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The application of Acoustic Emission for detecting incipient cavitation and the best efficiency point of a 60KW centrifugal pump; case study

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Abstract

Pumps play a significant role in industrial plants and need continuous monitoring to minimise loss of production. To date, there is limited published information on the application of Acoustic Emission (AE) to incipient pump cavitation. This paper presents a case study where AE has been applied for detecting incipient cavitation and determining the best efficiency point (BEP) of a 60KW centrifugal pump. Results presented are based on NPSH (Net Positive Suction Head) and performance tests. In conclusion the AE technique was shown to offer early detection of incipient cavitation, furthermore, the technique has demonstrated the ability to determine the BEP of a pump.

Keywords: Acoustic Emission, best efficiency point, cavitation, condition monitoring, pump performance

1. Introduction

Pumps are used in most of our domestic and industrial applications. Every pump manufacturer supplies characteristic curves for their equipment illustrating pump performance under given conditions. These curves demonstrate the inter-relationship between discharge capacities, pump head, power and operating efficiency. The ideal operating point for a pump is known as the best efficiency point (BEP). This is the point where pump capacity and head pressure combine to provide the maximum efficiency of the pump. If the pump operates outside the BEP, not only will its efficiency be compromised, but it will be subject to increased wear, reducing operational life.

Typically the pump manufacturer will undertake performance and NPSH (Net Positive Suction Head) tests on supplied pumps, the significance of the latter is to determine the 3% drop in head at which serious cavitations will occur. The NPSH can be expressed as the difference between the suction head and the liquids vapour head. The concept of NPSH was developed for the purpose of comparing inlet condition of the system with the inlet requirement of the pump. Cavitation causes a loss of pump efficiency and degradation of the mechanical integrity of the pump. It must be noted that cavitation starts to develop before the 3% drop in head. It is generally accepted that the critical pressure for inception of cavitation is not constant and varies with operation fluid physical properties and the surface roughness of the hydraulic equipment.

Application of the high frequency Acoustic Emission (AE) technique in condition monitoring of rotating machinery has been growing over recent years [1-9]. Typical frequencies associated with AE activity range from 20 KHz to 1MHz. The most commonly used method for identifying the presence of cavitation is based on observations of the drop in head. Whilst other techniques such as vibration analysis and hydrophone observations for pump fault diagnosis are well established, the application of AE to this field is still in its infancy. In addition, there are a limited number of publications on the application of AE to pump health and cavitation monitoring.

Derakhshan et al [10] investigated the cavitation bubble collapse as a source of acoustic emission and commented that the high amplitude pressure pulse associated with bubble collapse generated AE. With the AE sensor was placed on the actual specimen experiencing cavitation Derkhshan observed increasing AE r.m.s levels with increased pressure of flow and cavitation. However, with the AE sensor mounted on the tank wall the reverse was observed, decreasing AE r.m.s levels with increasing pressure and cavitation. This was attributed to a visible bubble cloud that increased with pressure. It was commented that this cloud attenuated the AE signature prior to reaching the transducer on the wall casing. Neill et al [11,12] assessed the possibility of early cavitation detection with AE and also noted that the collapse of cavitation bubbles was an impulsive event of the type that could generate AE. It was observed that when the pump was under cavitation the AE operational background levels dropped in comparison to non-cavitating conditions. In conclusion Neill stated that loss in NPSH before the 3%

drop-off criterion was detectable with AE and evidence of incipient cavitation was detectable in the higher frequency band (0.5 to 1MHz).

The papers reviewed above have clearly associated AE with the collapse of cavitation bubbles. The presence of cavitation has been shown to increase or decrease operational AE noise levels [10, 11, 12]. This paper presents a case study to ascertain the applicability of the AE technique for detecting incipient cavitation, and, to access the opportunities offered by the AE technique for determining the best efficiency point (BEP) of a pump.

2. Experimental setup

A series of performance and NPSH tests were undertaken on a two stage 'David Brown' 60KW centrifugal pump (Model DB22) with a maximum capacity of 204m^3/h at an efficiency of 70.6%. These tests were undertaken using a closed loop arrangement with a vacuum facility in accordance with BS 9906. It must be noted that best endeavours were undertaken to reduce the time taken to reach the required flow rate during performance and NPSH tests.

