A Simplified 3d Model Approach in Constructing the Plain Vane Profile of A Radial Type Submersible Pump Impeller

Gundale V.A.[1], Joshi G.R.[2]
[1]School of Mechanical Engineering, Universidad Empresserial De Costa Rica, San Jose, Costa Rica
[2]Department of Mechanical Engineering, Manav Bharti University, Solan, INDIA

Abstract

This paper presents a simplified, working radial type vane profile design procedure. This paper offers a detailed picture of radial type vane profile design procedure based on fundamental understanding of published procedures. There are limited numbers of published vane profile design procedures which generally lack the explanation and detailed step by step procedure available for designers to systematically design and develop radial type vane profile, so the designers are forced to reverse engineer the vane profiles popularly available in the market. In the case of published procedures great problem arises while following them since some of them are contradictory to each other. In this paper while designing the vane profile, the overall dimensions of an existing impeller were not changed. Commercial 3D CAD software is used to create the 3D model. This approach will encourage the designers to enhance the performance of existing as well as new models of pumps.

Keywords: Radial, 3D CAD software, 3D model, vane profile.

Introduction

Radial type impellers are widely used impellers nowadays. In recent years lots of efforts are being made by pump manufacturers to simplify the radial type impeller vane profile design procedure with improvement in pump performance. There are limited numbers of published vane profile design procedures[1-10] There is lack of explanation as well as detailed step by step procedure available for the designer to systematically design and develop radial type vane profile. A great problem arises while following these procedures, since some of the procedures are contradictory to each other. The designers have to use their own judgmental skills for designing the vane profile.

The vane profile design procedure presented by John S. Tuzson[6] uses simple computer programs and their program listing has to be used to execute the calculation steps. Implementation of different computer programs have to be executed to calculate the variables required to design the whole impeller. The variables such as radius of curvature cannot be used directly to generate the vane profile because this procedure recommends for using the CAD software to construct the vane profile and also problem arises while constructing the vane profile because the method to fix the centre of curvature and starting point of arc is not explained. To design a vane profile it requires design data such as inlet and outlet blade angle, inlet and outlet diameter of impeller and radius of curvature, also blades should produce uniform angular momentum distribution.

The vane profile design procedure presented by Val S. Lobanoff[8] has similar kind of deficiency. The procedure explains about the selection criteria of vane angle and the impeller diameter, but problem arises while constructing the vane profile because basic relation to calculate the radius of curvature, method to fix the centre of curvature and starting point of arc is not clearly specified in the procedure. In Industries, sometimes a popular geometric method is also being used for many years. The simple method published by G.K. Sahu[9] of constructing vane profile is to draw a single radius circular arc using the calculated angle β_1, β_2 and radii R_1, R_2 but this may have serious implications on the performance of the pump. In this method first line AM is drawn which makes an angle β_2 to AO as shown in Figure-1. Then an angle of $\beta_1 + \beta_2$ is drawn at O with the radius OB and a line is drawn from A to the point B, the intersection point on radius R_1 and is extended up to D. Then a perpendicular line is drawn in the middle of AD which intersects at M. MA will be the radius of arc and arc AD will be the vane profile.
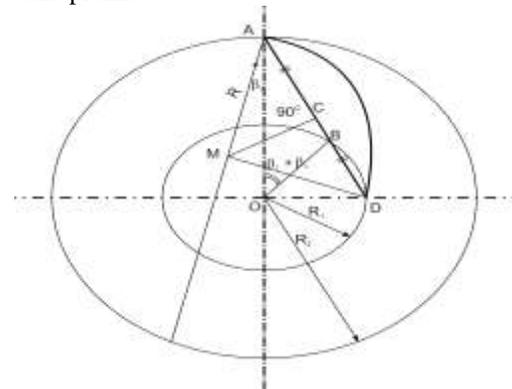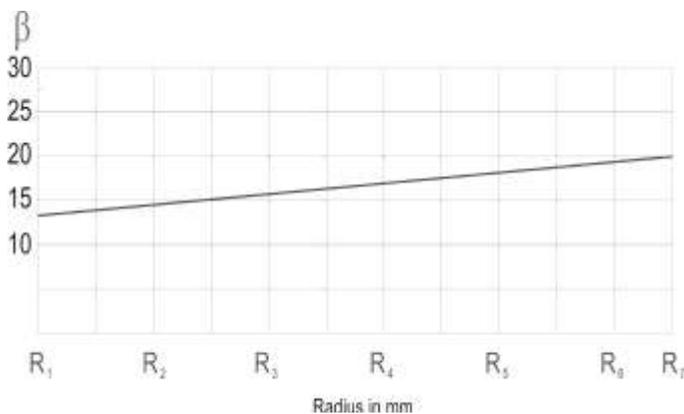

