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An Analysis of the Many Approaches to Radial Flow Centrifugal Pump Blade Design

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Abstract: When a moderate head and discharge are needed for the pumping of water across a short to medium distance via a pipeline, centrifugal pumps are often utilized. The correct design of the vanes is essential for the pump to operate at its best. Because there aren't many papers outlining the steps for designing a radial type vane profile, designers have to resort to reverse engineering the profiles that are already on the market because it's so hard to come up with their own. Using what is known about published processes as a starting point, this study attempts to provide detailed instructions on how to construct a radial type vane profile.

Keyword: Equations of radial flow, vane, CFD, design, and impeller govern the operation of a pump.

1. Introduction

When the necessary head and discharge are moderate, radial flow centrifugal pumps are often employed. A radial type vane's vane profile is the arc that runs from the impeller's intake to its exit. The length of the vane and, by extension, the passage length, may vary given the same diameter D1 and D2 and the same blade angles β1 and β2, even if an infinite number of curves can be constructed between these two locations. Therefore, the form of the vanes must be specified. Short passages allow the divergence angle to rise slowly, causing the flow to split and eddies to develop. Frictional loss is greater in longer passages. The only way to ensure minimal losses is to choose an adequate route length. The selection of a suitable blade design process is essential for the creation of an effective blade profile. point system. Computational Fluid Dynamics' commercial package: solid works flow simulation (SWFS) was used to conduct the experiment. Analysis of the vane profile with both forward and backward curves revealed that the backward curved circular arc approach had the highest efficiency

2. Methodology

Different researchers have studied the effect of blade design method on the efficiency of pump like Anagnostopoulos et. al.(2006) performed CFD analysis and design effects in a radial pump impeller. CFD software was used for computations of the steady flow field in the impeller and the characteristic performance curves were constructed. The results showed that hydraulic efficiency of pump can be increased by modifying the impeller geometry [3]. Kyparissis et. al.(2009) conducted parametric study on performance of a centrifugal pump based on simple and double-arc blade design methods-1,2 and 3. They found that when pump was operated at nominal flow rate simple arc method and double arc method-3, models gave best efficiency but when the pump was operated below nominal flow rate double arc method-3, caused a significant improvement of the hydraulic efficiency. On the other hand for flow rates greater than nominal simple arc method analysis gave higher hydraulic efficiency [5]. A simplified 3d model approach in constructing the plain vane profile of a radial type submersible pump impeller using 3D CAD software was developed by Gundale et.al.(2013). The impeller of a radial flow centrifugal pump was developed with different blade generation method and it was concluded that concentric circular arc method is the most simple method to generate a blade profile [6]. Singh and Natraj (2014) investigated the performance of impeller by developing the vane profile with circular arc method and point bySingh and Natraj (2014) used the circular arc approach and point by point analysis to build a vane profile and study the impeller's performance.

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Table 1: Design parameters of the impeller used to construct the blade profile

S.No	*Description*	*Values*
1	Impeller inlet diameter (D_1)	66 mm
2	Impeller outlet diameter (D_2)	173 mm
3	Vane inlet angle (β_1)	23°
4	Vane outlet angle (β_2)	29°
5	Number of blades (Z)	7
6	Vane or blade thickness	5 mm
7	Shaft diameter (D_{sh})	25 mm
8	Blade inlet height (B_1)	15 mm
9	Blade outlet height (B_2)	6 mm
10	Mass flow rate (Q)	7.4 kg/s
11	Head (H)	30 m
12	Rotation (N)	2870 RPM

2.1 Simple Arc Method

According to Pfleiderer's analytical method as discussed by Kyparissis et. al.(2009), in simple arc method the blade mean line is drawn with a single curve. The blade mean line AC is drawn from centre of curvature E with radius of arc R. To draw the blade mean line first an auxiliary circle C_a is drawn concentric with suction and pressure side of the impeller with diameter d_1 given by

$$d_1=D_1\sin\beta_1$$

The centre of curvature E is defined at the tangent of the auxiliary circle C_a which starts from A and point E is at a distance equal to the radius R of the blade mean curve from point A.
Where D_1 and D_2 are impeller diameters at suction and
pressure side respectively and β_1 and β_2 are vane angles at leading and trailing edge respectively [5]. Fiigure 1 shows blade mean line generated using simple arc method

