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Design and Fabrication of impeller for Single Suction Centrifugal Pump

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Abstract- This paper presents the calculation and production procedure of impeller for single section centrifugal pump. The pump type is single stage centrifugal pump with close impeller type. This impeller develops a head of 20 m and delivers 0.9 m^3 /min of water. The designed impeller has 97 mm inlet diameter, 226 mm outlet diameter, 20˚ inlet vane angle and 23˚ outlet vane angle. The total number of vane is 6 and input shaft power is 6 hp. The inlet and outlet width are 26 mm and 18 mm respectively. The discharge pipe diameter is 80 mm to operate the desired head and capacity. Based on the designed results, the impeller is also fabricated. There are four steps to produce the impeller. The first step is to draw a pattern design and then the pattern machining on CNC milling machine (Optimum, F 105) for pattern making. The mould making and casting process are used the sand casting method. This method is suitable for cast iron material and cheaper than the other methods. In this foundry process, Cupolar type furnace is used. Moreover, this study supports to develop the manufacturing method of pump impeller and to be able to produce in localization and with low costs. The designed single-suction centrifugal pump can fulfill the requirements of chemical plants, domestic applications, water supply process and agricultural process.

Index Terms- Impeller, head, flow rate, speed, production process.

I. INTRODUCTION

A centrifugal pump plays a major role in moving liquids over a wide range of volumes and pressures. Single stage single-suction Centrifugal pump is widely used in domestic water rising from surface water supplies such as river, lakes, cannel to a higher level. Moreover, they are widely used in many other industries such as chemical plants, steam power plants, food processing factory, hydraulic system and so on. The principal pumping units of a centrifugal pump are the volute and impeller and general components of centrifugal pump is also shown in figure (1). The impeller is attached to a shaft and the rotating shaft is powered by the motor or engine with the pulleys and belts. The fluid enters into the eye of the impeller and is trapped between the impeller blades. The impeller blades contain the liquid and impart speed to the liquid as it passes from impeller eye toward the outside diameter of the impeller.

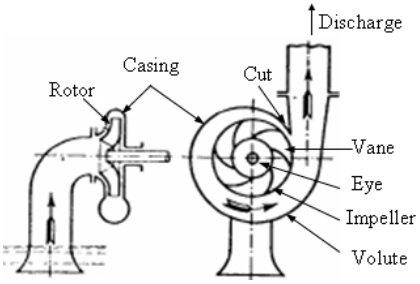


Fig 1. Components and Operation Principle of Centrifugal Pump [1]

II. DESIGN OF CENTRIFUGAL PUMP'S IMPELLER

The centrifugal pump has two main parts, impeller and casing. The impeller is enclosed in a water tight casing which is converted the kinetic energy of water into pressure energy before the water leaves the casing. The design of pump's impeller can be divided into two parts. The first is selection of proper velocities and vane angles needed to obtain the desired performance with the best possible efficiency. The second is the layout of the impeller for the selected angles and areas. The specifications of pump that will be designed are:

Pump head, $H = 20$ m
Discharge, $Q = 0.9\ m^3/min$
$Q_s = (Q/60) = 0.015\ m^3/sec$
Rotational speed, $n = 1800$ rpm
Density of water, $\rho = 1000\ kg/m^3$

Specific speed is firstly specified and it is an essential criterion to determine the impeller shapes. It is mathematically expressed as

$$n_s = \frac{n \times \sqrt{Q}}{H^{3/4}} \qquad (1)$$

In this study, the calculated vale of specific speed based on designed head and capacity is 180 rpm. Therefore this is low specific speed pump ($80 < n < 600$). So, end-section type single stage centrifugal pump with closed impeller is chosen.

