Design of Centrifugal Pump Volute-Type Casing

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Abstract: Every centrifugal pump has four main components, namely, casing, impeller, suction pipe and discharge pipe. The important principles and fluid mechanics theories on centrifugal pump are introduced in firstly. The detailed design procedure for volute type pump casing is carried out.

In this paper, various kinds of pumps and operational sequences are described. And then, application and characteristics of centrifugal pump are also expressed. This paper relates to the design of casing of single-suction centrifugal pump that can develop a head of 30m and discharge 1.7m^3/min of water at the speed of 1880 rpm. The designed impeller has 115 mm inlet diameter, 256 mm outlet diameter, 19.5˚ inlet vane angle and 22.5˚ outlet vane angle. The number of vanes is 6. The outlet width is 15mm. The discharge diameter is 3in (96mm) to operate the designed head and capacity. The maximum efficiency of the pump is 72 %. The designed single-suction centrifugal pump can fulfil the requirements of agricultural processes.

Keywords: Centrifugal pump; Fluid mechanic; Volute type casing; Single-suction pump; Pump casing design.

1. INRODUCTION

Centrifugal pump is the device for converting of mechanical energy of the drive shaft to hydraulic energy of the handling fluid to get it to the required place or height by the centrifugal force of the impeller blade and the change in pressure and velocity in the volute casing. The input power for centrifugal pump is the mechanical energy of the drive shaft driven by the prime mover such as electrical motor. The output energy is hydraulic energy of the fluid being raised or carried. So, its purpose is to provide the necessary pressure to move the fluid at the desired rate.

The centrifugal pump moves liquid by rotating one or more impellers inside a volute casing. The liquid is introduced through the casing inlet to the eye of the impeller where it is picked up by the impeller vanes. The rotation of the impeller at high speeds creates the centrifugal force that throws the liquid along the vanes, causing it to be discharged from its outside diameter at a higher velocity. This velocity energy is converted to pressure energy by the volute casing prior to discharging the liquid to the system.

2. GENERAL DESCRIPTION OF CENTRIFUGAL PUMP

The centrifugal pump is so called because the pressure increase within its rotor due to centrifugal action is an important factor in its operation.

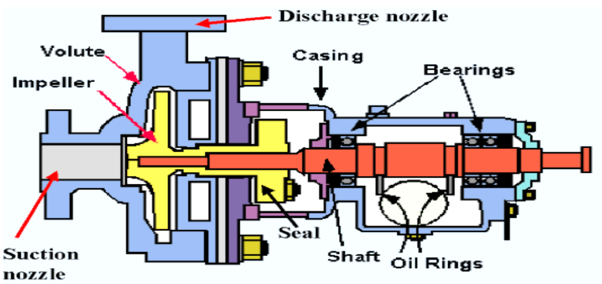

Figure 1. Single-suction Centrifugal Pump

In the single suction pump, the water enters the impeller from only one side. Because of this action, a single-suction centrifugal pump impeller is exposed to a large axial hydraulic thrust force resulting from the unbalanced hydraulic pressure on the impeller. This force tends to move the impeller away from the suction side. "Figure 1" shows a single-suction pump.

2.1 Volute-Type Centrifugal Pump Casing

In a volute casing, the impeller discharges into a single casing channel of gradually increasing area called a volute, and the major part of the conversion takes place in the conical discharge nozzle. The volute centrifugal pump has no diffusion vane but instead of the casing and is of a spiral type. The casing is as shown in "Figure 2". So it makes as to produce an equal velocity of flow at all sections around the circumference and also to gradually reduce the velocity of the water as it flows from the impeller to the discharge pipe. The spiral is often called the nozzle. A centrifugal pump volute increases in area from its initial point until it encompasses the full 360 degrees around the impeller and then flares out to the final discharge opening. The wall dividing the initial section and the discharge nozzle portion of the casing called the tongue of the volute, or the cut-water.

