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Experimental Investigation of the Effect of Suction Valve Opening on the Performance and Detection of Cavitation in the Centrifugal Pump Based on Acoustic Analysis Technique

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The pump performance and occurrence of cavitation directly depends on different operating conditions. To cover a wide range of operation conditions for detecting cavitation in this work, investigations on the effect of various suction valve openings on cavitation in the pump were carried out. In order to analyse various levels of cavitation in different operation conditions, the effect of the decrease in the inlet suction pressure of the centrifugal pump by controlling the inlet suction valve opening was investigated using this experimental setup. Hence, the acoustic and pressure signals under different inlet valve openings and different flow rates, namely, 103, 200, 302 l/min were collected for this purpose. A detailed analysis of the results obtained from the acoustic signal was carried out to predict cavitation in the pump under different operating conditions. Also, the acoustic signal was investigated in time domain through the use of the same statistical features. The FFT technique was used to analyse the acoustic signal in the frequency domain. In addition, in this work an attempt was made to find a relationship between the cavitation and noise characteristics using the acoustic technique for identifying cavitation within a pump.

Keywords: centrifugal pump; cavitation; suction valve opening; acoustic analysis technique.

1. Introduction

Generally, most of the industrial processes require the transfer of fluids from one place to another. Therefore, the pump is an indispensable and essential component for industry, as it is extensively used for the above purpose. Pumps are used in many applications, such as agriculture, nuclear power plants, chemical plants, pharmaceutical and petroleum plants (Nelik, 1999; Wee, 2011; Spraker, 1965; Girdhar, 2004). Centrifugal pumps are widely used in industry and the reasons behind that are their high efficiency, a wide range of applications, ease of maintenance and operation. Cavitation is an unwanted phenomenon in a centrifugal pump as it causes reduction in efficiency, and increase in vibration, noise, and erosion. When cavity implosions are sufficiently strong, cavitation erosion occurs and may affect nearby solid material. Cavitation erosion can be recognised through the specific rough marks on the surface of the pump components when it runs under cavitation conditions for a lengthy period of time (Brennen, 1994). This mechanism is related to the phenomenon where the collapsing bubbles become unstable resulting in their collapse on a nearby solid surface. Observations reveal that the development of spherical asymmetry takes the shapes of a rapidly accelerating jet liquid, allowing the bubble to enter from the furthest side of the wall as shown in Fig. 1 (Lohrberg, 2001).

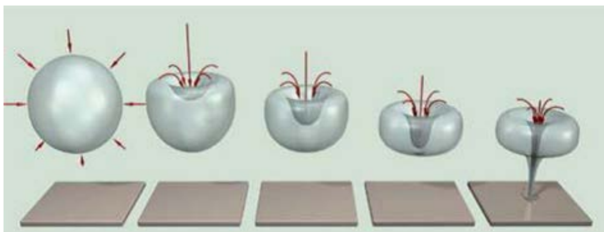

Fig. 1. Collapse of bubbles due to cavitation.

The process of cavitation produces more noise in the pump; such mechanism termed cavitation noise occurs due to the liquid pressure in the inlet eye of impeller. This decreases the liquid vapour pressure resulting in very small bubbles emerging and collapsing randomly as a consequence of cavitation. Thus, such random bubbles create turbulent acoustic that can be analysed in time and frequency domains. The noise in a centrifugal pump can occur due to internal pressure fluctuations in the tongue region and a number of various mechanisms (e.g. turbulence, flow instabilities, cavitation, high velocities and internal recirculation) (Chudina, 2003). Generally, when the pump works at a condition higher than design flow rate, it might produce more turbulence or cavitation, as illustrated in the previous chapter. Whereas when the pump operates under low flow rate conditions, the pump may face further internal recirculation. Differences in flow rates induce more pressure variation and eventually lead to the occurrence of high acoustic, which leads to an increase in noise level of the pump (Guelich, 1992; Ramroop, 2001; Jones, 2006; Grist, 1998). The higher frequencies appear either as a result of interaction between the flowing liquid and the moving components (e.g. impeller blades, impeller with volute, and cooling fan) or due to the interaction between the rotating impeller blades with the nearby volute parts. The flow field and detection of cavitation within a centrifugal pump was investigated by many researchers using acoustic and vibration signals, for example, the work done by Chudina (2003) used noise as an indicator in investigating cavitation within the pump. The author carried out analysis of the noise signal in frequency domain under different operating conditions. The results showed that the cavitation increased at high flow rate, particularly, at the high range of frequency. Černetič *et al.* (2008) detected and monitored cavitation in the pump by using vibration and acoustic signals. They used two types of centrifugal pumps, the first one was a closed impeller with six blades and made of metal alloy, the second one was semi open impeller with six blades and made of plastic material. The results showed that each pump has different vibration spectra and noise levels with various discrete frequencies. In addition, they found that the difference between vibration and noise under cavitation and non cavitation conditions was between 30 to 40 dB. Albraik *et al.*. (2012) investigated and diagnosed centrifugal pump faults through the use of vibration signal. They used a closed impeller pump with some parameters of the pump considered in their design such as $Q = 30\ \text{m}^3/\text{h}$, $H = 55$ m, $N = 2900$ rpm. They predicted the relationship between the NPSHA and NPSHR by decreasing the discharge valve progressively with the suction valve fully opened. NPSHR for the system increased when flow rate increased. The results showed that when the flow rate increases the level of vibration increases as well. Luo *et al.* (2015) made research of statistical features of vibration signals in the centrifugal pump. The parameters used for the test pump were $Q = 50\ \text{m}^3/\text{h}$, $H = 32$ m, and $N = 2900$ rpm. The number of blades used for their impeller was six, impeller inlet and outlet diameters sizes were 75 mm and 174 mm, respectively. The results showed that when the pump worked under flow instability conditions, the dynamic characteristics of the pump changed. Therefore, the statistical analysis of vibration signal (probability density factor PDF, standard deviation, and kurtosis) could be used to predict unstable flow in the pump. The statistical features of vibration signal in time and frequency domains were good indicators for predicting intensity changes and the onset of cavitation in the pump. Čdina (2003) detected cavitation in the pump using the sound signal. The specifications of the pump were as follows: $Q = 0.150\ \text{m}^3/\text{s}$, $H = 80$ m, and $N = 2535$ rpm. The noise occurrence on the pump depends on the flow rate, speed of the pump, and the instability of the pump. Moreover, instability can occur due to cavitation causing vibration, noise, deterioration of the performance of the pump, material erosion, and pitting. Čudina and Prezelj (2009) detected cavitation in pumps using the acoustic method. The results of their study showed that the spectrum of the acoustic related to inception and development of cavitation within a pump. In addition, the level of the spectra frequency peak increased with the inception of cavitation, which further increased with the development of the cavitation, and it reached a maximum value when the cavitation process was fully developed. The literature review that is presented above, for predicting cavitation in centrifugal pumps and the effect of this phenomenon on the performance of the pump has highlighted gaps in the knowledge base and the following can be noted: there is a lack of information related to the use of different frequency ranges in frequency domain analysis that might be more sensitive to detect cavitation within the centrifugal pump. The cavitation is still not well analysed, particularly when the pump operates under a wide range of operational conditions such as various flow rates and decrease in the suction valve openings.

