ACQUISITION OF VIBRATION SIGNALS THROUGH PIEZOELECTRIC ACCELEROMETERS

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1. Abstract

In the following section we have concentrated on the vibration measurements of a crankshaft by means of a piezoelectric accelerometer in order to determine the rotation speed of the shaft.

2. Description of the instruments

The piezoelectric accelerometer bases its operation on the piezoelectric effect present, for example, in crystalline materials without charge symmetry center.

The structure of such crystals consists of microscopic electric dipoles. In quiet conditions, these electric dipoles are arranged in such a way that the faces of the crystal all have the same electrical potential. When a force is applied from the outside, compressing the crystal, the crystal structure is deformed and the condition of electrical neutrality of the material is lost.

A PCB 356A17 triaxial piezoelectric accelerometer was used for the laboratory test as follows:

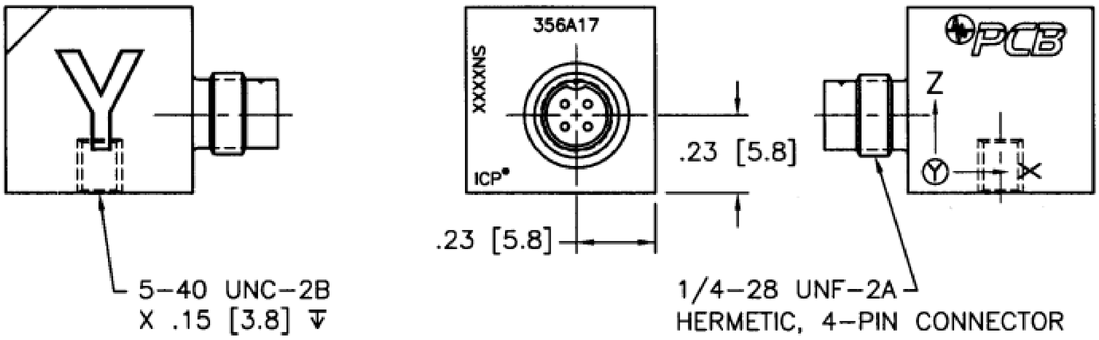


Figure 1 - Product drawing from www.pcb.com

Whose dynamic characteristics are described by module and phase graphs:

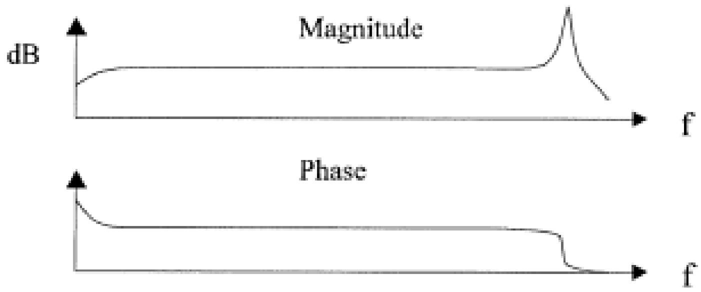


Figure 2 - Installation Response Accelerometr Test and Operating Manual on www.pcb.com

In the present case, having to use only one axis of this accelerometer the Calibration Data Card attached by the manufacturer shows:

MODEL	356A17
SERIAL	30083 (y axis)
SENSITIVITY [mV/g]	523
SENSITIVITY [mV/m/s^2]	53.3
BIAS LEVEL	11.6
RANGE [Hz]	0.5-3000

Table 1 - Calibration Data Card

To choose the **sampling frequency** there is a need to look at the signal at the oscilloscope, at least to get an idea of the dynamics of the latter. To do this, a TDS3032B was used as a digital benchtop and two-channel oscilloscope:

Figura 1 - TDS3032B da www-mouser.it

To acquire the signal it was necessary to use an acquisition card with sufficient number of bits (encoded levels) to provide a coherent representation of the signal of our interest. In our case a 16bit Student Data Acquisition Device:

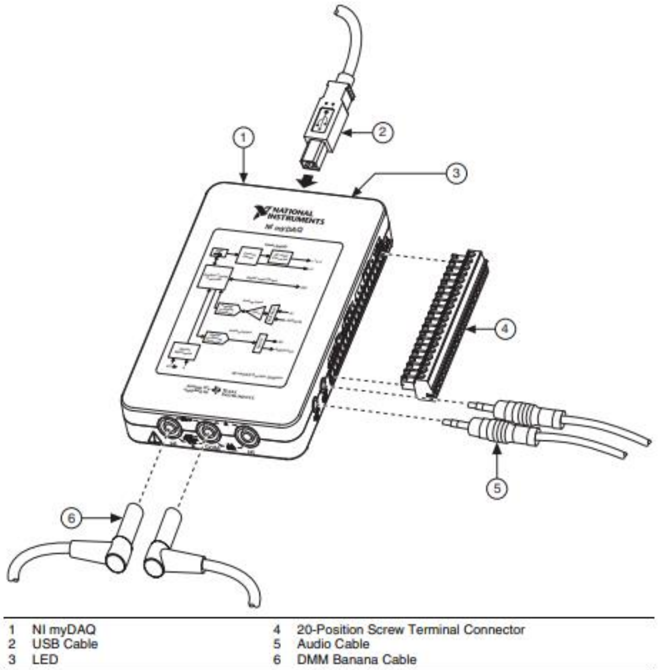


Figura 2 - NI myDAQ Connection Diagram da www.ni.com

3. References to Theory

The acquisition board is a device designed to transform the signals coming from the transducers, which are analog or time-continuous with continuous amplitude, into digital signals or discrete in time and amplitudes. Thus, such boards perform substantially two tasks:

- Discretization in amplitudes;
- Discretization in time.

As for the discretization in amplitudes, it is obvious that it is not possible to represent the signal by adopting the infinite resolution of the analog signal, but we will have to be satisfied with a certain resolution and accept a certain approximation. Defined as ΔV the range of values to be converted and with b the number of bits of the acquisition card, the resolution of the converter (often equal to the smallest appreciable voltage variation) is given by the formula:

$$ris = \frac{\Delta V}{2^b}$$

Figure 5 shows how reducing the resolution value results in a more representative discretization of the original signal.

