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FLOW INVESTIGATION IN A DIAGONAL FLOW PUMP

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ABSTRACT
The work describes flow investigation in a diagonal flow pump of specific speed of 95 rpm (metric) which is widely used in pump storage plant and thermal power stations throughout the world. A pump impeller was designed using the fundamental concepts of turbomachine theory and with a minimum of empiricism. The experimental study was carried out in a specially designed pump test cum water tunnel test facility and had provision for control of rig static pressure and temperature. Provision was made for detailed velocity and angle measurements at 2 diameter upstream and 2 diameter downstream of pump. Flow measurements were done with the use of a compact four hole probe that measured total and static pressures as well as three component of velocities. Detailed flow traverses were made immediately upstream and downstream of the impeller at various flow rates and tip clearances. An attempt has been made to understand the actual flow in the pump and verify the concepts implicit in the design methodology with the help of experimental measurements.

Keywords: Diagonal Flow Pump, Test Rig, Stodola Slip Model.

1. INTRODUCTION
A rotodynamic pump is a device for moving a fluid by means of a rotating impeller through centrifugal or propeller action. In moving fluid, a pump overcomes resistance to flow by supplying the fluid with necessary energy from an external source. The impeller consists of a set of blades fitted on a rotating hub. The passages between the blades are usually divergent in nature. Thus, when the impeller rotates, then the fluid velocity relative to the impeller decreases. The reduction of relative velocity causes an adverse pressure gradient which, in turn, results in a large dissipation and possible flow separation leading to low efficiencies and limited working range for the pump. There is thus a continuing effort for developing pump with improves efficiency and larger working range. The work describes here is an experimental work of a diagonal flow pump of specific speed 95 rpm which corresponds to the range of specific speed of cooling water pump in large power station in India and abroad. The emphasis was on obtaining a detail physical picture of flow and understanding the underline phenomenon thus helping to lay foundation for rational design. The investigation was carried out on a special pump test facility that was built and design for the same purpose. A diagonal flow pump has been design using the fundamental concept of turbomachine theory and with the minimum empiricism.

2. OUTLINE OF DESIGN METHOD
The specification of model pump was chosen to be compatible with a specific speed of 95 rpm (metric) and available rig power of 11 kW. This led to Q = 414 m^3/hr. (0.115 m^3/s), H = 5.45 m, N = 1000 rpm. The expected efficiency of this pump is 75% [1]. Five equally spaced stream surfaces chosen. Values of C_2 at the trailing edge of the blade were calculated from Euler equation of pump and together with a meridional velocity. From the known flow rate and velocity this enabled the velocity triangle be calculated and the inlet and outlet relative flow angles to be determined. It can be shown that the meridional stream lines remain straight and parallel to the hub and casing if the absolute whirl velocities follow the free vortex law. The inlet and outlet velocity triangles were drawn on this basis. The slip velocities were calculated using the Stodola model [2] with effective relative vorticity of $-2\Omega\sin\Psi$, (where Ψ is the semi cone angle of the diagonal impeller), and then used to modify the velocity triangles to keep the relative flow angles leaving a non rotating

impeller. Two dimensional straight cascades were now designed with 10 C 4[3] blading to match the same blade outlet angles. Simple deviation rules [4] were used in the cascade design. The acceptability of the cascades was checked using Leiblien blade loading criteria. Analysis of the flow to the design cascade was verified by the surface vorticity method. Finally the straight two dimensional cascade was transformed to conical cascade using the conformal transformation. The impeller fabricated at the Hydraulic Laboratory of Jadavpur University as shown in Fig.1.

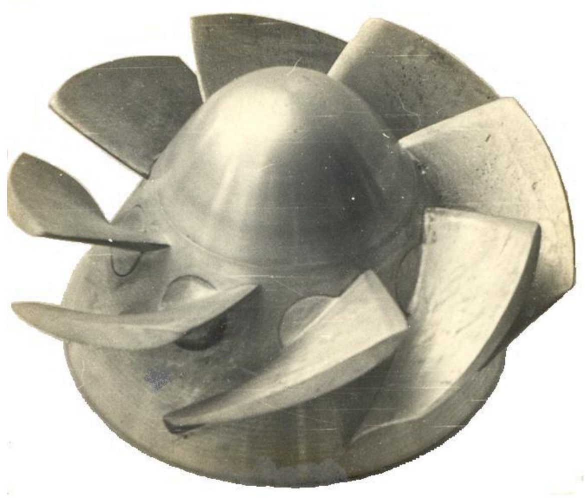

Fig 1. Test Impeller

3. TEST RIG

The layout of the test rig is shown in Fig.2. A straight pipe line length of 10 diameter is provided at inlet to ensure standard repeatable conditions at pump entry. This pipes comes on a vertical tank of 1 m diameter in which flow straighteners are provided to ensure the flow entering the pipe always swirl free.