Figure-1
A simple geometric method of constructing vane profile

Another method suggested by A.J. Stepanoff[4] and Church[1] is briefly explained as follows: First the selection for inlet and outlet vane angles β_1, β_2 is to be done. The usual angles used for β_1, β_2 are 13^0 and 20^0 as recommended by A.J. Stepanoff and Church. For smooth flow, the vane must be designed such that these angle increases smoothly from 13^0 to 20^0. The graph of vane angle β against vane radius r for inlet and outlet station is to be plotted as shown in figure-2 to obtain intermediate values of radii r corresponding to intermediate values of the angle β. Then Plot the radii against position angle θ to give the shape of the trailing edge of the vane. Use sufficiently close spacing of radii to obtain smooth shape of vane profile. Here θ can be calculated by using the relation $d\theta = dr/r\tan\beta$. To calculate the value of θ i.e., to solve the given equation software's like MATLAB or other computer software should be used. Here in this procedure the method to locate the start point of curve, centre of curvature and the relation to calculate the radius of curvature is not clearly specified, so the designer will meet the Problem while constructing the vane profile.

There are some other methods like the singularity method[11] as an inverse problem. In this method a numerical approach is used. Wrapping angle of blade is found by applying trapezium rule. Here, a cubic Bezier curve has been drawn with the help of a control polygon. A mathematical expression has been used to express the density of bound vortex intensity. The blade angle and warping angle has to be calculated which will give a way to generate modified camber line.

Figuer-2
A graph for vane radius vs. vane angle

Impeller Vane Profile design using CAD/CAE

In recent years the rapid development in both computer software and computer hardware has made it possible for a trial and error design process e.g. Computer Aided Design (CAD) and Computer Aided Engineering (CAE). Without the actual manufacture of the impeller, a 3D model can be generated using commercial 3D CAD software's like Unigraphics, CATIA, SolidWorks, etc. and models can be simulated for flow visualization using CFD (Computational Fluid Dynamics). CFD is closer to experimentation than to theoretical fluid dynamics.

However, just as experimental fluid mechanics, CFD has its own difficulties and limitations. CFD can definitely be useful in helping the designer to understand what is happening in the flow. The accuracy of CFD being relatively poor and is highly dependent on mesh refinement and the type of turbulence models which are being used. Effective use of CFD also relies heavily on experienced users. Some of the commercially available CFD software's are ANSYS FLUENT, ANSYS CFX, SolidWorks flow simulation, Flow 3D, OpenFOAM, etc. This paper does not includes the CFD approach, but focuses only on a simplified working vane profile design procedure using simple mathematics, geometry assisted by modern CAD software. Another interesting technology being used is rapid prototyping.

Proposed Design of Plain Vane Profile

It is interesting to know that the available published procedures lack both in explanation as well as detailed step by step procedures, so they are difficult to implement. After studying and fundamentally understanding various published procedures as well as current industrial practices, a proposed simplified vane profile design procedure is presented in this paper.

It was decided that the overall dimensions of the existing impeller were to be maintained and only the vane was to be redesigned. The existing impeller was taken from one of the leading manufacturer of submersible pump who used this particular design for quite a number of years. Table-1 shows the specifications of this impeller.