2. Experimental setup for the centrifugal pump

The main aims of this present study are to determine the pump performance and detect cavitation in the centrifugal pump experimentally. The detection of cavitation experimentally has been achieved with the help of an acoustic technique by using microphone and pressure, with two pressure transducers at suction and discharge of the pump under a different range of operation conditions. To achieve these aims experimentally, it was essential to design and construct an appropriate experimental setup for the centrifugal pump. The designing of this experimental setup will be discussed in more detail in the next section.

Figure 2 depicts the different parts of the flow loop of experimental setup of the centrifugal pump. The centrifugal pump can supply water to the tank with a maximum pressure about 10 bar. The selected flow loop system was recirculatory and included a plastic water tank, PVC clear pipe, and PVC connections components. The tank capacity has been based on the maximum flow rate. The inlet pipe diameter of the pump was 2 inches. Also, the outlet pipe diameter of the pump used was 1.25 inches. Thus, a reducing coupling of 1.25 to 1.5 inches has been used to connect the outlet pipe to the water flow meter line because the diameter of water flow meter was 1.5 inch. The tank was made of plastic with dimensions of $95 \times 90 \times 110$ cm. The entire section pipes are a transparent pipe. The reason behind that was to permit observation when the cavitation occurs. There are several reasons behind selecting the latter type of pipe. Firstly, the clear pipes are easier to install. Secondly, they are easy to connect, and, thirdly, their cost is low as compared to the stainless steel pipes. Furthermore, the PVC pipes do not necessarily allow for complicated tools to be used in connecting different pipes together, as the entire connection between pipes is made using a solvent welding type (solvent cement and cleaning fluid). However, the PVC clear pipes have some disadvantages such as lack of rigidity. The connections of the flow loop of the centrifugal pump and the water tank are made using various sizes of PVC pipes. At the input, the voltage signal obtained from the microphone has been collected then sampled at 96 kHz in the data acquisition system. The number of data points in these experimental measurements was equal to 2 880 000 points. In this study, several tests have been carried out for variety microphone positions. As a result, it was found that the optimal position is 50 mm apart from the outlet of the pump.

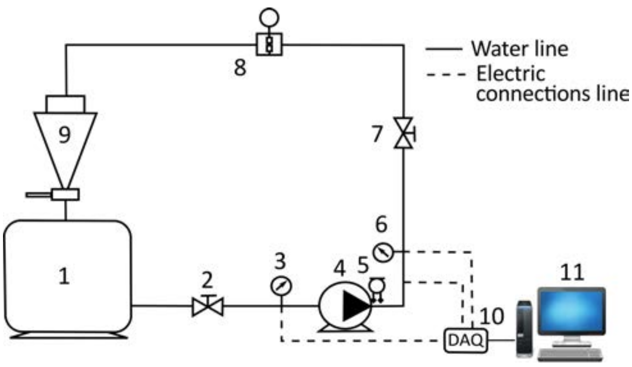

Fig. 2. Experimental setup of components and flow loop system: 1 – water tank, 2 – suction valve, 3 – suction pressure transducer, 4 – centrifugal pump, 5 – microphone, 6 – discharge pressure transducer, 7 – discharge valve, 8 – water flow meter, 9 – hopper, 10 – DAQ, 11 – PC.

2.1. Effect of suction valve opening on performance of the centrifugal pump

The pump performance and occurrence of cavitation directly depends on operating conditions. In order to cover a wide range of operation conditions for detecting cavitation in this section, investigations on the effect of various suction valve openings on cavitation in the pump were carried out.

In order to analyse the various levels of cavitation at different operation conditions, the effect of the decrease in the inlet suction pressure of the centrifugal pump by controlling the inlet suction valve opening was investigated using this experimental setup. Hence, the acoustic and pressure signals under different inlet valve openings and different flow rates, namely, 103, 200, 302 l/min were collected for this purpose. The inlet suction valve is first fully open (100%) at the beginning. Later this is changed through throttling the suction valve progressively, step by step for every 10%, and by using a protractor instrument that measures angles, as shown in Fig. 3, until cavitation occurs due to decreasing the inlet pressure in the inlet pipe by keeping the pump rotational speed constant at 2755 rpm. This process is based on the collection of experimental measurements at different suction valve openings and various flow rates. The collection of the experimental data allows evaluation of different indicators connected to cavitation condition within a pump. Such indicators include the performance of the pump, the head suction valve opening curve, and acoustic generated by cavitation, which are analysed in both time and frequency domains. All of these indicators provide useful information regarding predicting cavitation in the pump with high certainty. The next section presents the results obtained from the experimental calculation under different inlet suction valve openings. Each experimental test in this study was repeated at least three times.

Fig. 3. Protractor instrument for measuring angles at suction valve of the pump.

2.2. Calculation of the NPSH of the centrifugal pump under different suction valve openings at flow rate of 103 l/min

To analyse the effect of inlet suction valve openings on the performance of the centrifugal pump under various flow rates through the use of acoustic technique, it is important first to investigate and calculate the NPSH against head of the pump in relation to the different inlet valve openings presented in the next section.

Figure 4 depicts the NPSH-head curve for the pump based on some operating conditions such as flow rate of 103 l/min and N = 2755 rpm. It can be seen that when the NPSH decreases from 7.5 m to 6.5 m, no significant change in the pump head is evident and no cavitation occurs in this region. When the NPSH goes lower than 5.5 m, the head is decreased by 3% and inception of cavitation occurs. Furthermore, it can be seen that when the NPSH value also decreases, the pump head rapidly decreases and the development of cavitation then increases. The reason is due to the pressure at the suction line of the pump which gradually decreases when the suction valve opening decreases leading to a decrease in NPSH.