Acoustic Emission sensors were located at a distance of 0.5 m from suction flange; at the suction flange; on the pump casing in the vicinity of impeller suction eye; on the casing in the vicinity of the impeller discharge tip; 0.5m from discharge flange, see figure 1.

3. Data acquisition systems

The AE sensors used for all of the experiments were broadband type sensors with a relative flat response in the region between 100 KHz to 1MHz (Model: WD, 'Physical Acoustics Corporation'). The output signal from the AE sensors was pre-amplified at 40dB. Continuous AE r.m.s values were calculated in real time by the Analogue to Digital Converter (ADC). The sampling rate for acquisition was set at 100ms for all tests and the time constant for calculating the AE r.m.s was also set at 100 ms.

Figure 1 60KW centrifugal pump which underwent perfomance and NPSH tests showing AE sensor locations

4. Experimental results and observations

4.1 Performance test

Figure 2 details the performance characteristics of the pump, highlighting the BEP at 94.5m^3/hr. The performance test were undertaken twice to ensure repeatability. Observations of AE r.m.s activity during the performance test are displayed in figure 3. During the performance test, AE activity from the sensor located in the vicinity of impeller on pump casing was found to have the largest magnitude, providing the best position for correlating AE activity to pump performance. It was observed that the minimum AE r.m.s value was obtained for a flow rate of 94.5m^3/hr. At this flow rate the AE activity generated from the fluid flow within the pump and pipes was lowest in comparison to other flow rates. Either side of this flow rate resulted in increasing AE r.m.s activity with increased flow rates. Based on these observations it was concluded that the BEP must occur where there was minimal flow turbulence in the system, and hence minimum AE activity. The predicted efficiency point of 94.5m^3/hr was checked with the manufacturer's performance test and was found to be accurate. Interestingly this is the first known correlation between AE activity and the BEP and agrees with observations of McNulty [13], though McNulty's investigation was centred at frequencies in the audible range; lower than the AE range. The advantage offered by the AE technique is the inherent rejection of typical mechanical and process operational background noise (less than 20 KHz).

