

OPTIMUM NOISE REDUCTION ANALYSIS AND REMEDIES FOR CENTRIFUGAL PUMP WORKING CONDITIONS

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ABSTRACT

Particle Image Velocimetry (PIV), pressure and noise measurements are used to study the effect of modifications to tongue and impeller geometries on the flow structure and resulting noise in a centrifugal pump. It is demonstrated that the primary sources of noise are associated with interactions of the non-uniform out flux from the impeller (jet/wake phenomenon) with the tongue. Consequently, significant reduction of noise is achieved by increasing the gap between the tongue and the impeller up to about 20% of the impeller radius. Further increase in the gap affects the performance adversely with minimal impact on the noise level. When the gap is narrow, the primary sources of noise are impingement of the wake on the tip of the tongue, and tongue oscillations when the pressure difference across it is high. At about 20% gap, the entire wake and its associated vorticity trains miss the tongue, and the only (quite weak) effect of non uniform out flux is the impingement of the jet on the tongue. An attempt is also made to reduce the non-uniformity in out flux from the impeller by inserting short vanes between the blades. They cause reduction in the size of the original wakes, but generate an additional jet/wake phenomenon of their own. Both wakes are weak to a level that their impacts on local pressure fluctuations and noise are insignificant. The only remaining major contributor to noise is tongue oscillations. This effect is shown to be dependent on the stiffness of the tongue.

Keywords: *Vorticity, Particle Image Velocimetry (PIV), oscillations, volute.*

I. INTRODUCTION AND RATIONALE

Experiments discussed in Chu et al. (1993, 1995 a, b) demonstrated that interactions of non-uniform outflux from the impeller with the tongue can be primary contributors to noise generation within the volute of a centrifugal pump. That study included PIV measurements in sufficient spatial and temporal resolutions, that enabled computations of the phase averaged, unsteady pressure from the velocity distributions (by integrating the Reynolds Equations). The results pointed directly at specific sources of noise. Included were effects of the jet/wake phenomenon (introduced and discussed by Dean and Senoo, 1960 and Eckardt, 1975), particularly the wake, and tongue oscillations due to high pressure differences across it. The present paper continues this effort by focusing on attempts to reduce noise either by modifying the tongue geometry or by reducing the non uniform out flux from the impeller. Another approach to noise reduction involves tackling the nonuniform outflux from the impeller. Using the original velocity distribution an attempt is made to reduce the "wake"

(region of high circumferential velocity, v_6 , at the exit from the impeller) by inserting short vanes inside the impeller. Unlike typical attempts to install symmetric vanes at the center of a blade passage (Cumpsty, 1989), the location and orientation of the present vanes are selected based on prior data on the flow. As will be shown shortly, this attempt results in partial success. The overall noise level, particularly the noise associated with the wake is reduced. However, the new vanes cause additional unsteady phenomena.

II. EFFECT OF MODIFICATIONS TO THE IMPELLER

As discussed in the previous section and in Chu et al. (1995), when the tongue is located at r/r_J the flow around it and resulting noise are dominated by nonuniformities in the outflux from the impeller. Thus, it is likely that any reduction in the jet/wake phenomenon would have a direct impact on decreasing the noise level. To achieve this goal we inserted short vanes (Figure 11) within the wake based on the data at 270 gpm, i.e. $Q/Q_0=1.35$, where $Q_0=200$ gpm (the corresponding flow coefficient of 0.07), 10° behind the origin of the negative vorticity train (Figure 7). Their exit angles, 18° , was set to reduce the magnitude of v_e within the wake to $v_{91U_r} -0.5$, namely to levels comparable to the flow outside of the wake

