ISSN 1726-5479

SENSORS & TRANSDUCERS

12/08 vol. 99

Sensor Market Trends

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers Journal

Contents

Volume 99
Issue 12
December 2008

www.sensorsportal.com

ISSN 1726-5479

Research Articles

International Frequency Sensor Association (IFSA).

Sensors & Transducers

Volume 99
December 2008

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).

Sensors & Transducers Journal, Vol. 99, Issue 12, December 2008, pp. 43-52

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Fault Diagnosis and Condition Monitoring of an All Geared Lathe Machine Using Piezoelectric Sensor

Amiya BHAUMIK, Nabin SARDAR, Nirmal Kumar MANDAL
National Institute of Technical Teacher's Training & Research, Block-FC, Sector-III,
Saltlake City, Kolkata-700106
E-mail: amiya67@rediffmail.com, Nabin.sardar@rediffmail.com, mandal_nirmal@yahoo.com

Received: 8 September 2008 /Accepted: 22 December 2008 /Published: 30 December 2008

Abstract: Undesired vibrations are serious problems that affect and deteriorate the quality of the product. This paper investigates dynamic and vibrational characteristics of a newly installed All Geared Lathe Machine with piezoelectric sensor. A comparison is drawn with the data measured and acceptable data as per ISO 10816 and thus concluded that the machine is in working condition. *Copyright © 2008 IFSA.*

Keywords: Decibel, Piezoelectric sensor, Pico scope analyzer (Analog to digital), P.C, Panther lathe machine

---

1. Introduction

The increasing demands of higher productivity and economical design lead to higher operating speeds of machinery and efficient use of materials through lightweight structures. These trends make the occurrence of resonant conditions more frequent during the operation of machinery and reduce the reliability of the system. Hence the periodic measurement of vibration characteristics of machinery and structures becomes essential to ensure adequate safety margins. Any observed shift in natural frequencies or other vibration characteristics will indicate either a failure or a need of maintenance of the machine.

Most machines produce low levels of vibration when designed properly. During operation, all machines are subjected to fatigue, wear, deformation, and foundation settlement. These effects cause an increase in the clearances between mating parts, misalignments in shafts, initiation of cracks in parts and unbalances in rotors - all leading to and increase in the level of vibration, which causes additional dynamic loads on bearings. As time progresses, the vibration levels continue to increase, leading ultimately to the failure or breakdown of the machine. The common types of faults or operating conditions that lead to increased levels of vibration in machines include bent shafts, eccentric shafts, misaligned components, unbalanced components, faulty gears, impellers with faulty blades, and loose mechanical parts.

Undesired vibrations are a serious problem that affects and deteriorates the surface finish of the work piece. It also affects the dimensional accuracy of the work piece, and reduces tool/machine lifetime. For controlling and elimination of vibration, the source of vibration must be searched out. Vibrations can be initiated in machine tools by non homogeneities in the work piece material, built up edge of cutting tools, component defects, unbalanced parts and the poor assembly. Other problems in machining are plastic deformation and friction in the contact between the cutting tool and the work piece. If the vibrations are controlled, higher cutting data can be used and the time varying loads on the cutting tool are decreased. The result is longer tool/machine lifetime.

Reducing the noise and the undesired vibrations is clearly a very important goal. This can be achieved by using actuators, which automatically modifies the structural response of a mechanical system. The actuator is used to enhance the performance of a structural system by inducing a favorable structural deformation according to the applied voltage. It develops canceling force to reduce the vibration level and acoustic noise level. There are several types of actuators that could be used to solve vibration problems in mechanical systems, for example magnetostrictive and piezoelectric actuators.

2. Literature Review

Benbouzid [1] reviewed the advanced data processing techniques that have been used in induction motor monitoring. Time-domain analysis using characteristic values to determine changes by trend setting, spectrum analysis to determine the trends of frequencies, amplitudes and phase relations, as well as spectrum analysis to detect periodical components of spectra, are used as evaluation tools.