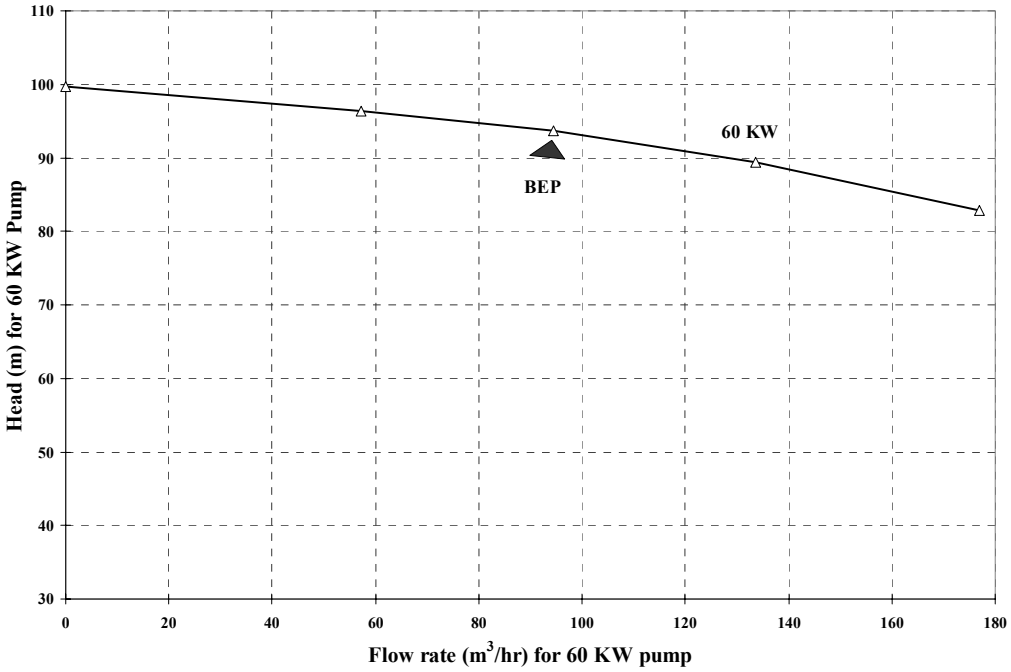

Figure 2 **Performance test result of the 60 KW centrifugal pump**

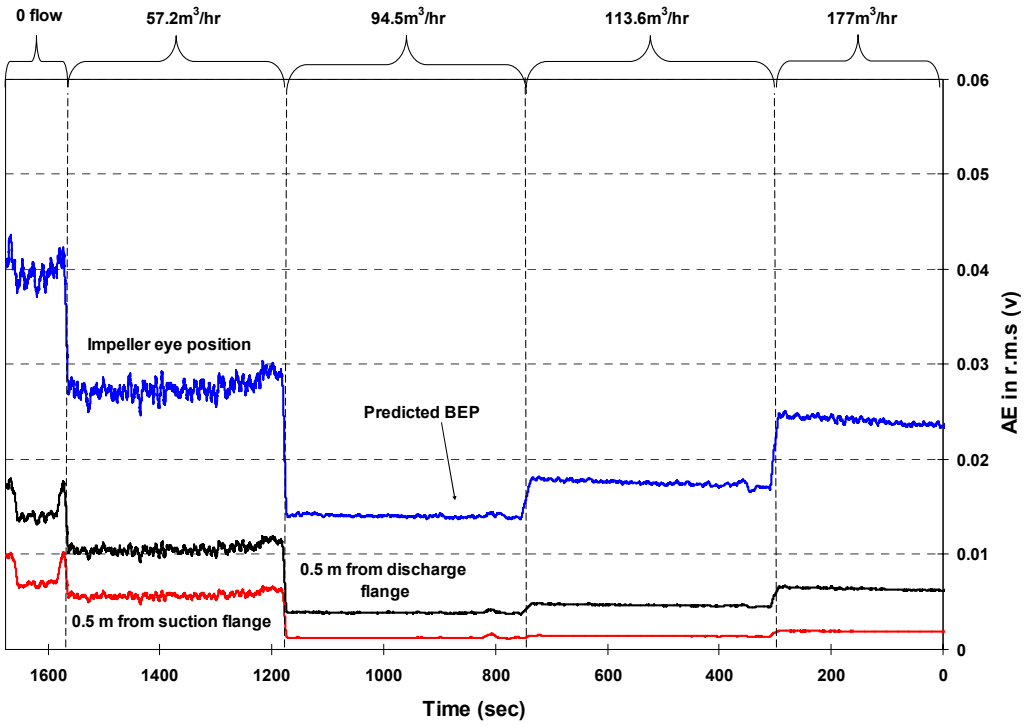

Figure 3 **AE r.m.s levels associated with the performance test**

4.2 NPSH tests

A total of three NPSH tests were undertaken at flow rates of 101, 141 and 180m^3/hr, see figure 4. As with the performance tests, the best AE signature response was located on the pump casing in the vicinity of the impeller eye.