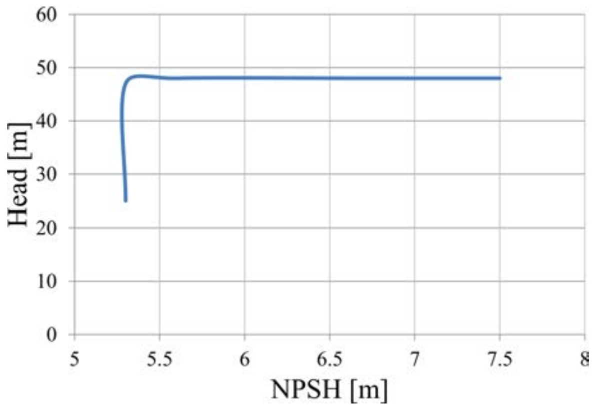

Fig. 4. Cavitation characteristics NPSH-head curve of the pump.

The pump performance is also analysed in relation to the different inlet suction valve openings. Figure 5 depicts the pump head via the inlet suction valve openings curve for the pump based on operational conditions such as flow rate of 103 l/min and N = 2755 rpm. The head drop curve for the pump can be seen to correspond to inlet suction valve openings of 100, 90, 80, 70, 60, 50, 40, and 35%. In this figure, the head drop curve can be seen to be divided into three parts because of the decrease in the inlet suction pressure. The first part shows inlet suction valve openings between 100% and 50%. It can be further observed that there is no significant change in the head of the pump and no cavitation occurs in this region. The second part displays the development of cavitation occurring when inlet suction valve opening was at 40% due to the head drop of 7.85%. The final part illustrates full development of cavitation when the inlet suction valve opening was at 35% as the head drop was 37.66%. It can be concluded that decreasing the inlet suction valve openings leads to the lowering of the inlet suction pressure, and cavitation on the suction side of the pump starts occurring and developing.

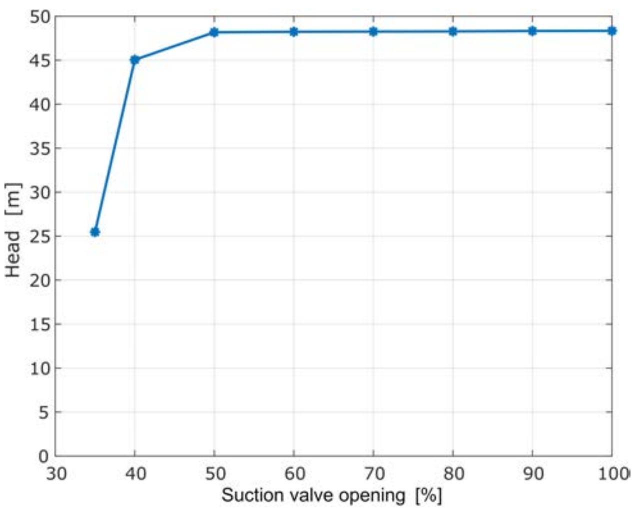

Fig. 5. Relation between head and different suction valve openings at 103 l/min.

2.3. Effect of suction valve opening on prediction of cavitation in a centrifugal pump using acoustic signal

To analyse the various levels of cavitation under different operation conditions, the effect of the decrease in the inlet pressure of a centrifugal pump can be investigated through controlling the inlet suction valve openings. The acoustic signal can be collected from the experimental setup of the centrifugal pump under different suction valve openings using microphone at various flow rates of 103, 200, 302 l/min selected for this analysis. The flow at the suction and discharge sides of the pump was adjusted through the two valves. The suction valve of the pump is used to control the inlet pressure between the inlet pipe and the inlet impeller in order to simulate cavitation condition through decreasing the pressure at the inlet pipe below the water vapour pressure. The suction valve is first fully open (at 100%) and then changed through throttling of the valve progressively, step by step at 10% intervals until cavitation occurs due to decrease of the inlet pressure in the inlet pipe. The pump rotational speed N = 2755 rpm is constant. The next sections represent and analyse the acoustic signals that were obtained from the experimental test based on the different suction valve openings.

2.4. Analysis on the acoustic signals in time domain under different suction valve openings at flow rate of 103 l/min

This section analyses the acoustic signals in time domain using the same various statistical features such as peak, RMS, peak-to-peak, and variance values in order to obtain more details regarding the change in the acoustic amplitude under different suction valve openings and hence to predict cavitation within a pump based on different operation conditions.

Figure 6 depicts the analysis of the acoustic signal for the pump, using the above mentioned features, at different suction valve openings. It can be seen from these figures that there is no significant change in the trend for the acoustic amplitude when the pump operates between suction valve openings of 100% and 40%. However, the trends for the above features rapidly increase when the pump operates between the suction valve openings of 40% to 35%. The main reason is because when the suction valve openings decreases, it leads to decrease in the inlet suction pressure below the water vapour pressure. In that case, cavitation starts to occur within a pump and it rapidly increases when the inlet suction pressure continuously decreases. Due to

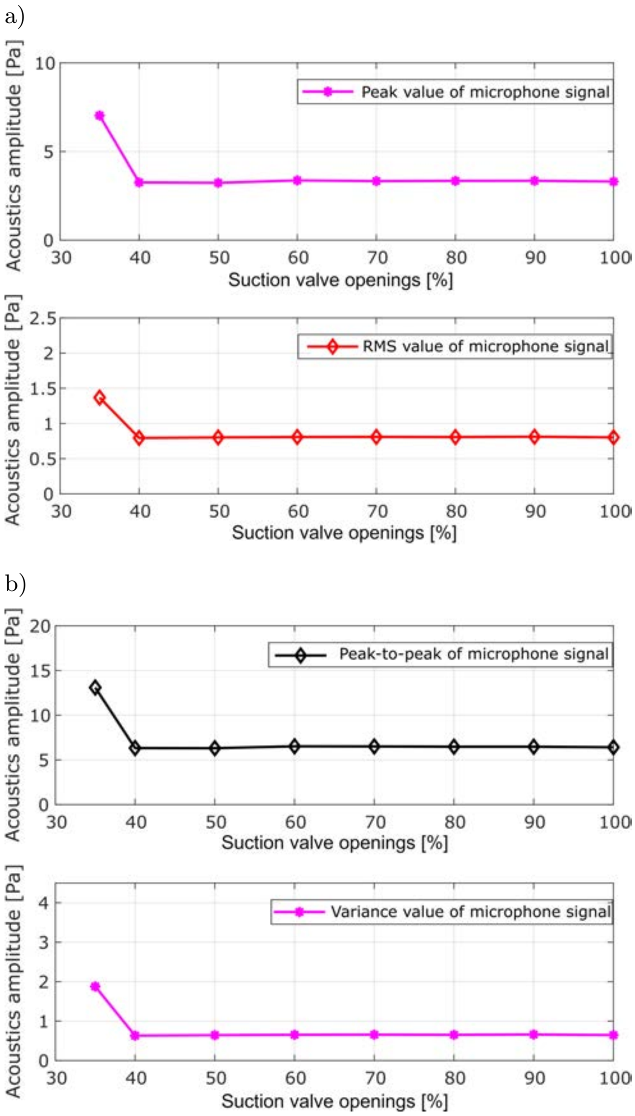

Fig. 6. Trends of different statistical features of the acoustic signal in time domain at different suction valve openings at 103 l/min: a) peak and RMS, b) peak-to-peak and variance.

these conditions, cavitation should be fully developed, which then causes quick reduction in the performance of the pump.