Nandi et al. [2] have a broad classification of the major faults in electrical machines: stator faults resulting in the opening or shorting of one or more stator coils or phase windings, abnormal connection of the stator winding, broken rotor bars or cracked end rings, static and/or dynamic air-gap eccentricities, bent shaft, shorted rotor field winding, bearing and gearbox failures.

Eren & Devaney [3] applied this technique successfully to detect bearing faults, which are one of the major causes of induction motor failures and, at the same time, one of the most difficult problems to figure out from the motor current spectrum. The proposed method in Eren & Devaney [3] enables the analysis of frequency bands that can accommodate the rotational speed dependence of the bearing defect frequencies.

Text books [4] [5] [6] describe the basic principles and theoretical background of vibration analysis. ISO standard [8], [9] gives the acceptable limits of various vibrational parameters.

3. Forced Vibration in Multiple Degree of Freedom (MDOF) Systems

Fig. 1 illustrates an undamped system with n translation degrees of freedom.

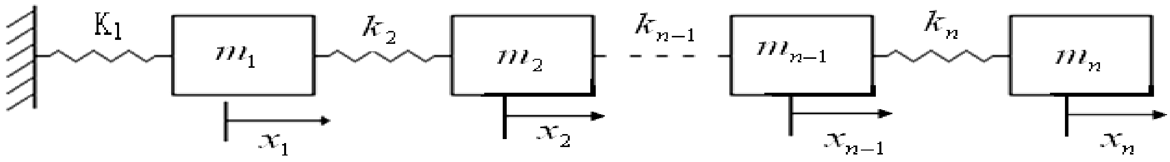


Fig. 1. Undamped MDOF-system.

The forces from the springs acting on each mass are determined through a free body diagram, see Fig. 2.

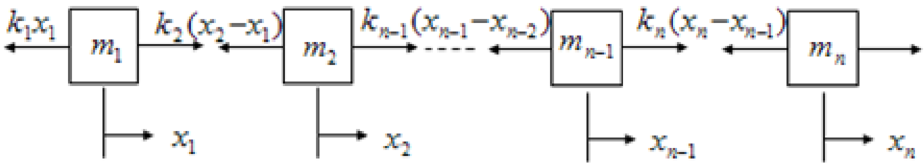


Fig. 2. Free body diagram for the undamped MDOF system.

Using Newton's second law equations of motion for each mass can be written as

$$
\begin{aligned}
& m_1\ddot{x}_1 + x_1(k_1 + k_2) - x_2k_2 = 0 \\
& m_2\ddot{x}_2 + x_2(k_2 + k_3) - k_2x_1 - k_3x_3 = 0 \\
& m_2\ddot{x}_2 + x_2(k_2 + k_3) - k_2x_1 - k_3x_3 = 0 \\
& . \\
& . \\
& m_{n-1}\ddot{x}_{n-1} + x_{n-1}(k_{n-1} + k_n) - k_nx_n - k_{n-1}x_{x-1} = 0 \\
& m_n\ddot{x}_n - k_nx_{n-1} + k_nx_n = 0
\end{aligned}
\quad (1)
$$

Equation (1) consists of n coupled second order differential equation and can be written in matrix form as

$$M\ddot{X} + KX = 0, \quad (2)$$

where M is the mass matrix and K is the stiffness matrix, and x is the displacement vector. Dots indicate time derivatives.

Fig. 3 shows a turning operation which is a simplest form of machining processes used to generate external, cylindrical surfaces by removing material by a cutting tool. The primary motion is rotation. This is a two DOF system. The feed motion is normally a rectilinear movement, when machining, the work piece is perpendicular to the cutting tool.

