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DIAGNOSING THE FAULTY MODEL OF A MOTOR BASED ON FFT ANALYZER WITH VIBRATING ANALYSIS

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Abstract

The most of the signal analysis techniques which rely on spectral approaches plays a vital role in the diagnosing a variety of vibration related problems in the rotating machines. One of such techniques is known to be as the Fast Fourier Transform (FFT). In the critical machines, there is a continuous online monitoring system. This ability provides the early detection of the faults and protective action is established with high reliability. In this paper, we described the fault and un-fault models of the machine, with chosen hardware and software solutions. By integrating the traditional algorithm with rule-based for fault detection, has the advantageous approach, especially the fault diagnostic high performance of the machinery, which is more than 99% correctness in all of the situations.

Keywords:

Spectral approach,

Rotating machines,

Fault model,

Un-fault models,

Fault diagnostics.

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1. INTRODUCTION

In the field of signal analysis techniques, based on the fast Fourier transform, diagnosing of on-line and rotating machinery are very effective in analyzing the vibration [1]-[5]. The analysis of the vibrating signals is obtained with the two domains namely time-domain and frequency-domain. As mentioned in [6]-[8], the time domain approach, it is not successful in the multi-tone vibration signals as a complete insight is provided. But the frequency domain approach allows identifying the phase spectrum and the amplitude. [9] and [10] noticed that, the resulting spectrum must be diagnosis to obtain the more valid information after the further processing of the vibrating signal.

The instrument that is commonly used in the vibrating analysis only in the frequency domain in Dynamic Signal Analyzer (DSA) [11]. It enables to evaluate the changes in the spectrum in time, and time-limited event. The other DSAs which are also used for the vibration analysis, based on the elaborating speed, display resolutions, cost and portability of the system. Some of them are handheld, benchtop instruments, computer-controlled systems are on the market. The primary goal of the continuous on-line monitoring system is that early alarm and the correctness in the data acquisition. The following are some of the requirements for an effective vibration analysis for the on-line monitoring system.

1. Real-time analysis
2. Optimum choice of measurement values (sampling frequency, number of points, window function) for sensitivity in the fault identification [12].
3. Integrated software diagnostic system in DSA for determining the fault severity.

But unfortunately, these requirements cannot be satisfied by the general-purpose instruments. In fact,

1. Visualization of the spectrum is more time consuming. In real-time, the spectrum evaluation cannot be performed in most of the DSAs.
2. As there is no automatic configuration phase, the DSA set-up is not that efficient.
3. There is no availability of exchange of data in the DSA and diagnostic software in the real-time scenarios for on-line fault isolation.

In the real-time practices, the authors designed an intelligent FFT analyzer for high performance states[13]&[14]. The configuration procedural development evolves an automatic adaption of the operating parameters in signal spectrum. This instrumentation is customized in typical applications like tone monitoring, detection etc. For as in the real-time practices, the usage of 50-kHz band-with signals are needed in the two-DSP parallel architecture for analysis processes. We also described for a brief understanding the customized intelligent FFT analyzer for modifying the software [15]. The model-based diagnostic approach [16], [17], consists of pattern matching procedure that detects and isolates the fault by comparing the actual device with both fault and un-fault models.

This experiment primarily shows the identification of fault and un-fault models, secondly the designed measurement system with hardware and software characteristic features. Lastly, the proposed technique is then verified with various faulty and un-faulty operating conditions for witnessing the high performance of the system.

2. RECOGNIZING THE FAULTY AND UN-FAULTY MODELS

In the model based diagnostic approach, the identification of the faulty and un-faulty model identification is required. This consists of suitable parameters of vibration signal spectra in the frequency-domain analysis. Some of the studies as mentioned earlier presents the relations among the defects and the characteristics of the vibrations in the electrical machinery systems.