2.5. Analysis of the acoustic signal in frequency domain under different suction valve openings at flow rate of 103 l/min

Figure 7a depicts the acoustic signals in frequency domain under various suction valve openings, corresponding to the occurrence of cavitation within the pump at flow rate of 103 l/min, N = 2755 rpm, and for 0 Hz to 1 kHz range of frequency. It can be observed that the acoustic peak amplitude occurred at two dominant distinctive frequencies. The first one is the rotational frequency at 45.9 Hz and the second is BPF at 229.58 Hz and their harmonics. It can be seen from this figure that no significant change occurs in the level of acoustic amplitude when the pump operates between suction valve openings of 100% and 40%. However, at this range of frequency, it can be seen that there is a small change in the acoustic amplitude when

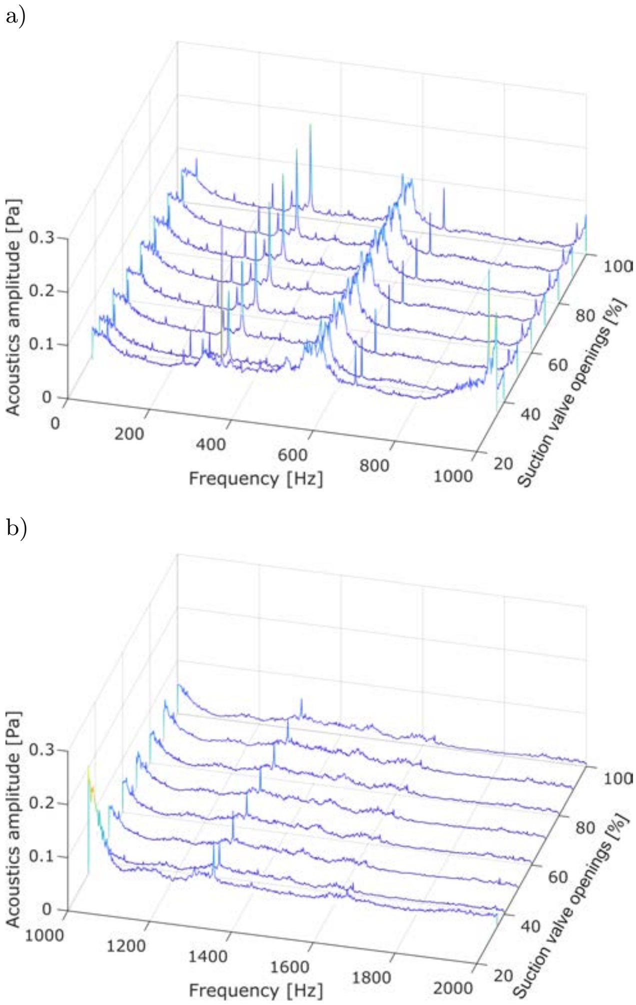

Fig. 7. Acoustic signal in frequency domain under various suction valve opening and the frequency range from (a) 0 Hz–1 kHz to (b) 1–2 kHz at 103 l/min.

the pump operates between suction valve openings of 40% and 35%. Therefore, it can be concluded that this range of frequency was effective to predict cavitation within a pump.

For more details, Fig. 7b depicts the analysis on the acoustic signal at the range of frequency between 1 kHz and 2 kHz, in order to obtain more information regarding the prediction of cavitation in the pump. The same two dominated frequencies can be observed as in the previous range of frequency. The first one is the rotational frequency while the second is the BPF and their harmonics. It can be observed from this figure that there is no change in the acoustic amplitude between suction valve openings 100% and 40%, as changes in the acoustic amplitude occur when the pump operates between suction valve openings from 40% and 35%. The reason for this is because when cavitation occurs within the pump it generates smaller bubbles and the collapse of these bubbles inside the pump then create more random noise, hence, the amplitude of acoustic amplitude increases. This leads to the observation that this range of frequency is also effective to predict cavitation, as many high peaks occur in the acoustic amplitudes after suction valve opening of 40% as shown in this figure.

It can be noticed that analysis in the level of acoustic amplitude in 1 kHz to 2 kHz range of frequencies provides suitable indication to predict cavitation.

In order to obtain more information regarding acoustic signals in the frequency domain, Figs 8 and 9 depict the mean and RMS acoustic amplitude features that were calculated from the frequency domain at the different suction valve openings. It can be seen that the mean and RMS acoustic amplitude features for the various range of frequencies have approximately the same trend for the different suction valve openings. Also, there is a small change between the suction valve openings from 100% to 40%, which then increases for the suction valve openings between 40% and 35%

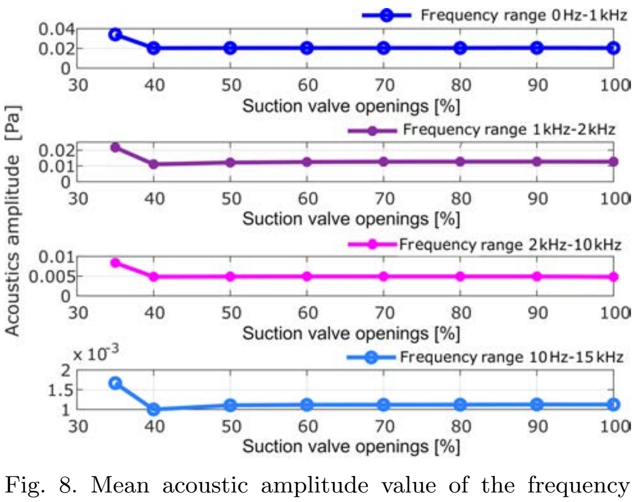

Fig. 8. Mean acoustic amplitude value of the frequency range from 0 Hz to 15 kHz at 103 l/min.