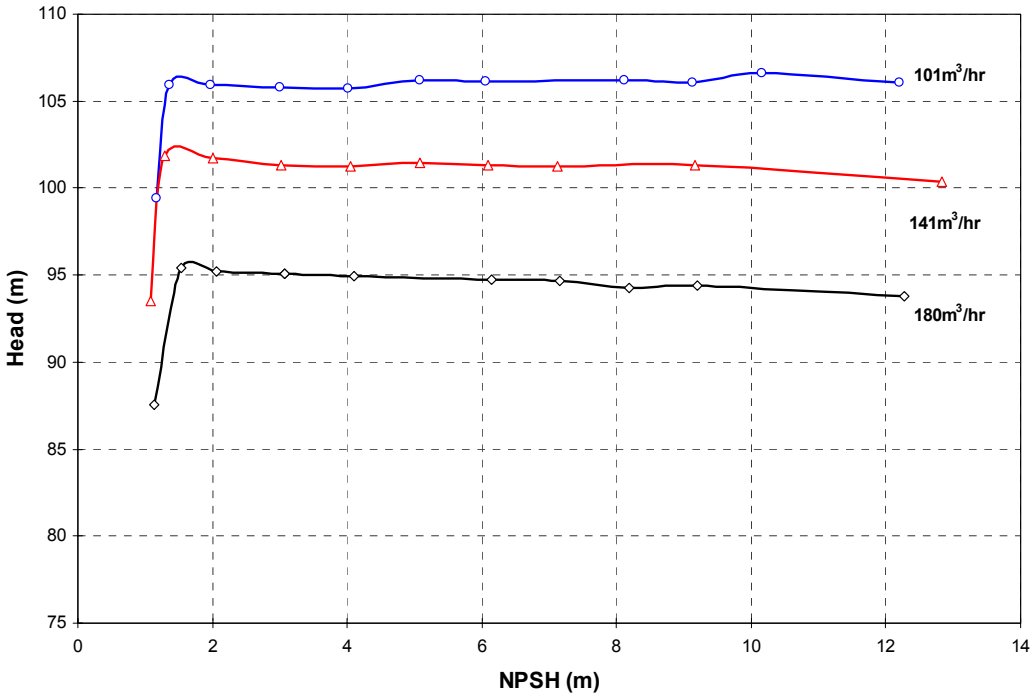

Figure 4 NPSH test results for 60 KW pump at flow rates 101, 141 and 180 m^3/hr

Figures 5 to 7 detail the associated AE r.m.s levels for the three flow rates considered. The following observations were noted:

i) At a flow rate of 101m^3/hr an increase of 165% in AE r.m.s levels was observed from an NPSH value of 8.2m to 7m. Relatively constant levels followed until an NPSH of 5.8 m when a rapid decrease in AE r.m.s levels was noted. With further reductions in NPSH, spikes in AE r.m.s signal

response were observed as the 3% drop in head was reached. This phenomenon of spiky AE r.m.s levels associated with cavitation was also observed by Neill [11]. Observations of AE levels from the suction and discharge pipes mirrored this observation.

ii) At a flow rate of 141m^3/hr an increase of 43% in AE r.m.s was observed at NPSH value of 12.7m to 9.3m. A rapid decrease in level was noted at an NPSH of 9.3m. With further reductions in NPSH, spikes in AE r.m.s signal were observed as with the test a flow rate of 101m^3/hr. Again, observations of AE levels from the suction and discharge pipes mirrored this observation.

iii) At a flow rate of 181m^3/hr an increase in AE r.m.s of 223% was observed at NPSH value of 11m to 7.3m. A gradual decrease in the AE levels followed to an NPSH of 1.7 m, where an increase in the r.m.s value was observed.

