Classification of Vibration Signal to Detect Pump Cavitation using Discrete Wavelet Transform

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ABSTRACT

This paper concentrates on cavitation detection using discrete wavelet transform by classifying the pump vibration signal. Vibration signal acquired from centrifugal pump cavitation test rig carry more information about the cavitation classes. In this paper two classes has been defined namely, no cavitation class and developed cavitation class. This method uses the deviation from zero mean value of detailed components of wavelet coefficients, obtained from five level decomposition of vibration signal to detect the signal belongs to normal class or cavitation class in centrifugal pump. The main advantage of this proposed algorithm is it requires no training. In addition to this advantage a more robust results show that this algorithm has better detection response.

General Terms

Condition monitoring, Fault Diagnosis, Signal Analysis

Keywords

Cavitation, Cavitation test rig, Discrete Wavelet Transform, Decomposition Levels

1. INTRODUCTION

In industries, centrifugal pumps are the most widely used device than others, because of its robustness and wide ranging suitability. One of the severe problems developed in centrifugal pump is cavitation. Cavitation is a vaporization process that involves heat and mass transfer, the physical properties of the liquid and its vapor, and the flow conditions can affect the process, and thus the performance of hydraulic equipment as well[1]. This increasing critical role in industrial processes underscores the level of attention given to detection or diagnosis of potentially destructive faults like cavitation.

Many research literatures extensively documented the methods for prediction and detection of cavitation, in many of these methods vibration signal is used for the analysis purpose. Saeid Farokhzad etal.,[2] mentioned both vibration and acoustic signals carry rich and useful information about the condition of the system and it has been very popular for condition monitoring and early fault detection of pumps. Hence, vibration sensor is used here to measure the pump vibration signal.

In this research, experimental studies and analysis are carried out on centrifugal pump, to detect classes of cavitation using vibration analysis. Wavelet transform are widely used for classification and fault diagnosis. This paper presents a novel method of detection of pump cavitation system. The method used is wavelet analysis to classify cavitation vibration signal as no cavitation and developed cavitation class. Specifically mean of wavelet coefficients is used for this purpose. The main advantage of this algorithm is frequency information of pump do not have to be known in advance as in FFT algorithm.

2. EXPERIMENTAL SETUP AND DATA COLLECTION

The schematic illustration of experimental test loop is shown in Figure 1. The core component of the test rig facility is the pumping system. It contains a centrifugal pump with the suction side connected to the circular-closed reservoir tank and discharge side is routed back to the reservoir tank to form a closed-loop flow system. This setup has facility to induce cavitation by Net Positive Suction Head (NPSH) 3% drop [3] method, which is fabricated at Sathyabama University, Chennai, India. The parameters that affect cavitation are identified and to measure these parameters suitable measurement devices are installed at the appropriate locations.

A state-of-the-art study has shown that vibration signal based approaches are largely used for cavitation detection in hydraulic components[4,5]. Many published methodologies use vibration and noise as features to detect the cavitation, moreover vibration monitoring is probably a convenient and a worldwide accepted method in various industries. Therefore an accelerometer is installed at various locales of the centrifugal-pump cavitation test-loop so as to collect the vibration signal.

Vibration signal is acquired from the cavitation test-loop for various suction conditions by varying vacuum pressure. The vacuum pressure is varied by means of a vacuum pump which is connected with partially filled circular tank. Both cavitation and non-cavitation signals are collected, high impulsive spikes are prominently observed in the cavitation signal.

The research data base is obtained by varying vacuum pressure using vacuum pump above the liquid in the reservoir tank, that is the suction conditions are varied. Vibration signal acquired from suction side accelerometer of the test loop for various vacuum conditions are as shown in Table 1 at 50,000 lph flow rate.

Table 1. Research Data Base

S. No	Sensor Position	No. of signals	Description of Signals (at various vacuum conditions)
1	At suction side	14	0, 50, 100, 150, 200, 220, 240, 260, 280, 300, 320, 340, 360 and 380 mm of Hg

3. FEATURE EXTRACTION AND DETECTION USING DISCRETE WAVELET TRANSFORM

Multi-resolution analysis based on DWT has been used for signal analysis in a variety of applications. With the wavelet-based approach adapted, a simple quantification procedure is proposed to detect the cavitation classes in centrifugal pump by performing a multi-resolution analysis of the vibration signal, based on DWT. Vibration signal acquired from test loop for various suction conditions is decomposed into several frequency levels by discrete wavelet transform with db4 as mother wavelet. Discrete Wavelet Transform is applied to expose the hidden information in the cavitation signal [6]. The db4 wavelet has been chosen because of its simplicity. The extracted coefficients provide a compact representation that shows the energy distribution of the signal in scale and frequency. To reduce the dimensionality of the extracted feature vectors, mean based analysis of the wavelet coefficients are utilized [7].