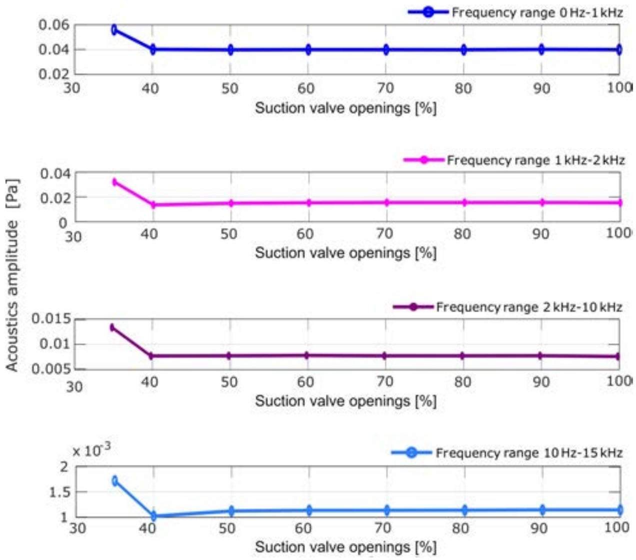

Fig. 9. RMS acoustic amplitude value of the frequency range from 0 Hz to 15 kHz at 103 l/min.

due to the operation of the pump at certain flow rate through the fixed discharge valve. After that, the suction valve was progressively closed until the occurrence of cavitation at the suction side of the pump, which led to the generation of high noise and vibration. The reason for this is due to the high amount of bubbles that were formed making these bubbles clearly visible in the inlet pipe. It can be concluded from these figures that the range of frequency between 0 Hz and 2 kHz is sensitive for detection of the occurrence of cavitation within a pump under different suction valve openings.

2.6. Performance of the centrifugal pump under different suction valve openings at different flow rates

For comparison purposes between the different cases (Q = 100 l/min, Q = 200 l/min, and Q = 302 l/min), investigating the effects of decrease in the suction valve on the performance of the centrifugal pump was performed. Figure 10 depicts the head of

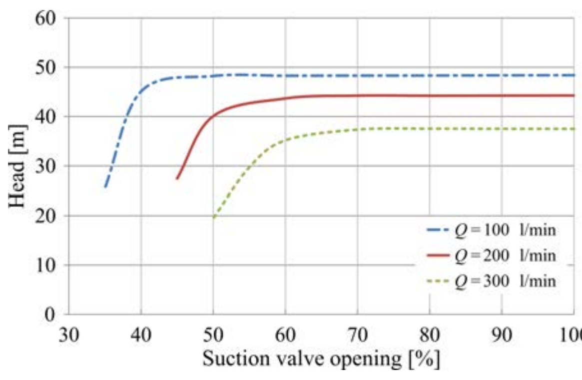

Fig. 10. Effect of different suction valve openings on the performance of a pump.

the different cases under different inlet valve openings at the suction side of the pump. It can be clearly seen that the head for Q = 100 l/min is considerably higher than for the other two flow rates 200 l/min and 302 l/min. The results showed that at flow rate of 100 l/min the pump starts operating under cavitation conditions when inlet suction valve opening is 40%. However, at the flow rate of 200 l/min it started at 50%, and at the flow rate of 302 l/min it did at 60%, respectively. That means that when a pump operates at the high flow rate it leads to a decrease in the inlet suction pressure faster than at low flow rate and hence this leads to the fact that cavitation will occur quicker. From the above findings, it can be concluded that the inlet suction valve openings are inversely proportional with cavitation occurrence within the pump, meaning that when the inlet suction valve opening is decreased this leads to cavitation being increased.

2.7. Analysis on the acoustic signals in time domain under different suction valve openings and flow rates

Figure 11 depicts the various statistical features which include the peak, RMS, peak-to-peak, and variance values under different flow rates and different suction valve openings for comparison purposes for the aforementioned cases. It can be observed that the maximum peak value for Q = 302 l/min is considerably higher than for the other two cases Q = 200 l/min and Q = 103 l/min by 35.59% and 72.03%. Also, for the maximum RMS value, it is higher by 32.47%, and 65.81% for the other two cases. For the maximum peak-to-peak, it is higher by 33.88% and 70.44%, and for the maximum variance value by 54.09% and 88.34%, respectively, as shown in Table 1. From the above findings, it can be concluded that the suction valve opening is inversely proportional to increase in the acoustic amplitude. This means that when the suction valve opening decreases, it leads to increase in the acoustic amplitude.

Table 1. Summary of the maximum statistical features results for the acoustic amplitude at different flow rates.

Flow rate l/min	Peak [Pa]	RMS [Pa]	Peak-to-peak [Pa]	Variance [Pa]
103	7.03	1.36	13.09	1.87
200	7.60	1.58	14.34	2.52
302	11.80	2.34	21.69	5.49