The expected pump efficiency, η is assumed by using Fig A1. And the suction pipe diameter D_s is also estimated from this chart. The discharged pipe diameter D_d is usually equal to or one size smaller than D_s. Thus, the velocities in these pipes are given by

$$V_s = \frac{Q_s}{\pi \frac{D_s^2}{4}} \qquad (2)$$

$$V_d = \frac{Q_s}{\pi \frac{D_d^2}{4}} \qquad (3)$$

The input power of pump can be estimated by the following equation.

$$L = \frac{\rho Q_s gH}{\eta} \qquad (4)$$

For charge condition of the pump work, maximum shaft power or rated output of an electric motor L_r (KW) is decided by using Equation (5).

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

Where, F_a is the allowance factor, and 0.1~ 0.4 for an electric motor and larger than 0.2 for engines, and it is shown in Table I. And then, η_{tr} is the transmission efficiency, and 1.0 for direct coupling and 0.9 ~ 0.95 for belt drive.

Table I. Rated Output of Electric Motor [2]

Rated output (kW)	0.4	0.75	1.5	2.2	3.7	5.5	7.5	11	15	18.25	22	30	37
Allowance factor F_a	0.4			0.4~0.25		0.25~0.15							

The shaft diameter at hub section of impeller is

$$d_s = \sqrt[3]{\frac{16\ T}{\pi\ \tau}} \qquad (6)$$

Where, T is the torsional moment and it can be estimated by

$$T = \frac{60\ L_r}{2\ \pi\ n} \qquad (7)$$

Allowable shear stress of material for the pump shaft, τ is taken as 24.5 MPa because the main shaft is made of S30C. The estimated shaft diameter will be increased 20% because it is difficult to predict the bending moment at this time.

The hub diameter, D_h and the hub length, L_h are depending on the shaft diameter and these are usually taken from 1.5 to 2.0 times of the shaft diameter and from 1.0 times to 2.0 times of the shaft diameter respectively.

The diameter of impeller eye, D_o is calculated by

$$D_o = \sqrt{\frac{4Q_s'}{\pi V_{mo}} + D_h^2} \qquad (8)$$

Where, the flow rate through the impeller, Q_s' is Q/η_v and volumetric efficiency η_v is estimated by

$$\eta_v = \frac{1}{1+\frac{1.124}{n_s^{2/3}}} \qquad (9)$$

For Equation (8), the velocity at the eye section is given by

$$V_{mo} = K_{mo}\sqrt{2gH} = (1.5\sim3.0) \leq V_{m1} \qquad (10)$$

$$K_{mo} = (0.07\sim0.11) + 0.00023 n_s \qquad (11)$$

The simplified inlet and outlet velocities diagrams for the impeller are shown in Fig. 2. In this figure, the effect of circulatory flow on the outlet diagram is shown in solid lines and the virtual diagram is dotted. For a fluid flowing through the rotating impeller, u is the tangential velocity, V is the absolute velocity and v is the relative velocity of a fluid particle to impeller rotation. The angle between V and u is $\alpha$and the angle between v and u is β and it is the angle made by tangent to the impeller vane and a line in the direction of motion of the vane. The tangential component and radial component of absolute velocity V are V_u and V_r respectively.

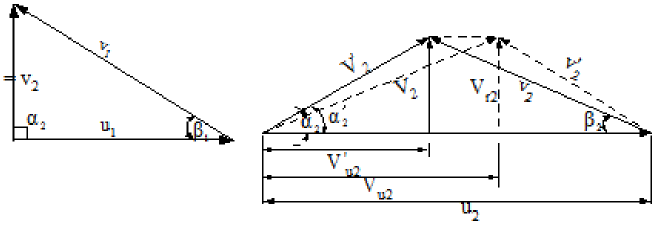


Fig 2. Impeller Inlet and Outlet Velocity Diagrams

The parameters K_u (speed constant), K_{m1}, K_{m2}, and D_1/D_2 are obtained on the value of specific speed in Fig A2. The outlet diameter D_2 is decided by considering the following relationship.