A window size of 65,536 samples at 200 kHz sampling rate is used as input to the feature extraction. The MATLAB^{TM} program is written to decompose the vibration signal and also to extract the mean value from detail component coefficients. These values in each sub-band are used as a feature, which provide information about the frequency distribution of the signal. Initially the maximum decomposition level has been computed. In this case, the maximum level is five; hence five levels of decomposition are performed.

The mean as a feature is extracted from the wavelet coefficients and compared with the cavitation and no-cavitation signals to detect the stages of cavitation. In this research, instead of typical checking of the mean value of vibration signal the mean value of detailed components at fifth decomposing level signal is checked for its minuscule changes. The mean values are obtained for all d1 to d5 signal and showed in Table2. From the tabular column, it is observed that the mean values of fifth level signal also changed over scale.

The mean of wavelet coefficients obtained from different decomposed signal windows refer to various classes of cavitation. This type of analysis can improve the capability of diagnosing the cavitation classes of centrifugal pumps.

4. RESULTS AND DISCUSSION

Cavitation classes are detected based on mean value of detail components of wavelet coefficients with respect to deviation from zero mean. These wavelet coefficients are able to pick up the small vibration disturbance caused by the cavitation. The mean values of detailed components at all five levels are extracted and fifth level values are tabulated in Table 2 also shown as graph in Figure 2. Figure 2 shows the mean value of detailed component coefficients at 5th level decomposition using db4 wavelet for various vacuum conditions. The dependence of mean with various cavitation classes are studied from the graphs. A strong correlation was found between cavitation classes and mean value of detail components, seeing as there is a significant difference found among the vibration signal of both the cavitation classes.

From the graph it is observed that the mean value of d1 signal (dark blue) is almost very close to zero mean line

for all vacuum conditions. Similarly in case of d2 (red) and d3 (green) signal, very very small deviation from zero mean line is observed for all vacuum conditions. But in the case of d4 (purple) and d5 (light blue) signal, there is small deviation from zero mean for 0 to 200 mm of Hg vacuum conditions and much deviation from 220 to 380 mm of Hg vacuum conditions. Based on these observations author can conclude that because of the high impulsive spikes present in the cavitation signal the mean values detail components are also changed.

This indicates 0 to 200 mm of Hg belongs to no cavitation class and 220 to 380 mm of Hg corresponds to cavitation class. The results of cavitation detection algorithm for pump using discrete wavelet transform technique are provided in Table 3. In this analysis, mean value of detail coefficient was considered for classification purpose. The decision on two different stages of cavitation was made with respect to deviation from zero mean. To conclude, the pump vibration signal is classified into no cavitation and developed cavitation class based on deviation from zero mean value of detail coefficients.

5. CONCLUSION

In this paper, the proposed methodology is mean based discrete wavelet transform algorithm for classification of cavitation signal. This algorithm examines the deviation from zero mean value of detailed dwt co-efficient at various level of both cavitation and no cavitation signals, which are collected from centrifugal pump cavitation test loop. This proposed mean based DWT algorithm was tested on over 3 different flow sets with 3 different sensor positions data samples, and detected cavitation stages with 100% reliability. Therefore it offers a reliable solution for detecting the cavitation. The results indicate that the proposed algorithm is an efficient way of classifying the various cavitation signals. The proposed DWT algorithm with db4 wavelet has five decomposition levels and based on deviation from zero mean value of detailed wavelet coefficient is used for detecting various cavitation stages of centrifugal pump in cavitation test loop.

This research demonstrates a comprehensive perspective of cavitation detection methods based on wavelet transform and their application in centrifugal pump cavitation test rig. The cavitation detection algorithm discussed in this paper could identify cavitation class present in pump. Detecting cavitation in a timely manner is vital to maintaining a properly functional system. Cavitation class detection task is performed with mean as a feature. The main advantages of this algorithm are it requires no training as in the case of neural network and provides a more robust solution. The wavelet analysis proves to be successful for detection of cavitation in a centrifugal pump.