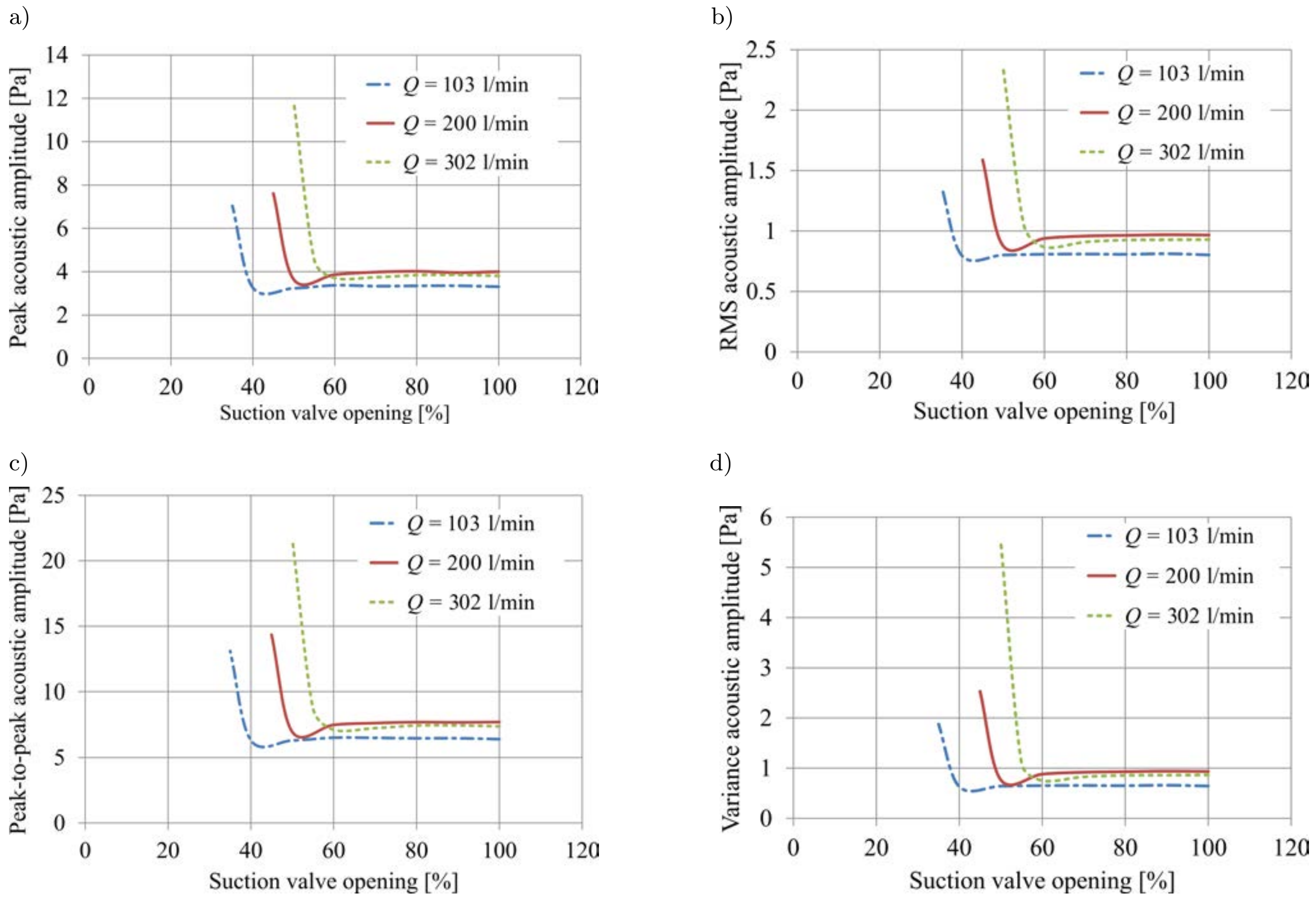

Fig. 11. Comparison between different statistical features of the acoustic signal in time domain under different flow rates and suction valve openings: a) peak, b) RMS, c) peak-to-peak, d) variance.

It can be concluded that the use of the above statistical features for the acoustic amplitude provides a good indication regarding the cavitation occurrence in the pump. Also, the results showed that the level of acoustic stability of a pump is associated directly with the suction valve opening under different flow rates.

2.8. Analysis of the acoustic signal in frequency domain under different suction valve openings and flow rates

Figure 12 depicts the analysis on the acoustic signal at different flow rates of 200 and 302 l/min, N = 2755 rpm, under different inlet suction valve openings, and for the range of frequency from 0 Hz – 1 kHz to 1–2 kHz. It can be seen that the first peak of the acoustic amplitude was at frequency 49.5 Hz, representing the rotational frequency with the second, third, and fourth harmonics at 91.8, 173.75, and 183.66 Hz, respectively. The second dominant peak of the acoustic amplitude was at frequency 229.58 Hz, representing the BPF. The peak acoustic amplitude considerably increases upon cavitation occurrence in the pump. Furthermore, it is obvious that acoustic amplitude follows the same trend as in the previous case where Q = 103 l/min. For Q = 200 l/min no significant change occurred in the level of the acoustic amplitude under suction valve openings between 100 and 50%. However, the change in acoustic amplitude was relatively higher at suction valve openings between 50 and 45%, compared to the suction valve openings between 100 and 50%. Furthermore, for Q = 302 l/min the change in acoustic amplitude was relatively higher at the suction valve openings between 60 and 50% when compared to the suction valve openings between 100 and 60% due to the cavitation condition.

For comparison purposes Figs 13 and 14 depict the mean and RMS acoustic amplitudes in frequency domain for the different range of frequencies including 0 Hz – 1 kHz, 1–2 kHz, 2–10 kHz, and 10–15 kHz, under different suction valve openings and flow rates for the aforementioned cases. The maximum mean acoustic amplitude value at different suction valve openings can be observed at Q = 302 l/min for 0 Hz – 1 kHz

