ON THE USE OF ULTRASONICS IN HYDRODYNAMIC CAVITATION CONTROL

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Abstract

In a recent study, we have shown the potential for the use of ultrasonics in travelling bubble cavitation control near inception. Here, we present results which demonstrates control under developed cavitation conditions. In addition we also discuss effects of different methods of excitation of a piezoelectric crystal on control.

1 Introduction

Cavitation refers to the formation and subsequent dynamic life of bubbles in liquids subjected to a sufficiently low pressure. If this required low pressure is created due to the flow of a liquid, then cavitation can be termed as hydrodynamic. In the field of applied hydrodynamics, effects due to cavitation, like: the loss in performance of hydraulic machinery, material erosion and surface damage, cavitation-induced noise and vibration, are mostly undesirable. Following Knapp et al(1970), three primary types of hydrodynamic cavitation can be identified: travelling bubble, fixed or attached and vortex. Among these, at least from the point of view of noise, travelling bubble type is the most dangerous. Therefore, any attempts towards the control of this form of cavitation would be highly desirable. With this objective in mind, in a recent study (Chatterjee and Arakeri 1997), we demonstrated the feasibility of the use of ultrasonics in travelling bubble cavitation control. Here, a device termed as Ultrasonic Nuclei Manipulator (UNM) was introduced upstream of the potential zone of hydrodynamic cavitation. The role of the UNM, as its name suggests, was to change the nuclei size distribution so that the onset of cavitation could be delayed. The principle behind its operation is to subject the potential nuclei passing through the UNM, to an acoustic pressure field superimposed on the flow so that they undergo transient bubble motion(Arakeri and Chakraborty 1990), fragment and get dissolved in the liquid before they reach the critical section. In the previous study using a blow-down venturi set up (Chatterjee and Arakeri 1997), the demonstration of cavitation control was limited to the near-inception conditions because of the appearance of sheet cavitation at the diffuser. This resulted in choking of the flow, and thus the maximum tension achievable at the throat was limited to about 5.7 kPa. In the present work, we have been able to overcome these constraints by using a gravity-driven set up and modified venturies. The new set up and the present method of experimentation is described in the next section.

2 Experimental apparatus and method

The gravity-driven set up used for the present experiments basically consisted of an inlet tank and a test section, located 8 m above an exhaust tank(figure 1). Some details of the test section along with a block diagram of the relevant instrumentation are presented in figure 2. The test section was made up of three essential components: the electrodes, the UNM and a venturi. One of the electrodes was a very fine wire(cathode) and was capable of seeding nuclei in the size range of about 5—10 μm(estimated by using a venturi as susceptibility meter(Oldenziel 1979) and the other electrode was a thick copper plate(anode). The typical voltage applied across the electrodes was 10 Volts. A cylindrical piezoelectric crystal(OD 25.4mm, ID 19mm,