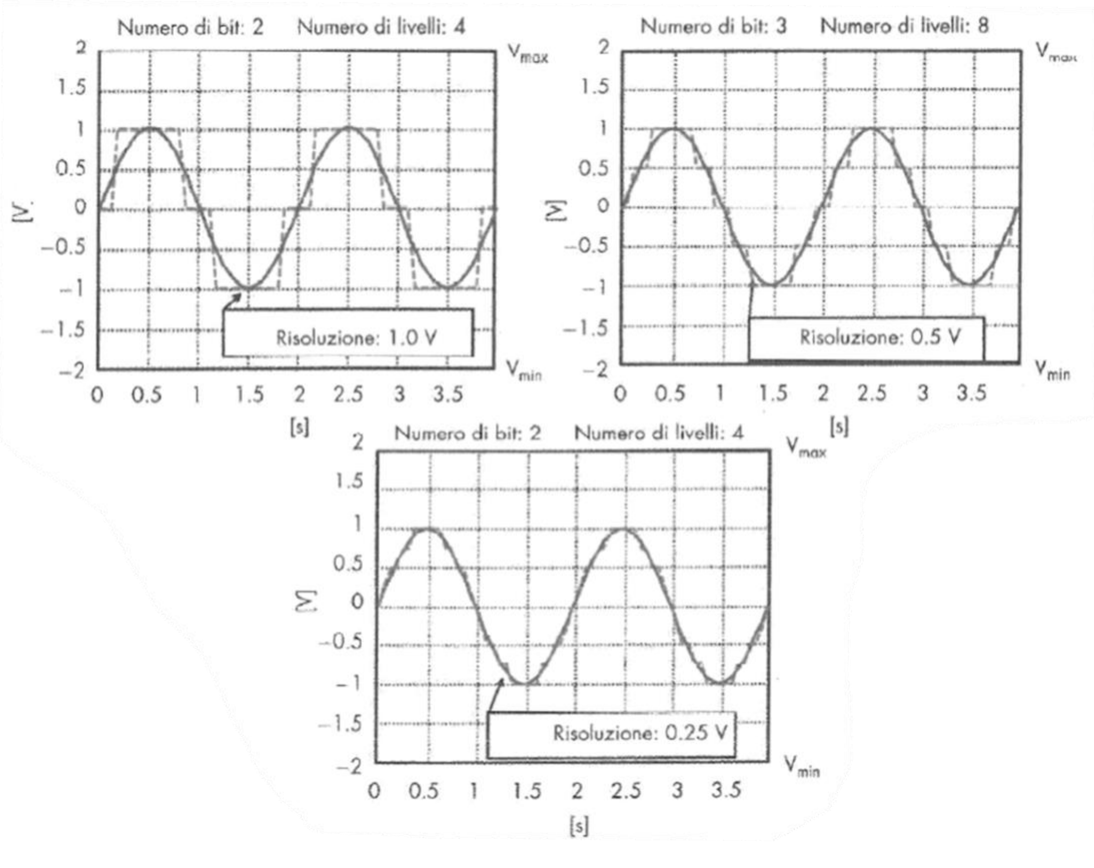


Figure 5 - Effect of resolution in sampling by E. O. Doebelin - Measuring instruments and methods

The discretization in time allows us to know the signal but only at certain moments of time well defined by the sampling frequency "f_C" that expresses the number of conversions made by the converter every second. Choose the right f_C is essential to perform a correct sampling and thus avoid irreversible errors in data acquisition.

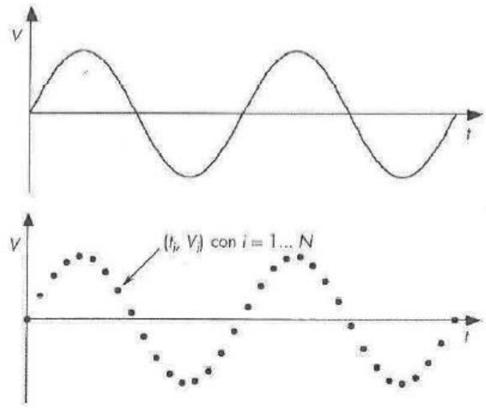


Figure 6 - Effect of discretization over time by E. O. Doebelin - Measuring instruments and methods

From figure 6 it can be observed that the sampling frequency adopted is adequate to preserve all the important information related to the analog signal, namely frequency, amplitude and position on the time axis of the harmonic signal. It is equally true, however, that it would probably have been possible to obtain an equally representative f_C lower, thus saving memory and facilitating data processing. Therefore, where possible, provided that a representative digital signal is obtained, it is always preferable to adopt a lower sampling frequency. However, the thinning of samples has a limit, in fact if you reduce too much the number of samples acquired per second would incur in the phenomenon of aliasing that attributes to the signal a lower frequency inventing harmonic components non-existent in the starting signal and irreversibly corrupting the signal.

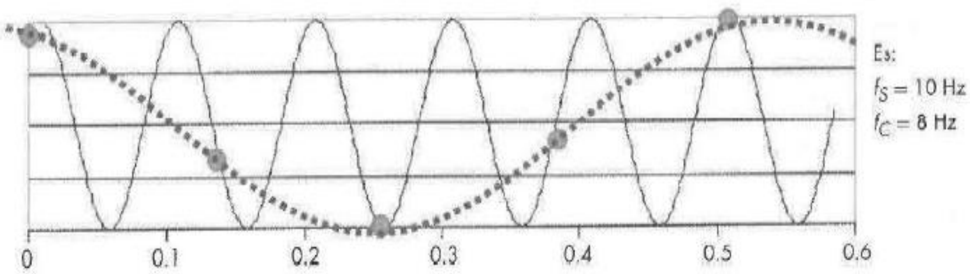


Figure 7 - Aliasing in the time domain by E. O. Doebelin - Measuring instruments and methods

In figure 7 it is shown as the choice of an inadequate sampling frequency is able to distort the original signal.

Since the information contained in the signal must be the same regardless of whether it is represented in the time or frequency domain, the phenomenon of aliasing can also be observed in the frequencies in Figure 8.

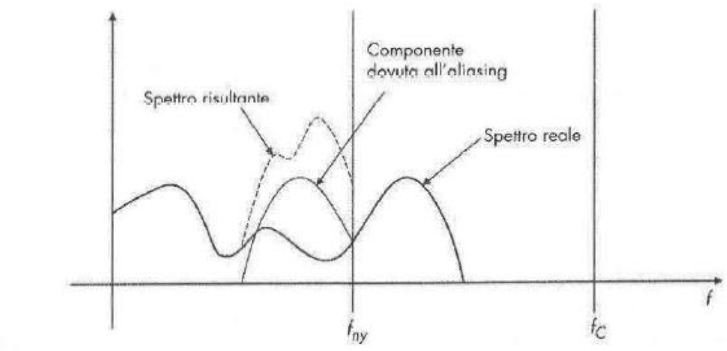


Figura 3 – Aliasing nel dominio delle frequenze da E. O. Doebelin - Strumenti e metodi di misura

It is possible to demonstrate that, in order to perform a correct sampling of the signal, the Nyquist-theorem must be respectedShannon who states that to obtain a representative signal, a sampling frequency must be adopted that is at least twice the maximum frequency of the signal;

$$f_C > 2f_{S,max}$$

→ This condition must necessarily be met if aliasing is to be avoided.