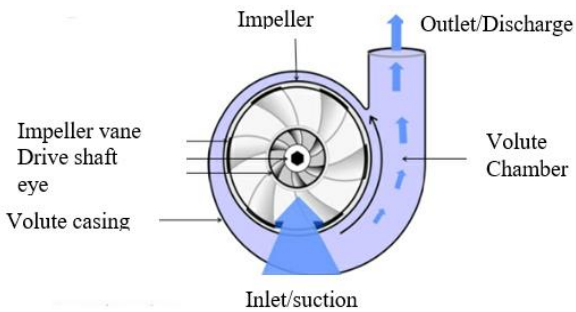

Figure 2. Volute Casing

3. DESIGN CONSIDERATION OF CENTRIFUGAL PUMP VOLUTE CASING

The hydraulic design of an end section single-stage centrifugal pump casing for fresh water is considered by the following:

3.1 Specific Speed

Using equation, we can calculate the specific speed, n_s (rpm) is considered,

$$n_s = n\frac{\sqrt{Q}}{H^{3/4}} \tag{1}$$

Pump efficiency η is assumed by using "Figure 3". And also the diameter of suction pipe D_s (or d_s) can be estimated from this chart. The discharge pipe diameter D_d (or d_d) is usually selected equal to or one size smaller than that of the suction pipe. Thus, velocities in these pipes are given by

$$V_s = \frac{Q_s}{\pi\frac{D_s^2}{4}} \tag{2}$$

$$V_d = \frac{Q_s}{\pi\frac{D_d^2}{4}} \tag{3}$$

The inner diameter, ID corresponding to D_s or D_d shown in "Table 1" is substituted for D_s or D_d in the above equations to calculate each of these velocities.

3.2 Input Power

The input power, L (W) is considered by

$$L = \frac{\rho Q_s g H}{\eta} \tag{4}$$

Rated output of an electric motor, L_r (KW) is decided from the following equation.

$$L = \frac{(1+F_a)\times L}{\eta_{tr}\times 1000} \tag{5}$$

Where, F_a is the allowance factor, and 0.1~0.4 for an electric motor and larger than 0.2 for engines. η_{tr} is the transmission efficiency, and 1.0 for direct coupling and 0.9~0.95 for belt drive. If an electric motor is used for driving a pump, "Table 2" is used for its selection.

3.3 Hub and Shaft Diameters

The diameter of the end of main shaft d_c is calculated from the next equation.

$$d_c \geq 0.365\sqrt[3]{\frac{L_h/n}{\tau_{al}}} \approx k\sqrt[3]{\frac{L_h}{n}} \tag{6}$$

The shaft diameter at the hub section d_{sh} is selected so as to satisfy $d_{sh} > d_c$. The dimension of hub at the impeller eye are usually decided from

Diameter: $D_h = (1.5 \sim 2.0)\, d_{sh}$

Length: $L_h = (1.0 \sim 2.0)\, d_{sh}$

The diameter of impeller eye D_o is calculated from the following equation.

$$D_o = \sqrt{\frac{4Q_s}{\pi V_{mo}} + D_h^2} \tag{7}$$

Where the velocity at the eye section is given by

$$V_{mo} = K_{mo}\sqrt{2gH} = (1.5\sim3.0) \leq V_{m1} \tag{8}$$

$$K_{mo} = (0.7 \sim 0.11) + 0.00023n_s$$

3.4 Impeller

3.4.1 Stepanoff Chart

The stepanoff chart shown in "Figure 5" is widely used to decide the impeller geometry. If the blade outlet angle β_{b2} near 22.5° is selected. The parameters K_u (speed constant), K_{m1}, K_{m2}, and $\frac{D_1}{D_2}$ are obtained, since n_s is given. Thus,

$$U_2 = K_u\sqrt{2gH} \tag{9}$$

$$V_{m1} = K_{m1}\sqrt{2gH} \tag{10}$$

$$V_{m2} = K_{m2}\sqrt{2gH} \tag{11}$$

3.4.2 Impeller Outlet

The outlet diameter D_2 is decided considering the following relationship;

$$D_2 = \frac{U_2\times 60}{\pi\times n} \tag{12}$$

The blade exit angle is set by the following,

$\beta_{b2} = 22.5$ (15 deg ~ 35 deg)

3.4.3 Impeller Inlet

The inlet diameter is considered from $D_1 = D_2\left(\frac{D_1}{D_2}\right)$.