The pump outlet flange is connected to the vertical discharge line, a butterfly valve is provided to control the discharge of the pump. The discharge pipe rises vertically up to a vertical rise 2.5 m.

Fig 2. Pump Test Rig

From the pump centre line and crosses over at an elevation of 3.25m and turns to an axial direction through a mitre bend. After the bend the flow is allowed to diffuse to a diameter of 750 mm and passes through a honeycomb section, screens and contraction cone from 750 mm to 250 mm before entering into an auxiliary water tunnel test section of 250 mm diameter and 1m long. After the test section the flow is allowed to diffuse to a diameter of 500 mm to reduce its velocity. Immediately after that the flow is allowed to flow through a resorber of 1 m diameter and 7 m long. The flow leaves the resorber in a pipe of 200 mm diameter at a centre line elevation of 500 mm and raises to form a metering section with a venturimeter. And this venturimeter is used for insitu calibration which in turn gives the discharge of the pump. The flow leaving the venturimeter and enters the inlet vertical tank at an elevation of 2.25 m thus forming a closed circuit. The entire test rig occupies about 40 square m of floor space.

4. RESULTS AND DISCUSSIONS

4.1. Head flow characteristics

The head developed by pump was estimated as a difference between the total head measured 2 diameters upstream and 2 diameters down streams of pump inlet and exit flanges. For pump head measurement the positional datum is considered as the pump centre line. Four static pressure tapings are symmetrically disposed around the circumference of the inlet and discharge pipes at a distance of 2 pipe diameters from the inlet and outlet pump flanges. They are connected through shut off cocks to a ring manifold.

Allowances were made for the experimental kinetic energy correction factor at these two stations. The head flow characteristic of the pump the value of the tip clearance 1.5 mm.

The curve rises steadily as the flows is throttled without any sign of discontinuity and retrace their path during unthrottling. So no discontinuity of flow is observed as founding axial and mixed flow impellers [4, 5, 6].

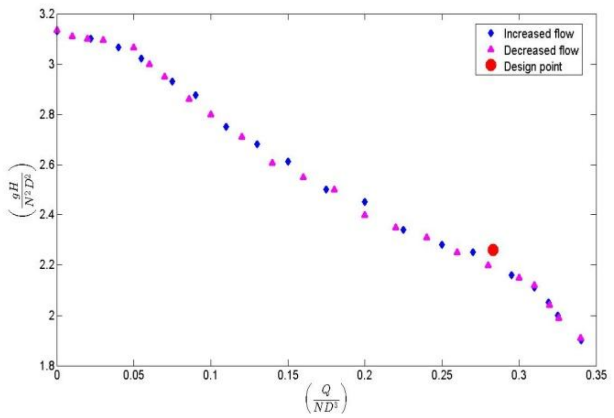

Fig 3. Head capacity characteristics of test pump

4.2. Flow Reversal

The meridional velocity distribution deduced from the variation of C_1 and yaw and pitch angle (which are not presented in this paper due to paucity of space) is presented in Fig. 4. When there was no flow reversal variation of C_{m1} is closely follows that of C_1. The flow reversal at the tip at reduced flows is clearly seen. The magnitude of the reversed meridional velocity is small, though there is a large increase in absolute velocity found when flow reversal occurs. The variation of absolute velocity, tangential velocity, pitch angle and yaw angle are not presented here but would be done so at the time of presentation, due to shortage of space.

The variation of the component of the meridional velocity parallel to the hub, C_{m2} for different flow rates are presented in Fig.5. The velocities rises rapidly from the hub to a peak and then fall almost linearly to about 80% of span and then rises to a minor peak before falling sharply to zero at the casing wall. The retarded region near the hub increases rapidly as the flow rate is decreased. As the flow rate is dropped to 0.2438 and below flow reversible occurs at the hub. This was confirmed by the yaw meter reading (four hole probe) which is greater than 90 degrees.