Table-1
Specifications of the impeller used to construct the vane profile

S. No.	Description	Values
1	Impeller inlet diameter (D_1)	73 mm
2	Impeller outlet diameter (D_2)	145 mm
3	Number of blades (Z)	5
4	Vane or blade thickness	5 mm
5	Shaft diameter (Ds)	25 mm
6	Blade inlet height (B1)	17.80 mm
7	Blade outlet height (B2)	15.11 mm
8	Mass flow rate (Q)	11.67 kg/s
9	Head (H)	12.3m
10	Rotation (N)	2800 RPM

Let β_1 and β_2 be the inlet and outlet angles of this impeller respectively. Selection of β_2 is made generally for an optimum efficiency. An average value of 22.5^o is called normal for all specific speeds. The limit of β_2 followed in a good design is from 17.5^o (minimum) to 27.5^o (max). The values for β_1 and β_2 are selected as 18° and 30°. For smooth flow, the vane must be designed such that this angle increases smoothly from 18^0 to 30^0 The next step is to construct the vane shape. There are several methods to construct the vane shapes. The one used in practice

consists of tangent circular arc. The radius of the Circular arc contained between the rings D_1 and D_2 is given by,

$$R = \frac{R_2^2 - R_1^2}{2(R_2 \cos \beta_2 - R_1 \cos \beta_1)} \qquad (1.0)$$

Where, R_1 and R_2 is the radius of Inner and Outer diameters of the impeller. While using this method, the diameter of the impeller is divided into a number of concentric rings not necessarily equally spaced. The value of R for any two consecutive concentric rings is calculated using the equation 1.0 and vane shape is plotted which is actually an arc tangent to both the rings. An accurate vane shape can be obtained by joining the areas as shown in the proceeding part below.

The radius of Inner diameter is given by 73/2 = 36.5 mm and the radius of Outer diameter is given by 145/2 = 72.5 mm. Now, the intermediate values of radius can be found out by $(R_2-R_1)/n$. where, n = number of intermediate concentric rings required. For better resolution the value of n is taken as 11. The values thus obtained are 36.5, 39.77, 43.05, 46.32, 49.6, 52.9, 56.14, 59.41, 62.7, 65.95, 69.23 and 72.5 mm. Similarly, the corresponding values for the vane angle β can be found out graphically using figure-3.
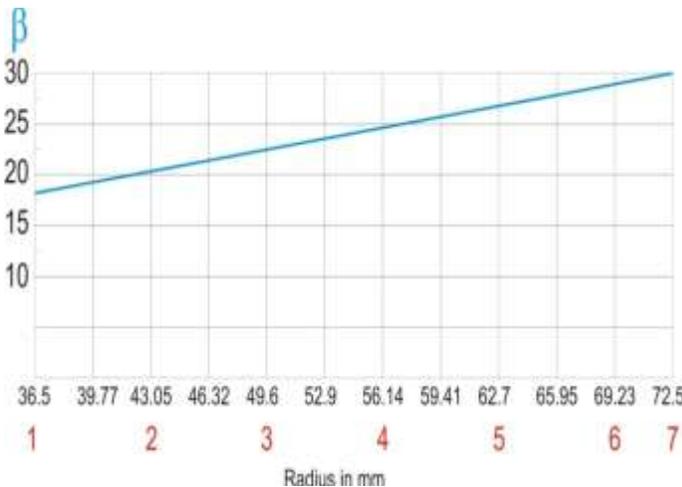

Figure-3
A graph for R vs. β

A table- 2 is constructed showing the calculated values of R_1, R_2, β_1 and β_2 for various values of R.

Table-2
Calculated values for R_1, R_2, β_1 and β_2

R_1	R_2	β_1	β_2	R
36.5	43.05	18	20.5	46.43
43.05	49.6	20.5	22.5	55.16
49.6	56.14	22.5	24.9	67.83
56.14	62.7	24.9	26.5	75.09
62.7	69.23	26.5	28.5	91.10
69.23	72.5	28.5	30	119.05

Using these values the Vane profile can be generated. SolidWorks 2013 software is used to construct the Impeller geometry as follows:

The circles of radius 75mm is to be drawn on front plane and extruded by 10 mm and name its centre as point C. This circle is to be used as a reference solid to generate the vane profile.