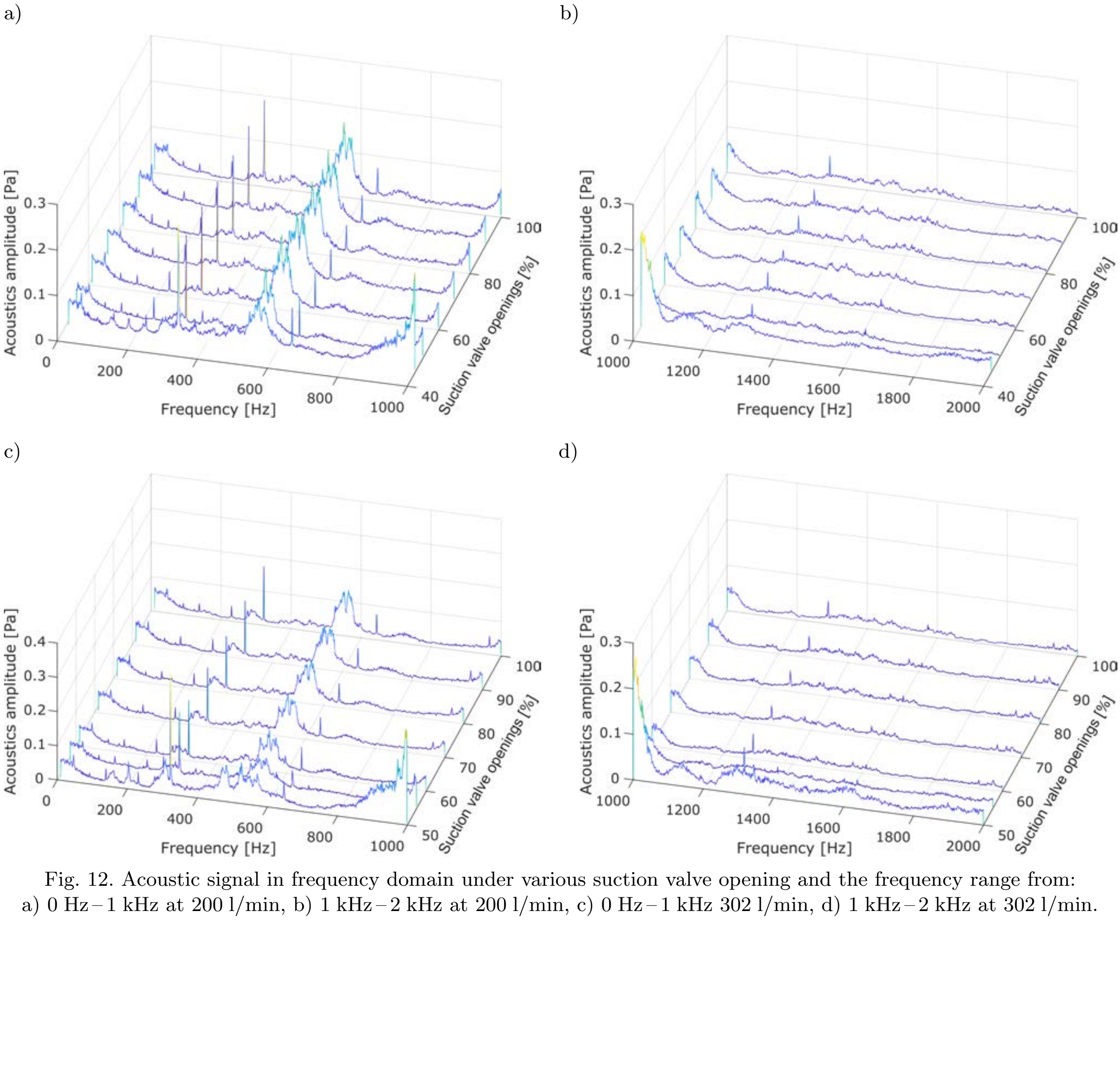

Fig. 12. Acoustic signal in frequency domain under various suction valve opening and the frequency range from: a) 0 Hz – 1 kHz at 200 l/min, b) 1 kHz – 2 kHz at 200 l/min, c) 0 Hz – 1 kHz 302 l/min, d) 1 kHz – 2 kHz at 302 l/min.

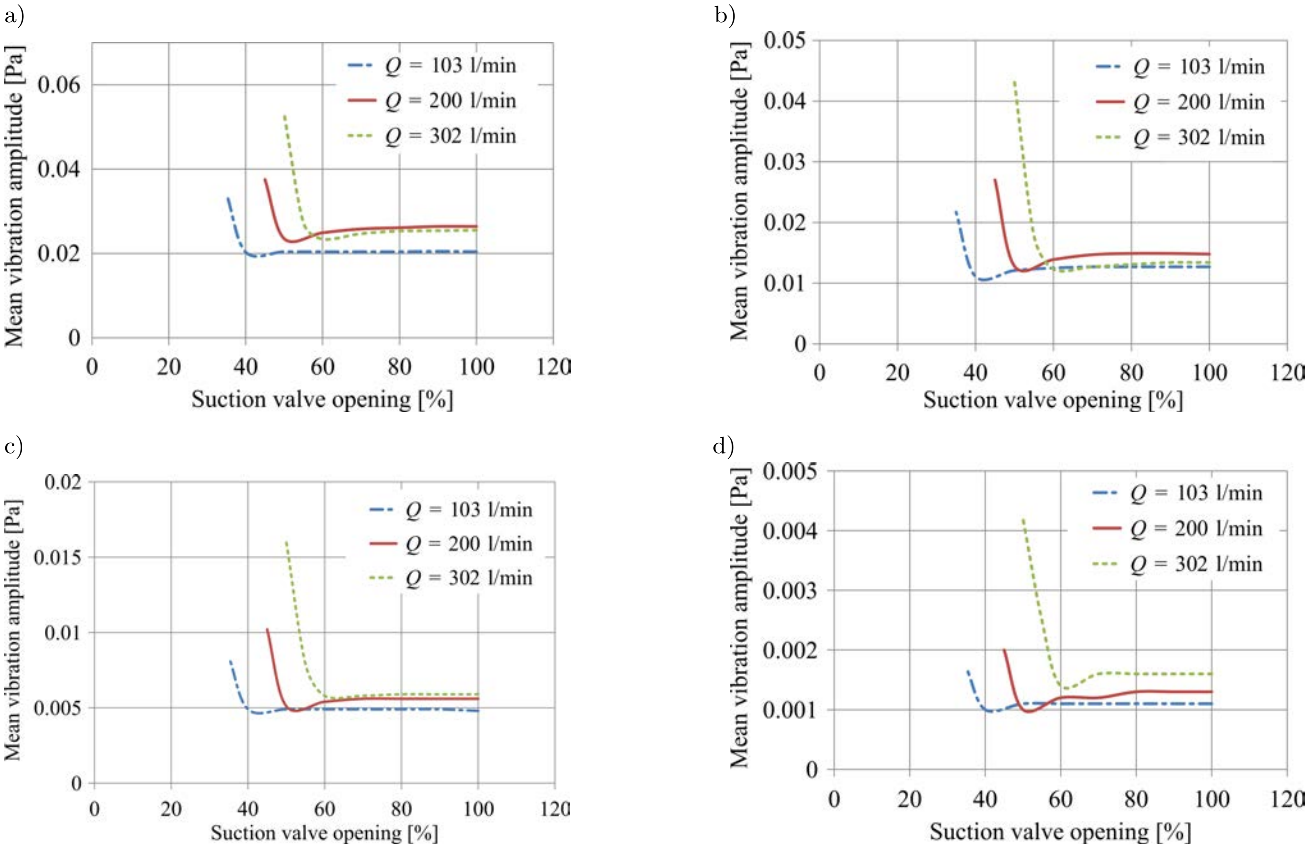

Fig. 13. Comparison between mean acoustic amplitude values in frequency domain for different frequency ranges under different flow rates and suction valve openings: a) 0 Hz – 1 kHz, b) 1–2 kHz, c) 2–10 kHz, d) 10–15 kHz.

