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ENERGY CONSUMPTION AND MACHINERY VIBRATIONS

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Abstract

The main objective of this paper is to establish a methodology to obtain relationships between machinery vibration levels and their power consumption, for different machine faults.

A survey of literature for this subject has shown that, in spite of the growing concerns about the effect of vibration levels on the power consumption, yet very little research has been done in this area.

The paper treats this subject in a very broad manner, taking into consideration not only the effect of vibration *levels* on the power consumption, but also the effect of the *frequencies* at which these levels occur. A good application for this phenomenon was taken as the machinery condition monitoring and fault diagnosis through vibration measurements and analyses.

Mobility measurements and Frequency Response Functions (FRF's) for the machines using impact testing were taken into consideration for the calculation of lost energy due to vibration. These were compared to actually measured energy losses. From this comparison a rationale methodology for predicting energy losses for vibrating machinery is suggested.

KEYWORDS: Maintenance, Power Consumption, Energy Losses, Condition Monitoring, Fault Frequencies, Vibration Level and Frequency, Impact Testing, Frequency Response Function (FRF), Operational Modal Analysis, Mobility.

1. INTRODUCTION

Machinery vibrations represent wasted energy and the higher the machine vibrates, the greater the energy wasted. That energy is being translated into movement which can ultimately cause damage to machine parts.

Machinery monitoring provides valuable data about the performance and condition of that machinery; data that can be used to optimise the operation and availability of plant, cost-efficiency of maintenance work, and can also be used in the evaluation of energy lost in the un-prevented damage.

The axiom of machinery condition monitoring is to prevent the occurrence of high machinery vibrations by the early prevention of their causes, hence keeping the machine always healthy, and saving the unnecessary power consumption.

Information-based predictive maintenance, using advanced vibration analysis and advanced sensor technology, together with model-based prognostic maintenance policies is expected to significantly reduce costs [1]. The electric power industry predicts a patented 50% reduction in maintenance costs due to prognostic maintenance (EPRI 1992 Annual Reports) [2]. One of the common problems, misalignment, is not only destructive to the bearings in the equipment, but also expensive in terms of electrical cost for motor driving units [3].

It is not unusual to find 3 to 4 Amperes difference in the power required for a unit that is out of alignment vs. a properly aligned unit. One example [4] showed that over one year period for 100 HP motor, 2 Amperes costs the user $690 per year.

In a large refinery for example, with hundreds of pumps and motors, the wasted power cost alone will run into thousands of dollars.

The main objective of this research is to establish a relationship between the Machinery Vibration level and its Power Consumption.

Survey of literature for this subject [5-8] have shown that in spite of the growing concerns about the effect of vibration levels on the power consumption, yet very little research have been made in the area.

2. THEORETICAL APPROACH

Vibration is considered the result of the product of Forces acting on the components of the machine and Machine Mobility (the inverse of mechanical impedance).

Vibration Velocity = Forces/Mechanical Impedance
= Forces x Mobility, (functions of frequency)

i.e.

$$V(\omega) = F(\omega) \times H(\omega) \tag{1}$$

Where:

$V(\omega)$	=	Vibration velocity (rms) at a frequency ω,
$F(\omega)$	=	Forcing function,
$H(\omega)$	=	Mobility function (Frequency Response Function, FRF) at frequency ω

Since Power (Energy per unit time) can be expressed as:

Power = Force x Velocity

i.e.

$$\text{Power} = F(\omega) \times V(\omega) \tag{2}$$

Then from 1 and 2, Power lost due to vibrations at any frequency ω;

$$\text{Power} = V(\omega)^2 \; / \; H(\omega) \tag{3}$$

Equation (3) represents the Energy (per unit time) consumed in vibration of velocity level V for a component of mobility H, at a frequency ω.

This requires measuring both, the Mobility of the Machine as function of the frequency (FRF), and the vibration Spectrum of the machine at any deteriorated condition.

The mobility can be expressed as the transfer function (H) measured in units of vibration velocity per unit force ((m/s)/N) and can be easily estimated from the Frequency Response Function (FRF) of the system under consideration.

FRF's can be obtained using impulse hammer tests for any given machine at any given point. FRF spectra represent the values of Machine Mobility at any given Frequency as shown in figure1 below.

