Experimental Investigation of Critical Submergence Reduction using Anti-Vortex Device in a Pump Intake

Gangipamula Rajavamsi^{1*}, Shyam Shukla², Ravindra Birajdar³

^{1,2,3}Corporate Research & Engineering Development, Kirloskar Brothers Limited, Pune -411045, India

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ABSTRACT

Specific hydraulic phenomena in a pump intake which can cause adverse effects on pump performance include free surface vortices, pre-swirl magnitude, and air entrainment. In this regard, critical submergence is a significant parameter which is defined as the depth at which the free surface vortex begins entraining air. Identification of air entrainment at pump intakes and the recommendation of possible solutions to them is usually done by conducting experiments on reduced scaled models. In the present case study, the surface vortex formation is investigated in a 1:10 pump intake model. A novel Anti-vortex device (AVD) has been proposed in the present work and the efficacy of the same has been investigated through experimental study. The provision of AVD and other elements in the pump intake have resulted in the reduction of required submergence by 64% relative to submergence as per Hydraulic Institute Standards (S_{HIS}) at 1.5 F_m (Model Froude number) in a 1:10 scale model.

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1. Introduction

Surface vortices at pump intakes are produced by the pressure drop resulting from pump suction and the non-uniformity available in the approaching flow. These are highly dependent on approach flow patterns and the stability of these patterns, as well as the Froude number. Surface vortices can cause a reduction of pump flow and fluctuations of impeller load that results in noise and vibration which can further cause damage to the pumps. To achieve a satisfactory flow quality in pump intake with reduced surface vortices near the pump, modifications can be made to allow pump operation at practical submergence depth. Any reduction in submergence reduces the depth of excavation of sump without affecting the pump performance and its operating life. The reduction in submergence in pump intakes causes huge saving as excavation and concrete lining reduces. Classification of surface vortices is usually made by visual observation. They can be classified as 6 types which are given in Table 1[3].

The approximate total size of the present prototype intake structure is 125m X 30m X 15m (L X B X H). It consists of 3 Cooling water circulation pumps (CW) and 2 Auxiliary cooling water pumps (ACW) with duty flow rates 8833 L/s and 1528 L/s respectively. In this intake geometry, water from each cooling tower falls into the cooling tower basin and then flows towards the pump chamber (Figure 1 (a)). Flow from each cooling tower is getting accumulated in the next cooling tower and then enters the CW and ACW pump chambers. The absence of forebay in the intake geometry has made the geometry very critical for providing the uniform

Table 1: Classification of free surface vortices

Type	Vortex Description
1	Surface swirl
2	Surface dimple
3	Dye core to intake
4	Vortex pulling floating trash but not air
5	Vortex pulling air bubbles to intake
6	Full air core to intake

flow. Also, the submergence requirement in the pump intake geometry is generally more than other conventional pump intakes. Therefore, the intake geometry has been selected for the detailed numerical study and model experiments to reduce the critical submergence by using Anti-vortex device (AVD) and other elements. Anti-vortex device is a novel device that helps in reducing submergence more than normal devices used in conventional methods. Numerical studies have been carried out for the intake geometry to check the flow uniformity near the pump chamber inlet and the swirl intensity near the pump impeller eye. The numerical simulation of the intake structure included cooling towers, screens, CW and ACW pump chambers, pipes which represent the vertical

* Corresponding Author: : raja.vamsi@kbl.co.in

pumps. The analysis results showed that the upstream flow conditions in the intake have resulted in adverse effects on the flow characteristics near the pump chamber entry and hence the pump bell mouth location. After a detailed numerical study, the final modifications are obtained as flow distributors (near the pump chamber entry), bottom wall splitter and curtain wall as shown in Figure 1 (b). Figure 1 shows the comparison of the 3d models of both original and modified intake geometries.

Figure 1: 3d models of intake geometry (a) Original (b) Modified.

The model testing of the modified intake geometry, in which modifications have been confirmed from CFD is conducted on a 1:10 scale model. The model test has been conducted for different working combinations of both the pumps CW and ACW at 1.5 F_m. The results obtained from the experiments are found to be satisfactory and aligned with the numerical results [5].

The aim of the present study is to check the effect of the conventional modifications (Curtain wall + Flow distributors + Bottom wall splitter) used in submergence reduction. Thereafter, use a novel device i.e. AVD over and above conventional devices to further reduce the submergence. The pump chamber area is prone to air entrainment due to the suction pressures resulting from pump suction. This can be avoided by placing an obstruction to the transfer of air media. The anti-vortex device is a two-plate geometry made with wood and the plates joining at the midline of the column pipe. The device is placed near the column pipe entry. AVD can be constructed at the site and no problem is foreseen during pump operation and maintenance. Sealing with AVD is to be ensured in the sump. Similar solutions were already given and are working without any problem.

