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Design, Analysis and Optimization of Axial Flow Pump For Enhancing Performance

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Abstract:

The main objective of this project is to Conserve Energy, without affecting productivity and performance. The case study is about aTraditional and outdated pumping system used in Paddy field all over the country for irrigation purpose. The efficiency of such pumping systems are lower, due to poor design. The manufacturer of the pumping system has not considered its efficiency because the electricity used is, made free of cost by the government. The PETTY and PARA# is one of the major Traditional Pumping system used in Kerala for irrigation purpose. A 100% modification is not possible as the system is already in place, rather optimizing the impeller blade to enhance the discharge is a viable solution.The project involves modification of Traditional Pumping system by re-designing its impeller.The so modified parts are analyzed using suitable software's such as Ansys to check its credibility.

Keyword:

Petty and Para, Impeller design, CFD simulation, Optimization

1.Introduction:

Axial flow pumps are widely used in kuttanad, Alappuzha district in Kerala for dewatering the agricultural field to render them for farming. Due to typical topography, intermittence dewatering of field are essential for their utilization. An axial flow pump (Traditionally known as petty and Para) has been used for years and the system has gone minimal modification from time to time.

The pump is very critical factor for farming in this region and its carpentry level construction without testing and calibration has motivated us to take up this pump for analysis and carry out the optimization. Electricity expenses are provided by Government of Kerala in the form of subsidies to farmers.

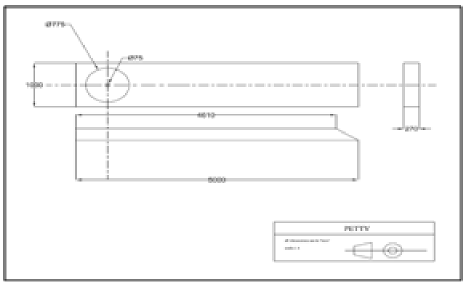
2. Design Premises:

Main parts of Traditional pumping system include- Discharge duct, suction duct, Shaft, Impeller, and Hub.

3. Elements of the system

3.1 Discharge duct (petty)

It is the main part of the system and is used for discharging the water. Usually it is 5 meter in length, 80cm wide and 18cm in height. Wood is the preferable material.



3.2 Suction duct (para):

Para is another main part of Traditional pumping system. It is used for sucking the water from paddy field. It is a wooden part, cylindrical in shape, which contains impeller and part of the main shaft. It has two parts, upper and lower. The upper part is 1 meter in length and lower part is 65 cm long, which is always filled with water.

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3.3 Pulley system:

This Pulley is driven by a motor with a cross belt. The motor pulley is very small as compared to this pump pulley so that the speed of pump is considerably reduced. Size of the pulley is 66 cm in diameter. Usually the material used for making pulley is of cast iron.

3.4 Impeller:

Impeller-Blade[1] is the main and important part of this Traditional pumping system, because its size and shape determines the efficiency. Usually the number of blades are limited to 5or 6.

4.Design

4.1 Design of pump[2]

Speed of Pump, N=500 rpm
Rated Discharge, Q=0.593m3/s
Diameter of suction Pipe, D_s=1m
Length of suction Pipe, L_s=1.37m
Darcy Frictional Factor, F=0.00925
Dimensions of Discharge Pipe
L =4.5m, B=0.7m, H=0.14m
Suction head, H_s=0m
Discharge head (Unflooded) H_d=1.18m
Discharge head (flooded) H_{d1}=0.18m
Diameter of top and bottom of hub
D_{m1}=0.42m, D_{m2}=0.22m
The total head of the pump is the sum of suction head, discharge head and all losses in pump, suction pipe, and discharge pipe with other miscellaneous losses.
Cross sectional area of suction pipe

$As = \frac{\pi}{4} \times ds^2 = 0.785\ m^2$

Velocity of liquid in Suction Pipe

$V_s = \frac{Q}{As} = 0.755\ m/s$

Cross sectional area of Discharge pipe=0.098 m^2
Velocity of liquid in Discharge Pipe= 6.051 m/s
Frictional Head Loss in Suction Pipe [3]

$H_{fs} = \frac{4 \times f \times L \times Vs^2}{2 \times g \times d} = 0.001\ m$

Frictional Head Loss in Discharge line

$H_{fd} = \frac{l \times Vd^2}{m \times c^2} = 0.8164\ m$, all constants were suitable evaluated.