$$D_2 = \frac{u_2\times 60}{\pi\times n} \qquad (12)$$

Where, the peripheral velocity at impeller outlet and inlet are

$$u_2 = K_u\sqrt{2gH} \qquad (13)$$

$$u_1 = \frac{\pi D_1 n}{60} \qquad (14)$$

And then, flow velocities at the inlet and outlet are

$$V_{r1} = K_{m1}\sqrt{2gH} \qquad (15)$$

$$V_{r2} = K_{m2}\sqrt{2gH} \qquad (16)$$

If the incoming flow has no pre-rotation, the blade angle β_1 (deg) is given by

$$\beta_1 = \tan^{-1}\left[\frac{K_{b1}V_{r1}}{u_1}\right] \approx \tan^{-1}\left[\frac{V_{r1}}{u_1}\right] + (0\sim6) \qquad (17)$$

Where, K_{b1} = 1.1~1.25

The vane outlet angle β_2 is usually made larger than the inlet angle β_1 to obtain a smooth, continuous passage. The amount of outlet angle β_2 usually has between 15° and 35°. So, the vane outlet angle is assumed that $\beta_2 = 23^\circ$ in this study. From the velocity triangles, inlet and outlet relative velocities are

$$v_1 = \frac{u_1}{\cos\beta_1} \qquad (18)$$

$$v_2 = \frac{V_{r2}}{\sin\beta_2} \qquad (19)$$

The virtual tangential component V_{u2} of V_2 is

$$V_{u2} = u_2 - \frac{V_{r2}}{\tan\beta_2} \qquad (20)$$

For radial-type impellers, the slip factor, η_∞ varies between 0.65 and 0.75 and it is assumed that η_∞ = 0.7 average. Thus, the actual tangential component V_{u2}' of V_2' is

$$V_{u2}' = V_{u2}\eta_\infty \qquad (21)$$

Thus, the actual outlet is found by

$$\tan\ \alpha_2' = \frac{V_{r2}}{V_{u2}'} \qquad (22)$$

The absolute outlet velocity from outlet velocity diagram is

$$V_2' = \sqrt{V_{r2}^2 + V_{u2}'^2} \tag{23}$$

The number of blades, Z is decided by using the Plfeiderer formula. It is

$$Z \approx 6.5 \frac{D_2 + D_1}{D_2 - D_1} \sin\left[\frac{\beta_1 + \beta_2}{2}\right] \tag{24}$$

In this design, blade thickness and shroud thickness are taken as 5 mm and 6 mm respectively. The inlet passage width b_1 and outlet passage width b_2 are calculated by

$$b_1 = [\frac{Q_s'}{\pi D_1 V_{r1}}][\frac{\pi D_1}{\pi D_1 - S_1 Z}] \tag{25}$$

$$b_2 = [\frac{Q_s'}{\pi D_2 V_{r2}}][\frac{\pi D_2}{\pi D_2 - S_2 Z}] \tag{26}$$

Where, S_1 is (δ_1/sin β_1), S_2 is (δ_2/sin β_2), and δ_1 and δ_2 are blade thicknesses near the leading edge and trailing edge respectively. Moreover, S_2 can also be determined by the following relationship equation.

$$\frac{\pi D_1}{(\pi D_1 - S_1 Z)} = \frac{\pi D_2}{(\pi D_2 - S_2 Z)} \tag{27}$$

A method of drawing the impeller blade by three circular arcs is used for this design. Each radius is given by

$$\rho_A = \frac{\left(R_A^2 - R_B^2\right)}{2\left(R_A \cos \beta_2 - R_B \cos \beta_B\right)} \tag{28}$$

$$\rho_B = \frac{\left(R_B^2 - R_C^2\right)}{2\left(R_B \cos \beta_B - R_C \cos \beta_C\right)} \tag{29}$$

$$\rho_C = \frac{\left(R_C^2 - R_D^2\right)}{2\left(R_C \cos \beta_C - R_D \cos \beta_1\right)} \tag{30}$$

Where, R_A, R_B, R_C and R_D are base circle radii, $R_A = D_2/2$ and $R_D = D_{1h}/2$.

$$R_B = R_A - \frac{R_A - R_D}{3} \tag{31}$$

$$R_C = R_B - \frac{R_A - R_D}{3} \tag{32}$$

The angles between β_1 and β$_2$ are divided into three angles.