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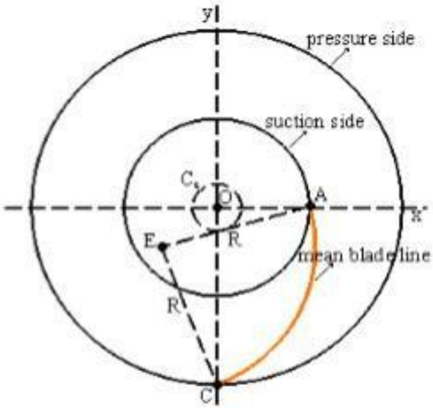

Figure 1: Blade mean line drawn using SAM (Simple Arc Method)

2.2 Double Arc Method

In double arc method the blade mean line is determined by construction of two curves. Pfleiderer has given three types of double arc method namely DAM1, DAM2 and DAM3 explained in Kyparissis et. al.(2009). DAM 1
Where r_g is equal to OB and β_g is the angle between E_1B and OB as shown in Figure 2.

In DAM 2 (Double Arc Method-2) keeping the initial point A_1 fixed the arc length A_1B is changed and the formula used for new arc length $A_1B$is given as

$$A_1B_{DAM2}=0.75A_1B_{DAM1}$$

As a result of this centre of curvature E_2 for second arc BC shifts downwards and the arc length of the blade decreases while the magnitude of E_1, R_1 and R_2 remains unchanged. In DAM3 (Double Arc Method-3) the radius R_1 is kept 20% bigger than the radius of DAM1 i.e.

$$R_{1DAM3}=1.2\,R_{1DAM1}$$

As a result of this the centre of curvature E_1 shifts to left and E_2 moves downward while radius R_2 remains constant. It is obvious that the shift of E_2 in DAM3 is greater when compared to DAM2. Thus, the arc length of blade DAM3 becomes shorter than the corresponding of DAM2 [5].

2.3 Circular Arc Method

In circular arc method the diameter of the impeller is divided into a number of concentric circular rings not necessarily equally spaced. The value of radius of circular arc R for any two consecutive concentric circular rings is calculated using the equation and vane shape is plotted which is actually an arc tangent to both the rings.
shown in Figure 2.

Figure 2: Blade mean line drawn using DAM1

The blade mean line consists of two arcs A_1B and BC with E_1 and R_1 as centre of curvature and the radius of arc A_1B respectively. In the same manner E_2 and R_2 are centre of curvature and radius of arc BC respectively. The auxiliary circle C_a is drawn in the same manner as drawn in Single arc method. The periphery of suction side is divided into equal parts, just as the no of blades. The tangent of the auxiliary circle from points A_1 and A_2 intersects at point E_1. The point B is end of first arc and it is defined at the extension of the line that connects the point E_1 and A_2 at a distance R_1, equal to the distance between points E_1 and A_1. The radius of second arc BC i.e. R_2 is defined as

Where D_1 and D_2 are impeller diameters at suction and pressure side respectively and β_1 and β_2 are vane angles at leading and trailing edge respectively.

The radius of inner diameter and outer diameter are R_1 and R_2 respectively. The radius of intermediate rings can be obtained by adding the term $(R_2-R_1)/n$ to the radius of preceding ring. Similarly, the corresponding value of β can be obtained by establishing a straight line relationship between β and R [7]. The blade mean line drawn using concentric circular arc method is shown in figure 3.