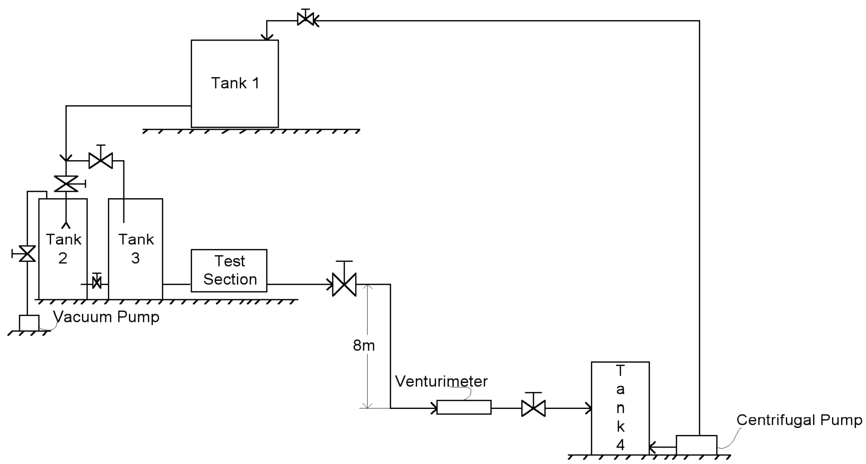

Figure 1: A schematic of the overall set up

length 50mm) with a resonant frequency in the radial mode of $\approx$ 52 kHz was used as an UNM. A sine generator(Wavetek model-29) was used to drive it through a power amplifier(B & K model-2713). The generator was capable of exciting the crystal in a continuous wave (CW) as well as in pulsed modes of operation. The driving voltages were set so that the maximum acoustic pressure amplitudes in both the cases were about the same. The pulsing frequency, for most of the runs, used was 250 Hz while the number of bursts in each cycle was restricted to 11. Downstream of the UNM, a perspex venturi was placed; it had a contraction ratio (defined as $A_{upstream}/A_{throat}$) of $\approx$ 3. In our previous study we used a contraction ratio of about 100; this resulted in laminar flow in the upstream section and as a result the flow was prone to laminar separation in the diffuser. With the use of a much smaller contraction ratio venturi in the present work, the flow was turbulent in the upstream section and this prevented separation. This could be verified by observing the cavitation patterns under developed conditions.

Cavitation can be diagnosed and quantified in many ways; presently, we used the acoustic method. The noise pulses from cavitation at the venturi throat were monitored with the help of a wall-mounted miniature

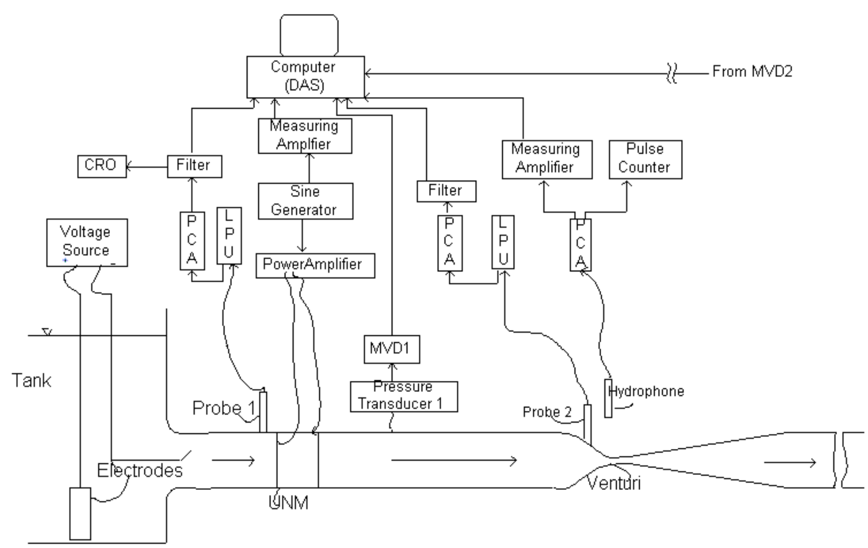

Figure 2: A schematic of the test section along with a block diagram of the instrumentation used

pressure transducer(PCB model-112A21). A second similar transducer was used to monitor any cavitation activity taking place near the UNM. These two transducers are designated as probes 2 and 1 respectively in the schematic of figure 2. A hydrophone(B & K model-8103) was also used to pick up air-borne noise and detect inception. The flow rate was computed by measuring the pressure difference across a venturi (located near the exhaust tank) with the help of a differential pressure transducer(HBM model-PD1). The upstream static pressure, near the UNM, was measured with a similar transducer. All the data from various transducers was stored in a 12-bit PC-based data acquisition system for later processing.

In some of the experiments the dissolved gas concentration levels(C_o) in the sample liquid was less than the saturation value(C_s). The degassing was achieved by spraying the water under vacuum. The dissolved air concentration was inferred from measurements using a dissolved oxygen meter.

The tests carried out can broadly be classified as the ones near cavitation inception ($\sigma \approx \sigma_i$) and the others in which developed cavitation was seen to occur as the flow rate was gradually increased to its maximum value. Cavitation number(σ) used to characterize the experiments is defined as follows:

$$\sigma = \frac{P_o - P_v}{1/2\rho {V_t}^2}$$

where P_o is the upstream pressure (close to the UNM location), V_t is the velocity at the venturi throat and P_v is the vapour pressure corresponding to the temperature of the water.

For the tests near inception, the flow rate was held constant and the electrolysis bubbles were allowed to cavitate and then the UNM was turned on to see its effect. In the other set of experiments, the flow rate was increased while the electrolysis process was kept on and the UNM was turned on and off successively to observe latter's effect on the cavitation phenomenon in the venturi at different flow rates. This procedure allowed the study on the effectiveness of the UNM at a range of cavitation numbers below the inception value in a single run.

