Proceedings of The Institute of Acoustics

AN APPLICATION OF RPM ORDER RATIO ANALYSIS TO DISTINGUISH NOISE SOURCES DURING VARIATIONS IN ROTATIONAL SPEED

KEN SCANNELL

Lucas CEL Instruments Ltd, Hitchin, England

INTRODUCTION

RPM order ratio analysis is the technique of using the pulse from a pulse generator mounted to a rotating body to synchronize the sampling of the vibration and noise signals from a rotating machine before spectrum analysis.

If variations in RPM are caused by varying loads on an engine or motor, the resulting spectrum peaks will also shift each side of the peaks on the frequency axis. This can cause the nearly peaks to overlap, making data comparison difficult.

Using order ratio analysis however, sampling by means of a pulse synchronized to the rotation, enables the spectral peaks to be fixed in position even if the RPM changes.

In contrast to time-pulse sampling, [in which horizontal (X-axis) is expressed in terms of frequency (Hertz)] order ratio analysis (sampling by means of a rotational pulse) means that the X-axis is expressed in terms of order of RPM.

RPM ORDER

The RPM order is a means of expressing the RPM of a rotating body as a ratio with respect to the reference RPM of the rotating body (which is assigned the value 1).

The first RPM order essentially means that there is one periodic change for each rotation of the rotating body.

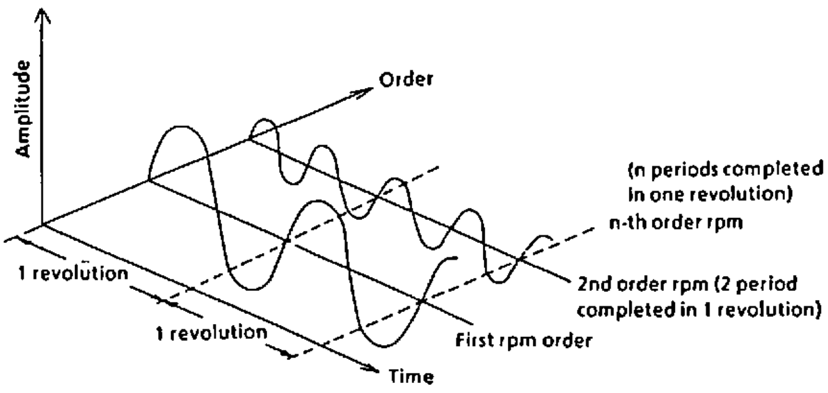
Example

If a rotating body is rotating at a speed of 600 RPM, the frequency corresponding to the first RPM order is simply found by dividing by 60.

i.e. first RPM order (fundamental order) = 600/60 = 10Hz

second order = 600/60 x 2 = 20Hz

n-th order = 600 x n/60 = 10n Hz



1. Figure 1 3.D Display of Amplitude, Order and Revolution

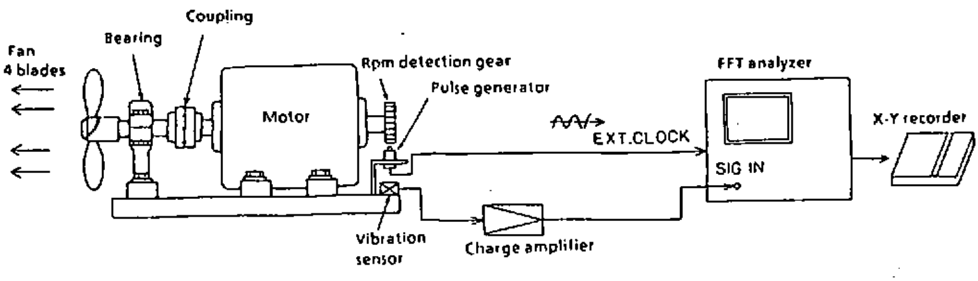
An example of RPM order ratio analysis

Figure 2 shows a simplified example of a rotating machine with the interconnection of the measuring instruments. If the motor RPM rated value is 1750 the main shaft fundamental frequency F_o is calculated as follows:

f_o = 1750/60 = 29.17Hz ..... 1st order

If we assume that the fan and bearing are the chief causes of vibration, the vibration frequency f_f caused by the fan blades (F = 4 blades) is:-