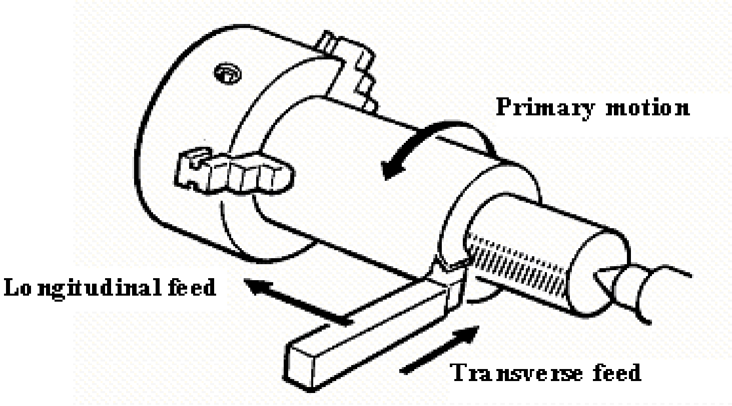


Fig. 3. A two degree of freedom system.

4. Elementary Components of a Vibrating System

Exciter: An exciter or source of vibration to apply a known input force to the structure or machine (Fig. 4). The force is generated by an alternating current that drives a magnetic coil. The maximum frequency limit varies from approximately 5 kHz to 20 kHz depending on the size of the shaker. The size of the exciter varies with force rating. For example, the smaller the exciter, the lower the force rating.

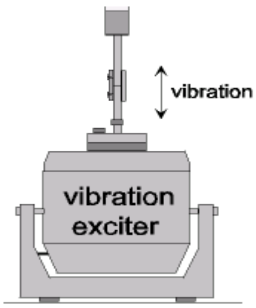


Fig. 4. Exciter.

Piezoelectric acceleration sensors: Measuring the acceleration and amplitude, and sometimes also the velocity, of an oscillating body is often referred to by the aggregated term of vibration measurement, because such measurements are those made in connection with investigation of vibration in machinery, mechanical structures etc. (Fig. 5).

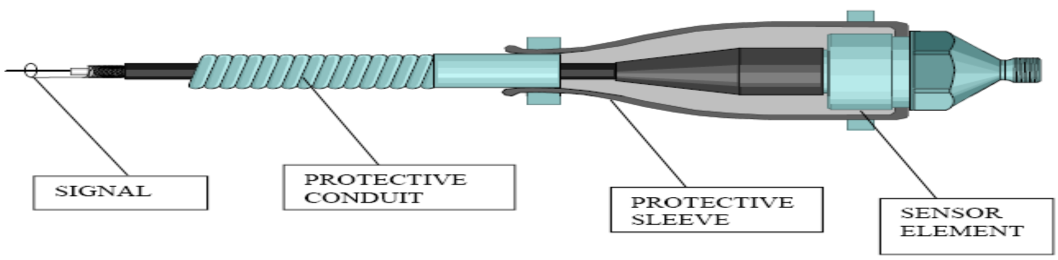


Fig. 5. Piezoelectric sensor.

Specifications of the sensor:

Vibration Sensor:	Piezoelectric accelerometer 100 mV/g with magnetic base, probe and 5 foot cable to BNC
Display:	LCD 3.5 digit, measurement, hold, low battery indicator
Measurement:	Acceleration 0.01-19.99 g (RMS)
Range:	Velocity 0.01-19.99 in/sec., 0.1-199.9 mm/sec (RMS)
	Envelope 0.01-19.99 ge (peak)
Frequency Range:	Overall 10 Hz - 10 kHz
	Envelope 0.5 kHz-10 kHz
Output:	Sensor Excitation: 12 Vdc @ 2 mA (BNC)
	Audio Out: 3.5 mm mini plug; 250 mW into 8 Ohms, 150 mW into 32 Ohms; Adjustable volume control with off position
Power:	(2) “AA” cells
Operating Time:	20 hours continuous without headphones
Weight: Instrument:	7 oz. (0.19 kg); Complete Kit: 2.85 lb (1.30 kg)
Dimensions:	6.3 x 3.3 x 1.25” (152 x 83 x 32 mm)
Operating conditions:	-14° to 122°F (-10° to 50°C)

Signal Conditioner: A signal conditioning amplifier to make the transducer characteristics compatible with the input electronics of the digital data acquisition system.

