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Fault detection of washing machine with discrete wavelet methods

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1. Introduction

In industrial systems computer-aided condition monitoring methods are generally used. By collection noise, current, temperature and vibration data from a running device, it can be determined that the device is working health or not in the environment noise, current, temperature or vibration information such as taking a healthy employment status of these engines can be decided. It can be found that most of the failures are associated with balancing problems, bearing problems, and the compliance of the constituent parts of the machine. [1-3]. Vibration analysis is one of the significant tools for the identification of faults of machines. With the help of vibration sensors that used for examining the signals taken from electric motor, a fault in the system can be found. Signals taken from electric motors by using vibration sensors are non-stationary signals. These marks have a dynamic structure and change over time. In order to understand and recognize the fault signal in these signals, the signals collected from the electric motor should be examined numerically [4]. There are two types of conventional analysis methods: time domain and the frequency domain. The frequency domain analysis is more attractive one because it can give more detailed information about the signal and its frequency components whereas; the time domain analysis can give overall qualitative information. Generally, a vibration signal taken from machine is composed of three parts: stationary vibration, random vibration, and noise. Traditionally, Fourier Transform (FT) was used to perform such analysis [5-8]. Although Fourier Analysis (FA) has some inherent limitations in the analysis of the non-linear phenomena and some short duration transient signals.

Over the past 20 years, the wavelet theory has become one of the emerging and fast-evolving mathematical and signal processing tools for its many distinct merits. Apart from the Fast-Fourier Transform (FFT), Wavelet Transform (WT) can use for multi –scale analysis of the signal through dilation and translation, hence it can extract the time-frequency specials of the signals most effectively. Wavelets are mathematical functions that cut up data into different frequency components. In addition to the study each elements with a resolution matched to its scale. The method has a lot of advantages over conventional Fourier methods in analysing physical case where the signal contains non-continuities and sharp spikes. Wavelets were used independently in a lot of scientific area [6-8]. Discrete Wavelet Transform is used as an important method of fault detection and analysis [9, 10]. Washing machines shows typical faults based on induction machine [11-13]. However, there is a washing machine vibration due to the washdrum; the machine creates a negative impact on. Washing machine manufacturers want to examine these effects. In this study, analyses were made with the actual data in a company that manufactures washing machine.

2. Wavelet transform

Wavelet transform is often used as time-scale signal analysis tool. Statistical signal analysis is crucial part of research in several technical domains, including network performance and signal processing field. In this article, statistical properties of signals and their representations in wavelet domain are investigated. This study focuses on the relationship between some statistical signal properties in time and wavelet domain and dependencies between coefficients at different scales in hierarchical wavelet domain representation [3, 14, 15].

Wavelet Transforms (WTs) is chosen to overcome the disadvantages of Short Time Fourier Transform (STFT) that provides constant resolution for all frequencies because it uses the same window for the analysis of the inspected signal $x(t)$. On the other hand, WTs use multi-resolution. They use different window functions for analyzing the different frequency bands of the signal $x(t)$. By using dilation or compression of a mother wavelet $\psi(t)$, different window functions $\psi(s,b,t)$; which are also called son wavelets, can be generated at different time frame. A scale is the inverse of its corresponding frequency. WTs can be grouped as discrete WTs or continuous WTs. For vibration-based fault diagnosis, usually continuous WTs are used. A continuous type of wavelet transform (CWT) that is applied to the signal $x(t)$ can be defined as,

$$w(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt, \quad (1)$$

where a is the dilation factor, b is the translation factor and $\psi(t)$ is the mother wavelet, $1/\sqrt{a}$ is an energy normalization term that makes wavelets of different scale has the same amount of energy [16].

