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APPLICATION OF ACOUSTIC SPECTRAL ANALYSIS TECHNIQUE FOR IN-SERVICE DETECTION OF PUMP DIAPHRAGM FAILURE

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Abstract

The main component of air-driven pumps are elastic diaphragms. These diaphragms are made from rubber or some other flexible material such as a thermoplastic elastomer. A method based on frequency analysis of the acoustic signal obtained from an air-driven pump during operation is described in this paper. A fully digital system for frequency analysis based on a personal computer was developed for practical implementation of this method. The system was tested under laboratory and in plant conditions. Two types of laboratory tests were performed: tests performed on diaphragm containing different types of artificial flaws and tests performed on different types of diaphragm. Three tests were performed under in plant conditions. The main goal of these tests were to demonstrate the ability of the system in early failure detection of the pump. The tests were performed under very high level of background noise and lasted between two days and two weeks in length. During this time the system performed acquisition and data processing at 10 seconds intervals. These tests have demonstrated that our system can indicate impending pump failure at least four hours before actual failure.

Introduction

Air driven pumps are used in applications where electricity cannot be used because of safety conditions or where special requirements indicate use of air driven pumps. The substances carried by this type of pumps include aggressive fluids such as solvents, radioactive waste, and gunpowder. In the event of failure of this diaphragm leakage of the substance being pumped occurs thought the air exhaust valve. The importance of this failure and its consequences depends on the nature of the fluid to be carried.

Monitoring of the diaphragm behaviour by inserting displacement devices inside the pump has met with limited success. The authors proposed a method based on the frequency analysis of the acoustic signal emitted by the elastic diaphragm during its normal operation in an air driven pump. This is a noncontact, nondestructive technique that is external to the diaphragm and, indeed to the pump itself.

Principle of the method

The main part of air driven pumps consists of two flexible diaphragms. They act as separation membranes between the compressed air supply and the liquid to be pumped. These diaphragms are made of flexible materials such as rubber or a thermoplastic elastomer. From the mathematical point of view the diaphragm can be considered as a thin circular plate clamped on its edges. The possibility of determining the effect of increasing pressure on one side of the diaphragm by frequency measurements is not a new idea. J.H. Powell and J.H.T Roberts [1] determined pressure-displacements curves in the elastic limit for metallic circular diaphragms. The Rayleigh-Ritz method was used [2] to find the frequency of the lowest mode of vibration. The relationship for the fundamental frequency for a circular plate having density ρ_d and oscillating in a medium with density ρ_m in conditions of non-isocronous oscillations was found to be:

$$f_1 = \frac{10.21}{a^2\sqrt{1+\beta}}\sqrt{\frac{gD}{\rho_d h}}\sqrt{\left(1+1.464\frac{a_1^2}{h^2}\right)} \quad (1)$$

where β is given by:

$$\beta = 0.6689\frac{\rho_m}{\rho_d}\frac{a}{h} \quad (2)$$

In relation (1), D is given by:

$$D = \frac{Eh^3}{12(1-\mu^2)} \quad (3)$$

In these relations the following notations have been used: *E*-Young's modulus; μ - coefficient of friction;*a* – diaphragm radius; *g* – acceleration of gravity; *h* – diaphragm thickness. Under dynamic conditions he diaphragm is subject to forced oscillations. The amplitude of the forced oscillations will increase by a factor proportional to the ratio of the frequency of the oscillating pressure (f) and the natural frequency (f_1) of the diaphragm. The expression of the amplitude of the forced vibration (y_n) as a function of static deflection (y_{sn}) and of the frequencies described above are derived in reference [3] for sinusoidal excitation with frequency f:

$$y_n = y_{sn}\frac{1}{1-\frac{f}{f_1}}\sin(2\pi f t) \quad (4)$$

The diaphragm reacts at this increased deflection by increasing its rigidity and oscillation frequency according to relation (1). The additional bending stress that appears may result in the gradual development of cracks, typically in the radial direction. Crack initiation and its propagation will cause a decrease in pressure applied to diaphragm and subsequently in its frequency response. The experimental set-up used to monitor the changes in frequency response of diaphragms is described in the next section.

Experimental implementation of the method

A digital system based on a PC-computer for data acquisition and processing was developed. A data acquisition board with 16 bit resolution and 200 Kc/s maximum sampling was used. Three analog input channels were used for these experiments. The acoustic signal from the pump was sensed using a miniature microphone. The electric signal from the microphone was amplified with a simple op-amp audio amplifier before being fed to the data acquisition board. The data acquisition board parameters were software selectable. For each channel, the input signal at given times was sampled in a sequence of 1024 data points. This sequence represented a measurement for one channel. The digital Fourier transform of each sequence was preceded by a windowing (Hamming window) applied to the input signal. All signal processing was software performed in the LabView environment. In addition to the data acquisition and digital signal processing, the software package performs other tasks such as: data display and save; spectra parameters extraction; post acquisition processing. The frequency peak (FP) and power peak (PP) were the parameters extracted from the spectra.

The measurements were performed 10 seconds apart, each measurement taking 10 seconds. A complex data structure was saved as a single record on the hard disk. This data structure has the following components: data; time; frequency peak for channel 1; power peak for channel 1; frequency peak for channel 2; power peak for channel 2 ; frequency peak for channel 3; power peak for channel 3. After each 180 measurements (one half hour) the full waveforms acquired from each channel were also included into the recorded data. In this way, sequential access to the recorded data was guaranteed and this then became available for off-line processing and display.

