Detection of incipient cavitation and the best efficiency point of a 2.2MW centrifugal pump using Acoustic Emission

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Abstract

Pumps play a significant role in industrial plants and need continuous monitoring to minimize loss of production. This paper investigates the application of Acoustic Emission (AE) for detecting incipient cavitation. In addition this paper presents results from an on-going programme to ascertain the applicability of the AE technique for determining the best efficiency point (BEP) of an operating system. A large-scale pump rig (2.2MW) formed the basis of this investigation that included a series of NPSH (Net Positive Suction Head) and performance tests. Results obtained demonstrate the successful use of the AE technique for detecting incipient cavitations and identifying the BEP for a system employing pumps.

Introduction

Pumps are generally 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, or BEP. This is the point where pump capacity and head pressure combine to provide the maximum efficiency of the pump. If the pump operates too far to the left or right of the BEP, not only may its efficiency be compromised, but it can also be subjected to increased wear, reducing operational life. In specifying pump requirements the purchase would attempt to simulate the actual operating conditions that the pump will experience. This is always an approximation and as such most processes employing pumps may not operate at the most efficient point.

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 Net Positive Suction Head (NPSH) can be approximated as the difference between the Suction Head and the Liquids Vapor Head. The concept of NPSH was developed for the purpose of comparing inlet condition of the system with the inlet requirement of the pump. It must be noted that cavitations start to develop before the 3% drop in head. Cavitation causes a loss of pump efficiency and degradation of the mechanical integrity of the pump. 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 [1-5]. Typical frequencies associated with AE activity range from 20 kHz to 1MHz. None of the currently employed diagnostic techniques can provide an early indication of cavitation. The most commonly used method 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 [6] investigated the cavitation bubble collapse as a source of acoustic emission and commented that the high amplitude pressure pulse associated with bubble collapse generate AE. It is interesting to note that 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 [7,8] assessed the possibility of early cavitation detection with AE and 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. It is worth stating that prior to, and during cavitation, vibration measurements showed no significant change. In conclusion Neill stated that loss in NPSH before the 3% drop-off criterion was detectable with AE. Hutton [9] investigated the feasibility of detecting AE in the presence of hydraulic noise. It was noted that artificially seeded AE bursts were detected above background operational noise for turbulent flow, with and without cavitations. Furthermore, Hutton noted that the presence of cavitations in the system increased the operational AE noise levels by a factor of 50. In addition, cavitation was found to generate a significant increase in noise level up to about 800 kHz.

The papers reviewed above have clearly associated AE with the collapse of cavitation bubbles. This paper presents results from an on-going programme to ascertain the applicability of the AE technique for determining the best efficiency point (BEP) of an operating system, and, the opportunities offered by the AE technique for detection of incipient cavitations. The results presented were centered on a 2.2MW centrifugal pump.

Sensors and Acquisition Systems

The AE sensors used for this experiment were broadband type sensors with a relative flat response in the region between 100 KHz to 1MHz (Model: WD, ‘Physical Acoustics Corporation’). AE sensors were located at five deferent positions; at a distance 6 ft from the pump suction flange; one foot from the suction flange, on the pump casing in the vicinity of the impeller suction eye; on the outboard bearing housing and one foot from pump discharge flange. 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 Analog to Digital Converter (ADC) controlling software. This software employed a hardware accelerator to perform calculations in real time. The hardware accelerator takes each value from the ADC and squares it. These results are added into an accumulator for a programmable time interval set by the user, 100 ms in this instance. The accumulator is cleared at the start of the time interval, and the accumulator value will only be stored at the end of the time interval. The r.m.s is then calculated by taking the square root of the sum of the accumulated squared ADC readings. The time interval for acquisition was also set at 100 ms.

Experimental setup and results

Two tests were undertaken; a pump performance test and an NPSH test. The pump employed was a 2.2MW David Brown Pump (Model DB34-D) with a maximum capacity of 2210 m^3/h at an efficiency of 85.54 %. These tests were undertaken using a closed loop arrangement with a vacuum facility in accordance with BS 5316. Acoustic Emission sensors were located at positions already described. Figure 1 shows the test pump. It must be noted that best endeavors were undertaken to reduce the amount of time required to reach the required flow rate during tests.