The first step is to draw the circle of radius 72.5 mm on above reference solid equal to outer radius of impeller by taking C as a center point. The second step is to construct all the concentric circles using radii R_1 calculated as shown in table-2 by taking C as a center point. Line AB represents the value of R which makes an inclination of 18° with AC or X- axis. The line AB of length 46.43 mm is to be drawn by taking point A of line AC as start point. The angle between X-axis or line AC and line AB must be equal to $\beta_1=18°$ as shown in figure-4.
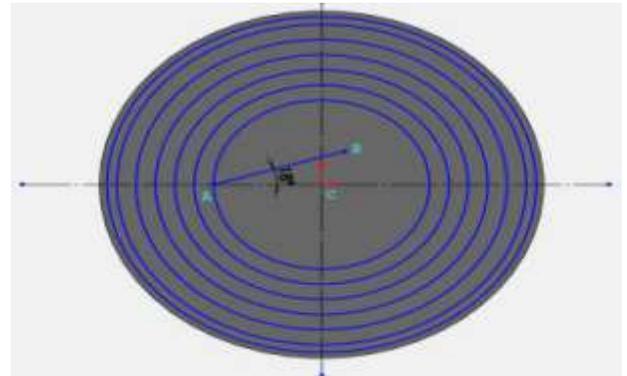

Figure-4
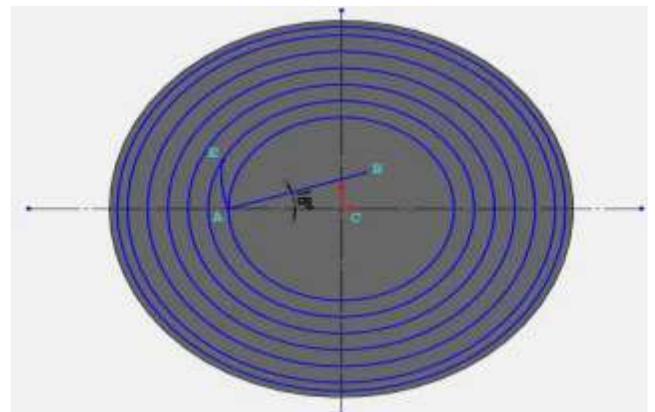**Concentric circles of radii R_1 and line AB making an angle of 18° with line AC**

Figure-5
Arc AE is drawn by taking line AB as radius, point B as centre, A as start point and E as end point

The third step is to construct the first arc AE having inlet vane angle $\beta_1=18°$ and radius of curvature 46.43 mm. The arc AE of radius 46.43 mm is to be drawn by taking end point B of line AB as a centre point of arc and point A of line AC as a start

point. The point where this arc intersects the second concentric circle is taken as end point for arc i.e., point E as shown in figure-5.

The fourth step is to construct the second arc EF of radius of curvature of 55.16 mm. For that the line ED of length 55.16 mm is to be drawn by taking point E of arc AE as a start point. The line should pass through the end point B of first line AB. Then the arc EF of radius 55.16 mm is to be drawn by taking end point D of second line as a centre point of arc and intersection point E as a start point. The point where this arc intersects the third concentric circle is taken as end point for arc i.e., point F as shown in figure-6.
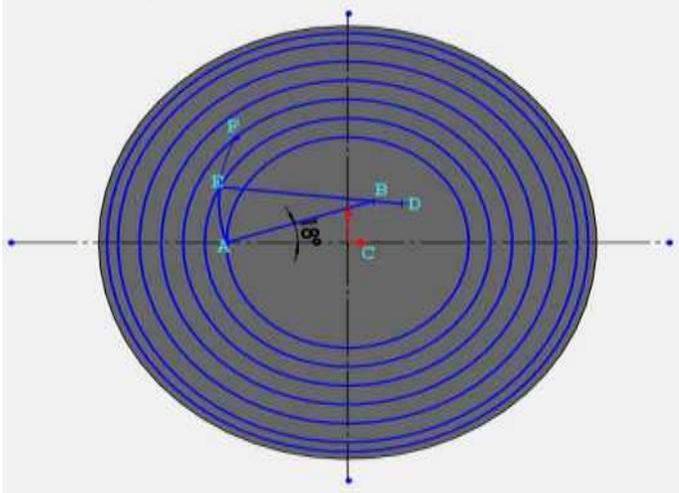