Thus, the peripheral velocity at the inlet is:

$$U_1 = \frac{\pi D_1 n}{60} \tag{13}$$

The blade inlet angle β_{b1} (deg) is considered by,

$$\beta_{b1} = \tan^{-1}\left(\frac{K_{b1}V_{m1}}{U_1}\right) \approx \tan^{-1}\left(\frac{V_{m1}}{U_1}\right) + (0\sim6) \tag{14}$$

where, $K_{b1} = 1.1 \sim 1.25$

3.4.4 Blade number

The number of impeller blade Z is decided by the following,

$$Z = 6.5\frac{D_2 + D_1}{D_2 - D_1}\sin\left(\frac{\beta_{b1}+\beta_{b2}}{2}\right) \tag{15}$$

When the impeller is made of bronze (e.g BC6), the minimum blade thickness is 2.0 mm and shroud thickness is 2.5 mm for an impeller having the diameter less than 200 mm. They are 2.5 and 3.0 mm respectively, if D_2 is greater than 200 mm.

3.4.5 Passage width

The width at the inlet b_1 and that of outlet b_2 are respectively decided based on the following equations where smooth variation in velocity is considered.

$$b_1 = \left[\frac{Q_S}{\pi D_1 V_{m1}}\right]\left[\frac{\pi D_1}{\pi D_1 - s_1 Z}\right] \text{or} \left[\frac{Q_S}{\pi D_1 V_{m1}}\right] \quad (16)$$

$$s_1 = \frac{\delta_1}{\sin\beta_{b1}}, \qquad s_2 = \frac{\delta_2}{\sin\beta_{b2}}$$

where, δ_1 = blade thickness near the leading edge (mm)
δ_2 = blade thickness near the trailing edge (mm)

$$b_2 = \left[\frac{Q_S}{\pi D_2 V_{m2}}\right]\left[\frac{\pi D_2}{\pi D_2 - s_2 Z}\right] \quad (17)$$

3.5 Casing

3.5.1 Average Flow Velocity in the Volute Casing

The average volute velocity V_v is determined from the relationship;

$$V_V = K_V\sqrt{2gH} \quad (18)$$

where , V_v = average flow velocity in the volute casing (m/s)
K_v = experimental design factor
g = gravitational acceleration (m/s^2)
H = head required (m)

So, to find the average flow velocity in the volute at the cut water, it is required to know the values of K_v, required head (H). The gravitational acceleration is 9.81 m/s^2.

The value of K_v varies with the specific speed of the design pump. It is determined by using the Volute Constants Chart as shown in "Figure 4". This chart is the value of specific speed versus the values of K_v, volute angle α_v, and the ratio of $(D_3–D_2)/D_2$.

3.5.2 Volute Areas

Since the volute casing is divided into eight volute sections of 45° angular spacing, which increase in proportion from cut-water to discharge nozzle and the average velocity in the volute at the cut-water V_v is used, the A_v is the volute area at the throat. It can be estimated by,

$$A_V = \frac{Q_S}{V_V} \quad (19)$$

where, A_v = volute area at throat (m^2)
Q_s = flow rate per second (m^3/s)
V_v = average flow velocity in the volute at the throat (m/s)

The value of Q_s is estimated by;

$$Q_S = \frac{Q_s}{60}$$

Since the volute casing is divided into eight sections A_v is the volute area at the throat and it is denoted by A_{v8} representing the area of volute section 8. Then, other volute sections are estimated by,

$$A_{Vi} = A_V \times \frac{i}{8} \quad (20)$$

Where, the value of i is from 1 to 8 representing the volute sections.

3.5.3 Other Requirements for Laying out Volute Casing

Other requirements are the values of ρ_{vi}, r_{vi} for laying out the cross-sectional shapes of volute sections.

The relationship between A_{vi}, ρ_{vi} and b_v is:

$$A_{vi} = 0.367\,\rho_{vi}^2 - 0.604 b_v \quad (21)$$

where, A_{vi} = volute section area (mm^2)
b_v = volute width (mm)
ρ_{vi} = parameter for laying out cross-sections of volute areas (mm)

Thus, after solving for ρ_{vi};

$$\rho_{vi} = \sqrt{\frac{A_{vi} + 0.604 b_v^2}{0.367}} \quad (22)$$

For, i = 1, i.e, for drawing the cross-sectional shape of the first volute section.