Pico Scope: Pico Scope (Fig. 6) is a software application enabling to use the PC to display voltage waveforms. Used in conjunction with a Pico Technology oscilloscope, Pico Scope becomes a powerful tool for recording, processing and displaying a wide range of measurements. The software provides four types of display:

- Oscilloscope.
- Spectrum analyzer.
- Meter.
- XY oscilloscope.

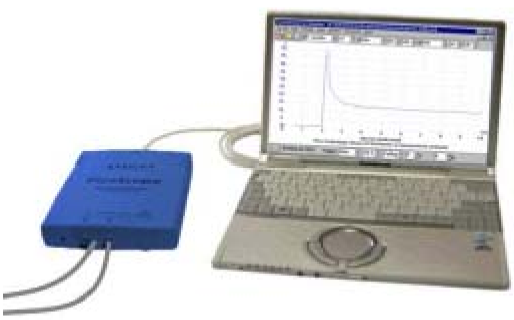


Fig. 6. Pico Scope 2000 Series.

An *analyzer* is used to perform the tasks of signal processing and modal analysis using suitable software. The response signal, after conditioning, is sent to an analyzer for signal processing. A commonly used analyzer is called a Fast Fourier transform (FFT) analyzer. Such an analyzer receives analog voltage signals (representing displacement, velocity, acceleration, strain, or force) from a signal conditioning amplifier, filter, and digitizer for computations. The analyzed signals can be used to find the natural frequencies, damping ratios, and mode shapes either in numerical or graphical form. The analyzer converts the analog time-domain signals, x(t), into digital frequency-domain data using Fourier series relations given by Eqs. (3) to (6), to facilitate digital computation. Thus the analyzer accepts the analog output signals of accelerometers or force transducers, x(t), and computes the spectral coefficients of these signals a_0, a_n and b_n using above equations in the frequency domain. The process of converting analog signals into digital data is indicated in Fig. 7 for two representative signals. In figure x(t) denotes the analog signal and $x_i = x(t_i)$ represents the corresponding digital record, with t_i indicating the i^{th} discrete value of time. This process is performed by an analog-to-digital (A/D) converter, which is part of a digital analyzer.

If x(t) is a periodic function with period τ , its Fourier's Series representation is given by

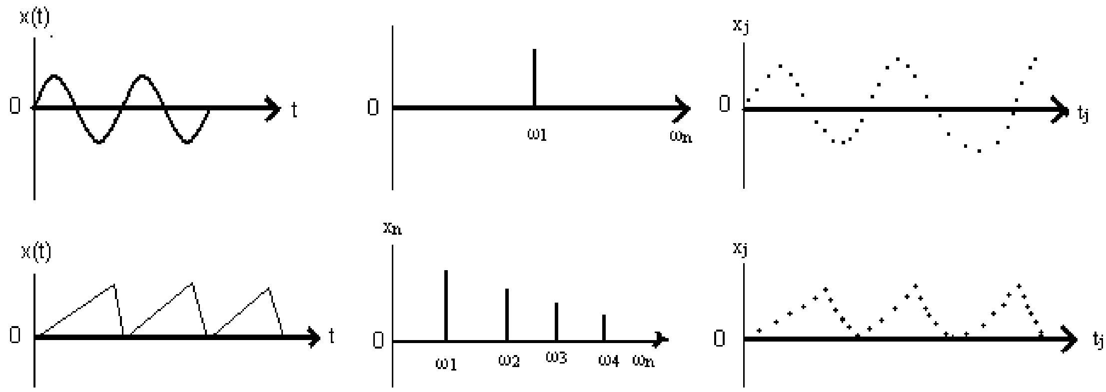
$$\begin{aligned} x(t) &= \frac{a_0}{2} + a_1 \cos \omega t + a_2 \cos 2\omega t + \dots\dots + b_1 \sin \omega t + b_2 \sin 2\omega t + \dots\dots \\ &= \frac{a_0}{2} + \sum_{n=1}^{\alpha} \left(a_n \cos n\omega t + b_n \sin n\omega t \right) \end{aligned} , \quad (3)$$