$f_f = f_o \times F = 29.17 \times 4 = 116.7$Hz ..... 4th order

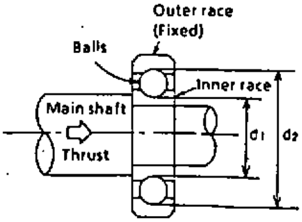


2. Figure 2 Rotating Machine with interconnecting of measurement instruments

The vibration frequency f_B caused by roughness in the bearings inner race groove as in Figure 3 is as follows:

$$f_B = f_o \times Z \times (d2/d1+d2) \quad [1]$$

$$= 29.17 \times 6 \times (36/20+36) = 112.5\text{Hz} \; ..... \; 3.86 \text{ order}$$



No. of balls Z : 6
Inner race diameter d_1 : 20mm
Outer race diameter d_2 : 36mm

Figure 3 Details of the Bearing

If the motor RPM (1750 RPM) varies slightly (+/-4%) due to load variations the vibration power spectrum will be as shown in Figure 4a. It can be seen that the moving peaks make the vibration sources difficult to distinguish. In contrast the order ratio analysis spectrum peaks do not change in position as shown in Figure 4b. Spectral peaks that shift position with changing RPM after order ratio analysis correspond to characteristic frequencies.

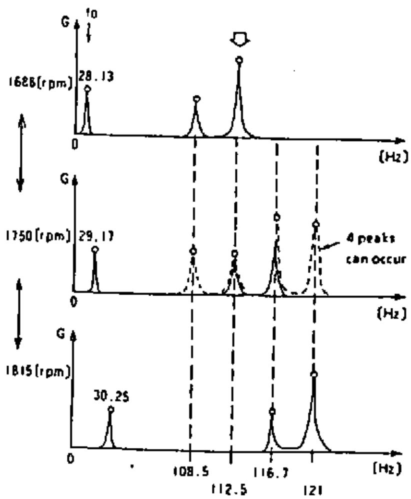
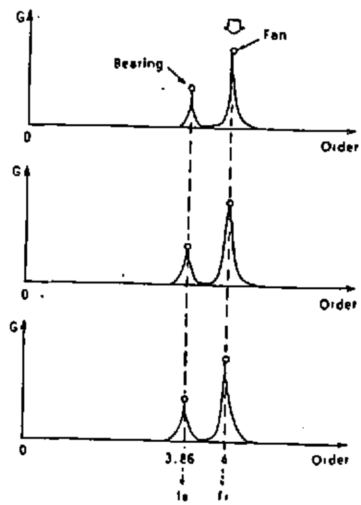


Figure 4a Vibration Sources (fan and bearing) difficult to distinguish



4b Vibration Sources are easy to distinguish

AN APPLICATION OF RPM ORDER RATION ANALYSIS TO DISTINGUISH NOISE SOURCES

SAMPLE RATE

In spectrum analysis the sample rate is constant with respect to time hence the number of samples per revolution will vary with the RPM for example the first revolution in Figure 5a has eight samples where the second revolution has over twenty samples.

In contrast the sample rate for order ratio analysis is constant for every revolution regardless of the RPM as shown in Figure 5b.

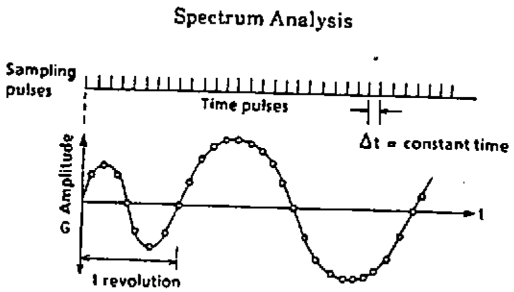


Figure 5a Sample Rate for Spectrum Analysis

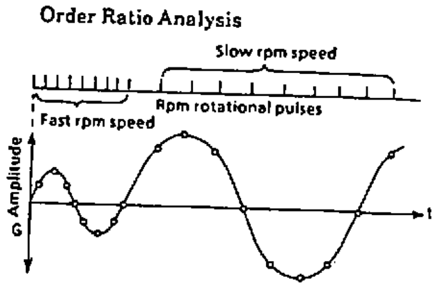


Figure 5b Sample Rate for Order Ratio Analysis

MAXIMUM ORDER AND RESOLUTION

If the pulse generator outputs n pulses (P) for each revolution (R) the maximum order X that can be analyzed is as follows:

$X = n/s$ order

where s is the nyquist number (which is at least 2 but usually 2.56 in FFT analysers).