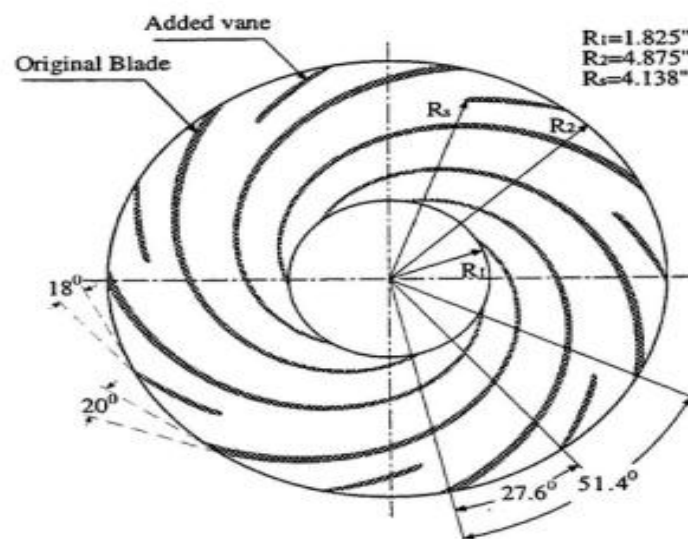


Fig. 1 A sketch of the modified impeller

For $0.5 < Q/Q_0 < 1.25$ the vanes improved the pump performance slightly, but reduced it at lower flow rates. The rms noise decreased above design conditions (the conditions for which they were designed) and at low flow rates, but increased at $0.4 < Q/Q_0 < 1$. Thus, for flows with significant outflux from the impeller near the tongue (above design conditions, according to Dong et al., 1992), the vanes contributed to noise reduction. The spectrum at 270 gpm clearly shows a substantial decrease in the magnitude of the primary harmonic (blade rate frequency - 105 Hz) and its odd multiples, no change in the second peak, but a slight increase in the fourth harmonics. The latter can be easily explained by the effective doubling of the number of blades. There is also a noticeable decrease in the broadband noise level.

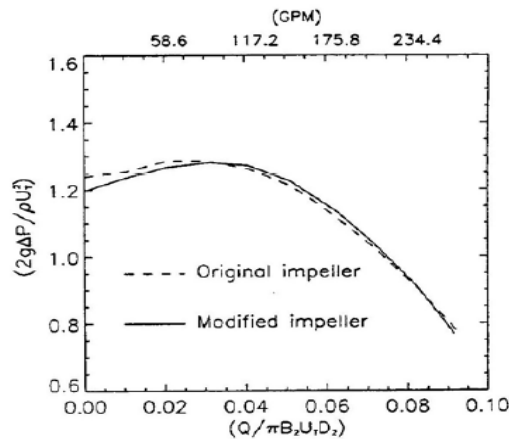


Fig2.Performance curves of the original and modified impellers.

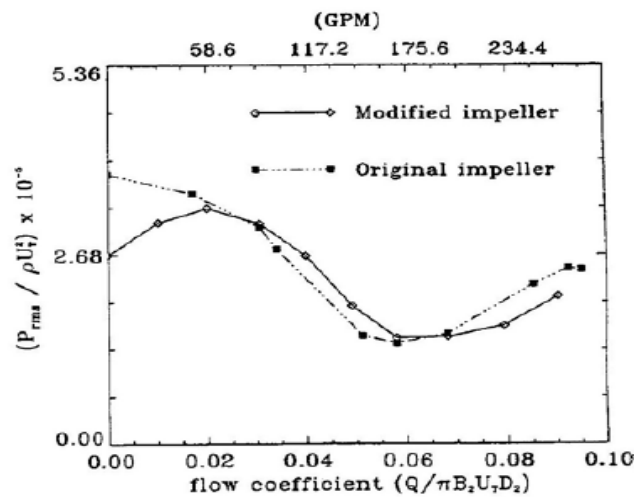


Fig3.Rms noise of the original and modified impellers.

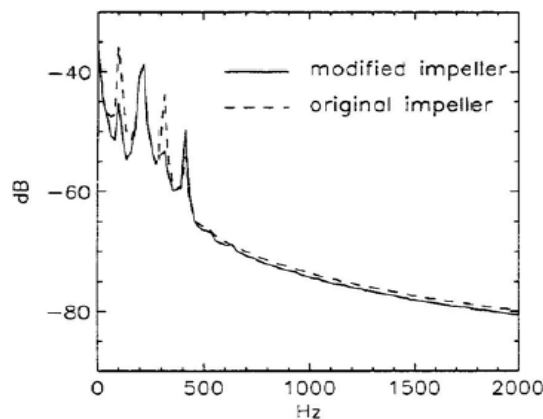


Fig. 4 Noise spectra of the original and modified impellers at 0=270 gpm.