where the digital spectral coefficients a_0, a_n, b_n are given by

$$a_0 = \frac{2}{N} \sum_{i=1}^{N} x_i \;; \quad (4)$$

$$a_n = \frac{2}{N} \sum_{i=1}^{N} x_i \cos \frac{2n\pi t_i}{\tau}; \quad (5)$$

$$b_n = \frac{2}{N} \sum_{i=1}^{N} x_i \sin \frac{2n\pi t_i}{\tau} \quad (6)$$



(a) (b) (c)

Fig. 7. Signal in time domain (a), signal in frequency domain (b), Digital Records of *x(t)* (c).

5. Experimental Setup

The accelerometer was adhesively bonded on required position of the machine tools surface. At the time of turning the excitation was measured by the accelerometer and then the signals were supplied to the FFT analyzer (Pico scope) via signal conditioners. The FFT analyzer connected with PC in which digital signals were displayed (Fig. 8).

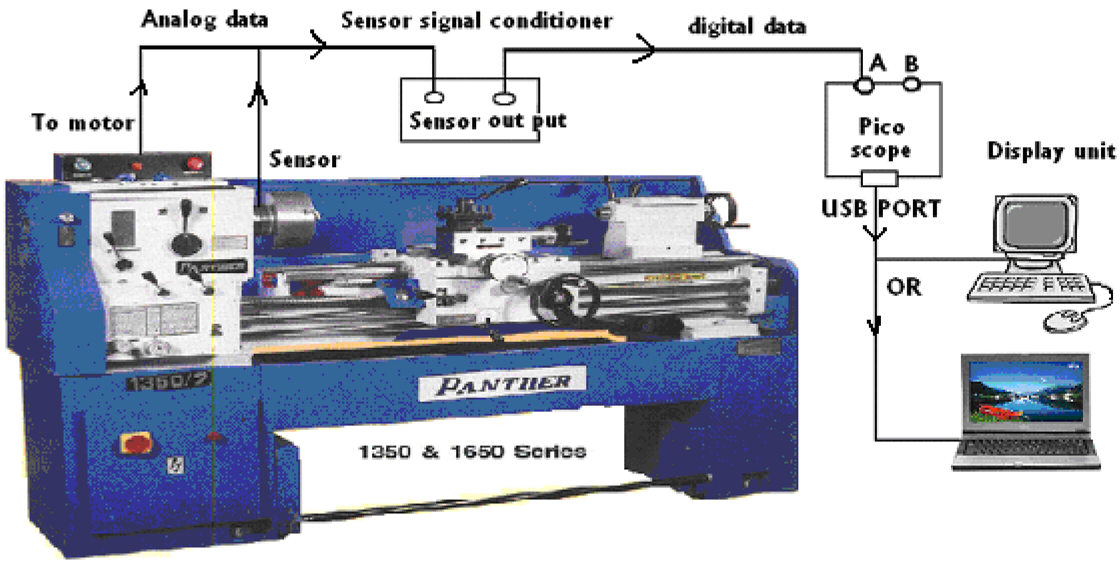


Fig. 8. Experimental setup.

6. Machine Condition Monitoring

A rational approach to successful and effective condition monitoring is that of trending the development of characteristic overall value measurements of machine condition over time (Figs. 9 and 10). The trend readings are plotted as shown here and compared with appropriate arming and alarm thresholds. When thresholds are exceeded (and not before then), detailed vibration diagnosis is performed in order to locate the exact source of trouble and to determine the corresponding maintenance remedy. Let us examine, then, the vibration monitoring and diagnosis techniques that hold particular relevance for electric motors.