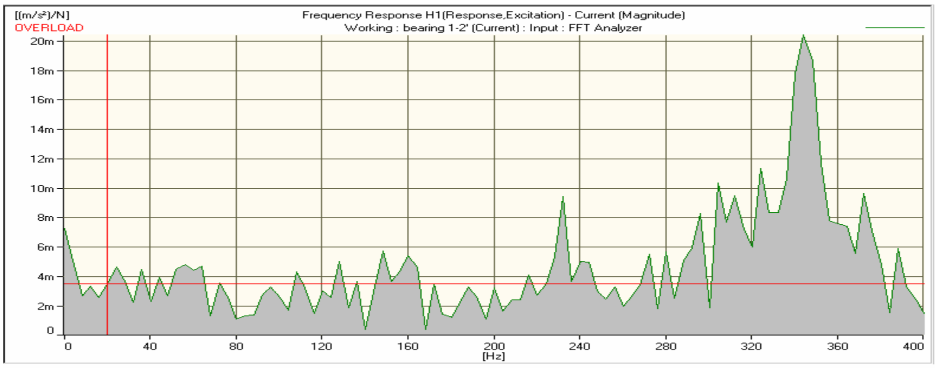


Figure 1. Example of frequency response functions.

When performing Condition Monitoring tasks, at any given time for any given machine, fault frequencies can be easily located on the vibration spectra, as shown in the figure 2 below.

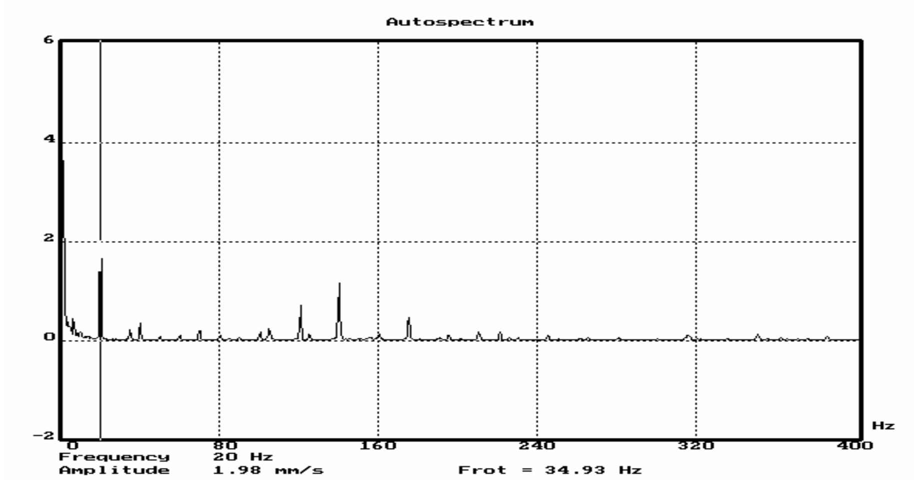


Figure 2. Example of fault vibration spectrum.

For each fault (at a given fault frequency ω), the value of power needed to (support) this fault can be calculated using the values of vibration velocity (V) from the vibration spectrum and mobility (H), from the FRF at the fault Frequency (see figure 3), and substituting in equation (3) above to get the power consumed at this frequency.