2. Experimental Study

The model testing of the sump has been conducted at a 1:10 scale ratio for the intake geometry. Figure 2 shows the hydraulic model set up in which C1, C2, and C3 represents CW chambers, A1 and A2 represent the ACW chambers. Flow rates in CW and ACW pumps are 41.96 L/s and 7.33 L/s respectively at 1.5 F_m. The uncertainty in the flow meter readings is $\pm 1\%$ and the uncertainty in the level measurements is ± 1 mm. The minimum submergence required as per Hydraulic Institute Standards (HIS) (S_{HIS}) at 1.5 F_m, has been considered as a reference for water level measurements and further calculations. The minimum water level in the intake model is set on the intake and scale of readings is marked on the pump chamber back walls. It has been planned to conduct the two tests Test 1 and Test 2 to establish the impact of the AVD on surface vortices and the swirl intensity near the bell mouth entry.

Figure 2: Hydraulic model setup of the pump intake with pump chamber notations.

2.1 Test 1- Modified Pump intake geometry without AVD

In this, the model test conducted for the modified geometry by reducing the water levels from a minimum water level by 7 percent for each observation. The value of the critical submergence is noted at which the surface vortices are noticed with air entraining (Type 2 vortices). The intensity of flow rotation is measured using a swirl meter which is located about four suction diameters downstream from the bell. The swirl meter consists of a straight-vane propeller with four vanes mounted on a shaft with low friction bearings. The tip-to-tip vane diameter is 75% of the pipe diameter and vane length is equal to 0.6 pipe diameters. The revolutions per unit time of the swirl meter are used to calculate a swirl angle,

$$\theta = \tan^{-1} \left(\frac{\pi d n}{u} \right)$$

where u = average axial velocity at the swirl meter

d = diameter of the pipe at the swirl meter

n = revolutions per second of the swirl meter

Readings have been noted during consecutive intervals of 30 seconds, covering a period of 10 minutes at each water level. Absolute values of swirl meter readings are averaged over this period and noted. These readings are further used to calculate the swirl angle magnitude near the bell mouth.

2.2 Test 2- AVD is placed in all pump chambers of modified pump intake geometry except in C1 pump chamber

This test gives us a comparison of flow in two side by side pump chambers and hence can understand the effect of the AVD relatively by visual observation. Similar to test 1, in this also water level reduced by 7 percent. The AVD is placed near the column pipe of each pump and cannot be located below this position in the present geometry, due to the limitations of the water levels in the pump intake. Figure 3 shows the plan and elevation of the 2d sketch of AVD in a pump chamber.

3. Results and Discussions

In the present pump intake, all pumps are kept working at a minimum water level and at 1.5 F_m which is the critical operation of pumps. S_{HIS} value is calculated using HIS standards and considered as a reference level, which is 100% in the present calculations.

3.1 Test 1- Modified Pump intake geometry without AVD

After conducting the experiments for test 1, the achieved critical submergence in the intake geometry is at a level of 41% of S_{HIS} (Type 2 vortices). Table 2 shows the type of surface vortices formed in the pump chamber with respect to the percentage of S_{HIS} calculated using HIS standards. The provided curtain walls and flow distributors at the pump chamber entry have resulted in the uniform flow entry in each pump chamber and also the reduction of critical submergence. The critical submergence is reduced by 59% in CW pumps due to the provision of the modifications. Swirl angle is measured at each water level in all the pumps using provided vortex meter rotations in the column pipe. Table 4 shows the values of the swirl angle in the column pipe which represents the vortex strength of the flow. The swirl intensity is found to be increasing

Figure 3: 2d sketch showing Plan and elevation view of AVD located in the pump chamber.

Table 2: Type of vortices in Test 1

S.No.	% of S_{HIS}	Type of vortex in pumps (without AVD)				
		C_1	C_2	C_3	A_1	A_2
1	86	No sign of any surface vortex				
2	79					
3	72					
4	65					
5	58					
6	50					
7	43	1	1	Nil	Nil	Nil
8	41	2	2	1	Nil	Nil
9	40	5	5	5	1	1
10	38	5	5	6	1	1

with the reduction in water levels. This is due to the increased velocities and non-uniformity due to the reduced water levels. Maximum swirl angle is observed in pump C_1 which is 3.3° in CW pumps and 4.4° in A_2 pump at a water level of 40% of S_{HIS} .