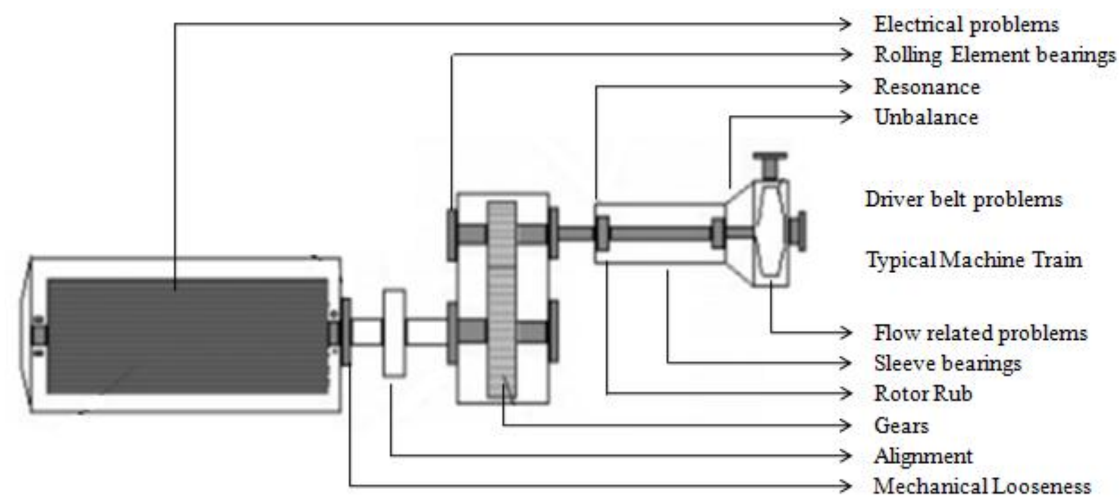


Figure 1: Electrical Machinery fault detection

When detecting the un-faulty operation of the vibratin spectrum, tones located in the shaft rotating frequency, the number of harmonics with amplitude is less than one-third of the amplitude of rotating frequency are generated. The following figure 2 shows the example of waveforms comparing in the wave terminology.

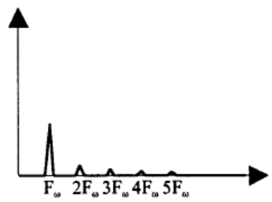
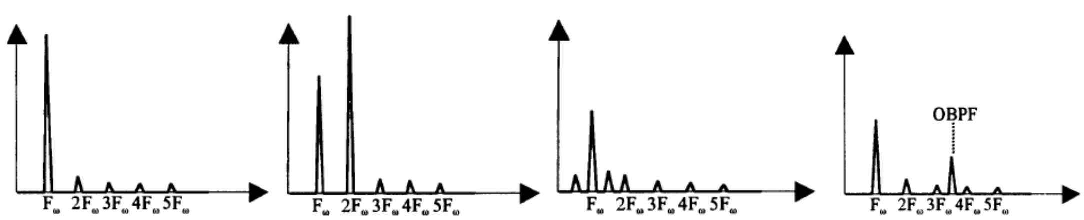


Figure 2: Figure 1: (a) Un-Faulty Model

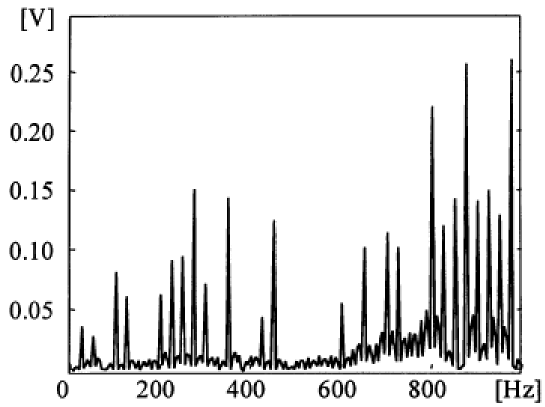
In the presence of gear, there exists three main additional tones appeared as - one at the running speed of the low-speed shaft, one at running speed of high-speed shaft and one at the gear mesh frequency. Where the F_w is the shaft rotating frequency. The other tones are generally goes under the un-faulty signal spectrum due to the vibrations of the structure as the motor is plugged on. Every kind of the machinery system failures needs specific alteration among the spectrum vibration analysis with respect to the un-faulty models. The figure 2 shows graphical notations for some common faults that occur in the systems. These characteristics defines the numerical and the logical model parameters. The number of tones, the fundamental(F_w), amplitude of first five harmonics of F_w, amplitude ratios between second harmonic($2F_w$) and the sum of all tone amplitudes are comes under numerical parameters. The frequencies like Out Ball Pass Frequency, Inner Ball Pass Frequency comes under the category of logical parameters.



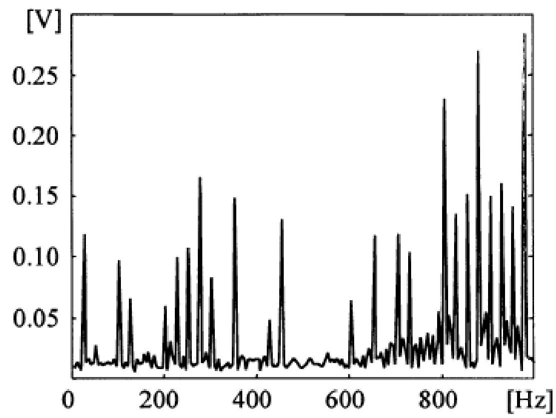
(a) Un-balance (b) Mis-Alignment (c) Looseness (d) Out ball bearing

Figure 2: Faulty Models

The following figure 3 gives the resultant values of the un-faulty and faulty models on the real-time data. This point out the clear differences between the vibrating spectra.