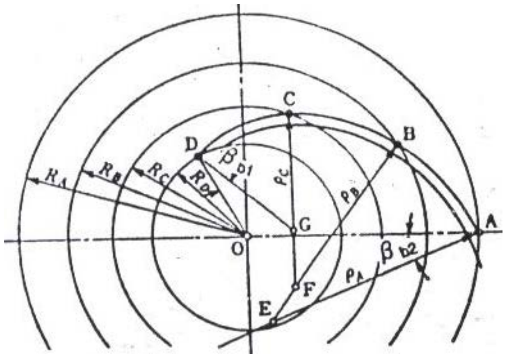


Fig. 3 Curvature of Impeller Blade

III. DESIGN RESULTS OF PUMP'S IMPELLER

The result data of the designed pump's impeller are expressed in table II. By using these results, the three dimensional model of designed pump's impeller is shown in Fig 4. The modeling of impeller is created by Solidwork software tool.

Table II. Results of Centrifugal Pump Impeller Design

No	Descriptions	Symbols	Results
1	Input Power	L_r	6 hp
2	Shaft diameter	d_s	34 mm
3	Hub diameter	D_h	51 mm
4	Hub length	L_h	68 mm
5	Impeller eye diameter	D_o	95 mm
6	Impeller inlet diameter	D_1	97 mm
7	Impeller outlet diameter	D_2	226 mm
8	Inlet angle of impeller blade	β_1	20°
9	Outlet angle of impeller blade	β_2	23°
10	Impeller passage width at inlet	b_1	26 mm
11	Impeller passage width at outlet	b_2	18 mm
12	Number of impeller blades	Z	6 blades