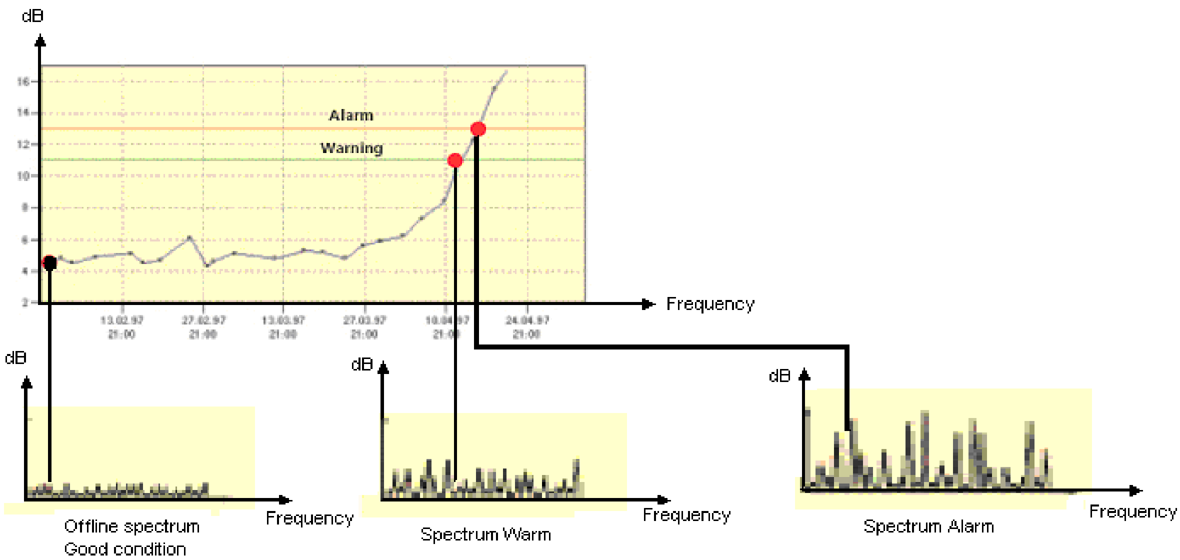
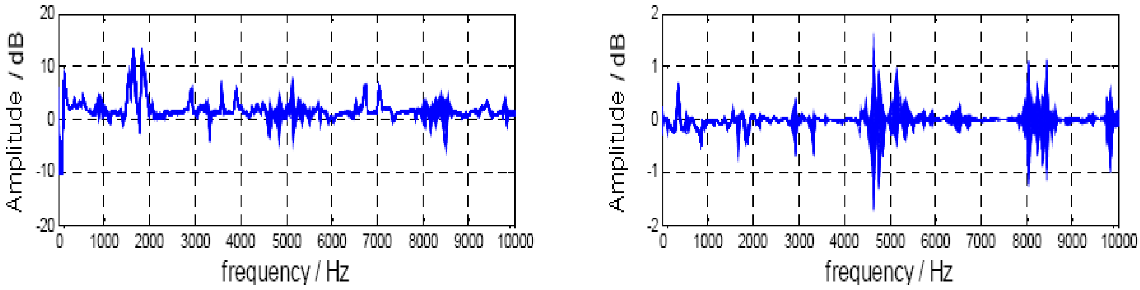


Fig. 9. Spectrum condition.



(a) (b)

Fig. 10. Machine condition monitoring: Machine low speed operating condition (a), Machine high speed operating condition (b).

Fig. 11 gives ISO 2372 (10816) standard which specifies the RMS vibration velocity limits on a basis of machine horsepower, and covers a frequency range from 10 Hz to 1000 Hz.