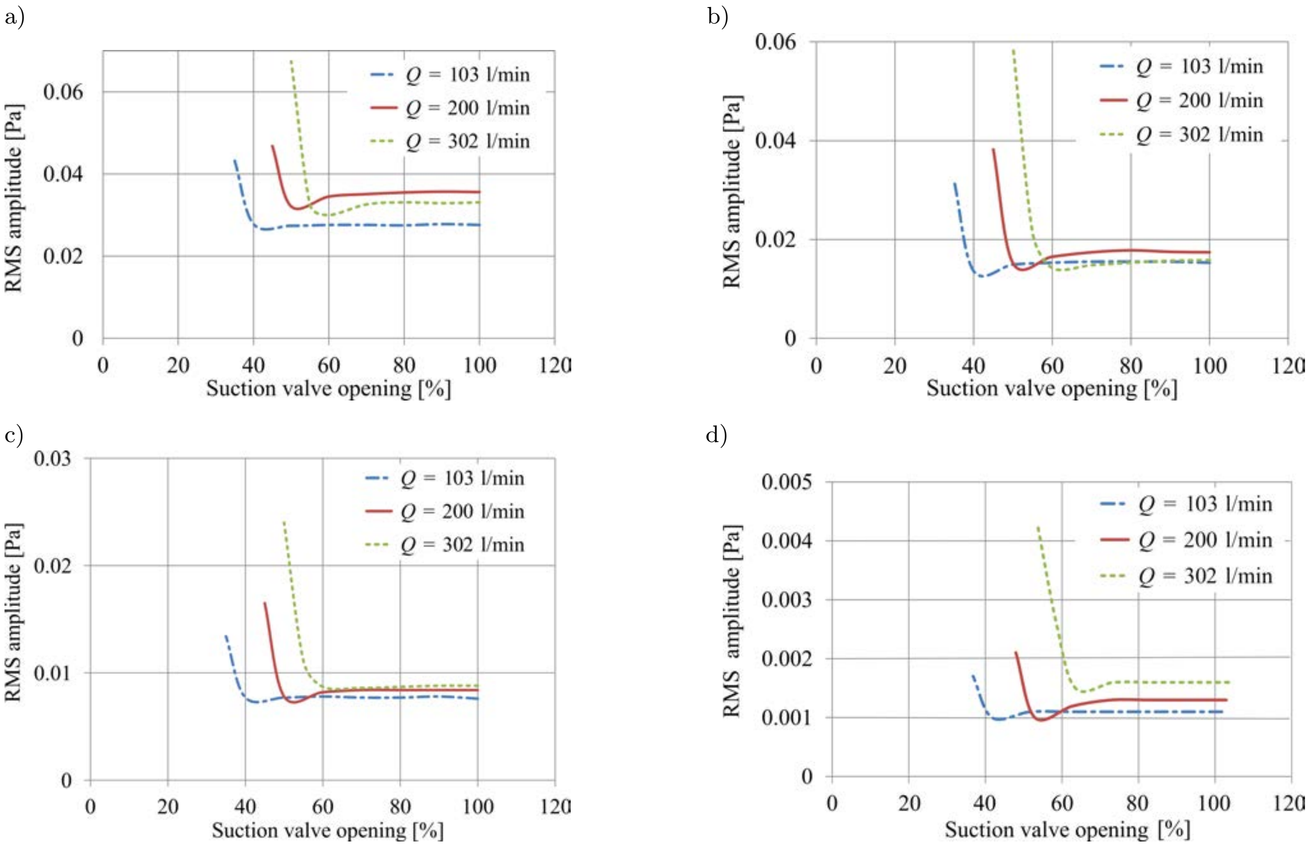

Fig. 14. Comparison between RMS acoustic amplitude values in frequency domain for different frequency ranges under different flow rates and suction valve openings: a) 0 Hz – 1 kHz, b) 1–2 kHz, c) 2–10 kHz, d) 10–15 kHz.

Table 2. Summary of the maximum mean acoustic amplitude values at different flow rates and suction valve openings and for frequency range (0 Hz – 15 kHz).

Flow rate [l/min]	Mean value 0 Hz – 1 kHz [Pa]	Mean value 1–2 kHz [Pa]	Mean value 2–10 kHz [Pa]	Mean value 10–15 kHz [Pa]
103	0.0341	0.0217	0.0084	0.0017
200	0.0375	0.0270	0.0102	0.0020
302	0.0530	0.0431	0.0160	0.0042

Table 3. Summary of the maximum RMS acoustic amplitude values at different flow rates and suction valve openings and frequency range (0 Hz – 15 kHz).

Flow rate [l/min]	RMS value 0 Hz – 1 kHz [Pa]	RMS value 1–2 kHz [Pa]	RMS value 2–10 kHz [Pa]	RMS value 10–15 kHz [Pa]
103	0.0432	0.0320	0.0134	0.0017
200	0.0468	0.0382	0.0165	0.0021
302	0.0674	0.0591	0.0240	0.0043

range of frequency, it is considerably higher than for the other two cases: Q = 200 l/min and Q = 103 l/min, by 29.42% and 35.66%. In addition, for 1–2 kHz range of frequency, it is higher than for the other two cases by 37.35%, and 49.56%. Also for 2–10 kHz range of frequency, it is higher by 36.25%, and 47.50%, and for 10–15 kHz range of frequency, it is higher by 52.38%, and 59.52%, respectively, as summarised in Table 2. The RMS value has the same mean value trend as it did when Q = 302 l/min, which is also considerably higher than for the other two cases (Q = 200 l/min and Q = 103 l/min) at different suction valve openings, as summarised in Table 3.

3. Conclusions

A detailed analysis of the effect of the different suction valve openings on the acoustic signal to predict cavitation in the pump revealed the following results:

1) The acoustic signal analysis in time domain using different statistical features can provide a good indication to determine when cavitation occurs in the pump under different suction valve openings.
2) Analysis on the acoustic signal using the above mentioned features show different regions. The first region revealed no significant change at the level of acoustic signal. The second region showed that the trends for the above features rapidly increase due to decrease in the suction valve opening and hence the pump operating under cavitation condition. The third region showed the maximum acoustic level related to a continuous decrease of the inlet suction pressure.
3) The maximum amplitude for the peak, RMS, peak-to-peak, and variance values in the time domain at different suction valve openings was at Q = 302 l/min.
4) Using frequency domain analysis to analyse the acoustic amplitude was a suitable technique to predict cavitation within a pump at different suction valve openings.
5) The mean and RMS acoustic amplitudes features in frequency domain at different inlet suction valve openings and various frequency ranges were studied. Different regions were also observed. The first region shows that the acoustic amplitudes do not go through any significant change. The second region also shows that acoustic amplitudes increase due to the cavitation occurrence.
6) The mean and RMS for acoustic amplitude in frequency domain increase as the suction valve opening is decreased and they increase with an increase in the flow rate.
7) Based on the above findings, the analysis of the acoustic signal in time domain can provide a primary indicating feature regarding quantifying the detection of the inception and severity of different levels of cavitation. A secondary indication can be quantified in the frequency domain analysis for the acoustic signals under different frequency ranges.

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