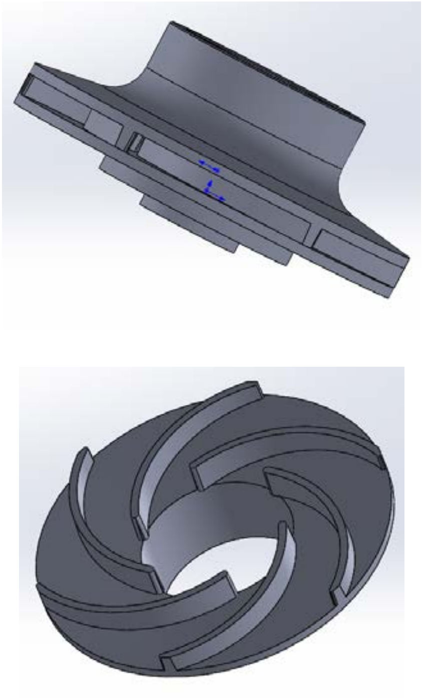


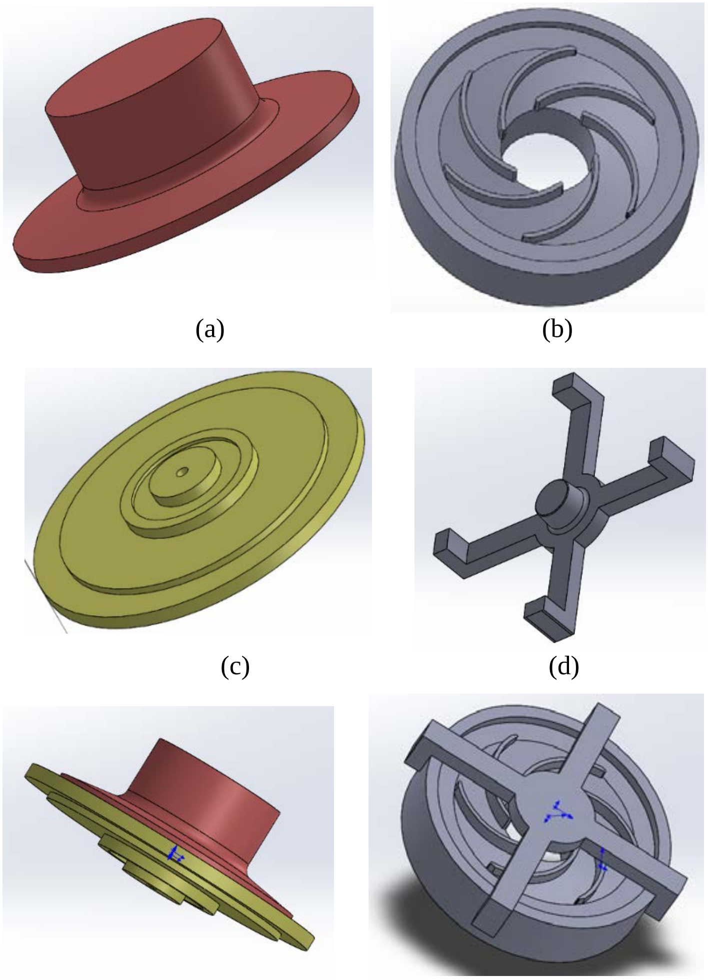
Fig.4 Three Dimensional View of Designed Impeller

IV. PRODUCTION PROCESS OF IMPELLER

There are many steps of production process for the single suction centrifugal pump' impeller. Firstly, 3-D model of impeller design is drawn. And then, the pattern design of designed impeller is created by using Solidwork software tool. After that, pattern making, mould making, sand casting and foundry process are made step by step respectively.

A. Creating Design Model and Patten Design of Impeller

In this study, the design model of impeller is firstly drawn by using Solidwork software tool from the calculated results. The next step is pattern making. Based on the finishing part drawing, the pattern size and shape are determined. Pattern means full size model of the casting, is used to produce a mould cavity into which liquid metal is poured. For this impeller design, there are four main parts of pattern design. These are core pattern for front impeller shroud, core pattern for impeller eye and blades, core pattern for back impeller shroud and core pattern for impeller shaft. These patterns are separately drawn because the pattern type used for design model is solid and single pattern type. In these pattern drawings, contraction allowance and machining allowance must be considered. The contraction allowance is depending on the material of impeller. In this study, the contraction allowance is taken about 2% because the designed impeller is made of cast iron (HRC 10 from applying load 150 Kg or HRA 60 from applying load 60 Kg by using the portable Rockwell hardness tester). Moreover, these patterns require the form taper; it is to remove easily from mould box in mould making process. In this pattern design, form taper is taken about 2 degree. Moreover, the material of designed patterns is made by wood (teak) because it is suitable for machining.


(a) (b)

(c) (d)

(e) (f)

Fig 5. Pattern Design of Impeller (a) Core Pattern for Front Impeller Shroud (b) Core Pattern for Impeller Eye and Blades (c) Core Pattern for Impeller Back Shroud (d) Core Pattern for Impeller Shaft (e) Assembly Pattern for Front and Back Impeller Shrouds and (f) Assembly Pattern for Impeller Eye and Blades