The relationship between r_{vi} and ρ_{vi} is:

$$r_{vi} = 0.206\,\rho_{vi} \quad (23)$$

where, r_{vi} = the radius of volute tangent circle (mm)

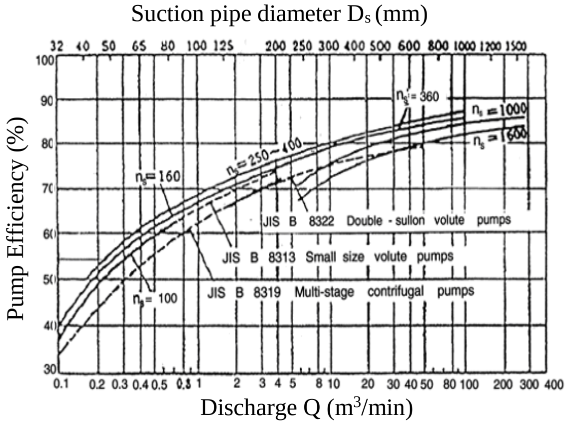

Figure 3. Pump Efficiency versus Discharge with vary Specific Speed

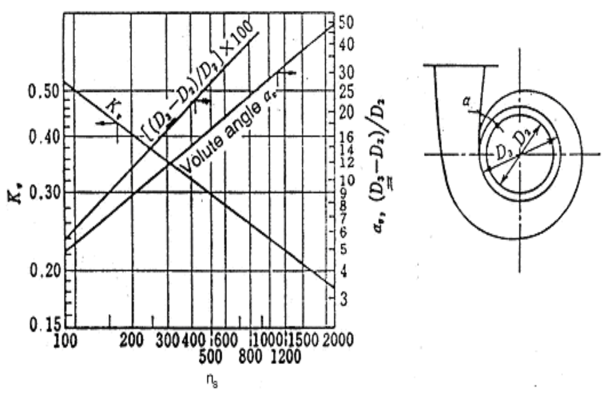

Figure 4. Volute Constant Chart

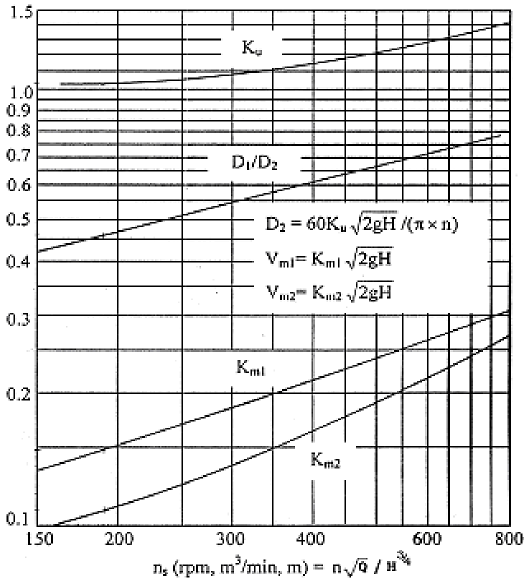

Figure 5. Stepanoff Chart

Table 1. Dimensions of Steel Pipe (S.G.P)

Nominal Pipe Size: A	Nominal Pipe Size: B	ID (mm)
40	1.5	41 6
50	2.0	52 9
65	2.5	67 9
80	3.0	80 7
100	4.0	105 3
125	5.0	130 8
150	6.0	155 2
200	8.0	204 7
250	10	254 2
300	12	304 7
400	16	390.6
500	20	492.2

Table 2. Rated Output of Electric Motor

Rated output (KW)	Allowance factor F_a
0.4	
0.75	0.4
1.5	
2.2	0.4~0.25
3.7	
5.5	
7.5	
11	
15	0.25~0.15
18.2	
22	
30	
37	

4. DESIGN CALCULATION OF CENTRIFUGAL PUMP VOLUTE CASING

The known parameters from impeller calculation are:

Flow rate, $Q = 1.7\ m^3/min$
Head, $H = 30$ m
Specific speed, $N_s = 191.22$ rpm
Suction pipe diameter, $D_s = 128$ mm
Impeller diameter at outlet, $D_2 = 256$ mm
Shroud thickness, = 3 mm
Impeller outlet width, $b_2 = 15$ mm

4.1 Calculation of Average flow velocity

The average flow velocity can be calculated by the Equation (18).