Figure-6
line ED passing through point B and arc EF drawn by taking D as centre

Same procedure has to be repeated for the remaining values of R as shown in the table-2 Finally, the plain vane profile is achieved in the form of a continuous arc as shown in figure-7.
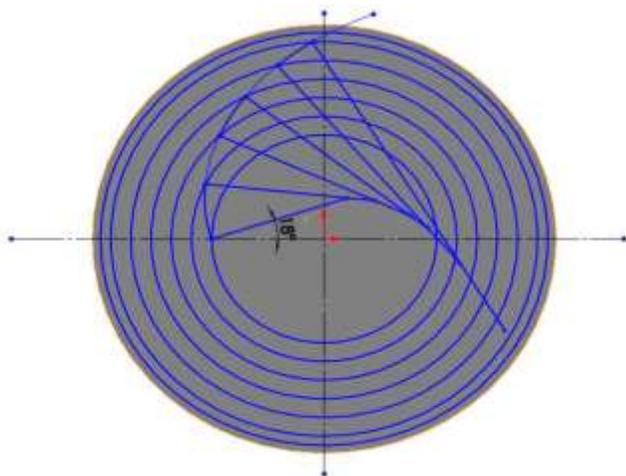

Figure-7
Completed view of plain vane profile

Since this impeller contains 5 number of vanes, the fifth step is to use the circular array or pattern command to have a 5 vanes around a Z-axis. To achieve the gradual increase in Blade outlet height (B1) to Blade inlet height (B2) i.e. from 15.11 mm to 17.80 mm a revolve cut operation is used. The final 3D model of the vane is thus obtained as shown in figure-8.
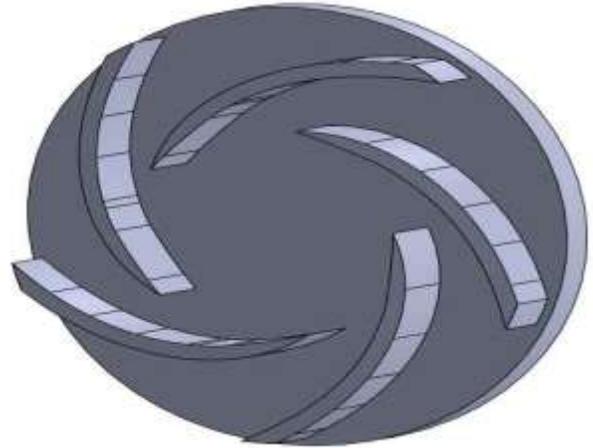

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Figure-8
3D model of 5 vanes revolved around Z-axis and gradual increase in blade height

Finally the assembling of various parts is to be done to get the final 3D model of impeller as shown in Figure-9.
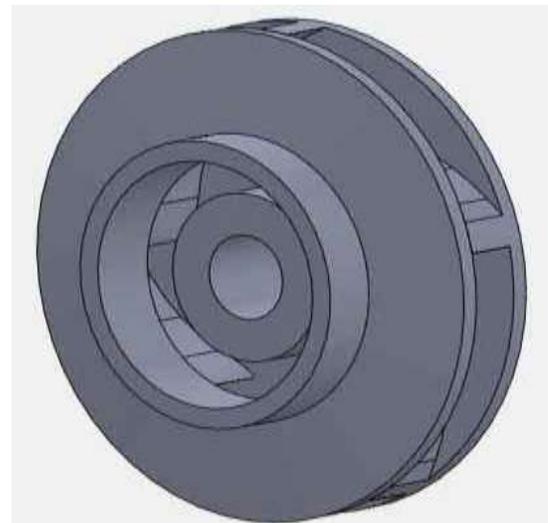

Figure-9
Finished 3D model of impeller

Conclusion

This paper thus presents a simplified, working radial type vane profile design procedure by using 3D model. The method presented here is quite fast and rapidly helps the designer to experiment with various values of Inlet and Outlet diameters D_1

and D_2 along with Inlet and Outlet angles β_1 and β_2. The industrial practices suggest that the values for β_1 and β_2 are to be selected as 18° and 30°. The designer may develop a small computer program or a excel worksheet to carry out the calculation fast. Once the 3D Model of the Impeller is developed then instead of going for the manufacture one may go for the CFD Analysis. Such analysis will assist the manufacturer in making the manufacturing decision more quickly. The vane profile design method presented here is applied on an Impeller whose dimensions are known. This method is equally effective when used on Impellers designed using the first principles.

Acknowledgements

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