In the example shown in Figure 2 the gear has 64 teeth hence the pulse to revolution ratio $n = P/R = 64$.

Therefore $X = 64/2.56 = 25$ order

The maximum order is 25, hence resolution of components would become impossible if the number of fan blades exceeds 25. In this case the number of pulses would need to be increased.

The pulse rate n output by the pulse generator is made 2.56 times (or greater) the maximum order to be analysed.

AN APPLICATION OF RPM ORDER RATION ANALYSIS TO DISTINGUISH NOISE SOURCES

$n > 2.56 \times X$

A convenient approach is to make the number of pulses 2^m where m is an integer.

To satisfy this condition the FFT analysis system used must have the ability to divide or multiply the sampling pulse signal. This can, for example, be performed internally by the Ono Sokki CF-880 FFT analyser. (Figure 6).

Figure 6 The Ono Sokki CF-880 FFT Analyser

Resolution

If the resolution of the analyser is for example 1/400 this would correspond, on the CRT display as follows:

400th point: n/2.56 order
yth point: xth order

hence $y = [x / (n/2.56)] \cdot 400 = 1024.x / n$

For example, since the fan in Figure 2 represents the 4th order this would appear on the display as the 64 point as computed below:

1024 x 4 /64 = 64th point

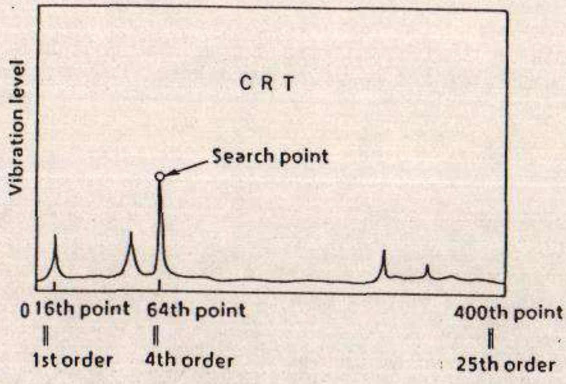


Figure 7 The Order Resolution is 1/400 of the Maximum Order

The order resolution is 1/400 of the maximum order

e.g. 25/400 = 0.0625 order

The fewer the number of pulses, the greater the resolution will be.

THE ALIASING PHENOMENA

The aliasing phenomena occurs with order ratio analysis just as it does with conventional spectrum analysis. [2] Having a variable sample rate and a fixed frequency low pass filter can be a problem. However, the Ono Sokki CF-880 solves this problem by using a lowpass filter, the cut-off frequency of which tracks to the RPM.

The maximum order frequency (f_x) is a function of the maximum order (X)

and the RPM of the motor i.e.:-

$$f_x = X\ RPM_{MAX}\ /60\ \text{Hz}$$

for example if the maximum order of interest is 25th and the maximum RPM of the motor is 2000

$$f_x = 25 \times 2000/60\ \text{Hz} = 833.3\ \text{Hz}$$

The sampling rate of the analysers (f_s) is a function of the pulse rate

(P) and the maximum RPM of the motor i.e.

$f_s = n \times RPM_{MAX}/60$

In our example the pulse rate is 64 pulses per revolution then the sampling frequency is

$f_s = 64 \times 2000/60$

$= 2133.3$ Hz

therefore $f_s = f_x \times 2.56$ and aliasing will not occur

If the maximum RPM increases the sample rate (which tracks the RPM) also increases and the problem of the aliasing is always completely eliminated in the Ono Sokki CF-880 analyser.