From "Figure 4", $K_v = 0.41$

$$V_V = K_V\sqrt{2gH}$$
$$= 0.41\sqrt{2 \times 9.81 \times 30}$$
$$= 10\ m/s$$

4.2 Calculation of Volute Areas

The volute areas can be calculated by the Equation (19).

$$A_V = \frac{Q_S}{V_V}$$
$$= \frac{1.7}{10 \times 60}$$
$$= 2.833 \times 10^{-3} m^2$$
$$= 2833\ mm^2$$

From Equation (20),

$$A_{Vi} = A_V \times \frac{i}{8}$$

For i = 1

$$A_{V1} = A_V \times \frac{1}{8}$$
$$= 2833 \times \frac{1}{8}$$
$$= 354.125\ mm^2$$

4.3 Calculation of Volute Base Circle Diameter

The volute base circle diameter, D_3 can be determined by ratio;

$$\text{ratio} = \frac{(D_3 - D_2)}{D_2} \times 100$$

From "Figure 4",
The value of this ratio is 11 at $n_s = 191.22$ rpm.

$$D_3 = \frac{\text{ratio} \times D_2}{100} + D_2$$
$$= \frac{11 \times 0.256}{100} + 0.256$$
$$= 284.16\ mm$$

4.4 Calculation of Volute Width

Volute width can be estimated in two ways.

The first method,

b_v = b_2 + 2 × shroud thickness + 2 × clearance on each side of impeller

= 15 + (2 × 3) + (2 × 4.5)

= 30 mm

Clearance on each side of impeller is according to the designer's choice.

The second method,

For low specific speed pump i.e ($100 \le N_s \le 500$)

$$b_v = 2\ b_2$$
$$= 2 \times 15$$
$$= 30\text{ mm}$$

So, b_v is taken as 30 mm.

4.5 Calculation of Volute Angle

Volute angle is read from volute constant chart if specific speed of the design pump is known.

The specific speed N_s being 191.22 in this design.

So, the volute angle $\alpha_v = 8.5°$.

4.6 Calculation of Volute Wall Thickness

Volute wall thickness is chosen according to suction pipe diameter by using the following "Table 3".

Table 3. Suction Pipe Diameter versus Volute Wall Thickness

Suction pipe diameter (mm)	40~80	100~250	300	400	500
Mini-thickness (mm)	5	6	8	10	12

Since the suction pipe diameter is 128 mm in this design.

So, the volute wall thickness t_v = 6 mm

4.7 Calculation of Other Requirements for Laying out Volute Casing

Other requirements are the values of ρ_{vi}, r_{vi} for laying out the cross-sectional shapes of volute sections.

ρ_{vi} can be calculated by the Equation (22).

$$\rho_{vi} = \sqrt{\frac{A_{vi} + 0.604 b_v^2}{0.367}}$$

For i = 1,

$$\rho_{v1} = \rho_1 = \sqrt{\frac{A_{v1} + 0.604 b_v^2}{0.367}}$$

$$\rho_1 = \sqrt{\frac{(354.125 + 0.604 \times 30^2)}{0.367}}$$

$$= 49.458\text{ mm}$$

Similarly, the same calculation procedure is repeated for the values of i from 1 to 8.

r_{vi} can be calculated by the Equation (23).

$$r_{vi} = 0.206\ \rho_{vi}$$

For i = 1,

$$r_{v1} = 0.206\ \rho_{v1}$$
$$= 0.206 \times 49.458$$
$$= 10.188\text{ mm}$$

This calculation procedure is repeated according to the volutes of i from 1 to 8 all volute sections. The overall calculated results are shown in following "table 4".