(a)



(b)

Figure 3: (a) Un-Faulty Spectrum ; (b) Modified frequency with 25Hz

It is impossible to generate a desired time instants when the motor in under operational mode. Since the in the real-time scenarios, the diagnostic systems cannot be reversible to recognize the faults in the machinery systems. To overcome this effective problem, a specified procedure is introduced based on the fault emulation. A suitable processing of un-fault signal performed by an arbitrary waveform generator. It has a special feature that allows the modification of the frequency in order to generate a fault spectrum as in figure 3. The use of an arbitrary waveform generator also allows the fault to be produced in any instant of the machine operation, by using test sequences composed of un-fault and fault subsequences. The correctness of the proposed emulated approach can then be verified by producing some reversible faults on the machine under test.

3. DESIGN SYSTEM OF A VIBRATION ANALYSIS

Some of the designed systems of a specific class motors are optimized in the hardware and the software applications. They are small-size, three-phase, two-pole pair, and asynchronous motors. This customization will not reduce the generality of the proposed design, as the hardware and the software are highly reconfigurable.

3.1 Hardware Design of the FFT Analyzer:

The Designed system of the vibration analysis for the fault diagnosis is typically works for the small-size electrical motors. From the figure 4, the system consists of

1. Acceleration sensor – 8710A50M1 characterized by:

Low output impedance (about 100), 6 kHz upper cut-off frequency, 1000 mV/g sensitivity, 5 g measuring range, and 51 g of mass loading.

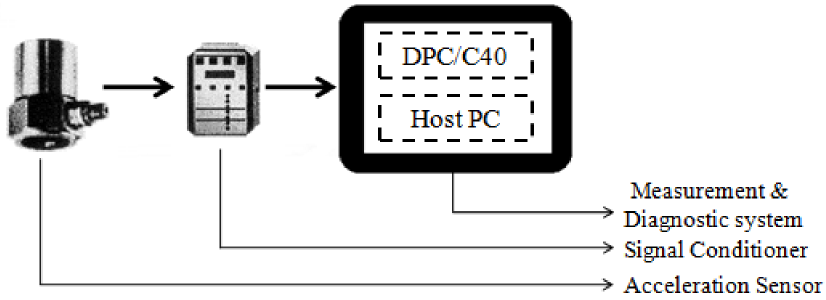


Figure 4: Block diagram of the Designed System

The accelerometer is magnetically mounted directly on the motor under monitoring, in order to assure an optimum coupling.

2. Signal Conditioner – 5118B1 is used to adapt the sensor output to the input range of the acquisition and the elaboration section.

3. Measurement and Diagnosis system – It is based on the PC-bus compatible carrier board and DPC/C40 with two concurrent DSPs and an on-board data acquisition system.

The two mounted DSPs are the TMS320C40 by Texas Instruments™; they use a floating-point numerical representation with 32 bits, and work at 40 mHz. The DSPs are in a Master/Slave configuration (only the Master DSP can directly access the board resources), and communicate by using six serial ports. The ADM is featured by two Delta-Sigma ADCs and two DACs with 16-bit resolution, 200 kHz maximum sampling frequency, V full-scale, and 20 k input impedance. The data transfer between the Master DSP and the host PC is carried out by using a shared 4 K 32-bit memory.

3.2 Software Design system

The previous discussions on the measurement system are based on the monitoring and diagnostic capabilities which are only possible with the dedicated software analyzers. These are divided into three types corresponding to the three steps needed to achieve the on-line monitoring and diagnosis. These procedures are implemented on DSPs in order to optimize the response time.

The signal processing: This software uses two DSPs in parallel execution, analyzes the vibration signal in the frequency domain, and evaluates the characteristics of its spectrum, chosen for representing the actual model of the motor under test. The software for the on-line spectrum evaluation is an optimization of the intelligent FFT-Analyzer measurement procedure [9] and [10], on the basis of the knowledge of the un-faulty vibration spectrum and on the expected fault ones. The measured un-fault spectrum (see Figure. 5(a)) has tones up to 8 kHz, and consequently the sampling frequency has to be fixed at 16 kHz to avoid aliasing. Theoretical analysis reported in the literature applied to the motor under test suggests that the considered faults give rise to additional meaningful tones not higher than 1 kHz. Thus, to improve the frequency resolution, the acquired signal is filtered (30th order FIR filter with 1.1 kHz cut-off frequency) and decimated (decimation factor = 4).