3.2 Test 2- AVD was placed in all pump chambers of modified pump intake geometry except in C_1 pump chamber

AVD is placed in all the pump chambers except in C_1 and conducted experiments similar to test 1. The sign of surface vortices is observed in C_1 chamber at a water level of 43 percent and air entrained vortices at 41 percent of S_{HIS} , which is identical to test 1. In the case of other chambers in which the device is placed, the flow is observed to be much stable. Table 3 shows the type of vortices formed with respect to the percentage of S_{HIS} . No sign of surface vortices is observed in all these chambers up to a level of 38% S_{HIS} . Sign of surface vortex started at a level of 38% S_{HIS} in C_2 and C_3 chambers and the type 2 vortices at a level of 36% S_{HIS} . The critical submergence is reduced by 64% in CW pumps due to the provision of the AVD and the other elements. Visually it has been observed that the location of the surface vortices shifted to the area near AVD entry. Table 5 shows the swirl meter rotations noted at each water level. The maximum swirl angle in CW pumps was observed in C_1 which is like test 1. The swirl intensity in chambers with AVD is found to be reduced relative to the test 1 which is without AVD. The maximum fluctuations in the levels are below ± 3 mm without AVD and reduced to ± 1 mm with AVD. Figure 4 shows the comparison of surface vortices without AVD and with AVD. In figure 4 (a), one of the scales marked is correct and referred during the experiments. For clarity, the other scale has been struck off.

Table 3: Type of vortices in Test 2

S.No.	% of S_{HIS}	Type of vortex in pumps (without AVD)				
		C_1	C_2	C_3	A_1	A_2
1	86	No sign of any surface vortex				
2	79					
3	72					
4	65					
5	58					
6	50					
7	43	1	Nil	Nil	Nil	Nil
8	41	2	Nil	Nil	Nil	Nil
9	40	5	Nil	Nil	Nil	Nil
10	38	5	1	1	Nil	Nil
11	36	6	2	2	1	1
12	34	6	5	5	1	1

Table 4: Swirl angle values without AVD

S.No.	% of S_{HIS}	Swirl angle in degrees (Test 1)				
		C_1	C_2	C_3	A_1	A_2
1	86	1.4	-0.7	1.0	1.2	1.6
2	79	1.4	-0.7	1.0	1.2	2.0
3	72	1.5	-0.7	1.0	2.0	2.8
4	65	1.8	-0.8	1.3	2.0	2.8
5	58	2.1	-1.0	1.6	2.4	3.2
6	50	2.4	-1.3	1.8	2.8	3.2
7	43	2.9	-1.6	2.2	2.8	3.6
8	40	3.3	-2.0	2.4	3.6	4.4

Figure 4: Comparison of surface vortices
a. Type 5 vortex in C1 without AVD.
b. Absence of vortices in C2 with AVD.

Table 5: Swirl angle values with AVD

S.No.	% of S_{HIS}	Swirl angle in degrees (Test 1)				
		C_1	C_2	C_3	A_1	A_2
1	86	1.4	-0.2	-0.2	0.8	1.2
2	79	1.4	-0.2	-0.2	0.8	1.2
3	72	1.5	-0.3	-0.2	1.2	1.2
4	65	1.8	-0.5	-0.4	2.4	1.6
5	58	2.1	-0.5	-0.5	2.4	1.6
6	50	2.4	-0.7	-0.6	2.4	2.0
7	43	3.1	-0.9	-0.9	2.4	3.6
8	40	3.4	-1.3	-1.1	3.2	3.6

4. Conclusions

Following conclusions can be drawn from all of the conducted experiments.

1. The critical submergence is reduced by 59% relative to S_{HIS} in CW pumps due to the provision of the modifications in the pump intake geometry which are flow distributor walls, curtain wall, and bottom wall splitters. The critical submergence is reduced by 64% in CW pumps due to the provision of the AVD in addition to the modifications at $1.5 F_m$ in 1:10 pump intake model.

2. The reduction in submergence due to the provision of AVD is 5% over and above 59%, which is critical in present case/site conditions. The physical reduction in submergence achieved due to the provision of AVD is 30 mm for a 1:10 model at $1.5 F_m$. For a prototype, the estimated submergence reduction is 300 mm at $1.5 F_m$.
3. Swirl intensity near the bell mouth entry in test 2 is found to be lower relative to test 1. The reduction in swirl intensity indicates the more uniform flow near the bell mouth.
4. The location of the surface vortices which are generated at lower water levels has been shifted near to the AVD entrance.

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