Model-Prototype Conformance of a Submerged Vortex in a Vertical Turbine Pump

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Abstract: Submerged vortices are commonly found in sump intakes of vertical turbine pumps. These vortices are known to cause increased vibration and at times degrade pump performance. Approach flow conditions and sump and pump bell geometry are very critical in the formation of submerged vortices. Scale model tests are a common method used to evaluate the presence of free-surface and submerged vortices in pumping plants. While scale effects in reproducing free-surface vortices are fairly well documented, scale effects involving modeling of submerged vortices are somewhat more unknown due to the difficulty in actually observing a prototype vortex.

This paper will discuss the comparison between measurements and observations of a 1:8.74 geometric scale model of Twin Peaks Pumping Plant and the prototype operation.

Introduction

Twin Peaks Pumping Plant is located near Tucson, Arizona and is part of the Central Arizona Project. The plant contains six vertical turbine single-stage pumps which lift project water about 23 m. Rated capacity at rated head is 17.58 m³/s. The plant contains three 4.25-m³/s units in individual sumps and three 1.42-m³/s pumps in a common sump. Upon initial startup of the plant, the larger pumps were undercapacity when compared to the shop tests. One suspected reason for this deficiency was the possibility that submerged vortices were present and entering the pump bells. Initial testing at Twin Peaks confirmed the presence of a submerged vortex attached to the floor and entering the pump bell (Nystrom, 1992). These tests included visualizing the vortex by injecting compressed air near the vortex location and recording it on an underwater video camera. Other instrumentation, accelerometers and proximity sensors, verified that there was a component of vibration at the blade-passing frequency which would be characteristic of a vortex.

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entering the pump bell; however, the magnitude was less than 10 percent of the component present at the rotational frequency.

The Model

As a result of these initial observations, a 1:8.74 geometric scale model of the Twin Peaks Pumping Plant was constructed in Reclamation's Denver hydraulic laboratory. The model included a portion of the canal, the inlet transition, and the pump sumps, figure 1. The pump bells and columns were constructed from acrylic and connected to PVC piping. The outlets were manifolded with the pipeline forming a closed loop system. A 11.2-kW centrifugal pump located inline provided the recirculation and

![Figure 1. 1:8.74 scale model of Twin Peaks Pumping Plant constructed in Reclamation's hydraulic laboratory.](image)

an orifice-venturi meter was used to measure discharges. Each pump column was equipped with an elbow meter so that individual unit flows could be adjusted when more than one unit was operating simultaneously.

Model similitude was based on equal Froude numbers in the model and prototype. The model scale was chosen to ensure that viscous and surface tension effects were kept to a minimum. The critical Reynolds number, based on the velocity of approach and the incoming depth, suggested by Knauss (1987) was matched.
Measurements

The Model: In addition to making visual observations with air bubbles and dyes as tracers, we made several different measurements to help us evaluate the sump performance. These measurements included velocity profiles in the sumps approaching the pumps, pre-rotation in the pump column, and velocity profiles in the pump column. The sump velocity profiles were taken with either an Ott propeller-type meter or a two-component Marsh-McBirney electromagnetic velocity meter. The pre-rotation measurements were taken with a vortimeter. This meter measured tangential velocity in the pump column, assuming solid body rotation (Lee and Durgin, 1980). The velocity profiles in the pump columns at the impeller location were measured using a standard pitot-static tube, traversed across the column on lines at 45° increments.

The Prototype: The main measurements used in evaluating the prototype performance were underwater video recordings. These video images were taken with a Deepsea Power & Light FM-1000 CCD camera which had a fixed focus and remotely controlled panning features. Compressed air was injected from a manifold mounted below the pump bell in order to visualize the vortex. In addition to these observations, we also measured runout at the lower bowl bearing with proximity sensors and pressure pulsations in the discharge line with a pressure transducer. Pump discharges were verified with a permanently installed ultrasonic flowmeter.

Results

Submerged vortices were present in all model sumps with every operating sequence tested. These vortices were only visualized with the aid of tracers (air bubble and dye). The vortex was not strong enough to pull vapor bubbles out of solution. The velocity measurements taken in the sumps indicated that the approach flows to the pump bells were skewed to one side, figure 2. The resulting velocity profile in the pump column showed this skewness also, figure 3. Swirl measurements showed inconsequential amounts of swirl (solid body rotation) present in the pump column. This corresponds to the thin vortex (3mm- to 5-mm diameter) present in the model, figure 4.