A dedicated algorithm performs the two operations in a single step [10], allowing a meaningful reduction of the computational load. The so-obtained sample sequence (2048 points) is windowed, and the FFT is evaluated. To identify the signal tones, the amplitude spectrum must be analyzed [10]. Then the frequency and the amplitude for every tone is interpolated with the samples of FFT [18], [19]. Finally, the numerical and the logical parameters can able to be estimated in the actul model of a motor. Table I reports the maximum elaboration times of each step of the signal-processing procedure. These times do not allow a diagnostic activity to be carried out at each sampling, but they are perfect in timing usually expected for the monitoring of apparatus working at industrial frequencies.

The fault detection: After completion of each signal processing procedure, the comparison goes on with the referenced un-faulty vibrations for fault detections. The high variability in successive measurements with some motor operating conditions, suggests the use of a statistical approach for identifying the reference vibration spectrum model parameters. In particular, the vibration spectrum in the absence of faults was calculated 20 times. Figure 5(b) reports the mean values and the variability of each tone amplitude, estimated as three times the standard deviation. As for the frequency variations, they prove to be always contained within ±0.5Hz around the measured mean values. A weighted squared sum of the difference between actual and un-fault numerical parameters is continuously evaluated and compared with a suitable threshold. In order to avoid false alarms, a fault is highlighted only when the threshold is overcome, or a check is positive in two subsequent spectrum analyzes.

The fault diagnosis: A correct fault diagnosis requires reasoning on spectrum parameters referring to a complete fault time interval. Consequently, the fault isolation procedure is activated on the signal processing results obtained after the fault detection. A rule-based diagnostic procedure was directly implemented on the Master DSP rather than on the PC, in order to obtain better time performance. First the checks on the logical parameters are performed, allowing the related faults to be highlighted or discarded.

For an example, a defect in the outer race of the ball bearing gives rise to a tone at OBPF. In these cases, the diagnostic procedure stops, and only the corresponding fault is given with a certainty factor equal to one. Table II reports the kind of faults that are identified by these demons with the corresponding characteristic frequency. If no one of these conditions is verified, the procedure goes on applying rules focused on increasing the certainty factor of other possible faults.

In particular, for each fault, the certainty factor is increased as a function of the distances between the actual model and its fault model. The certainty factors were tuned in the set-up phase in order to optimize the diagnostic performance.

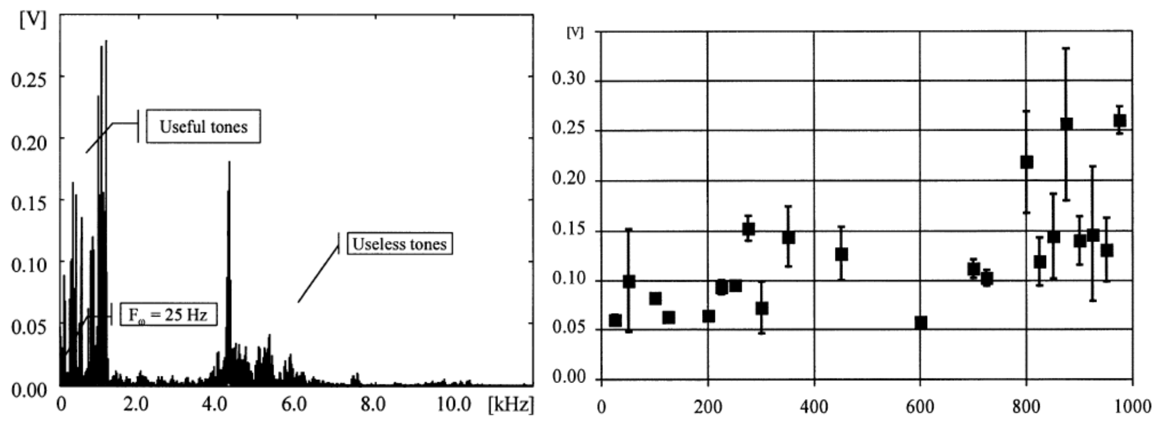
Table I: Maximum Elaboration time for two different algorithms of signal processing procedures

Algorithm	Filtering + Decimation	Windowing + FFT	Tone detection + interpolation + model parameter estimation
Elaboration Time	70 ms	11 ms	3 ms

Table II: Fault detection by Demons, frequencies and the causes of occurrences

Fault detection	Frequency (Hz)	Occurance
Looseness	12.5 - 37.5	0.5-1.5 F_ω
OBPF	127.5	Out ball bearing dimension
IBPF	112.5	Inner ball bearing dimension

The output of this procedure is a list of probable faults, each with its certainty factor. A fault is considered as “probable” if its certainty factor is greater than a suitable threshold (0.5) [20], [21].



