The task involves the diagnosis of small (localised) rolling element bearing faults using digital envelope analysis.

The signals to be analysed are time history signals from the UNSW gear test rig (shown in Figure 1). The rig consists of a 5.5 kW 3-phase electric induction motor, a single parallel-stage gearbox with a 1:1 ratio and 32 teeth on each gear, and a recirculating hydraulic pump/motor system that provides an adjustable torque load. Each shaft in the gearbox is supported by two deep-groove ball bearings, one of which was artificially seeded with a fault for these tests (see Figure 1).

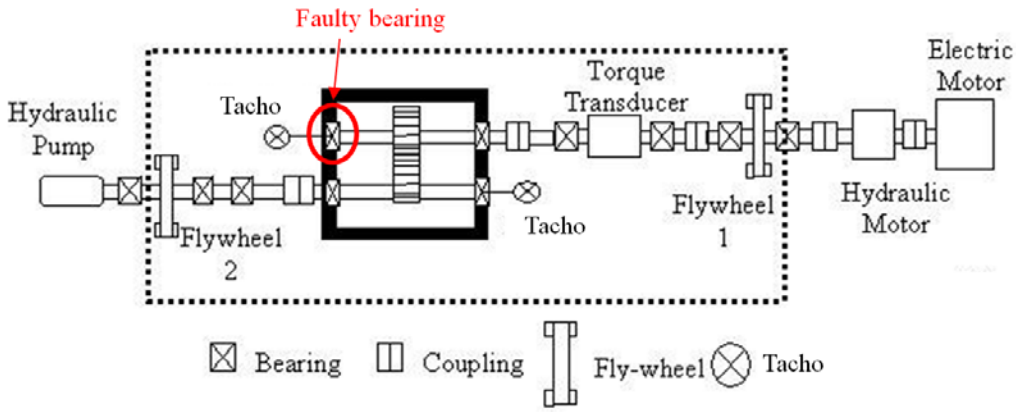

Figure 1: UNSW gear test rig

Testing was performed at a range of (constant) shaft speeds (3–10 Hz) and with a number of different torque loads (25–100 Nm). Three different bearing faults were tested – outer race, inner race and rolling element – although each of you will only analyse one fault case. Students have been allocated different records (in the form of Matlab data files) taken from the total dataset (i.e., one of the various combinations of fault type, machine speed and load). The files are denoted as:

'bg.mat': bearing in good condition (for the particular speed/load situation)

'bf.mat': bearing with a fault (in the outer race, inner race or rolling element) for the same speed/load situation as in the first file.

The Matlab files contain two columns for each signal. Column 1 is from an accelerometer near the bearing (signal scaled in ms-2) and column 2 is from a once-per-rev tachometer on the output shaft. The individual data files will be emailed to the UNSW student email address of each of you, or else provided through Moodle. The sampling frequency of the signals is 48 kHz, and the record length is 100,000 samples for each record. The bearing parameters are as follows:

Ball diameter	d = 7.12 mm
Pitch circle diameter	D = 38.5 mm
No. of rolling elements	n = 12
Contact angle	ϕ = 0°

Tasks

The aim of the assignment is to determine the type of fault in the faulty bearing, for your particular signal, using the following procedure:

1. **Preliminary calculations:** the speed of the shaft in the test rig should be identified by analysing the tacho signal (use the mean time between pulses rather than a frequency spectrum). From this shaft speed, the relevant potential bearing fault frequencies should be calculated using the well-known kinematic equations provided in the lecture notes (note that these may be in error by a few percent because of slip).
2. **Compare PSDs and select demodulation band:** compare the PSD of the faulty bearing signal with that of the reference (fault-free) condition. This can be done using the PWELCH command in Matlab, with a 1024 point transform and Hamming window length, and 50% overlap. The comparison should be done on a logarithmic (dB) amplitude scale and on the same set of axes, with the zero dB reference set to, say, 10-6 ms-2. From visual inspection, select a frequency band in which a large change occurred with respect to the reference spectrum. The band will need to be at least 3.5 times as wide as the highest expected fault frequency (in this case BPFI) to give a sufficient frequency range in the envelope spectrum, and can certainly be much wider. The selected band will be used for demodulation in the following step. Note that the valid bandwidth below the anti-aliasing filter is 20 kHz, but it is possible to use the spectra up to about 22 kHz before the filter roll-off becomes too steep.
3. **Conduct amplitude demodulation and form the squared envelope spectrum:** data in the selected band (from the complex spectrum, obtained via FFT of the whole time record, not merely the PSD) should be placed in a new buffer (i.e., a new variable) and padded with trailing zeros to at least double its original size. Note that this equates to making the lowest frequency in the band the new zero frequency point, and the effective sampling rate will now be at least double that of the original bandwidth selected. Inverse transforming (using IFFT) this signal gives a complex (analytic) time signal whose amplitude is the envelope, and its square the squared envelope. Use the FFT function to generate the amplitude spectrum of this squared envelope signal, and display it on a linear-linear plot over a useful frequency range (up to ~3.5-5 times the highest expected fault frequency).
4. **Analyse envelope spectrum and make diagnosis:** search the envelope spectrum for the suspected bearing fault frequencies and sideband patterns, and make conclusions about the fault. The in-built data cursor tool in Matlab can be used for this. Analyse the envelope spectrum of the reference signal by way of comparison. If no sign of a bearing fault is present in the 'bf.mat' data, return to step 2 and select a different demodulation band for analysis.
5. **Briefly summarise your findings:** give your conclusion as to which of the three fault types corresponds to your data (giving reasons). Also include with your submission: your preliminary calculations from step 1; the PSD comparison plot and your selected demodulation band (step 2); your final squared envelope spectrum (step 3); and, the Matlab code used to obtain your results. Note that a lengthy report is not required.

Suggested References

Lecture notes on condition monitoring from Weeks 9 and 10.

Randall, R. B. & Antoni, J. 2011, Rolling element bearing diagnostics--A tutorial, Mechanical Systems and Signal Processing, 25, 485-520. (Placed on Moodle)