2.1. Discrete wavelet transform

It is started by defining the wavelet series expansion of function $f(x)\varepsilon L^2(\Re)$ relative to wavelet $\psi(t)$ and scaling function $\phi(x)$. It can be written:

$$f(x)=\sum_k c_{j_0}(k)\phi_{j_0,k}(x)+\sum_{j=j_0}^{\infty}\sum_k d_j(k)\psi_{j,k}(x), \quad (2)$$

where j_0 is an arbitrary starting scale and the $c_{j_0}(k)$'s are normally called the approximation or scaling coefficients, the $d_j(k)$'s are called the detail or wavelet coefficients. The expansion coefficients are calculated as:

$$c_{j_0}(k)=\langle f(x),\tilde{\phi}_{j_0,k}(x)\rangle=\int f(x)\tilde{\phi}_{j_0,k}(x)dx \quad (3)$$

$$d_j(k)=\langle f(x),\tilde{\Psi}_{j,k}(x)\rangle=\int f(x)\tilde{\Psi}_{j,k}(x)dx \quad (4)$$

If the function expanded is a sequence of numbers, like samples of a continuous function $f(x)$. The resulting coefficients are called the discrete wavelet transform (DWT) of $f(x)$. Then the series expansion defined in Eqs. (3) and (4) becomes the DWT transform pair explains following equations:

$$W_\varphi(j_0,k)=\frac{1}{\sqrt{M}}\sum_{x=0}^{M-1} f(x)\tilde{\phi}_{j_0,k}(x), \quad (5)$$

$$W_\Psi(j,k)=\frac{1}{\sqrt{M}}\sum_{x=0}^{M-1} f(x)\tilde{\Psi}_{j,k}(x), \quad (6)$$

for $j \geq j_0$ and

$$f(x)=\frac{1}{\sqrt{M}}\sum_k W_\varphi(j_0,k)\phi_{j_0,k}(x)+ +\frac{1}{\sqrt{M}}\sum_{j=j_0}^{\infty}\sum_k W_\Psi(j,k)\Psi_{j,k}(x), \quad (7)$$

where $f(x)$, $\phi_{j_0,k}(x)$, and $\Psi_{j,k}(x)$ are functions of discrete variable x = 0, 1, 2, ... , M - 1, [16-18].

3. Application of wavelet transformation

Wavelet transformation has been applied in wide variety of engineering analysis. It includes machinery fault diagnosis, specially, time–frequency analysis of signals, fault feature extraction, singularity detection for signals, de-noising and extraction of the weak signals, compression of vibration signals and system identification [4, 7]. By combining the time domain and classical Fourier analysis, the wavelet transform provides simultaneously spectral representation and temporal order of the signal decomposition components, which is also applied to perform the analysis of NDE ultrasonic signal received during the inspection of reinforced composite materials. Wavelet transform can be used to process acoustic emission signals to find faults such as micro-failure modes and their interaction in composites.

For rotating machines fault detection, wavelet transform has been used for isolation and identification of electrical faults in induction machine, bearing and gear related faults. Recently, wavelet transform has also been applied to detect the stable and propagating cracks.

4. Application of wavelet transformation

Measurement and data collection system is shown in Fig. 1. Time-amplitude diagram belonging to a washing machine that working properly (healthy) is given in Fig. 2 whereas time-amplitude diagram belonging to the machine with same working specialties but having problems in it rotor is represented in Fig. 3 [7]. The nominal working specialties for the machine are given in Table 1.

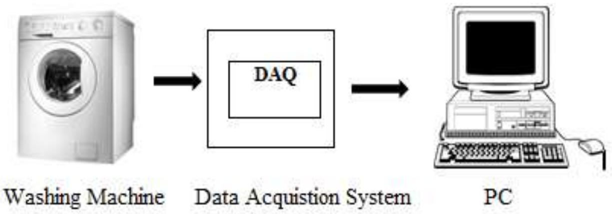


Fig. 1 Measurement and data collection system

The electrical data belonging to washing machines are shown in Table 1.

Table 1

The nominal working specialties for the washing machine

Electrical properties of washing machine	
Annual electricity consumption (kWh) (220 washing)	170
Squeezing speed, rpm	1000
Sound level during washing	58
Sound level during squeezing, dB	72
Power, W	2000-2350

The time amplitude plots of the healthy machine and faulty rotor are displayed as shown in the following two figures. When the plots are examined carefully the faulty rotor can be identified easily.