Another problem often encountered in sampling is leakage, a dispersion of signal energy, which redistributes along the frequency axis. It can be shown that two additional conditions must be met to avoid this problem, namely:

$$\begin{cases} T = nT_C \\ T_{oss} = mT \end{cases}$$
$$(\,n, m \ integer\ numbers)$$

→ This condition must necessarily be met if leakage is to be avoided.

The first condition requires the signal period to be a multiple of the sampling period (equal to $1/f_C$) while the second that the observation time of the signal is a multiple of the period of the same.

4. Testing

4.1 Study of the physical phenomenon

In the purely ideal case we would measure a single frequency harmonic (in the time domain) (in the frequency domain) dictated by the rotation speed of the shaft.

In the real case a very large sensor in terms of mass would affect the amplitude measurements of vibration and will have the overlap of several frequencies due to the following causes:

- eccentricity of the rotor;
- wear on bearings;
- curvature of the drive shaft;
- background noise.

4.2 Selection of the measurement parameters

To limit the influence of the sensor mass on the amplitude of oscillation of the fundamental, a piezoelectric accelerometer of reduced mass was chosen.

A sampling frequency of 3000Hz was chosen as the cutting frequency of the instrument.

4.3 Experimental setup construction and data acquisition

For the purpose of the experience the accelerometer is connected to the engine, more precisely on the housing in the position as close as possible to the fixed bearing rack, to have the best vibration reading.

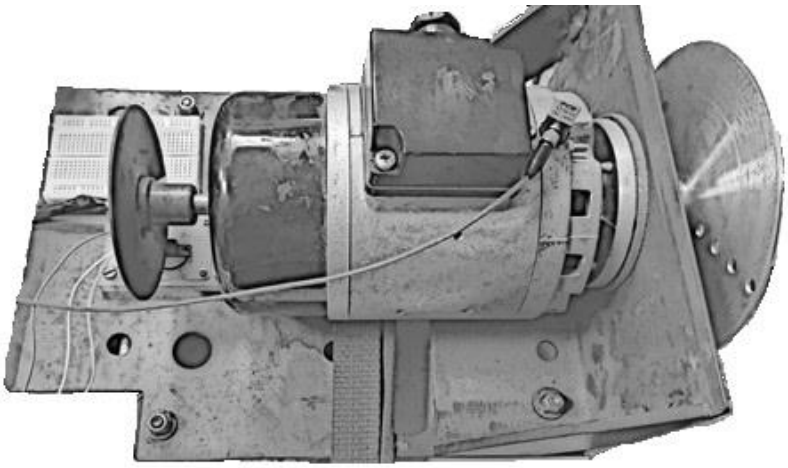
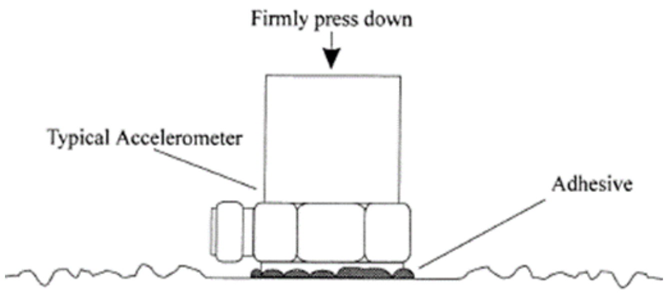


Figure 9 - Electric motor

The tested configuration was that of an electric motor that guarantees a rotation speed of 3000 RPM.