Table 4. Volute Areas and Parameters for Laying out Cross-sectional Shapes of Volute Sections

i	A_{vi} (mm2)	ρ_{vi} (mm)	r_{vi} (mm)
1	354.125	49.458	10.188
2	708.250	58.404	12.031
3	1062.375	66.151	13.627
4	1416.500	73.081	15.055
5	1770.625	79.409	16.358
6	2124.750	85.268	17.656
7	2478.875	90.750	18.695
8	2833.000	95.919	19.759

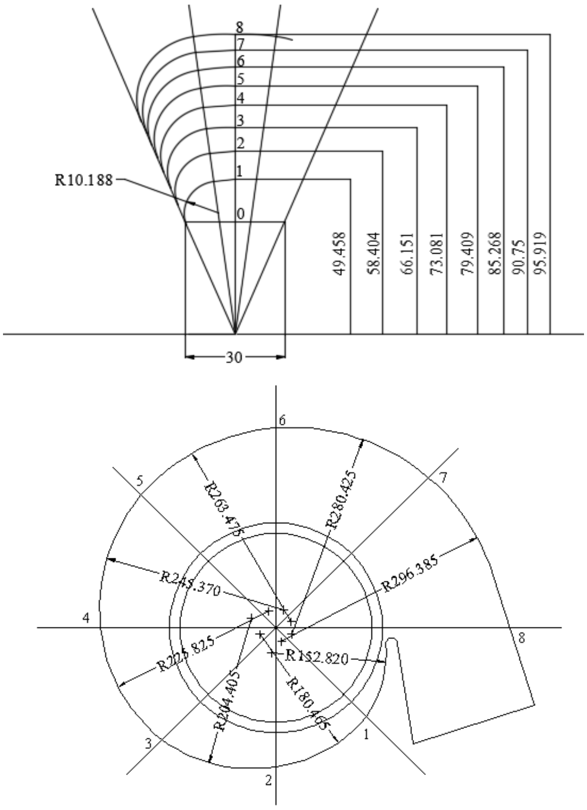

Figure 6. The Layout of Centrifugal Pump Volute Casing

4.8 Results and Discussion

In this paper, the casing is designed for the end-suction single stage centrifugal pump for fresh water.

The design pump is 18 hp motor drive single state centrifugal pump. The designed pump can develop a head at 1880 rpm. The designed impeller has 115 mm inlet diameter, 256 mm outlet diameter, 19.5° inlet vane angle and 22.5° outlet vane angle. The number of vanes is 6. And then, the outlet width is 15 mm. The diameter of discharge flange is 3 in 96 mm. The maximum efficiency of this pump may be obtained in 72%.

The design of volute is calculated depending on the impeller outlet diameter and impeller outlet width. In the design, the volute base circle diameter is 284 mm and it is used the laying out the volute casing. Volute width is 30 mm to draw the start of volute casing. According to suction pipe diameter, the volute wall thickness is 6 mm because the suction pipe diameter is 128 mm.

In this design, the volute casing is divided into eight volute sections of 45° angular spacing, which increase in proportion from cut-water to discharge nozzle. The design of volute areas or sections is very important in designing the volute casing. So, the volute area at the throat is calculated for eight volute sections from the value of average flow velocity in the volute casing. Volute angle is 8.5° and it is read from volute constant chart. After design calculation procedure, the layout of pump casing is drawn with AutoCAD. The results of calculated and existing are not much different. These are expressed in the following "table 5".

Table 5. Comparison of Calculated and Existing Results

Type	D_1(mm)	D_2(mm)	D_3(mm)	b_v(mm)
Calculating Result	115	256	284	30
Existing Result	119	265	295	31
Percentage Error	3%	3%	4%	3%

5. CONCLUSION

The design pump is a single stage single-suction centrifugal pump. In Myanmar, this type is used in irrigation of farmland. It has advantage of simple construction rationally. It is easy for installation, operation and maintenance. So this type is chosen for the paper.

According to the table 5, it can be seen that the error percentages are little difference between the calculation and existing results. It is due to system of unit conversion (SI or old unit SI). As a result, tables and figures cannot be read definitely and base design may be low or high in range. However, design calculation results of volute casing of centrifugal pump are satisfied in design.

6. ACKNOWLEDGMENTS

The author wishes to thank and always ready to acknowledge to all who support her to do this paper.

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