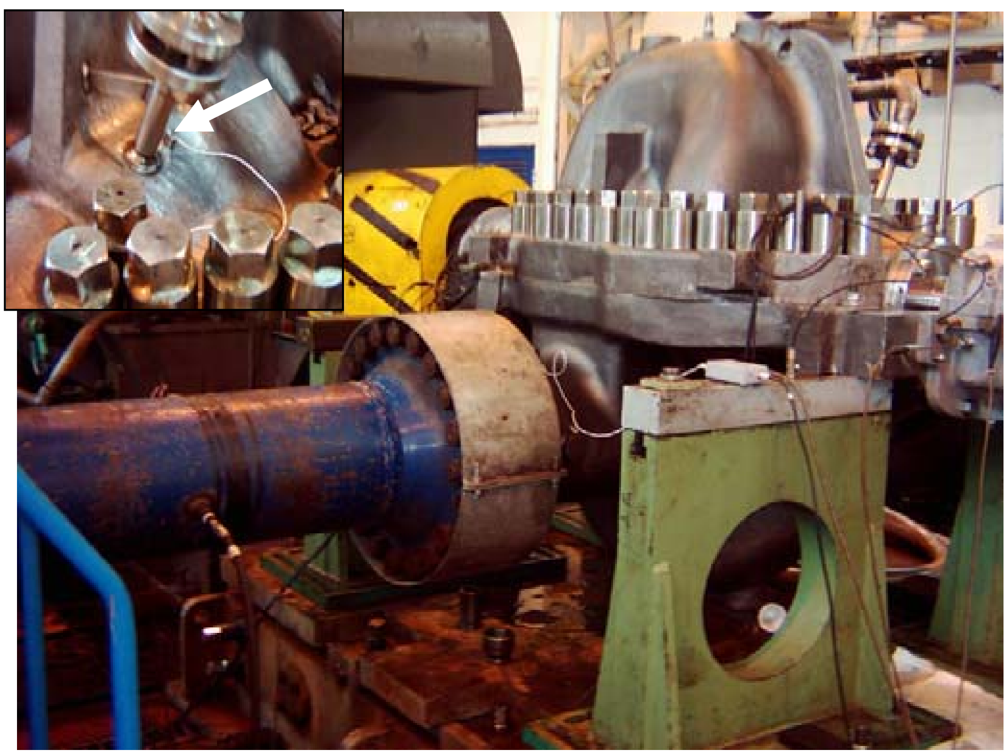

Figure 1 2.2MW centrifugal pump which underwent perfomance and NPSH tests (insert: location of AE sensor on the pump casing in the vicinity of the impeller suction eye

Figure 2 details the performance characteristics for seven test points (flow rates) with the BEP at 1760 meter^3/h. 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. Three separate NPSH were conducted at deferent flow rates 1686, 2192 and 1150 respectively. A result of the NPSH test at flow rate 1686 meter^3/h is shown in figure 4, while figure 5 highlights the AE r.m.s activity during the NPSH test.