Selected distributions of v , and vorticity within the modified pump are compared to the original data in Figure respectively. They demonstrate that the vanes decrease the original blade jet/wake phenomenon, but create additional similar patterns of non-uniform outflux. For example, in Figure the vane significantly reduces, but does not eliminate, the size of the wake region. However, as shown in Figure 4, the vane generates an additional

wake. Evidence for the formation of an additional vane wake is provided also by the vorticity distributions. In Figure 5 the new vorticity train extends from the impeller and in Figure 5 it appears on top of the tongue. As expected, Figure shows that the vane has little effect on the blade jet (it was not designed for it). Its own jet is much weaker as long as the vane is located far from the tip of the tongue (a sample for the latter, which will be discussed later, is presented in Fig. Finally, note that traces of wakes generated by the previous blade and vane can be identified on the left sides of Figure. The vorticity peak associated with the jet, that in the original pump appears near the blade (Figure 17a), does not exist when the impeller is modified. It does form as the blade moves closer to the tongue (data not shown) as the radial velocity at the exit from the impeller increases. This phenomenon is a direct result of increasing blockage to blade passage caused by the tongue, that increases the radial velocity in the unobstructed part. In the original impeller this vorticity peak "gets stuck" between the tongue and the impeller as the blade moves behind the tongue because of the low velocity there. In the modified impeller the new vane increases the radial velocity sufficiently (Figure 5) to push this blade vorticity away. Comparisons of phase averaged pressures and noise waveforms, are presented in Figure. It is evident that near the tongue (E6) and at the exit (EIS) the pressure fluctuations are considerably smaller, whereas somewhat far upstream of the tongue (EIO) they are slightly higher. Detailed explanations for the signals of the unmodified impeller, resulting from direct computations of pressure from the PIV data, are presented in Chu et al., 1995. It is demonstrated there that near the impeller (EIO and E6) the pressure minima occur when the blade passes by the transducer, under the negative vorticity train, and when the blade lines up with the tip of the tongue. The latter occurs almost simultaneously everywhere and is associated with operation above design conditions. The maxima appear when the transducer is located between the blade and the wake, and everywhere when the blade is located far (35°) upstream of the tongue. With the modified impeller, in addition to the pressure minima associated with the original blades (points C and F at E6 and EIO, respectively) there are new pressure minima when the vane passes by the transducer (points A and I). Reductions in pressure when the vorticity trains pass by are barely noticed near the modified impeller, mostly since they are overshadowed by simultaneous blade and vane effects. For example, the blade vorticity train reaches EIO (point E) at about the same time that the vane passes by (they are designed that way).

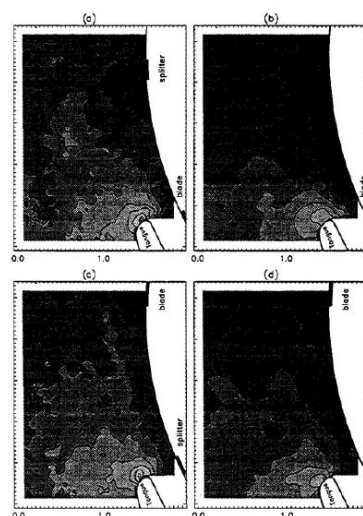


Fig. 5 v/U_r distributions at $\theta=270$ gpm: (a) blade is at 8° (modified impeller); (b) 8° (original); (c) 338° (modified); and (d) 338° (original). Increment between lines is 0.05. Scales are in inches.