3 Results and discussion

Before presenting our results on cavitation control, we note that the average cavitation inception number(σ_i) for the present venturi with electrolysis bubble seeding is found to be 0.89. From classical arguments we know that $\sigma_i \approx -C_{p_{min}}$ if there is a copious supply of nuclei in the liquid (Kodama et al 1979). Here $C_{p_{min}}$ is defined as:

$$C_{p_{min}} = \frac{P_t - P_o}{1/2\rho {V_t}^2} = \left(\frac{d_t}{d_o}\right)^4 - 1$$

where P_t is the pressure at the venturi throat, d_t is diameter of the venturi throat, and d_o is the diameter of the perspex tube upstream of the venturi location. For the present venturi configuration, the theoretical $C_{p_{min}} = -0.90$ and hence our observations are consistent with the expected behaviour.

Figure 3 shows the results from a typical run with the objective of control in which $\sigma \approx \sigma_i$. It is clearly seen that when the UNM is turned on, the cavitation activity near the venturi throat is reduced drastically which can be inferred from a sudden change in the probe-2 output levels. The UNM in this case was driven with CW-excitation and the relative gas concentration ($C = \frac{C_o}{C_s}$) in the water sample was 0.52.

In figure 4 we present the results in which the flow rate was gradually increased. The UNM, in this case, was turned on and off alternately to see its effect on the cavitation noise as picked up by probe-2. This type of a plot clearly highlights the difference in the cavitation noise pulses as sensed by the transducer with and without the UNM being operative. From the results presented in figure 4 it is clear that cavitation has been totally suppressed near inception with the UNM being on; however, more significantly it can be noted that its effectiveness still persists even under developed cavitation conditions, though it gradually decreases as the flow rate is increased. In somewhat of a surprising finding we have found that the effectiveness of the UNM in hydrodynamic cavitation control is reflected in an another manner. From figure 4 top plot, it can be seen that the choking of the system due to developed cavitation is postponed to larger flow rates. That is, at a fixed opening of the valve in the system, higher flow rates (lower σ values) are possible with the UNM being on. This clearly indicates that the controlling factor in choking was the extent of cavitation activity at the throat. Therefore, using our new set up we have been able to demonstrate control, in more than one

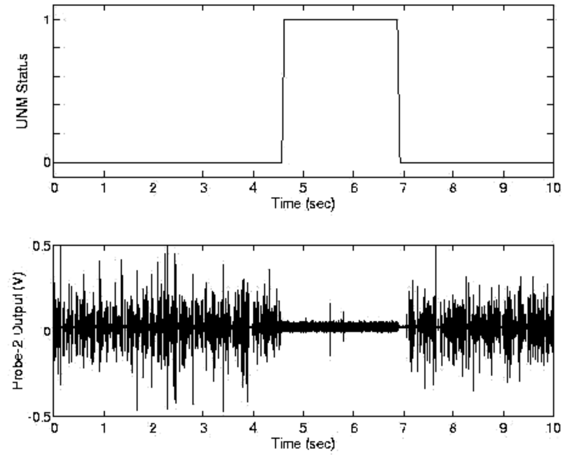

Figure 3: Noise levels as sensed by probe-2(lower plot) with a continuous wave(CW) excitation of the UNM. The UNM is ON when the UNM status(top plot) is 1 and OFF otherwise. C=0.52 and $\sigma = 0.88$.

way, under developed cavitation conditions. The results discussed so far are with the water sample being in a degassed state ($C = \frac{C_o}{C_s} \approx 0.5$). Under these circumstances, CW-excitation seems to have worked very well. However, from a practical point of view it is important to show a similar effectiveness with the liquid sample being at or near saturation conditions.