Results

Extensive laboratory work was necessary to identify the frequency component that can be related to the diaphragm behaviour under different operation conditions and to determine if the method is feasible. The experimental parameters necessary for in-plant experiments have been set following and based on these laboratory experiments. Three in plant experiments have been considerate to validate this method. In these tests the air pressure was set at or near the limit of the pump's specifications to encourage failure. The time when bubbles first appeared in the water tank was recorded by an operator as the pump's time of failure. The data recorded shows that the automated system responded promptly to the pressure variations in the pump (shutdowns). For a 1 minute shutdown a variation of 90% in the power peak between measurements recorded in two successive measurements (10sec apart).

Figure 1 shows the "failure initiation event" recorded in experiment 1. The peak that appears on 05/03 at 2 AM is the moment of failure initiation. This behaviour will be confirmed also in the next experiments. The failure was reported at 11:32 AM. Figure 5 shows a 50% drop in the frequency peak for channel 2, 270 minutes (at 7:00:20) before the reported time of failure. After the diaphragm's failure both channels recorded a decrease in the frequency peak.

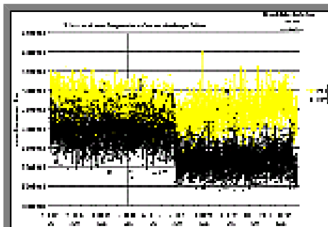

Fig 1: The data recorded on both channels for frequency peak in the last 9 hours of measurements. The red line marks the reported instant of failure. A large variation of the signal is noticed only on channel 2, 270 minutes (7:00 AM) before the reported instant of failure (11:32)

An "failure initiation event" as recorded in experiment 2 is shown in Figure 2. In this experiment a third channel was introduced. This channel was used to monitor a second pump in which diaphragm failure was not expected during the experiment. This channel is used as a monitor to indicate when the power was down and otherwise to have a controlled data set to compare to. Figure 2 shows a major change in the behaviour of pump 1 on July 18 at 6PM. A sharp decrease in the frequency peak on both channels was recorded. No change is observed on channel 3, corresponding to pump 2. At this point (6PM) the diaphragm on channel 2 begins to fail while the diaphragm corresponding to channel 1 seems to be intact. A similar decrease in frequency was recorded in experiment 1 (Fig. 1), 270 minutes before the reported time of diaphragm failure. Figure 2 shows that a difference between the behavior of CH1 and CH2 appears at 9PM. At this instant, a larger change corresponding to channel 2 (purple curve in Fig. 2) than that corresponding to channel 1 (yellow curve in Figure 2) is visible. No change is observed on monitor channel 3 (CH3).

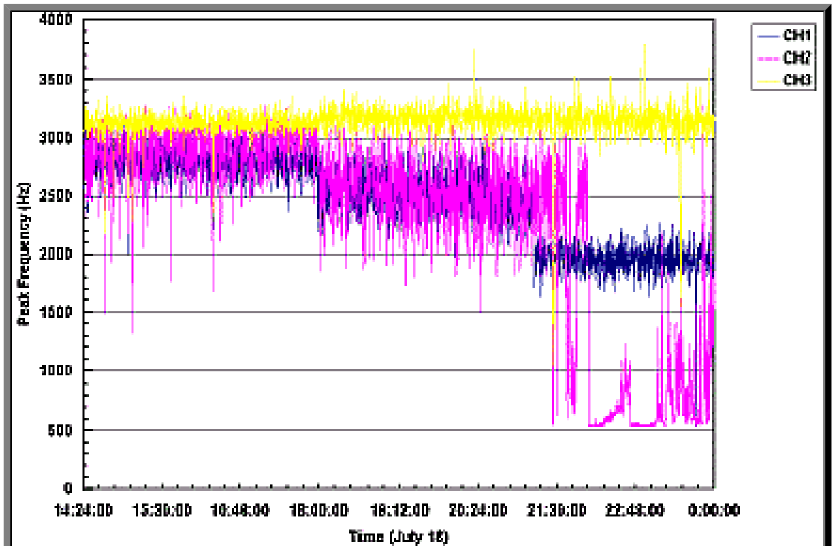

Fig 2: The data recorded on cannel 1 and channel 2 (blue and purple, respectively) show a large change in the operating condition of pump 1. No change is recorded for pump 2 (yellow)

The third experiment was performed between 07/23 and 08/06 2001. A total of 118715 recordings were saved. (partly to test the capability of the system to manage large amounts of data) with three separate failures all confirming the results above. The experiment consisted of three different tests. In these tests, the role of the monitor channel was played by each channel in turn. All failures have been recorded by the system.

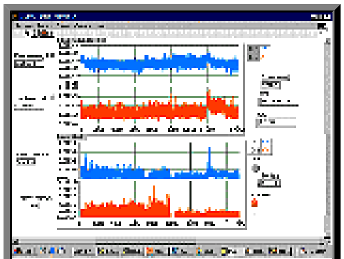
Fig 3: The control pannel of Labview application that allows data analysis.

Based on the previous results a Labview application was developed to signal the appearance of a "failure initiation event" based on preset threshold levels. The control panel of this application is shown in Figure 3. An "failure initiation **event" was signaled** on channel 2 at 10:23 AM in this experiment

Conclusions

This work proposes a new method for the detection of failure initiation in elastic diaphragms of air driven pumps. The method is based on frequency analysis of the acoustic signal transmitted during pump usage. Experimental tests were performed both in laboratory and in-plant conditions. The laboratory tests show that the presence of artificial flaws can be detected. In plant tests were between 2 days to two weeks long. In each test the failure initiation was demonstrated. Most importantly, the**re are about 4 hours** between the initiation of failure and the failure itself. This time lead ca be used t**o signal the** failure and to take corrective action.

References

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