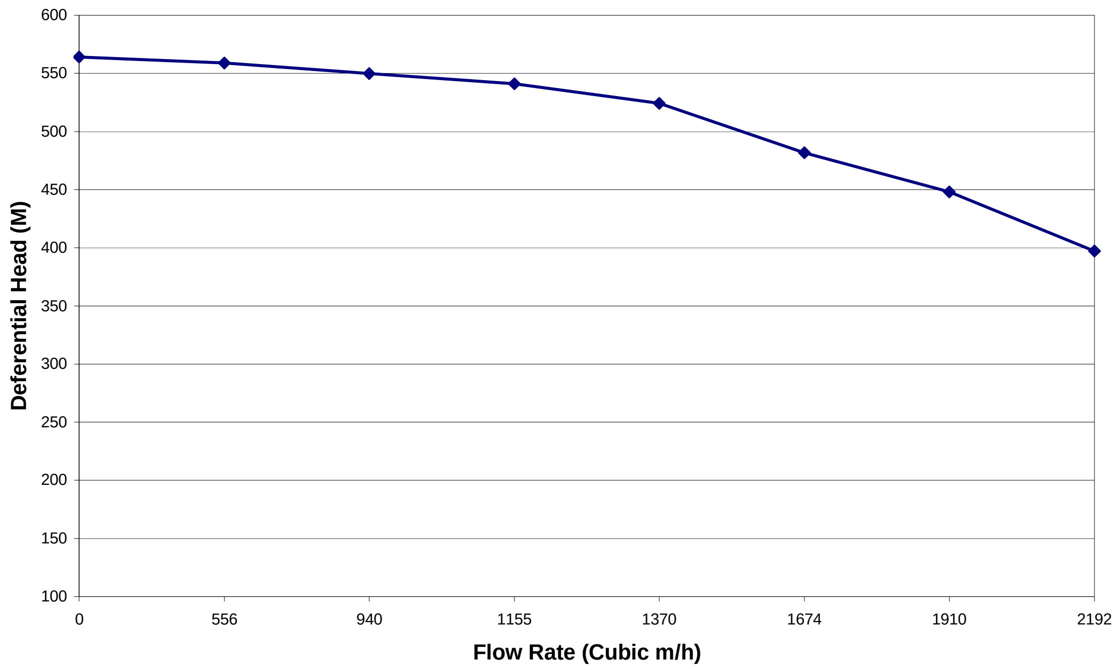

Figure 2 Performance test result

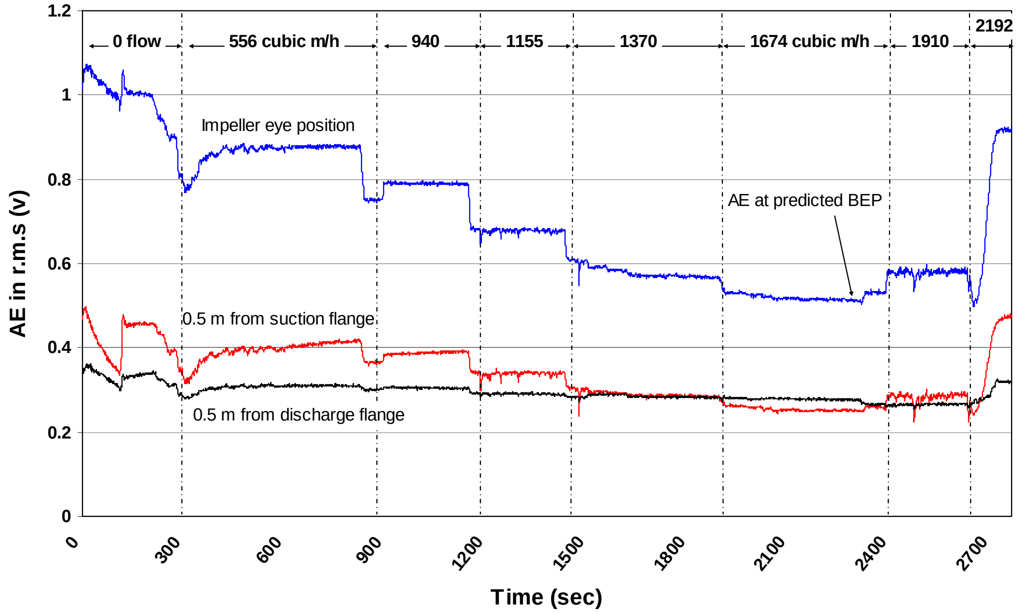

Figure 3 **AE r.m.s observations during performance test**

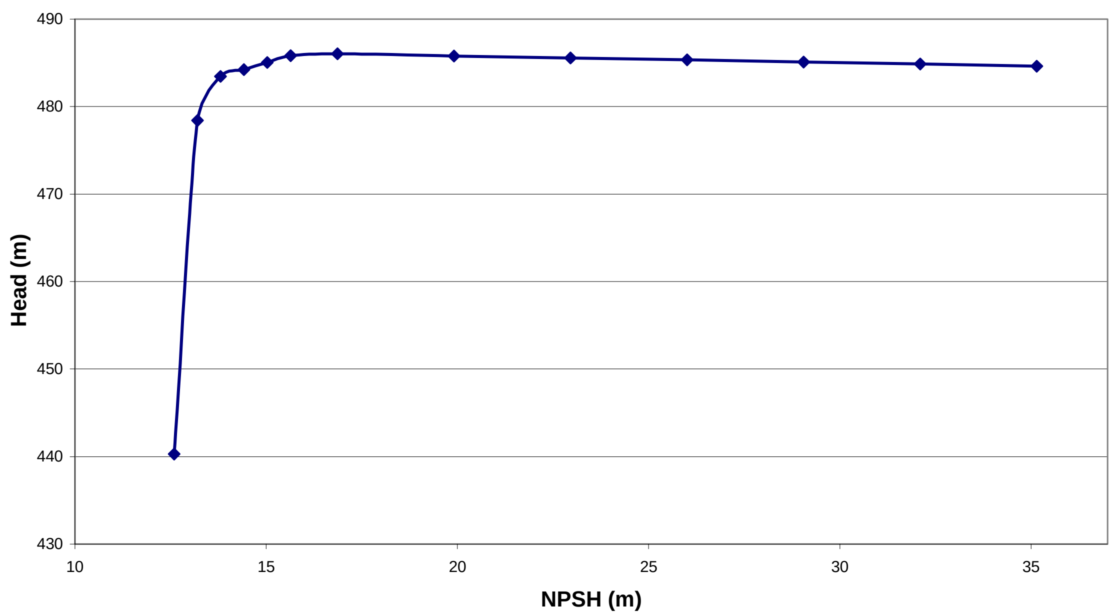

Figure 4 **Deferential Head vs. NPSH at flow rate 1686 meter^3/ h**

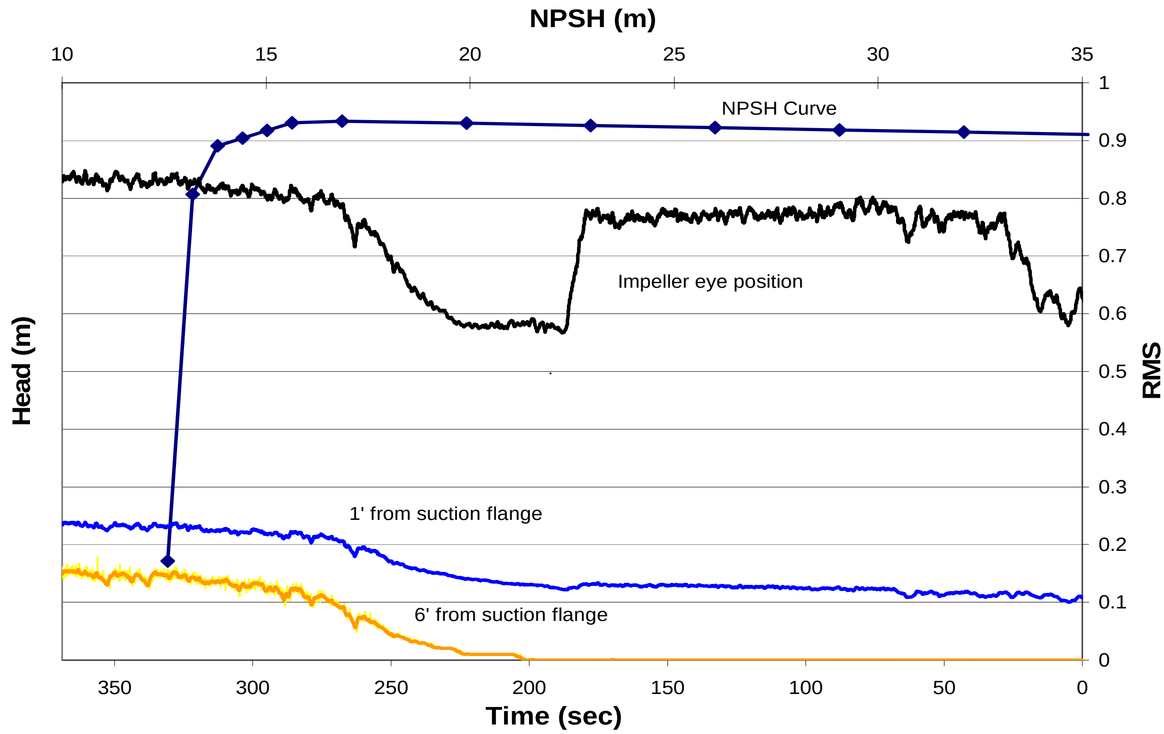

Figure 5 AE r.m.s activity during NPSH testing

Discussions

During the performance test, AE activity from the pump casing was found to have the largest magnitude, providing the best position for correlating AE activity to pump performance, see figure 3. It was observed that the minimum AE r.m.s value was obtained for a flow rate of 1830 m^3/hr. At this flow rate the AE activity generated from the turbulent flow within the pump and pipes, and associated interaction with boundaries, was lowest. 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 when there was minimal flow turbulence (loss of energy) in the system, and hence minimum AE activity. The predicated efficiency point of 1830 m^3/hr was checked with the manufacturers performance test and was found to be accurate within 70m^3/hr or 4%. The difference is attributed to experimentation and approximations made in estimating the BEP.