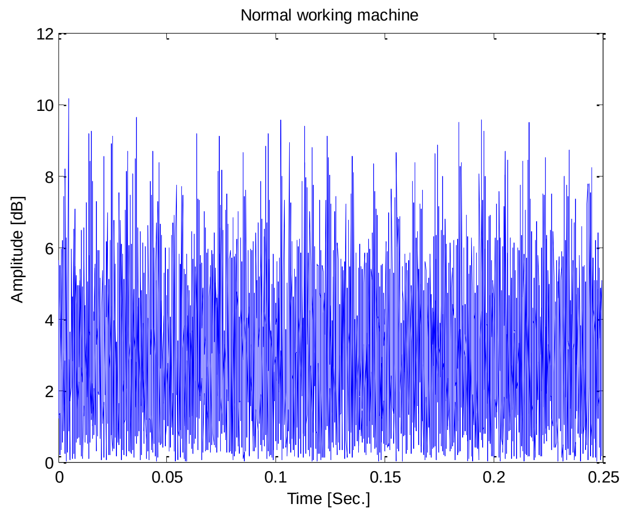


Fig. 2 Time-amplitude diagram belonging to a washing machine (healthy machine)

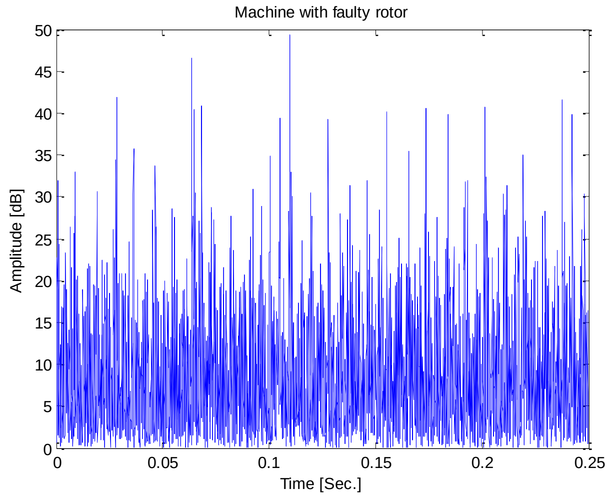


Fig. 3 Time-amplitude diagram (faulty rotor)

In Figs. 2 and 3 are given the time-amplitude graph normal and faulty of washing machine. The normal working washing machine is average amplitude of 10 dB while faulty machine average is 40 dB. This is despite the amplitudes of these machines are distinguished quite difficult to distinguish for a lot of different faults. For this reason, this study is made of the actual data to be used Wavelet analysis of the data and statistical methods.

5. Application of statistical & discrete wavelet analysis

In this experimental study was used the statistical and discrete wavelet analysis methods. The original and noise-free signals are represented in Fig. 4 for faulty washing machine.

In the Fig. 4, which indicates the number of data of the horizontal axis and the vertical axis is represented amplitude. And also from the figure can be distinguished from the original and de-noised signals. Noisy signal amplitude is higher than the other signal.

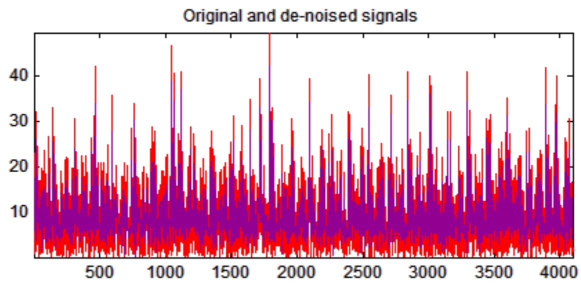


Fig. 4 Original and de-nosed signals

The discrete wavelet transform is made for the faulty washing machine can be shown in Fig. 5 DWT analysis of the properly working machine is given in Fig. 6, Dubachies 5 is used for the analysis of the DWT. In addition, the statistical analyses are shown in Figs. 7 and 8 [16-21].