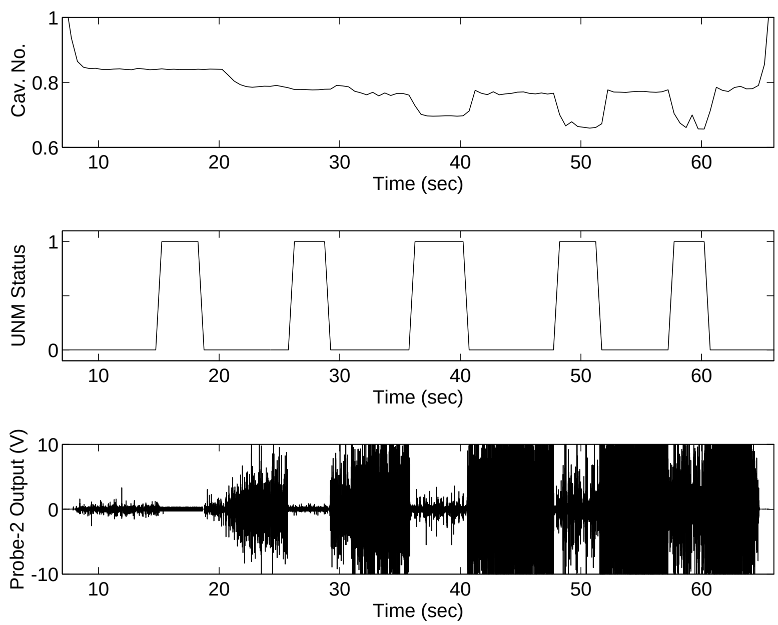

Figure 4: Noise levels(bottom plot) as a function of cavitation number(top plot) with the UNM being on or off. UNM is ON when the UNM status(middle plot) is 1 and OFF otherwise. C=0.47.

Results concerning this attempt are presented in figure 5(a and b) and it can be noted that the UNM is not effective at all, if anything the noise levels seem to have gone up during the period when the UNM was on. Most likely the nuclei size modification due to rectified diffusion has a role to play here and this point will be discussed later.

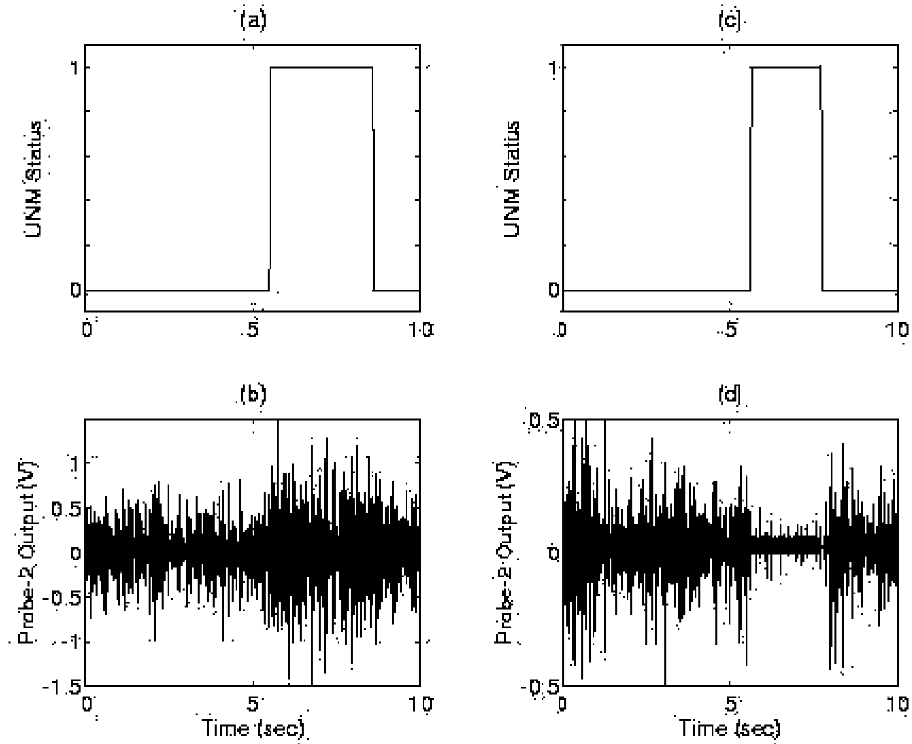

Figure 5: Noise levels with the UNM operated in CW (plot b) and pulsed (plot d) modes of excitation for C=0.92 and $\sigma = 0.89$. The UNM is ON when the UNM status (plots a and c) is 1 and OFF otherwise.