THE RPM TRACKING ANALYSIS CONCEPT

When a rotating machine goes into resonance and exhibits abnormal vibrations, it is posisble to detect the existence of this condition by observing the time-axis signal (raw data) alone. However this observation does not give information concerning which components with respect to RPM represent resonances or what order (multiple) of RPM corresponds to a resonance.

In Figure 8 the RPM-spectrum plot (3 dimensional display) gives a direct view of the order (frequency) spectrum changes with respect to RPM changes. This enables determination of which multiple (order) of RPM is a resonance on the 2 dimensional graph.

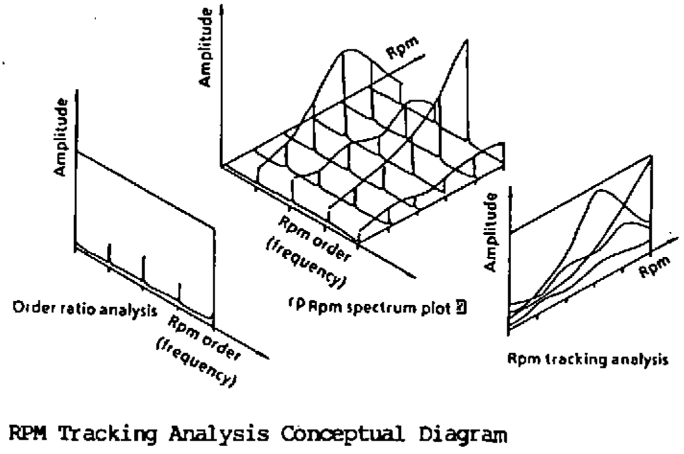


Figure 8 RPM Tracking Analysis Conceptual Diagram

AN APPLICATION OF RPM ORDER RATION ANALYSIS TO DISTINGUISH NOISE SOURCES

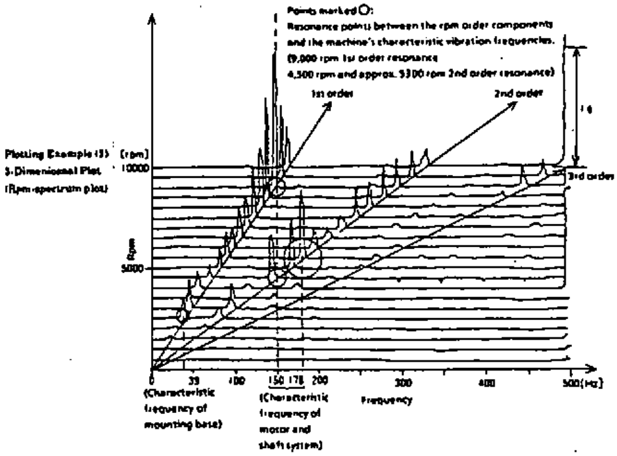


Figure 9   3 Dimensional Plot (RPM - Spectrum Amplitude)

Figure 9 shows a dynamic three-dimensional plot (vibration level - RPM - spectrum plot) and the example in Figure 10 shows the first four orders plus the overall value. It is clear that the resonances occur at 8900 RPM for the first order.

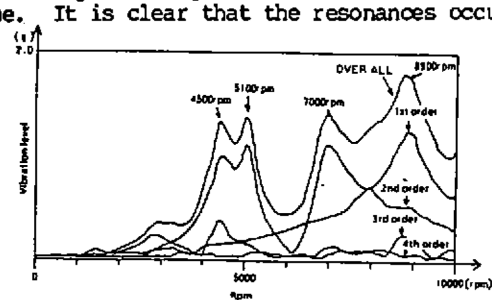


Figure 10 RPM - Tracking Analysis Results

REFERENCES

[1] Vibration and Acoustic Measurement Handbook, Blake & Mitchell, 1972
[2] Measurement and Analysis of Random Data, Bendat + Piersol, 1968

ACKNOWLEDGEMENTS

The Author would like to thank the Ono Sokki Company Ltd, Tokyo, Japan for permission to use examples and diagrams from the CF-880 Eight Channel Tracking Analyzer Handbook.

KS/CJS 1187
msp/rpm-ks