The connection of the sensor to the engine casing will be by adhesive mounting, as recommended by the manufacturer, as shown below:



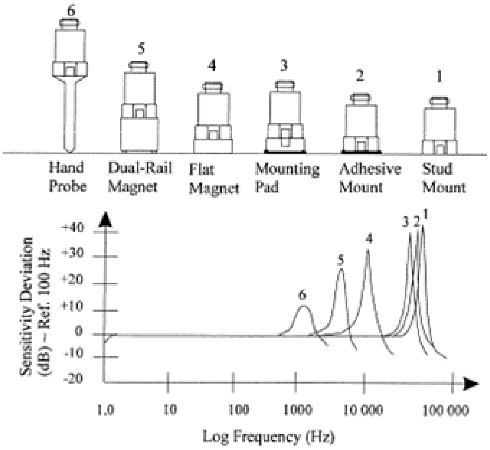


Figure 10 - Installation adhesive and Operating Manual on www.pcb.com

The measuring chain, for the acquisition of the signal, was completed by connecting the accelerometer to the pins of the acquisition card via cable + and cable - to port no 4 indicated in Figure 4.

4.4 Data processing

It reports the implementation of the script used to read the results obtained from the acquisition.

```
%time domain

load('X.mat');
load('t.mat');

X1=X.*(1/0.0533); %from volt to m/s^2 through sensitivity

figure(1)
plot(t,X1,'b')
title('Signal in time domain')
xlabel('t [seconds]')
ylabel('X(t)    [m/s^2]')
legend('signal','signal offset','mean max amplitude', 'mean min amplitude')

%frequency domain

Fs=3000.03;
L = length(X1);

Y = fft(X1);
P2 = abs(Y/L);
P1 = P2(1:L/2+1);
P1(2:end-1) = 2*P1(2:end-1);
f = Fs*(0:(L/2))/L;

figure(2)
plot(f,P1)
title('Single-Sided Amplitude Spectrum of X(t)')
xlabel('f [Hz]')
ylabel('|P1(f)|    [m/s^2]')
```

The code is constructed in order to load the inputs in automatic, to execute the fft of the signal and to return the signal in the domain of the time and the frequencies.

5. Results

Adopting the script shown in the previous paragraph you get two graphs:

- the first represents the time domain signal:

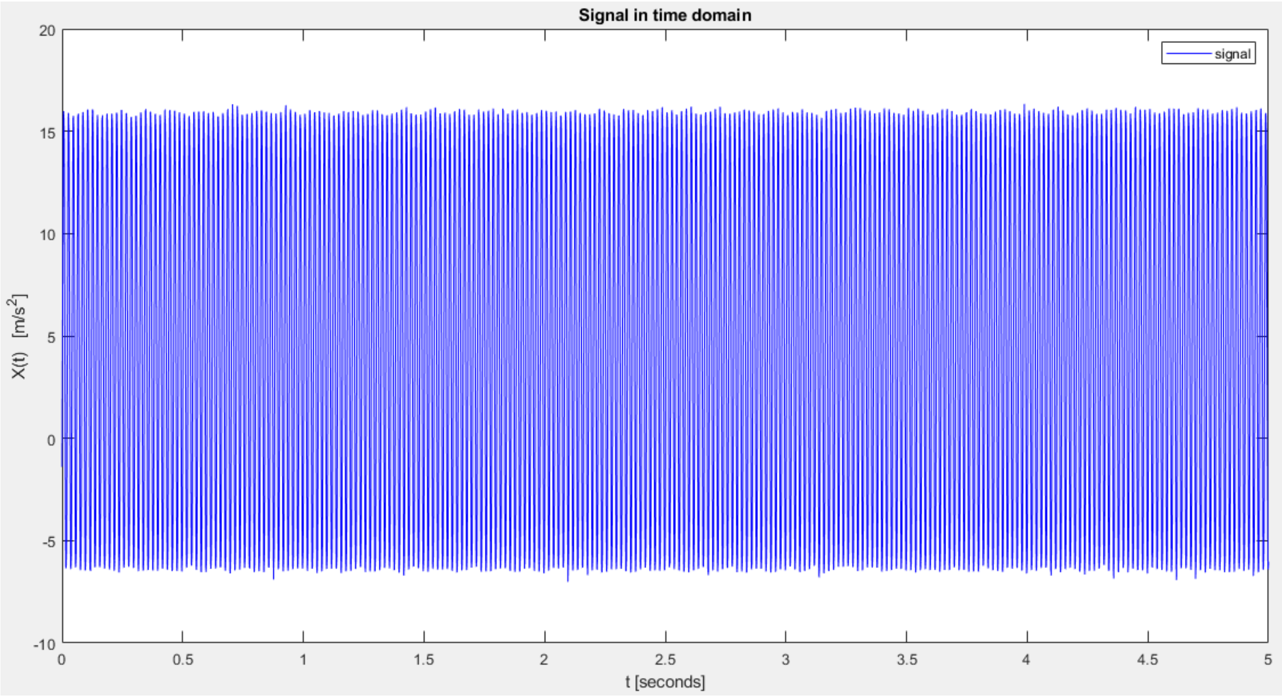


Figure 11 - Time domain signal from MATLAB software

- the second represents the signal in the frequency domain:

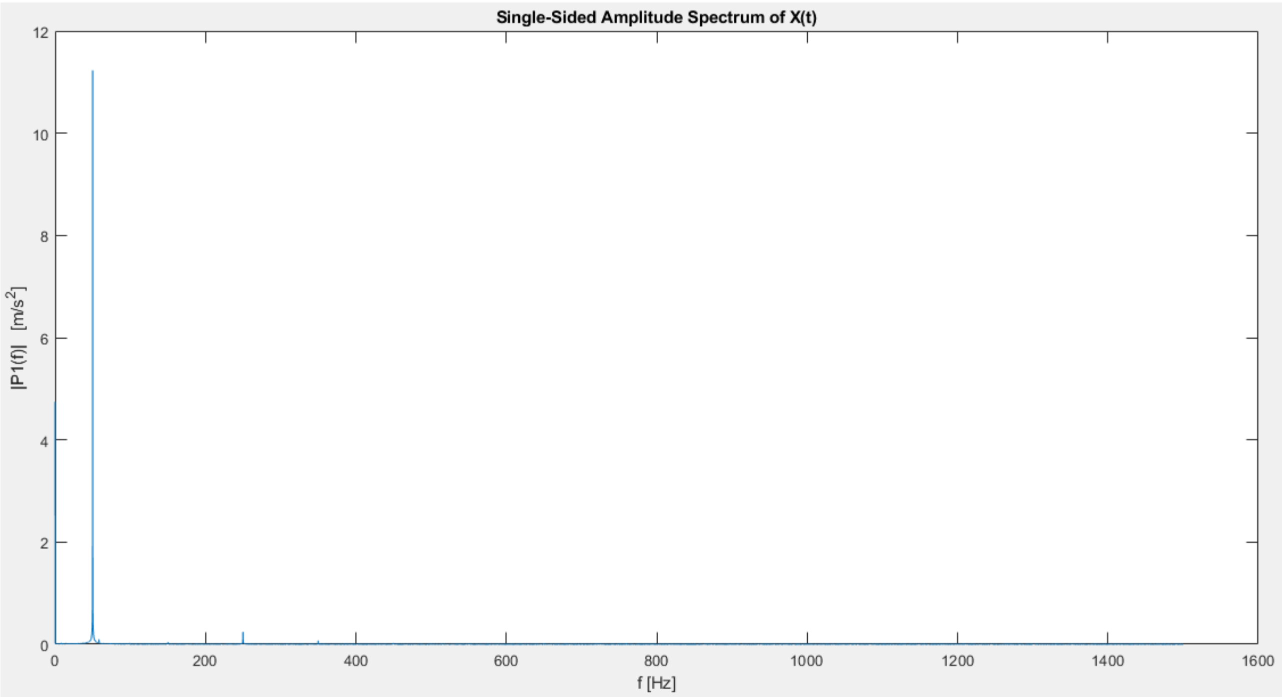


Figure 12 - Frequency domain signal from MATLAB software

Adopting the Signal Analyzer provided by the MATLAB software:

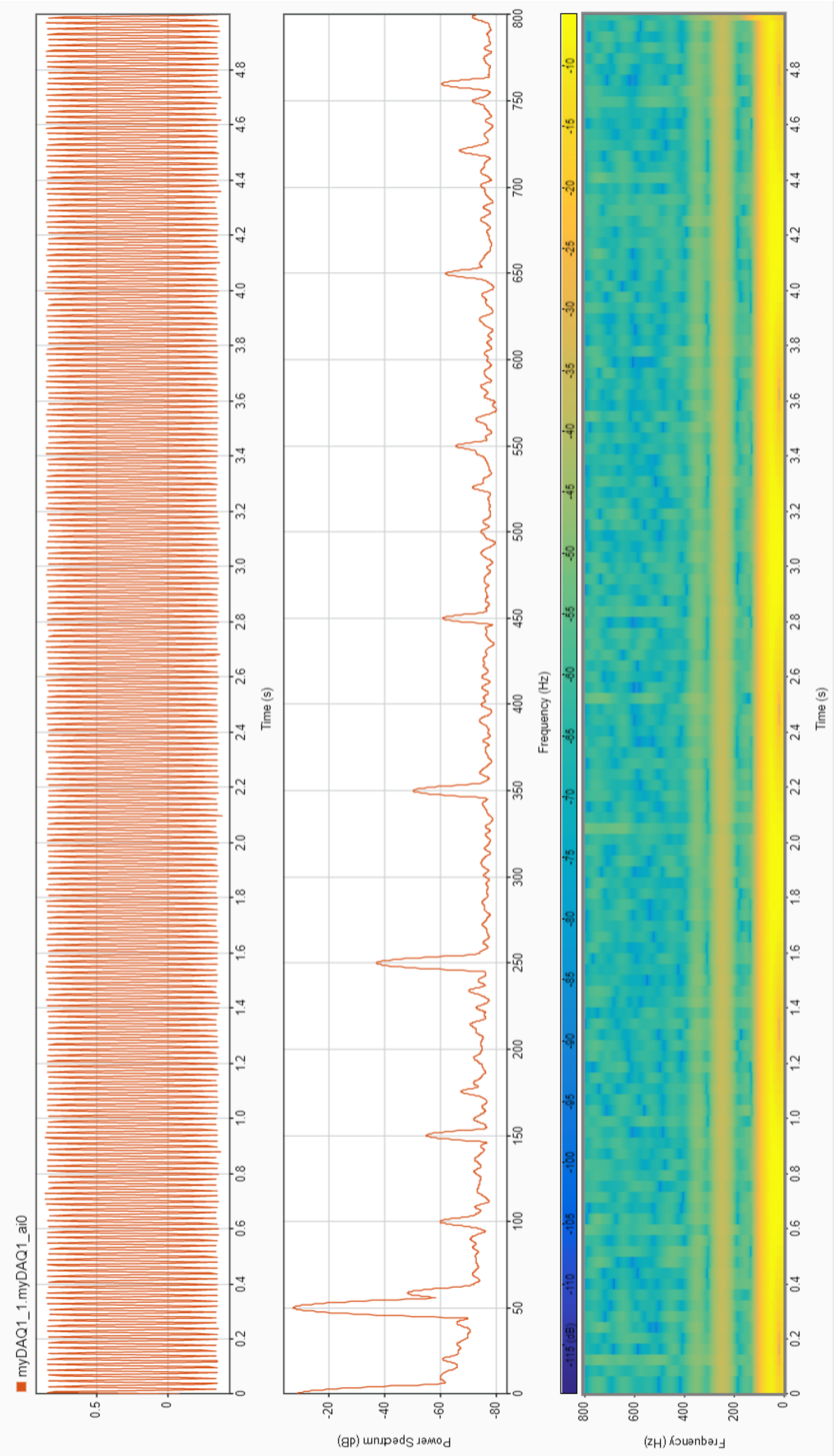


Figure 13 - Signal analyzer from MATLAB software

6. Conclusions

In the frequency domain you can identify the frequency of the fundamental at 50 Hz, which confirms the value of the rotation speed of the shaft, in fact:

$$f = \frac{rpm}{60} = \frac{3000}{60} = 50\ Hz$$

In the following figure you can see other peaks besides that of the fundamental:

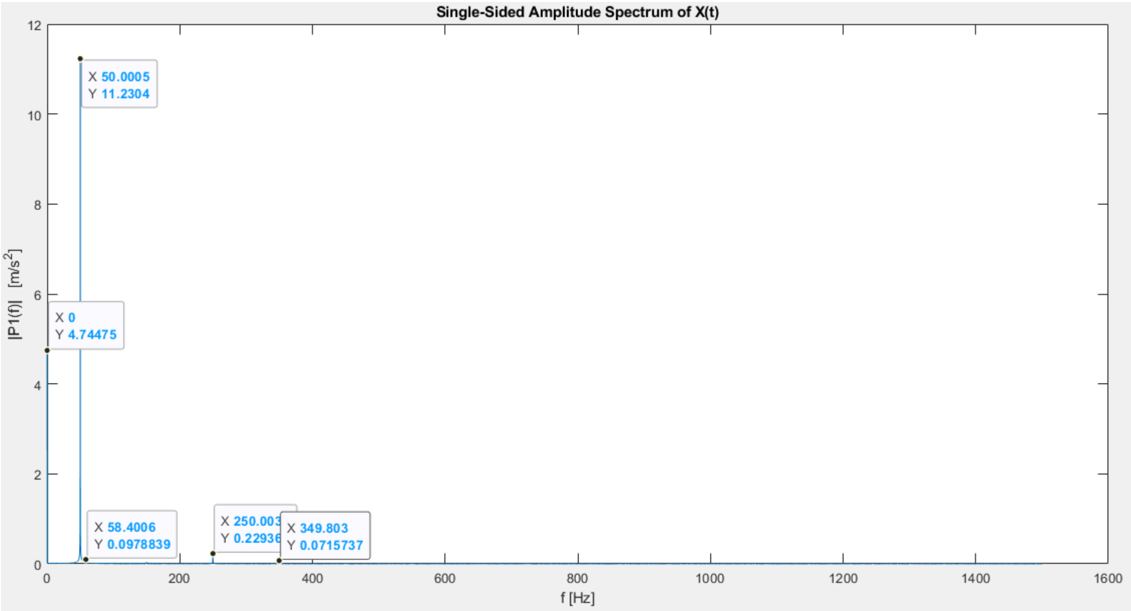


Figure 14 - Frequency domain peaks

Such peaks justify a non-perfectly sinusoidal signal pattern in the time domain as shown below:

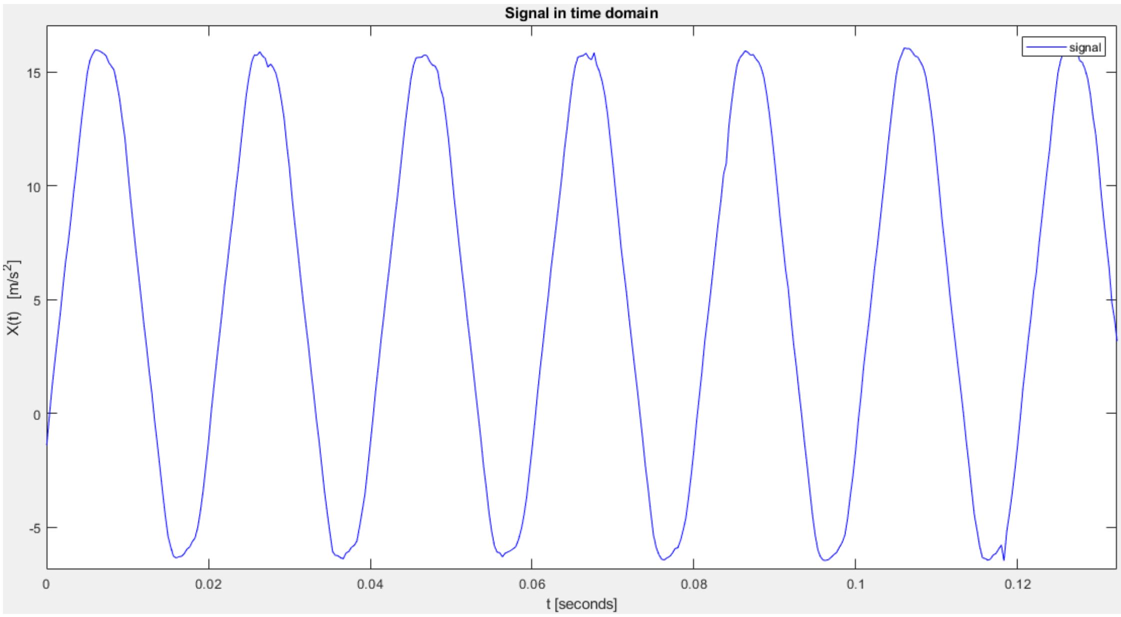


Figure 15 - Signal not perfectly sinusoidal in the time domain

One could say, from the data acquired, that the motor works correctly unless small signs of wear are discriminatable in the domain of the frequencies from peaks to multiple frequencies of the fundamental of reduced amplitude.

Having respected the sampling theorem thus excluding leakage and aliasing errors, the peak at 60hz is attributable to background noise.

Even if not for the purposes of the previous treatment, an offset in the sampled signal is deduced as a probable systematic error attributable to the instrument or the measurement setup.