During the NPSH tests an increase in AE r.m.s (0.6 to 0.77V) was observed at the start of cavitation, see figure 5. Relatively constant AE r.m.s levels followed until an NPSH of 23m when a rapid decrease in AE r.m.s levels was noted. With further reductions in NPSH the AE r.m.s levels rose again to the original levels prior to the sudden drop at 23m. 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 traveling 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 [10].

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. At an NPSH value of 23m the sudden drop in AE r.m.s was attributed to the attenuation caused by bubble clouds. The loss in AE strength due to the presence of cavitation was noted by Neill [7,8] and Derakhshan [6]. This is not surprising if cognisance is taken on the findings of Derakhshan [6] and Hutton [9] where it was noted that where direct contact between the cavitating liquid and the housing structure (pipe) existed, increases in AE activity correlated directly with increasing cavitation. In the case of the AE sensor mounted on the impeller casing, direct contact is not made with the impeller itself but rather the casing, and again as noted by Derakhshan [6] this arrangement causes a decrease in AE activity with increasing cavitation. At an NPSH of 19m, the AE r.m.s values increased again and eventually reached a level similar to original r.m.s levels attributed to incipient cavitation. This is due to the interaction between the high and low-pressure faces of the impeller, as ‘back flow’ (flow from the high pressure to low pressure regions of the impeller) will occur. This fluid circulation introduces more turbulent flow and further bubble collapse on the high-pressure side of the impeller, raising AE activity [10]. At an NPSH of 13m the 3% drop had been reached. Interestingly observations of AE r.m.s levels form the suction flanges showed continuous increase in levels with decreasing NPSH.

Conclusions

The results from acoustic emission analysis have shown a clear relationship between AE activity and the rate of cavitation. An increase in the AE r.m.s value was observed prior to the 3% head drop criteria. At a high NPSH value, when incipient cavitation is known to occur, significant increase in AE was observed. From several NPSH test at different flow rates, it was noted that the best correlation between AE activity and cavitation were obtained for flow rates close to the BEP. Experiments have been conducted for several flow rates to validate this assumption. AE was also found to have enormous potential in determining the BEP of a pump and/or process employing pumps. The sensor position was found to have a significant influence on the measured AE signal with the best position for placing the AE sensor was on the pump casing in the vicinity of the impeller.

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