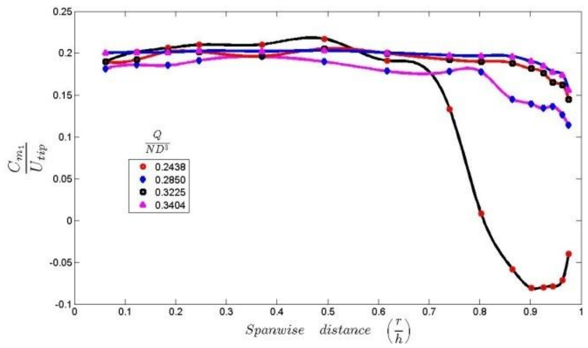

Fig 4. Spanwise variation of meridional velocity at impeller upstream

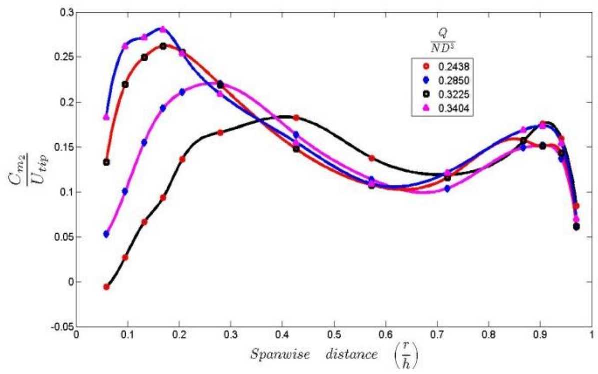

Fig 5. Spanwise variation of meridional velocity at impeller downstream

4.3 Spanwise variation of tangential velocity at stator outlet

It is normally expected that a well designed stator will remove the entire swirl coming out from the rotor and produce a uniform axial flow. The variation of tangential velocity is plotted along the height of the stator blade as shown in Fig. 6.

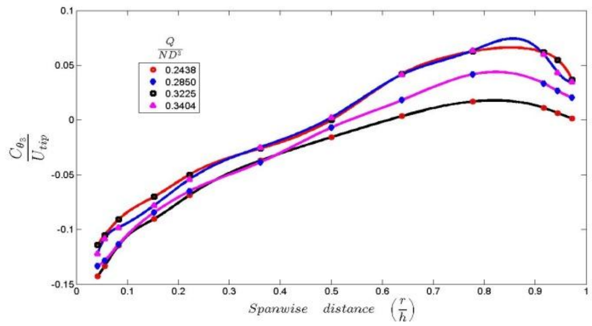

Fig 6. Spanwise variation of tangential velocity at stator outlet

The tangential velocities measured approximately between the two blades at stator exit. The change in direction of the tangential velocities from hub to the casing shows the existence of the passage vortices. The kinetic energy in this vortices represents a loss, though some of it's would be recovered by mixing downstream. In spite of the existence of these vortices the total and static pressure variation is remarkably uniform.

4.4. Static pressure variation of the pump

At attempt to made static pressure variation through the impeller by measurements of static pressure in a row of pressure taps situated on the casing. The static pressure variation measured as above is presented in Fig. 7. At the largest flow rate the static pressure drops very slightly along the casing from pressure tap no.1. The pressure begins to rise noticeably well ahead at the leading edge of the blade. The pressure rises rapidly in the blading region and continues to rise for some distance after the blading. Pressure falls slightly once the flow enters the guide vanes. The pressure drop in the guide vane is due to the decrease in to the flow area in the guide vane passages. As the flow rate as decreased the increased pressure downstream of the impeller drops as the flow approaches the casing.

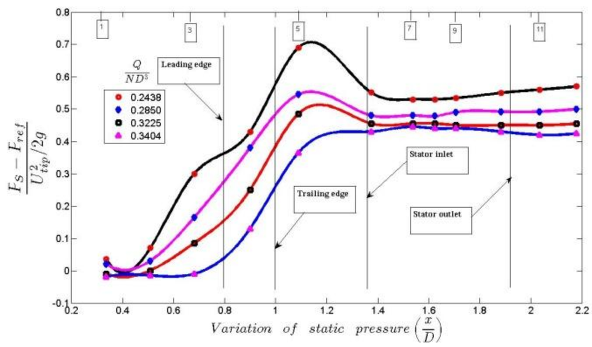

Fig 7. Variation of static pressure along casing

5. CONCLUSION

The head flow characteristic shows no evidence of groove or stall hysterisis. The results shows the stator blades however well designed can not remove all swirls leaving the impeller. Inter blade transverse circulation exist at the exit from the stator blade. There is also evidence of inter blade transverse circulation of the rotor. The flow reversal starts at the exit of the impeller and moves up to the tip of the casing and finally along the two diameter upstream of pump while throttling. Unlike an axial impeller, there is no evidence of an optimum tip clearance (supporting results would be presented in the conference).

6. NOMENCLATURE

Symbol	Meaning	Unit
C	Absolute velocity	(m/s)
C_θ	Component of absolute velocity in tangential direction	(m/s)
C_m	Component of absolute meridional velocity parallel to the hub	(m/s)
D	Impeller tip diameter at outlet	(m)
H	Pump total head	(m)
N	Impeller speed	(rpm)
Q	Pump discharge	(m^3/s)
θ	Yaw angle	(°)

Suffixes

1 : Impeller inlet
2 : Impeller outlet

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