Histogram and cumulative histogram results are quite similar to each other for healthy and faulty machine. The obtained similar statistical results for these two machines are due to the same working frequency of the machines (50 Hz), In addition, the auto-correlation and FFT spectrum results contain quite distinctive values, and this situation can be seen from Figs. 7 and 8.

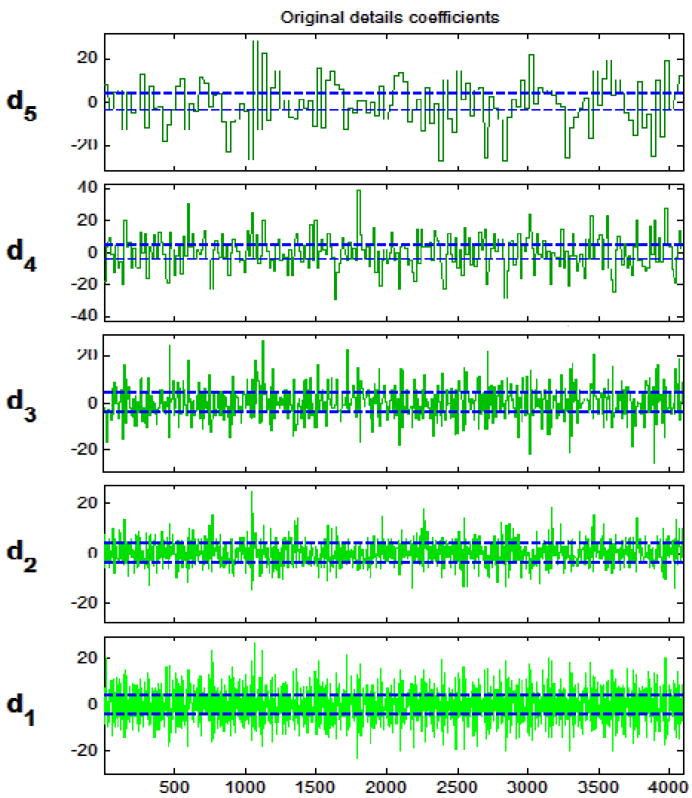


Fig. 5 DWT analysis for faulty washing machine

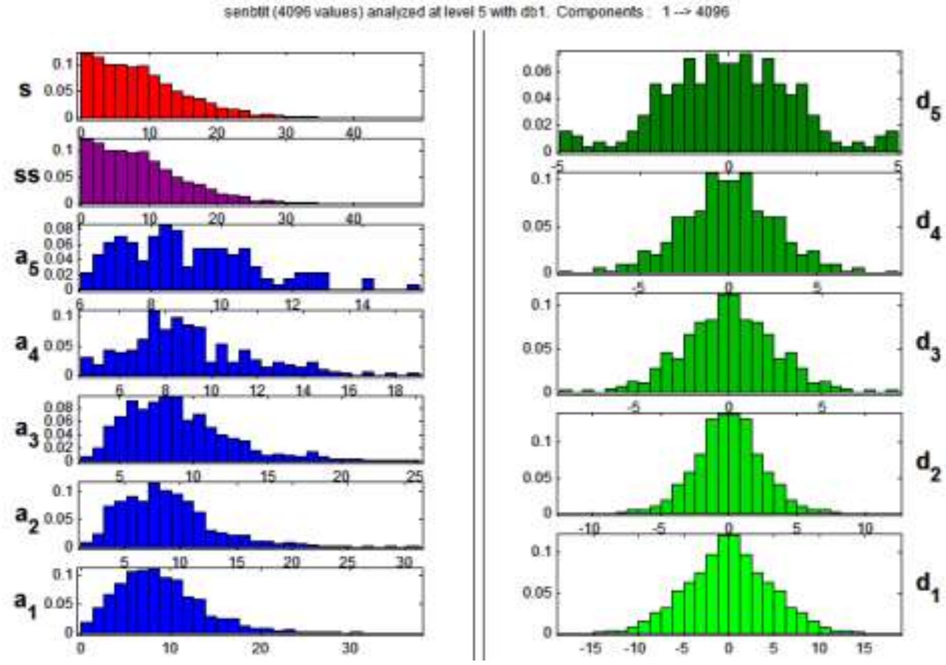


Fig. 6 DWT analysis for the properly working machine

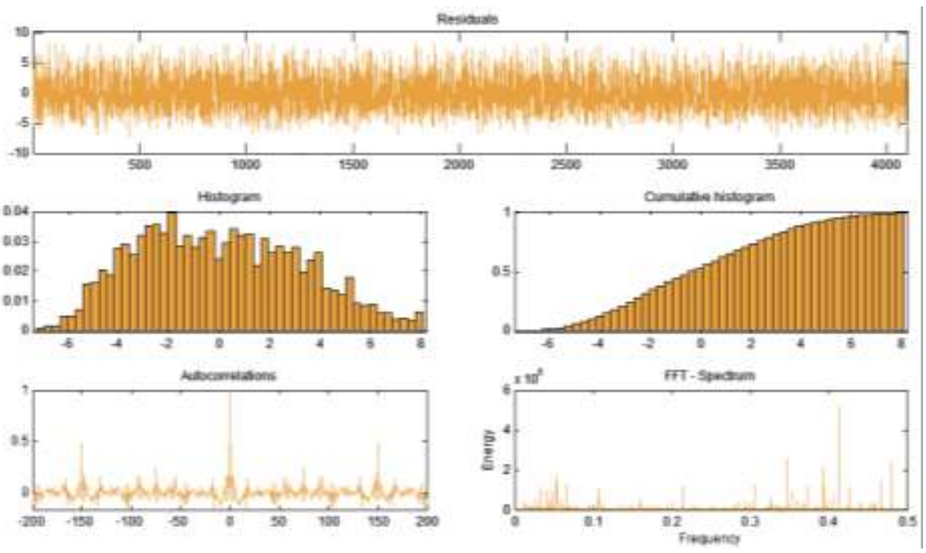


Fig. 7 The statistical and spectrum analysis for faulty washing machine

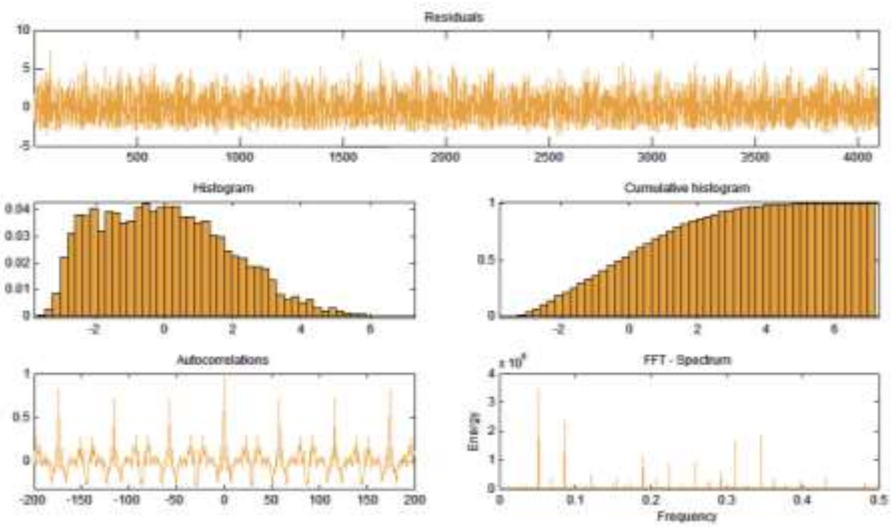
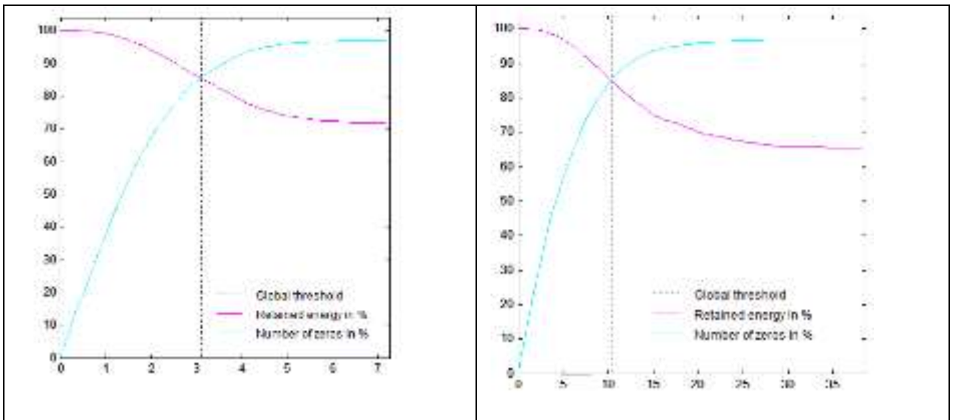