In view of the above observations, a different strategy was needed with the water sample being near saturation conditions. An obvious choice was to operate the crystal in a pulsed mode such that the time duration for which the nuclei are subjected to an acoustic pressure field is reduced considerably. This did succeed and the corresponding results are shown in figure 5(c and d) alongside with the results for CW-excitation. It is clear that there is a considerable improvement (inferred from a decrease in the noise levels) when the crystal is operative under pulsed mode. Therefore, for near saturated water samples only the pulsed excitation seems to work. A closer examination of the results presented in figure5(c and d), however, shows that the effectiveness is not so good, in the sense that the noise levels are not completely suppressed. This point is further highlighted from a comparison of the results between pulsed and CW-excitation modes obtained using a water sample having a much lower gas concentration($C \approx 0.5$). The results presented in figure 6 are with pulsed mode excitation and the control is seen to be again only partial; whereas, it was nearly total with CW-excitation(see figure 3). These observations can be explained on the basis of considering some finer points of the nature of acoustic field and nuclei interaction as done below.

We know that for the cylindrical piezo-crystal used as UNM, there would be a radial variation in the acoustic pressure; this pressure will be a maximum along the axis and a minimum near the walls. In the present experiments, corresponding to the driving frequency used, the estimated maximum and minimum values are about 3 and 0.6 bars under typical drive conditions. We suggest that this pressure variation together with the variation in the dissolved gas concentration is responsible for the observed differences in the effectiveness of control under various experimental conditions. We assume that the electrolysis bubbles, due to turbulence, get uniformly dispersed in the entire pipe cross-section before reaching the UNM. Due to the indicated radial variation of the acoustic pressure, bubbles that are passing through the UNM at a distance away from the axis would have experienced an acoustic pressure lower than the threshold value for transient motion. Then, instead of fragmenting to smaller size nuclei, they may undergo growth due to rectified diffusion if the liquid is locally supersaturated. These larger nuclei can grow to a greater maximum

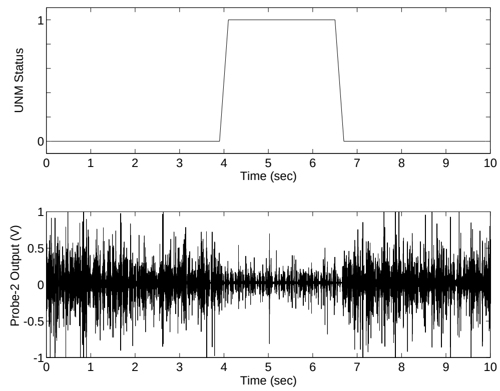

Figure 6: Noise levels(lower plot) with the pulsed excitation mode with a degassed water sample of $C \approx 0.5$. UNM is ON when its status (top plot) is 1 and OFF otherwise.

size due to cavitation at the throat resulting in increased noise levels. Pulsed excitation, on the other hand, does not give bubbles sufficient time to grow by rectified diffusion even with a saturated liquid. Hence control is effective in this case even with a saturated water sample and this will be independent of whether the nuclei pass through the center or near the walls of the crystal. If, however, the dissolved gas level, is sufficiently low, then the bubbles cannot grow by rectified diffusion and hence CW-excitation gives desirable results under these conditions.

The fact that the pulsed excitation does not work as well as the CW-excitation for degassed water samples(compare results in figures 3 and 6) needs to be analyzed. The possible explanation for this may lie in the fact that small nuclei(with sizes less than the resonant radius) tend to migrate towards the pressure maximum and in the process can experience transient motion even if they are initially near the walls of the crystal. Thus, all the nuclei irrespective of their initial locations are expected to go through transient motion and fragmentation under CW excitation. This is unlikely to be possible with the pulsed excitation. This may be the cause of difference between the effectiveness of control in the two cases: that is with CW and pulsed modes of crystal excitation. We are currently investigating these aspects by using a much larger(3 times) crystal as UNM in which case we are able to seed nuclei at selected spatial locations.

4 Concluding Remarks

The present study is one more step forward towards developing an effective method of controlling hydrodynamic cavitation. These experiments suggest that there is a limitation in the use of UNM with CW-excitation. Within the scope of the experiments done, it can be said that the pulsed excitation may be more promising with saturated liquids. The present experiments also suggest that a systematic study should be undertaken to understand the finer points of the bubble-acoustic field interactions. Finally, use of electrolysis bubbles as a source of nuclei serves the purpose of demonstrating the concept of the use of ultrasonics in hydrodynamic cavitation control; but to implement it in practice, control with natural nuclei cavitation should be attempted.

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