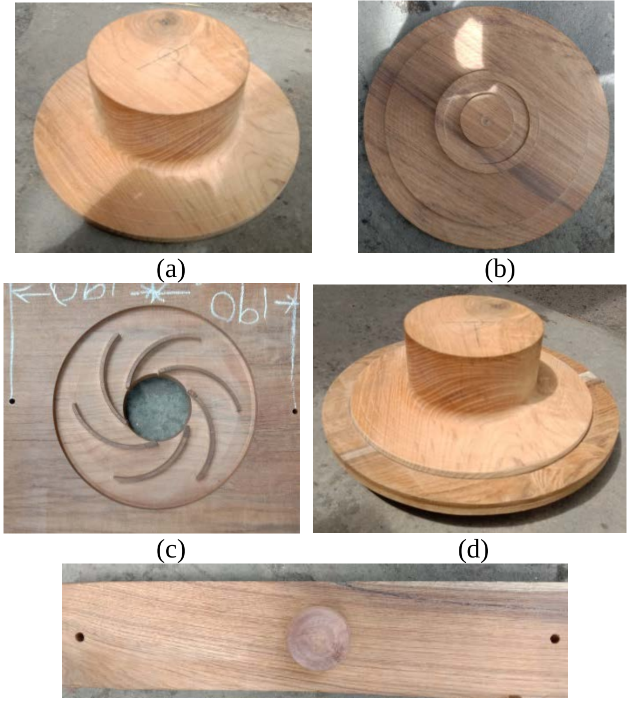
B. Pattern Making of Impeller

In pattern making for designed impeller, 3axis CNC milling machine (OPTIMUM,F 105) with SIEMENS control is used and machining program is produced by using the Master CAM software tool. The accuracy for machining is good finishing and rough height rating is 1.6 µm according to losses due to friction. The type of tool path, tool diameter, depth of cut, machining type and operation time for all pattern of impeller are shown in Table III.

Table III. Machining Process of Pattern Making

Name	Tool path	Tool	Depth of cut (mm)	Spindle speed	Feed rate	Cutting method	Operati-on time	Prepa-ation time
Core Pattern for Impeller Eye and Blades	Rough	End mill, Φ 12	1.5	2100	1000	True spiral	7 hr 45 min	1 hr
	Finish	Ball mill, Φ 8	0.2	2500	1200	parallel	4 hr 42 min	-
Core Pattern for Impeller Shaft	Rough	End mill, Φ 16	1.5	2100	1000	True spiral	40 min	15 min
	Finish	Ball mill, Φ 10	0.3	2500	1200	Radial	28 min	-
Core Pattern for Impeller Back Shroud	Rough	End mill, Φ 12	1.5	2546	1450	True spiral	7 hr 10 min	1 hr
	Finish	Ball mill, Φ 10	0.4	2546	1350	Radial	1 hr 27 min	-
Core Pattern for Front Impeller Shroud	Rough	End mill, Φ 16	1.5	2500	1500	True spiral	8 hr 51 min	1 hr
	Finish	Ball mill, Φ 10	0.3	3000	1650	Radial	1 hr 19 min	
Total time							35 hr 37 min	

Fig 6. Machined Process for Impeller Design



(a) (b)

(c) (d)

(e)

Fig 7. Machined Pattern of Impeller Design (a) Pattern for Front Impeller Shroud (b) Pattern for Impeller Back Shroud (c) Pattern for Impeller Eye and Blades (d) Assembly Pattern for Front and Back Impeller Shrouds and (e) Pattern for Impeller Shaft

C. Mould Making and Sand Casting of Impeller

After making the pattern of pump's impeller, the next step is mould making. The mould is split in center, which creates a parting line, parting line is flush with the top of the cavity and casting. The pattern not only makes the cavity but also the two impressions into which the sand core will fit. Cores are generally made of dry sand with high strength. The mould should be included runner, raiser and guide pin. In this study, single runner and single riser is used and the designed moulds are as shown in Fig 8.

Fig 8. Mould Making and Sand Casting for Impeller

In casting, the sand casting method is used. This method is simple and low cost, and also cheaper than the forgings and welding method. In this processes, the mould are housed in a flask which consist of two boxs. The upper box is called cope, which is including the pouring basin and raiser. The molten metal is poured through the pouring basin and the flows across the sprue into the cavity. The raiser basin should hold enough metal to feed the casting until complete solidification takes place. The lower box is called drag, these drags are made on the ground. After solidifying the metal, the sand mould is broken away and the casting is taken.