VIBRATION SEVERITY PER ISO 10816						
Machine			**Class I small Machine**	**Class II medium machines**	**Class III large machines foundation**	**Class IV rigid large soft foundation**
	in/s	**mm/s**				
Vibration Velocity V_{rms}	0.01	0.28				
	0.02	0.45				
	0.03	0.71				
	0.04	1.12				
	0.07	1.80				Good
	0.11	2.80				
	0.18	4.50				Satisfactory
	0.28	7.10				
	0.44	11.2				Unsatisfactory
	0.70	18.0				
	0.71	28.0				Unacceptable
	1.10	45.0				

Fig. 11. ISO 2372 chart.

7. Bearing Characteristic Analysis

As a rule, bearing race damage cannot be detected by elevated levels of low-frequency vibration parameters until damage is quite severe. The reason for this is that when the rolling elements pass over a damaged area of the race, a shock pulse is created that can be detected only in the high-frequency range at first. This is why special bearing characteristic overall values were developed for anti-friction bearing monitoring; there is no internationally-accepted standard for these so far, and so a variety of different characteristic overall values can be found in use today.

Anti-friction bearing damage diagnosis (Fig. 12) similar to vibration diagnosis via frequency spectrum measurement, in-depth diagnosis of anti-friction bearings may be performed through analysis of the signal ‘envelope’. The illustrations here explain the envelope analysis procedure, which begins with filtering out the appropriate range of frequencies that contain the signal emitted by the bearing during operation. This signal component is examined for the pulses that arise when bearing elements roll over damaged locations. Demodulation is used to calculate a curve that ‘envelops’ the bearing signal. If the time interval between periodically-occurring peaks in the envelope curve match one of the critical frequencies characteristic of bearing damage, then the corresponding bearing component can be assumed to be damaged. This procedure allows extremely accurate diagnosis of damage to anti-friction bearings, even in cases where extraneous signal components such as gear meshing noise tend to cover up the actual bearing signal.