(a) (b)

Figure 5: (a)Un-fault vibration spectrum ;(b)Un-faulty conditional values with measured tones

This diagnostic list is also passed by the Master DSP to the PC via Shared Memory. The DSP Master executes this fault diagnosis procedure, taking about 0.02 ms.

4. EVALUATING THE SYSTEM DIAGNOSTIC PERFORMANCE

As for the performance evaluation, in terms of diagnostic capabilities and response time, of the designed instrument, numerous experimental tests using real and emulated signals are carried out. The false alarm rate is evaluated by running the diagnostic procedure during the motor normal operation in different working conditions. No false alarm occurs in 20 tests lasting 30 min each. More than a hundred tests for each fault were carried out, and the obtained diagnostic results in detailed. The performances of the fault detection procedure are expressed in terms of correct and missed detection percentages. For the diagnostic procedure, some classes are identified, and the percentages of each class are reported in the Table III.

Table III: Diagnostic performance of the Designed System

Fault Type	Correct Location	InCorrect Location	Missed Location	Quasicorrect Location	Correct Detection	Missed Detection
Unbalance	99.5	0	0	0.5	99.5	0.5
Mis-Alignment	99	0	1	0	99.5	0.5
Looseness	99	0	1	0	98.5	1.5
Outer ball bearing	99.5	0	0.5	99.5	100	0

The arbitrary signal generator can provide an additional signal (marker), with only two amplitude levels (0–2 V), that can be synchronized with the generation of a specific sample. The fault instant can be exactly identified by synchronizing the marker with the beginning of the fault signal in the sequence. On the other hand, one ADM D/A converter can be used for highlighting the instants in which the DSP-based system reaches the detection and the diagnosis. In particular, a 3-V voltage pulse is generated as soon as a fault is detected and when the diagnostic process is ended. These two signals are displayed on a digital oscilloscope (Tektronix TDS 520D, 500 MHz bandwidth, four input single-ended channels), allowing the response time of both fault detection and fault diagnosis to be measured (see Fig. 6).

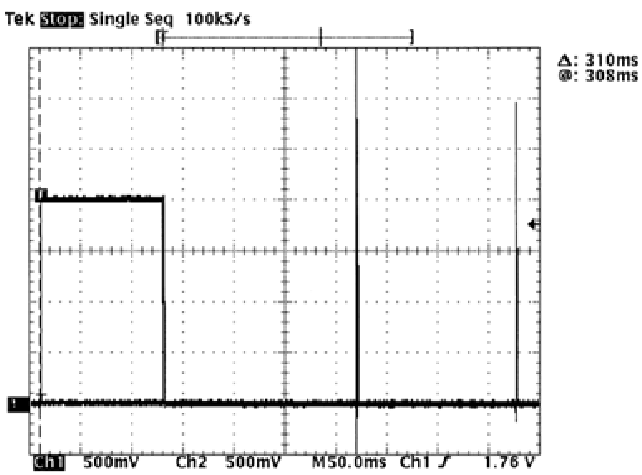


Figure 6: An example of a response time

The measured response times are not constant since they depend on a number of factors; a mean delay of 300 ms for the fault detection and of 470 ms for the diagnosis is measured. A set of unbalance faults was also produced on the motor in order to check the proposed fault model as well as the emulated approach. Different values of the weights (77.5 g, 65 g, and a couple of 40 g weights) are placed on the shaft at different angles, in order to test the system for different faults of this class. Diagnostic results in optimum agreement with the one obtained by the emulation approach were obtained.

5. CONCLUSION

In this paper, we described a DSP-based architecture for vibration analysis. It allows machine to on-line monitoring, with a consequent increase in the system and in environmental safety. The integration of the traditional signal-processing algorithm with rule-based reasoning for fault detection and isolation presents many advantages, especially concerning the diagnostic performance of the system, with correct diagnosis in more than 99% of the situations. The emulation-based method used to estimate the vibration signal in the faulty condition proves to be very effective and can be easily extended to numerous application fields.

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