Results from the prototype are mostly in the form of underwater video footage. As in the model, we had to use a tracer (compressed air) in order to visualize the vortex in the prototype. This would indicate that the vortex strength is similar to that observed in the model. With air injected into the vortex core, it appeared to be between 25-mm and 75-mm in diameter. Shaft runout at the lower pump bowl bearing and pressure pulsations in the discharge line did not indicate significant vibration due to the presence of the submerged vortex.
Figure 2: Elevation view of velocity profile in sump No. 1, one pump bell diameter in front of the pump bell, minimum water surface elevation, $Q=4.39$ m$^3$/s, velocity in m/s.

Figure 3: Normalized velocity profile in pump column, original configuration, $Q=4.39$ m$^3$/s, values in parentheses show range of data due to fluctuations caused by the submerged vortex.
Modifications

After verification of the prototype vortices in the scale model - including similar size and strength - we proceeded to modify the model sump to eliminate the vortex. After many iterations, we installed a series of floor and wall splitters which were successful in eliminating all submerged vortex action, figure 5.

This arrangement is similar to ones recommended by other researchers (Nakato, 1989; Prosser, 1977). The measurement of the velocity profile in the pump column showed a much more even distribution, typical of an acceptable radial inflow pattern, figure 6.

Verification

The sump modifications developed in the model were installed in sump No. 1 at Twin Peaks Pumping Plant. The video taping and additional measurements were repeated. No visual evidence of a submerged vortex was observed with the underwater video, with or without the compressed air tracer. Runouts and pressure pulsations were essentially unchanged from the previous tests. The discharge capacity and efficiency did not change from the values measured during the previous test with the original sump design.
Figure 5: Final sump modification which eliminated all submerged vortices.

Figure 6: Normalized velocity profile in pump column. Normalizing velocity is the average of all point measurements.
Discussion

Submerged vortices (floor-attached), directly beneath the pump bell were verified in all sumps. This type of vortex is usually generated by local flow conditions near the pump bell. Considering the uneven velocity distributions approaching the pump bell and that several of the sump dimensions (based on the supplied pump bell diameter) were outside of the recommended guidelines, the conditions were prime for submerged vortex formation (Triplett, 1988; Sweeney, 1979). Very little information is available about scale effects in modeling submerged vortices because of the difficulty in actually visualizing prototype vortices. In this case our ability to observe the prototype vortex through underwater video and actually compare it to the vortex observed in the model was especially meaningful.

In the past, many techniques have been used to assist in the modelling of vortices. In general, the current feeling is that a model should be of a large enough scale that the Reynolds numbers remain large enough (Re > 10^5) that viscous effects are negligible. Many researchers distorted the discharges up to 1.5 times the scaled discharge to aid in the production of vortices in models. However, the majority of present-day studies have abandoned this technique, especially on larger scale models, because of the distortion which results from the increased flows incorrectly modeling the streamlines and shear zones around and near the sump boundaries.

Perhaps the most meaningful of the model measurements in evaluating sump performance were the velocity distributions taken in the pump column at the impeller location. As previously mentioned, the pre-rotation at this location was small, having a swirl angle of only 2° maximum. Observations showed that the submerged vortex does not appear to have a significant influence on the large-scale swirl (or pre-rotation) at the impeller location. Drop off in performance or insufficient pump capacity is generally related to large scale swirl. The velocity distribution measured for the original design indicated that point velocity measurements deviated up to 10 percent from the mean velocity. Uneven velocity distributions have been shown to be consistent with higher head losses in the pump bell and the presence of vorticity. The final configuration (no vortices) showed that all velocity measurements were between -3 and +2 percent of the average velocity. This uniform distribution indicates a lack of vorticity with essentially uniform radial flow approaching the impeller location.

The data collected during the prototype testing proved to be very valuable. In general, pump shaft runout at the lower bowl bearing and pressure pulsations in the discharge line did not show any sensitivity to the presence of a submerged vortex. In addition, pump discharge capacity also remains unchanged. However, the video tape revealed that, indeed, the sump modifications were successful in eliminating all vortex activity. In addition, size and strength of the vortex (prior to the sump modifications) seemed to scale quite well. The sizes were estimated from the video footage and the prototype vortex appeared to be 8 to 10 times larger (core diameter) than what we observed in the model. The only true measure of vortex strength is
a measure of the minimum pressure in the core. While we were not able to measure this, neither the model or the prototype vortex were strong enough to pull air/vapor out of solution. In both cases we had to use a tracer (air bubbles or dyes) in order to visualize the submerged vortex.

Through our ability to compare relative size and strength of submerged vortices from a model to a prototype facility, we can have increased confidence that if current state-of-the-art practices in modeling pump/sump intakes are followed, the results will be representative and free from scale effects.

References


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