D. Foundry Process for Impeller

Foundry process is the process of forming object by putting liquid material (cast iron) into a prepared mould. A casting is a objected formed by allowing the molten metal to solidify. In this case, the traditional old design furnace (Cupolar type furnace) is used. This furnace is suitable to melt cast iron metal and is separated to two portions. In the upper portion of it, metallic raw material and coke are placed together. This furnace has 8 holes tuyeres. The melting occurs and proceeds and molten metal is collected at the bottom of furnace. Molten metal may be tapped at intervals before each skimming, or the tap-hole may be left open with metal flowing constantly. In most cupolas slag is drained from the slag hole at the back of furnace. When metal is melted completely the bottom bar is pulled sharply under the plates and bottom is dropped. All remaining slag, un-burned coke or molten metal drops from the furnace. Molten metal is collected in ladles from furnaces and is poured into the mould. In this process, the capacity of the furnace is ½ tons of raw materials and the ratio of the raw material and the coke is 8:1. The melting time is taken about two and half hours.

Fig 9. Foundary Process of Impeller

E. Machining Process for Impeller

After inspecting the casting, the final process is machining process. The casting of designed impeller is machined on the lathe machine to obtain the required dimensions of designed centrifugal pump impeller.

Fig 10. Machining for Finishing Product

V. CONCLUSION

The designed pump is aimed to use in agricultural application especially for river pumping project. Moreover, this study promotes to develop the manufacturing method on centrifugal pump and to able to construct the most effective type of pump in localization and with low cost. The designed pump can develop a head of 20 m and deliver 0.9 m^3/min of water at 1800 rpm. The designed impeller has 97 mm inlet diameter, 226 mm outlet diameter, 20° inlet vane angle and 23° outlet vane angle. The number of vanes is 6. And then, the inlet width and outlet width are 26 mm and 18 mm respectively. The material of designed impeller is made of cast iron (HRC 10 or HRA 60). In fabrication process of impeller, the machining costs for all patterns are 150000 kyats ($ 100). In pattern making, 3-axis CNC Milling machine is used and the total machining time is taken about 35 hr and 37 min. The costs of casting are 10000 kyats ($ 6) for one item. To obtain the finishing product, lathe machine is used and the machining costs are 5000 kyats ($ 3). Therefore, these costs are so reasonable to produce in localization and are less than the price in local market. The designed single-suction centrifugal pump can fulfill the requirements of domestic application and industrial application.

APPENDIX

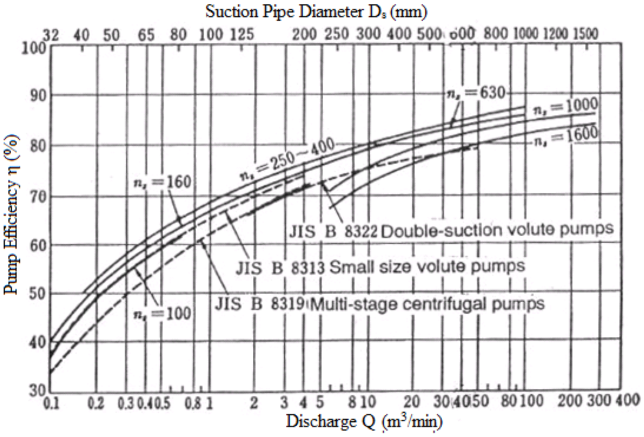


Fig A1. Overall Efficiency Curve

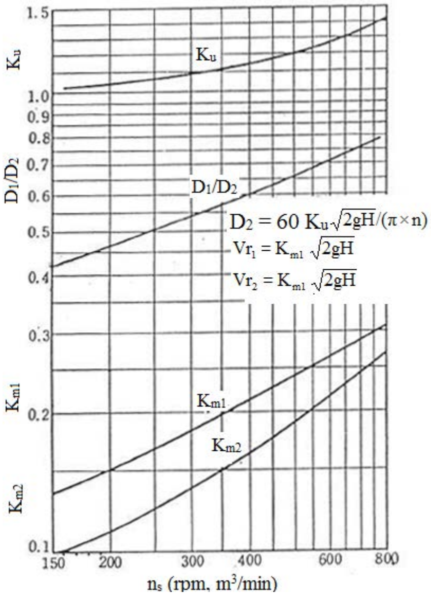


Fig A2. Stepanoff Chart

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