Relevant classification techniques can also be used for other hydraulic equipments and also for any signal analysis. The conclusions reached as an outcome of the research work performed for this paper point to prospect avenues of analysis. Future research needs to be done to investigate under which conditions the pump generate cavitation. In order to successfully investigate this problem, a parameters based approach would be required. And also future work can focus on integrating the feature extraction efficiency of the wavelet transform with the classification capabilities of neural network for signal classification in the context of detecting the cavitation.
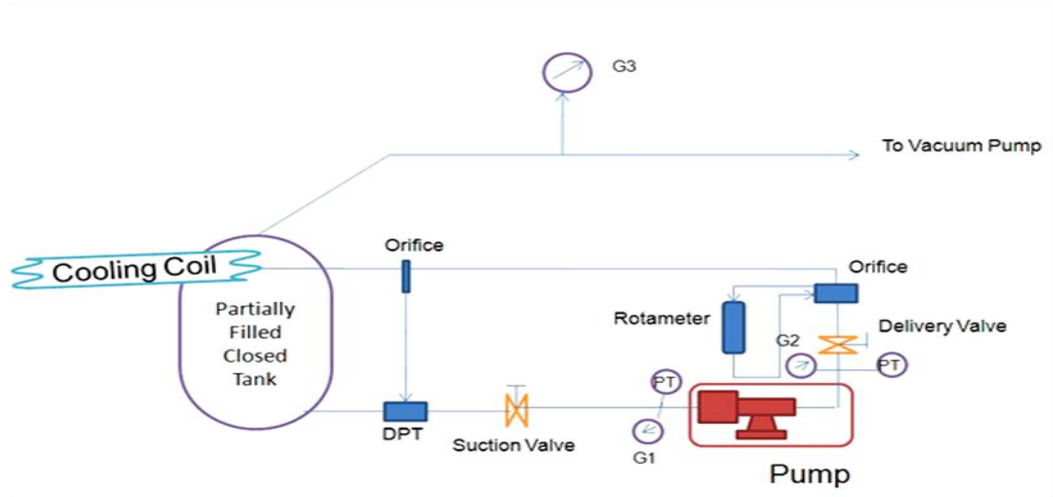
Fig 1: Schematic illustration of Experimental Test Loop

Table 2 Mean Value of db4 Wavelet Coefficients

Vacuum Pressure (mm of Hg)	d1	d2	d3	d4	d5
0	0.001273	0.000312	-0.0003197	-0.003067	-0.0009571
50	-0.001721	-0.0002037	0.007633	-0.00132	-0.02337
100	-0.0007855	-0.0002007	0.000305	-0.003299	-0.009273
150	-0.0002095	0.0009986	0.0001861	0.003006	-0.000234
200	-0.001129	0.0007532	0.0009549	0.00553	-0.02471
220	-0.0002196	-0.0006355	-0.0002649	-0.01128	0.001588
240	-0.001154	0.0004873	-0.0006655	-0.114	0.08928
260	-0.0001475	-0.000217	0.001353	-0.01158	0.02213
280	0.001155	0.0002889	0.002207	-0.03594	0.06113
300	-0.0003482	-0.002307	-0.0006033	-0.03712	-0.1564
320	-0.0004147	-0.001252	-0.004605	0.01521	-0.1924
340	-0.0001261	-0.0005213	-0.001106	-0.006392	-0.03711
360	-0.001296	0.0002093	0.001572	-0.01657	-0.06455
380	-0.001211	0.000832	0.00232	0.001325	-0.0348
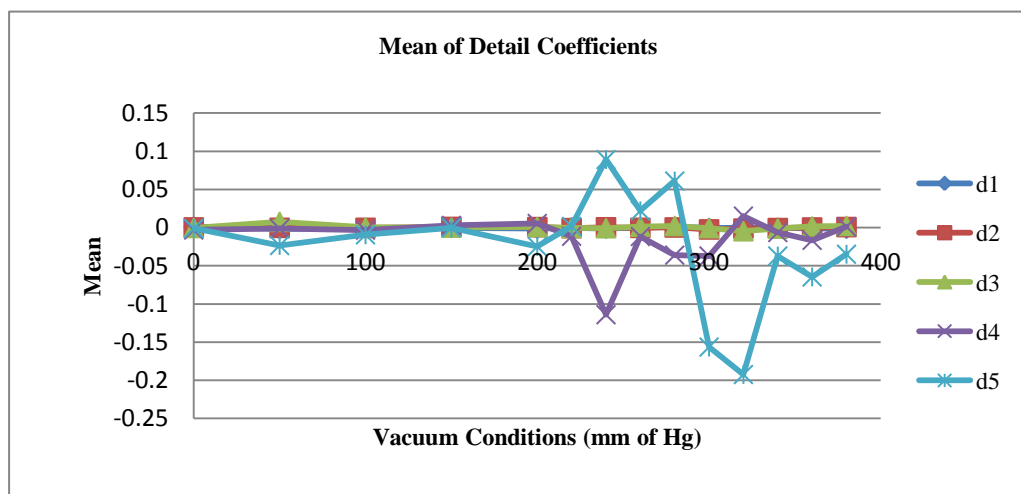
Fig 2: Mean Values of all five levels Detail Component Coefficients

Table 3 Classification results of DWT based algorithm for db4 wavelet

Parameters Considered	Suction Conditions Classified into	
	No Cavitation Signals	**Developed Cavitation Signals**
Mean value of Detail Components	0, 50, 100, 150 and 200 mm of Hg	220, 240, 260, 280, 300, 320, 340, 360 and 380 mm of Hg

6. ACKNOWLEDGMENTS

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