Fig. 8 The statistical and spectrum analysis for properly working washing machine

6. Conclusion

This experimental study is analyzed for properly working and faulty washing machines of the same company with the same characteristics in order to collect data about some statistical and wavelet analysis and properties of the washing machine. DWT energy distribution of working and faulty washing machine is shown in Fig. 9. Percent of the energy level of the chart at the intersection points for working machine and fault machine are different. As a result of in Fig. 9 healthy and faulty machines can be distinguished by examine energy levels of machines.



a) Healthy b) Faulty

Fig. 9 Energy distribution of DWT

Table 2

Statistical properties of properly the healthy and the fault machine

	Mean	Median	Mod	Max	Min	Range	*L*1 Norm	*L*2 Norm	Max Norm
Original	3.072	2.926	2.874	10.14	0.0014	10.14	1.258e+004	232.9	10.14
Faulty	-2.006e-0.15	-0.1231	-0.53	7.19	-3.683	10.87	6329	119.9	7.19

The data in Table 2 collected from the healthy and faulty machines were analyzed. The basic statistical characteristics Mean, Median and Mode values explicitly determine the characteristics of the machines. Healthy and fault machines can be easily distinguished by examine the data in the table too. The study was carried out to improve quality control the standards of the washing machine manufacturer. The results obtained from the study can be used to improve the product quality. Vibration in washing machine is one of the most important factors affecting quality of production.

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SKALBIMO MAŠINOS DEFEKTŲ ATSKLEIDIMAS DISKRETINIAIS BANGINIAIS METODAIS

R e z i u m ė

Paskutiniame dešimtmetyje naujas matematinis metodas leido inžinieriams ir mokslininkams detalizuoti pereinamuosius ir kintančius laike reiškinius, kurių neįmanoma atskleisti tradicinėmis priemonėmis. Šis išradimas, pavadintas bangine transformacija, sudarė prielaidas revoliuciniams pokyčiams signalų apdorojimo ir vaizdų suspaudimo srityse. Šioje studijoje abi tiek gerai veikianti, tiek sugedusi skalbimo mašinos yra išskirtos pasitelkiant diskretinę banginę ir statistinę analizę. Statistinės analizės rezultatai, išskiriant abiejų mašinų ypatumus, buvo gana sėkmingi. Pagrįsti analize atskiri energijos lygiai yra svarbūs mašinų išskyrimui. Elektrinės mašinos dinamika ir valdymas ar analizė yra būtini efektyviam valdymui. Tyrime išanalizuota skalbimo mašinos virpesių dinamika.

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FAULT DETECTION OF WASHING MACHINE WITH DISCRETE WAVELET METHODS

S u m m a r y

In the last decade, a new mathematical method has allowed scientists and engineers to view the details of time varying and transient phenomena that are not possible through conventional tools. This invention, called wavelet transform, has created revolutionary changes in the areas of signal processing, and image compression. In this study, both properly working and fault washing machine is distinguished by using discrete wavelet analysis and statistical analysis. The result of statistical analysis to distinguish the properties of both machines has been quite successful .Based on the analysis, particular energy levels are important to distinguish the machines. All the dynamics and control of electrical machines and analysis is necessary for effective control. In the study vibration dynamics of the washing machine was analyzed.

Keywords: vibration, washing machine, discrete wavelet analysis, data analysis.

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