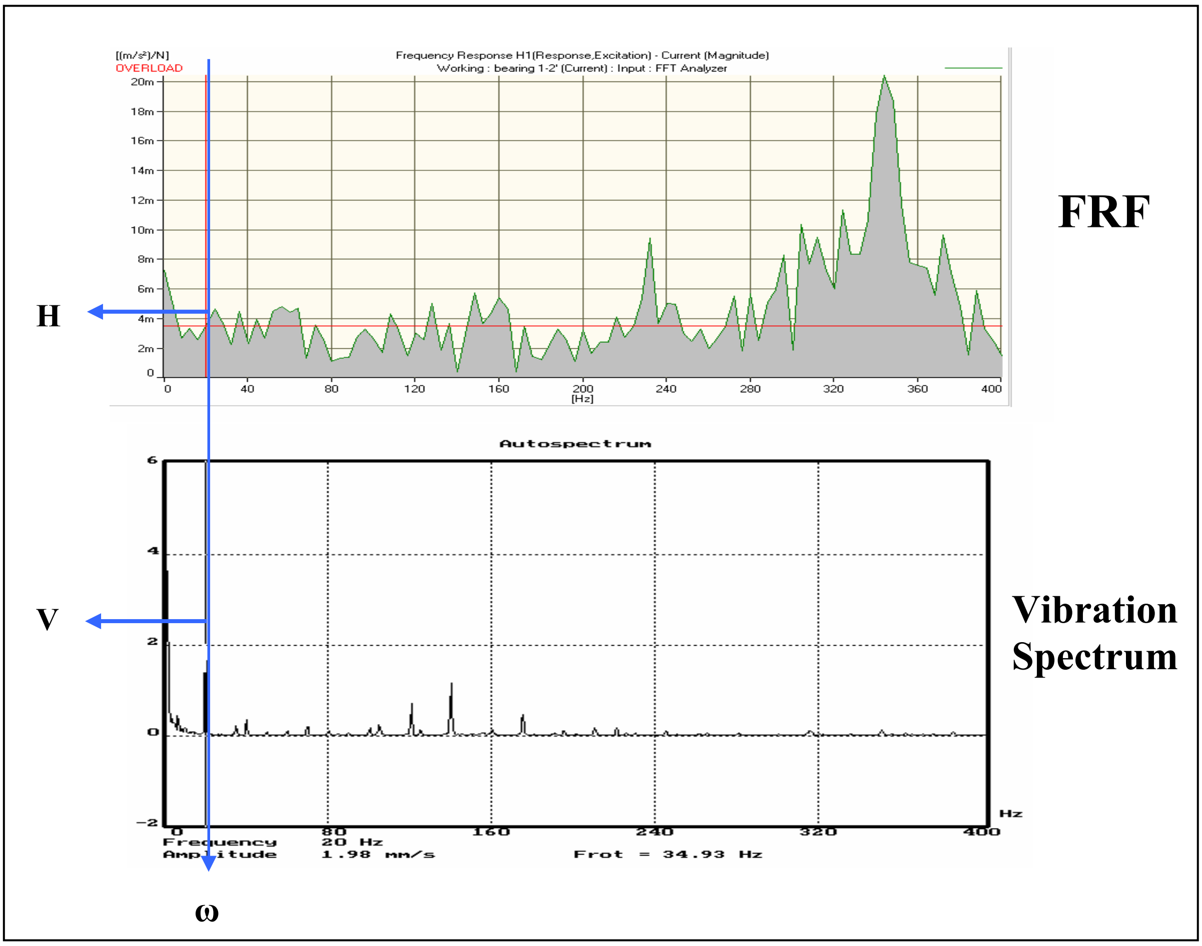


Figure 3. FRF and vibration signal at frequency ω.

For a machine with (n) bearings, and (k) faults (fault frequencies) extracted by vibration condition monitoring at each bearing, the total power consumption will be:

$$TotalPower = \sum_{i=1} \sum_{m=1} V^2 im / Him \quad [Watts] \tag{4}$$

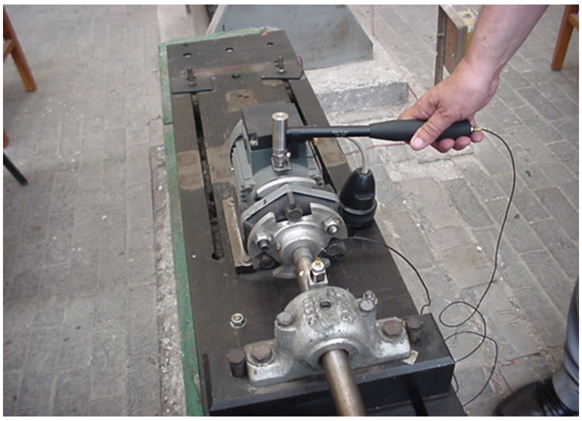
Where i = n and m = k

We can also add the direction of vibration for each measured bearing, i.e. Vertical, Axial and Horizontal.

3. EXPERIMENTAL VERIFICATION

To verify the validity of the above mentioned theory, experiments were conducted on a specially designed test rig (Figure. 4) that contains rotating shaft driven by motor which its power consumption can be readily measured through measuring both the current consumed as well as the voltage value at the instant of measurement. The test rig is equipped with bearings, coupling, and rotating discs to facilitate inducing known faults (Unbalance, Misalignment, Bearing errors, …etc) and for each induced fault (or a combination of faults), the consumed power can be measured, as well as the resulting vibrations (complete vibration spectra), on the bearings in different directions through vibration sensors mounted on each bearing.

(a) Condition Monitoring



(b) Modal Testing (for FRF)

Figure 4. The test rig.

Before inducing any faults in the test rig components, a complete condition monitoring set-up was carried out using vibration monitoring and fault diagnosing on each bearing and at each direction, for the set running speed, so as to match the power consumed at this stage with the corresponding (no load, no fault) condition.

An impact hammer test was carried out on the test rig structure while running for the cases with no load and with different fault conditions. From this test, the frequency response functions (FRF's) for the structure at each condition was available.

Comparing the power consumption which was directly measured from the motor drive, with that derived from applying the above mentioned theory gave results with errors not exceeding 7%, which is within acceptable experimental errors. The details of measurements and results will be published in an upcoming paper, due to limitations of space.

4. CONCLUSIONS

From the results of extensive experimental work on the designed test rig, the following conclusions can be drawn:

1. There is strong correlation between *Vibration Levels* measured on machine bearings, and the *Power Consumption* of these machines.
2. The expression derived for the *Power Consumption* due to vibration, if correctly applied for different bearings and different fault frequencies (at different directions), can be used to calculate the excessive power consumption due to vibrations resulting from machine faults.

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