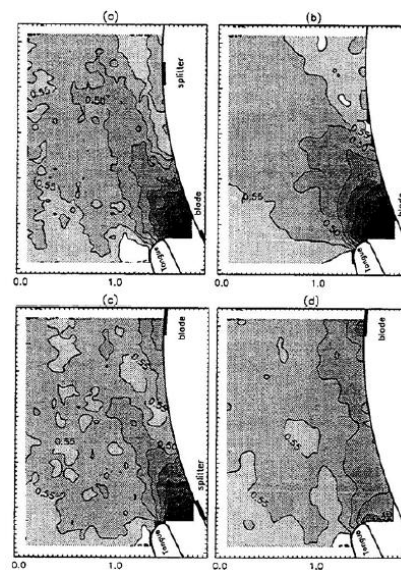


Fig. 6 v JUr distributions at $\theta=270$ gpm: (a) blade is at S_0 (modified impeller); (b) S_0 (original); (c) 338° (modified); and (d) $33S_0$ (original). Increment between lines is 0.05. Scales are in inches.

Similar to the impact of the blade, the pressure decreases everywhere in the exit region when the vane lines up with the tip of the tongue (points A and E at E6 and EIO, respectively). Pressure maxima occur simultaneously (point D at E6 and J at EIO) when the blade is past the tip of the tongue and the vane is still far upstream of it. These peaks occur earlier than the original impeller because of the added vane and the pressure dip near it (point A). Simultaneous pressure maxima occur also when the blade is still about 14° upstream of the tongue and the vane is relatively far (IOj past it (points B and .G). To recapitulate, maxima occur everywhere when the blade and the vane are far from the tip of the tongue, and the minima appear when they are very close to the tongue. Pressure minima occur also when the blade passes by the transducer, but they are barely noticed under the vorticity trains. The latter conclusion is the only result which is inconsistent with the trends observed with the original impeller. Behind the tongue (E4) the vane impacts the pressure waveform only in its vicinity, causing a new minimum as the vane passes by (point K). Close to the blade, the signal remains quite similar to the original impeller. On the other side of the Tongue, near the exit (E I5), there are two minima (points Land N), that occur, like anywhere else in the exit region, when the blade and the vane coincide with the tip of the tongue. In the original pump there is a high pressure peak at E15 (point M) when the wake impinges on the tip of the tongue. Although the impingement still occurs (Figure 7), it has little impact on the pressure at E15. It is possible that weakening of the wake in the vicinity of the tongue reduces its impact to a level that it is barely noticed. One of the contributing reasons for this weakness is the jet of the vane. As noted before this jet is fairly small until very close to the tongue, where blockage to blade passage induced by the tongue, causes an increase in radial velocity in the unobstructed space (an example of such a process with the main blade is illustrated in Figure 5). This jet "blows" the wake away from the tongue, before it has a chance to impinge on it. A clear illustration of this blowing process is provided in Figure 7. For this reason the vorticity train of the original impeller appears continuous up to the tongue (Figure 7), whereas the train of the modified impeller is much more fragmented. Similar conclusions can be drawn from the

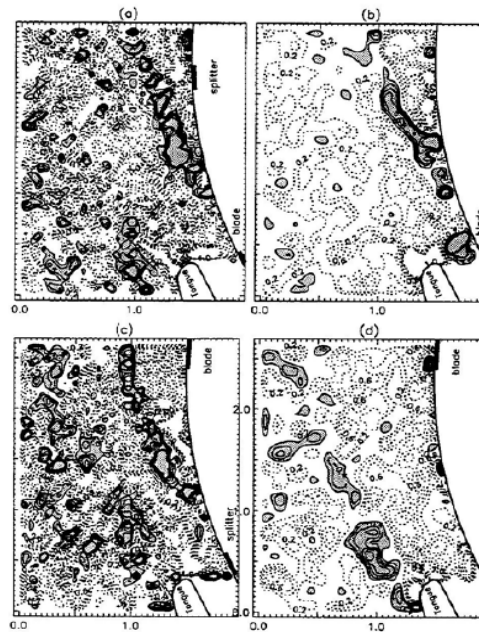


Fig 7 Vorticity distributions at 0=270 gpm: (a) blade is at 8° (modified impeller); (b) S0 (original); (c) 338° (modified);

and (d) 338° (original). Solid line represents negative vorticity, and dashed line positive. Increment between lines is 0.2 UJrr. Scales are in inches. distributions of v_e . Thus, the vane not only reduces the size of the wake, it also prevents impingement on the tip of the tongue. The blade has a similar effect on the wake of the vane (data not shown here).