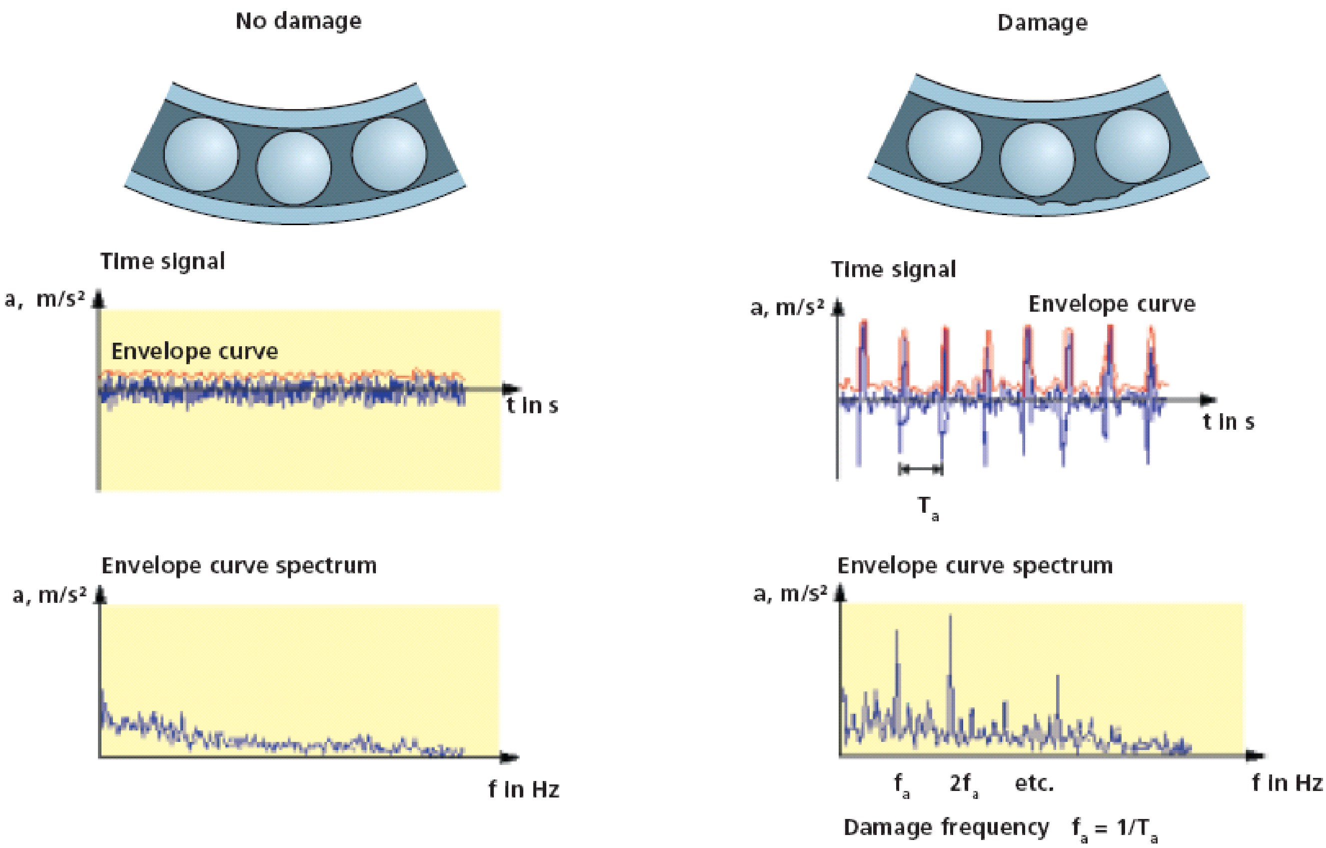


Fig. 12. Bearing evaluation.

8. Conclusions

A comparison is drawn between the measured data (speed frequency etc) and the acceptable data as per the ISO standard and there by a conclusion is drawn that the machine is in working condition.

Vibration signature analysis backed by good signal analyzers (like Pico Scope, piezoelectric sensor) results in excellent machine fault detection and correction. Similar experiments can be performed on various balancing experiments conducted with different unbalance configurations. This lead to drastic reduction in the overall vibration levels.

References

[1]. Benbouzid, M. E. H., A Review of Induction Motors Signature Analysis as a Medium for Faults Detection, *IEEE Transactions on Industrial Electronics*, Vol. 47, No. 5, October 2000, pp. 984-993.
[2]. Nandi, S., Toliyat, H. A., Xiadong, L., Condition Monitoring and Fault Diagnosis of Electrical machines - A Review, *IEEE Transactions on Energy Conversion*, Vol. 20, No. 4, December 2005, pp. 719-729.
[3]. Eren, L., Devaney, M. J., Bearing Damage Detection via Wavelet Package Decomposition of the Stator Current, *IEEE Transactions on Instrumentation and Measurements*, Vol. 53, No. 2, April 2004, pp. 431-436.
[4]. Singiresu S. Rao, Mechanical Vibrations, Fourth Edition, *Prentice Hall*, 2003.
[5]. P. Srinivasan, Mechanical Vibration Analysis, Second Edition, *John Wiley & Sons Inc*., 1996.
[6]. Madhujit Mukhopadhyay, Vibrations, Dynamics and Structural Systems, *Oxford & IBH Publishing Company Pvt. Ltd*., New Delhi, 2000.
[7]. http://en.wikipedia.org/wiki/Piezoelectric_sensor
[8]. ISO 2954:1975 Mechanical vibrations of rotating and reciprocating machinery - Requirements for instruments for measuring vibration severity.
[9]. ISO 8579-2:1993 Acceptance code for gears - Part 2: Determination of mechanical vibrations of gear units during acceptance testing.

___

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2008.pdf