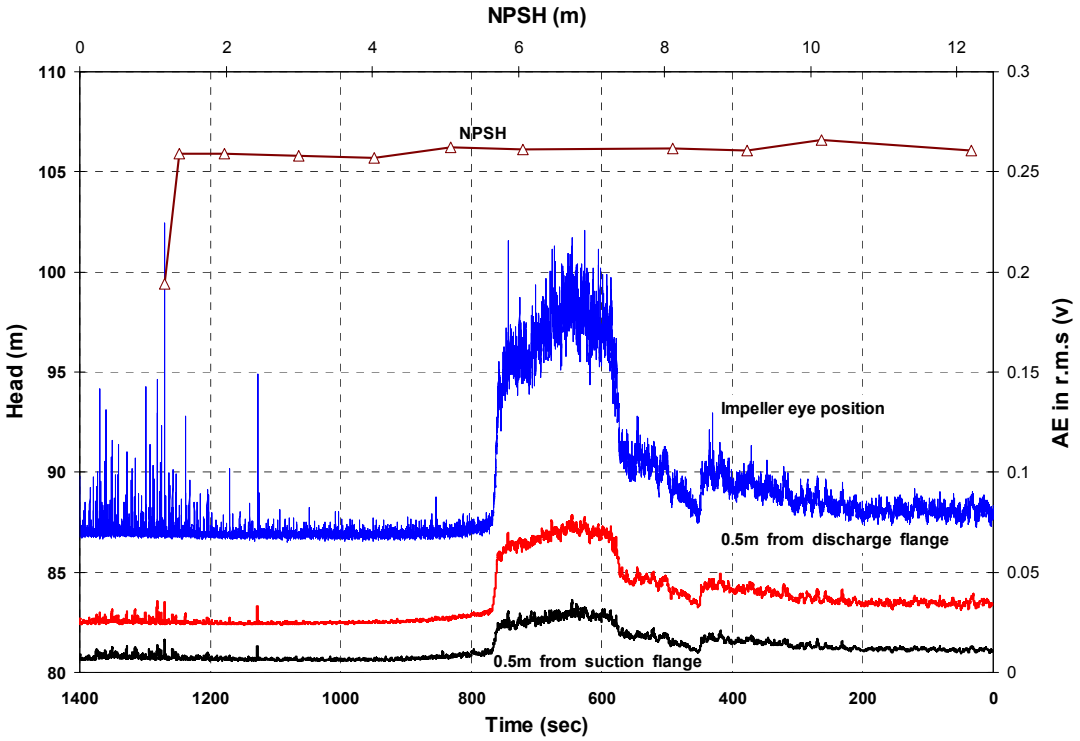

Figure 5 AE r.m.s levels at a flow rate of 101m^3/hr

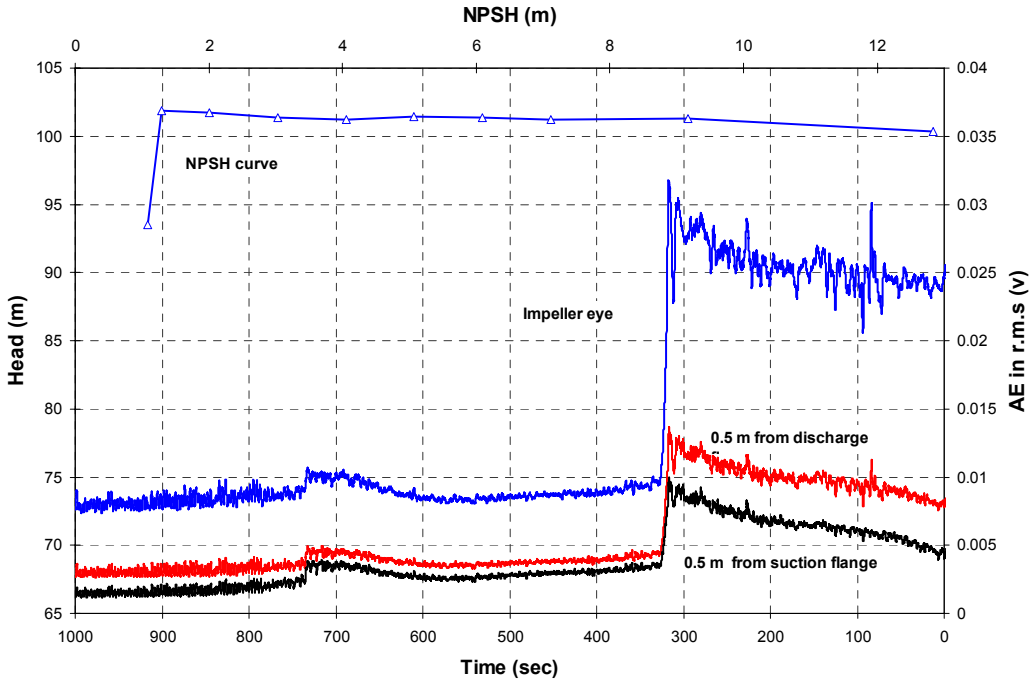

Figure 6 AE r.m.s levels at a flow rate of 141m^3/hr

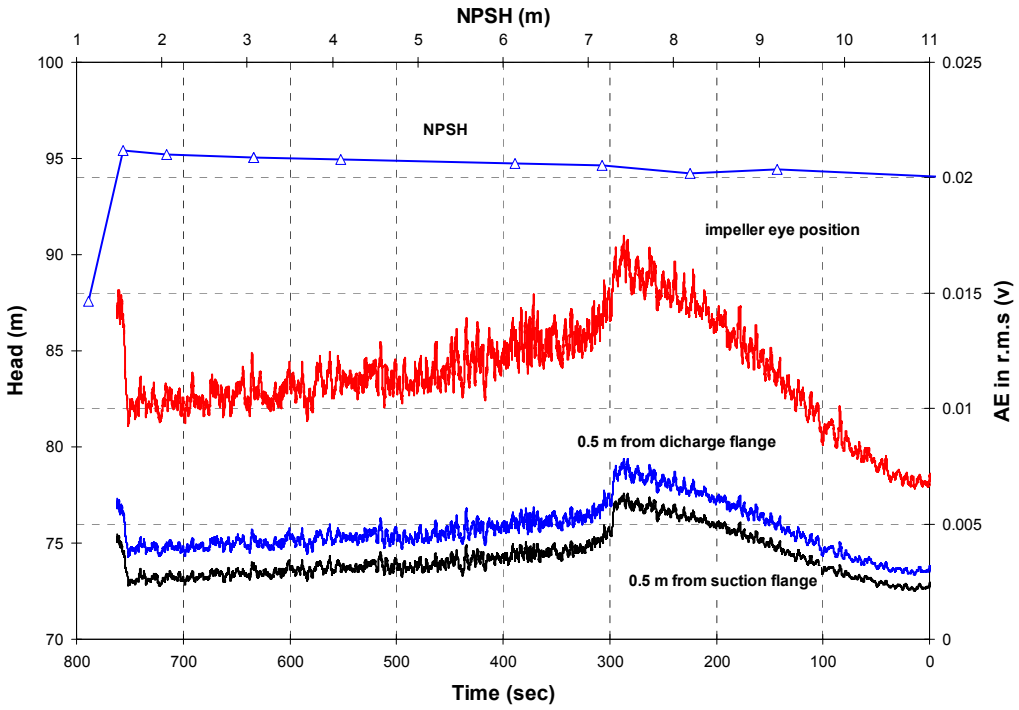

Figure 7 AE r.m.s levels at a flow rate of 180m^3/hr

6. Discussions

6.1 Performance test

The observations of AE activity during the performance test were very encouraging. The ability to predict a systems BEP by observing variations in the AE r.m.s response offer process engineers a powerful tool for monitoring plant performance. Whilst further research is still required the opportunities offered by such a tool could be applied to determining system BEP irrespective of the type of medium (liquid, gases, semi-solids, etc) in the system. The observations noted in this investigation correlate with hydrophone

measurements undertaken by McNulty [13], where the minimum sound intensity coincided with the pump BEP.

6.2 NPSH test

It is essential to understand the cavitation sequence if it is to be correlated to observed AE activity. Once the suction pressure starts to decrease, vortexes start to occur at the impeller blade tips. With further reduction in pressure these vortexes take the form of travelling bubbles in the liquid. These bubbles are initially created in lower pressure area on the suction surface of the blades. Eventually the bubbles move to higher-pressure areas where they collapse. With even further reduction in the suction pressure, the bubbles combine into larger cavities. These cavities are usually formed on the impeller blade suction surface.

For all NPSH tests an increase in AE r.m.s levels was noted as values of NPSH started to decrease. A maximum level of AE r.m.s was reached after which further reductions in NPSH resulted in a decrease in AE r.m.s levels. This was also observed on the sensors located on the suction and discharge flanges. It is postulated that at the start of the NPSH test the increase in AE r.m.s levels was attributed to the onset of cavitation. The drop in AE r.m.s with decreasing NPSH values was attributed to the attenuation caused by bubble clouds. Following the creation of bubbles, and the eventual formation of the bubble cloud, the AE r.m.s levels were expected to drop. The loss in AE strength due to

the presence of cavitation and the bubble cloud was noted by Neill [11, 12] and Derakhshan [10] respectively.

6. Conclusions

The results from acoustic emission analysis have shown a clear relationship between AE activity measured from the pump casing, suction and discharge pipes, and incipient cavitation. At a relatively high NPSH value, when incipient cavitation is known to occur, an increase in AE r.m.s levels was observed. However, as cavitation developed a reduction in AE r.m.s levels due to attenuation was noted. This would suggest that the AE technique is more suited to detecting incipient, and not developed, cavitation. AE was also found to have enormous potential in determining the BEP of a pump and/or process employing pumps though further research on this observation is required.

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