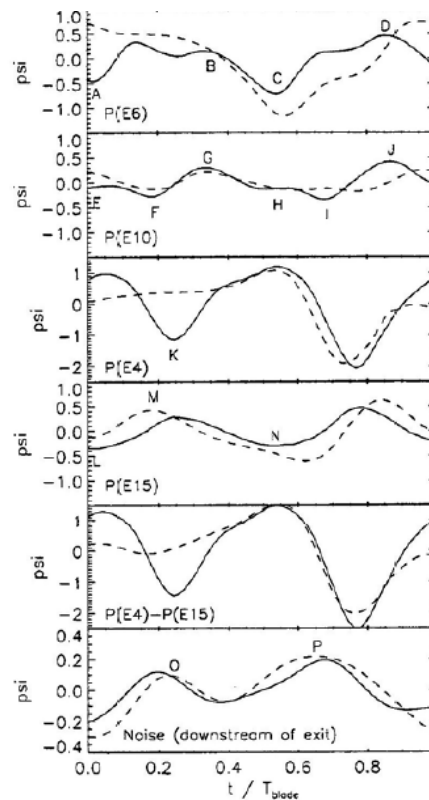


Fig. 8 Phase-averaged pressure and noise waveforms of the original (dashed line) and modified (solid line) impellers. (Note the differences in scale.)

As discussed and demonstrated in Chiu et al. (1995), wake impingement causes also a peak in the noise signal (point O) of the original impeller. The delay between points M and O is approximately the time required for the pressure pulse to travel between EIS and the hydrophone. This relationship is obviously not the case with the modified impeller, first since the hydrophone peak occurs before the maximum at EIS, and second, since the pressure at EIS in the modified impeller is not affected by the impingement. Thus, it is unlikely that the first peak in the noise signal has anything to do with wake impingement.

Furthermore, the data in Figure 8 suggests that the hydrophone signal has no any clear resemblance or correspondence to the pressure in EIS, E6 or EIO. The only consistent relationship exists with the pressure at E4, or even more clearly, with the pressure difference across the tongue ($P(E4)-P(EIS)$). Recall that with the original impeller the second noise maximum (point P) is clearly a result of tongue oscillations, induced by the pressure differences across the tongue. There, the delay between maxima in pressure difference and noise signals is about 0.7 msec, approximately the time required for sound to travel between the transducers and the hydrophone (the distance is 3.3ft.). With the modified impeller, both noise peaks appear only about 1.4 msec after the maxima in pressure difference across the tongue. This delay is about twice the time required for sound to travel between the tongue and the hydrophone. To explain this discrepancy we note that with the original impeller, the pressure maximum behind the tongue occurs almost simultaneously everywhere when the blade lines up with the tip (there are some blade induced variations). Thus, the maximum force on the impeller should occur almost at the same time as the peak at E3. With the modified impeller, the added vane causes a pressure dip 27° ahead of the tip (similar to point Kat E4). Thus, the maximum force on the tongue does not necessarily coincide with the maximum in $P(E4)-P(EIS)$ and a slight delay is quite possible. These results suggest that with the modified impeller tongue oscillations remain the only primary source of noise at the exit from the pump.

III. CONCLUSIONS

PIV, surface pressure and noise measurements have been used to study the effects of modifications to tongue and impeller geometries on the flow structure, local pressure fluctuations and noise. It is demonstrated that increasing the gap between the impeller, up to about 20% of the impeller radius, reduces the impact of nonuniform outflow from the impeller (mostly the jet/wake phenomenon) on the flow around the tongue and noise. Further increase in the gap affects the performance adversely with minimal impact on the noise level. When the gap is narrow, the primary sources of noise are impingement of the wake on the tip of the tongue, and tongue oscillations when the pressure difference across it is high. At 20% gap, the entire wake and its associated vorticity trains miss the tongue, and the only effect of nonuniform outflow from the impeller occurs when the jet impinges on the tongue. This effect is quite small, at least for the present pump. Based on the available data we attempted to reduce the nonuniformity