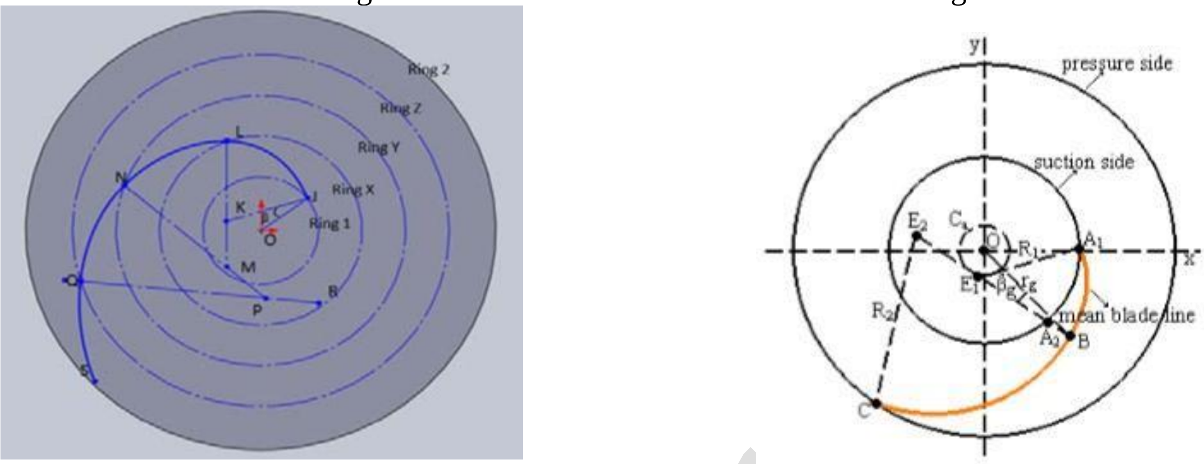

Figure 3: Blade mean line drawn using concentric circular arc method

2.4 Point By Point Method

In point by point method the blade mean line is drawn by determining number of intermediate points between the inner and outer diameter of the impeller and the final blade profile is obtained by drawing a smooth curve through these points joining the inner and outer diameter of the impeller. We know that, to specify a point here we need two parameters radius R and angle θ [1]. Figure 4 show the representation of blade mean line using point by point method.

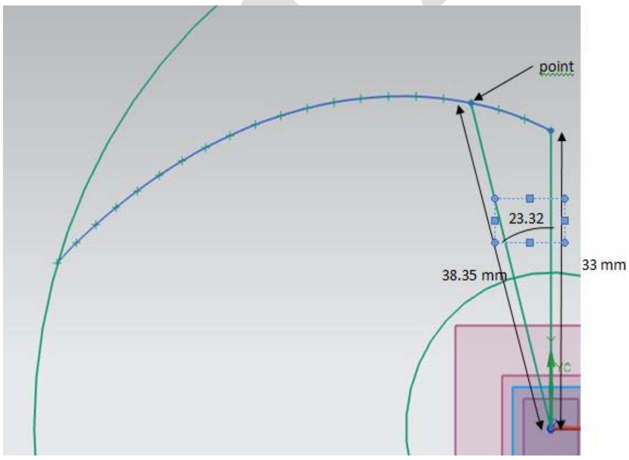

Figure 4: Blade mean line drawn using point by point method

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3. Results

On the basis of blade design methods discussed, calculations for concentric circular arc method and point by point method for the pump parameters are given where table-2 and table-3 shows the calculation for concentric circular arc method and point by point method respectively based on the procedure explained in this paper.

Table 2: Calculated values for R1, R2, β1, β2 and R

R_1	R_2	β_1	β_2	R
33.00	37.86	23.00	23.55	39.77
37.86	42.72	23.55	24.09	45.62
42.72	47.58	24.09	24.64	51.65
47.58	52.44	24.64	25.18	57.74
52.44	57.30	25.18	25.73	64.08
57.30	62.16	25.73	26.27	70.44
62.16	67.02	26.27	26.82	77.12
67.02	71.88	26.82	27.36	83.78
71.88	76.74	27.36	27.91	90.86
76.74	81.60	27.91	28.45	97.87
60	86.50	28.45	29.00	105.35

Table 3: R and θ values calculated using point by point method

4. Conclusions

To help designers create a blade mean line that connects the pump impeller's intake and outlet diameters, this document details many ways for designing blades and the necessary computations. To compare the efficiency and head produced with different blade design approaches at various discharge circumstances, further modeling of the pump impeller using these methods and CFD analysis may be done to generate the performance curve.

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