in outflow from the impeller by inserting short vanes between the blades. Their location and orientation were selected to reduce the size of the wake and the magnitude of circumferential velocity within it. The experiments were performed only with the narrowest gap between the tongue and the impeller. The results showed that although the original intent was successful, namely the size of the original wake was reduced, the vanes generated a jet/wake phenomenon of their own. However, both wakes were considerably weaker to a level that

their impacts on local pressure fluctuations and far field noise were insignificant. The jet in front of the vane was an added benefit, since it blew the wake of the blade away from the tongue shortly before impingement, eliminating any direct impact of the wake on noise. The only remaining contributors to noise were tongue oscillations caused by the pressure difference across it. They reach maximum level when either the blade or the vane line up with the tip of the tongue. This effect was particularly noticed with the present fairly narrow lucite tongue. As the experiments with the other tongues have shown, the impact of tongue oscillations decreases with increasing tongue thickness and stiffness.

REFERENCES

- [1] Chu, S., Dong, R., and Katz, J., (1993), "Unsteady Flow, Pressure Fluctuation and Noise Associated with the Blade-Tongue Interaction in a Centrifugal Pump", Symposium on Flow Noise Modeling, Measurement and Control, ASME Winter Annual Meeting, New Orleans, Louisiana, Nov. 28 - Dec. 3.
- [2] Chu, S., Dong, R., and Katz, J., 1995a, "Relationship between Unsteady Flow, Pressure Fluctuations and Noise in a Centrifugal Pump. Part A: Use of PIV Data to Compute the Pressure Field", to appear in the J. of Fluids Engineering, Vol. 115, No. 1.
- [3] Chu, S., Dong, R., and Katz, J., 1995b, "Relationship between Unsteady Flow, Pressure Fluctuations and Noise in a Centrifugal Pump. Part B: Effect of Blade-Tongue Interaction", to appear in ASME J. of Fluids Engineering, Vol. 115, No. 1.
- [4] Cumpsty, N. A., 1989 "*Compressor Aerodynamics*", Publisher: Longman Scientific & Technical.
- [5] Dean, R. C., and Senoo, Y., 1960, "Rotating Wake in Vaneless Diffusers", ASME J. of Basic Engineering, Vol. 82, No. 3, pp 563-574.
- [6] Dong, R., Chu, S., and Katz, K., (1992a), "Quantitative Visualization of the Flow within the Volute of a Centrifugal Pump. Part A: Technique", ASME J. of Fluids Engineering, Vol. 114, No. 3, pp 390-395.
- [7] Dong, R., Chu, S., and Katz, K., (1992b), "Quantitative Visualization of the Flow within the Volute of a Centrifugal Pump. Part B: Results", ASME J. of Fluids Engineering, Vol. 114, No. 3, pp 396-403.
- [8] Eckardt, D., (1975), "Instantaneous Measurements in the Jet/Wake Discharge Flow of a Centrifugal Compressor Impeller", ASME J. of Engineering for Power, Vol. 97, No. 3, pp 337-346.
- [9] Hamkins, C. P., and Flack, R. O., (1987), "Laser Velocimeter Measurements in Shrouded and Unshrouded Radial Flow Pump Impellers", ASME J. of Turbomachinery, Vol. 109, pp 70-76.
- [10] Hira, O. S., and Vasandani, V. P., (1975), "Influence of Volute Tongue Length and Angle on the Pump Performance", Journal of Mechanical Engineering (Indian), Vol. 56, pp 55-59.
- [11] Ms. Kirti Singh, Dr. Vijay L. N. Gangal. "MICRO INSURANCE: GROWTH AND SOCIAL DEVELOPMENT TOOL FOR GRASS ROOT PEOPLE IN INDIA." *International Journal of Advanced Technology in Engineering and Science* 3.Special Issue No. 01 (2015): 168-183.