Velocity head at discharge, $V_{d1} = c\sqrt{(m \times i)}$

$58.817 \times \sqrt{(0.0583 \times 0.181)} = 6.051\ m/s$

Loss	Evaluation	Result
Bending Loss	10% of velocity head	0.1866 m
Impeller Loss	$Hi = \frac{(Vi - Vs)^2}{2g}$	0.00037 m
Foot valve losses	10% of velocity head at foot valve	0.0029 m

Total head (Manometric head) – un flooded
$H_m = Hd + H_{fs} + H_{fd} + H_{dl} + H_b + H_i + H_{fv}$
H_m = 4.055 m= 13.303 ft
Total head (Manometric head) – flooded
$H_{m1} = H_{m-1}$
H_{m1} = 3.055 m= 10.022 ft
Rated discharge in Gallons per minute
Q' = 15850×Q
Q' = 15850×0.593
Q' = 9399.05 gpm
Specific Speed of pump (unfloodedcondition)

$$Ns = \frac{N\sqrt{Q}}{H^{\frac{3}{4}}} = 6959\ rpm$$

For flooded, N=8605.8 rpm,Axial pumps give best performance for specific speeds above 7500 rpm. Specific speeds within the range of 7500 rpm to 15000 rpm are the region where the efficiency obtained is high. Axial pumps within this range can pump up to a head of 35 feet.In our case, the manometric head lie within 15 feet.Recalculating the new design speed with specific speed as 8000rpm

$$N_1 = \frac{Nss \times Hm^{\frac{3}{4}}}{\sqrt{Q'}} = 574.8\ rpm$$

4.2 Design of pulley[4]

Power of the motor,P = 50HP
Diameter of Driver pulley, D = 200 mm
Thickness of Belt used,T_b=10 mm

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Speed of Driver (Motor) pulleyNm=960rpm
Speed of Driven Pulley,Np=580rpm
Width of Belt used,b =140 mm
Diameter of Driven Pulley D= 400 mm
Breadth of Pulley B= 180 mm
No. of arms, i = 6, if D > 450
Thickness of Rim tr= 5 mm
Hub Length H=120 mm

Belt Type: Heavy duty/single belt

As per standards,

$$D=\frac{Nm}{Np}\times(d+tb)-t$$

$$D=\frac{960}{580}\times(200+10)-10$$

D= 337.58 mm, Safe.

Similarly all checks are made as per standards and no substantial deviation was found.

4.3 Design of shaft

Diameter of Shaft, d =75 mm (Provided) Shaft Material: Mild Steel
Weight of hub and bladesW1 =150 kg Weight of shaft, W2 =4.68 Kg
Maximum Induced Bending Momen

$$M=\frac{(T1+T2)\times 1000}{4}=3281479.66 \text{ Nmm}$$

Maximum Induced Torque

$$T=\frac{60P}{2\pi N}=614118.56 \text{ N mm}$$

Methodology Followed	Induced Stress (MPa)	Allowable Stress (MPa)	Result
Per Normal stress theory	79.92	144	Safe
Per Shear stress theory	40.30	96	Safe
Per ASME code for Normal stress theory	119.87	144	Safe
Per ASME code for Shear stress theory	60.45	96	Safe
With axial load per Normal stress theory	120.40	144	Safe
With axial load per shear stress theory	60.72	96	Safe

Stress Analysis[5] shows that the shaft is safe The design of impeller, shaft, belt, pulley and recommendation of bearing is the major part of design. To know whether the design can generate required amount of output power, discharge, we have to analyze of the design
Recommended speed of pump N = 580 rpm
Recommended dimensions of pulley
Diameter D = 400 mm
Breadth B = 180 mm
Rim thickness = 5 mm
Hub length = 120 mm
Recommended shaft diameter d = 75 mm
Belt material - canvas
Belt length (cross belt) L = 11.93 m
Recommended bearing-SKF 621

5. Analysis

The project Design is validated through Ansys. The design can't be declared safe, until it is subjected to suitable simulation.The two types of analysis that was conducted was:

1. CFDanalysis [6] of the pump under variable conditions.
2. Static load analysis of the pump shaft using

ANSYS:

For optimization of the pumping system [7], two parameters are varied, one is the number of blades and the other is blade angle [8].To reach the optimum configuration, the number of blades and vane angle is varied over a range.

The numbers of blades are varied from 3 to 6, i.e. models of 3 vanes, 4 vanes, 5 vane, and 6 vanes are created and for each set of vane, the vane angle is varied from 38 to 46 degrees. So for each impeller having a definite number of blades, we have a set of 5 impellers having blade angles of 38, 40,42,44,46. Analysis is performed for each set

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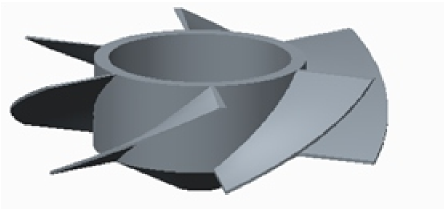
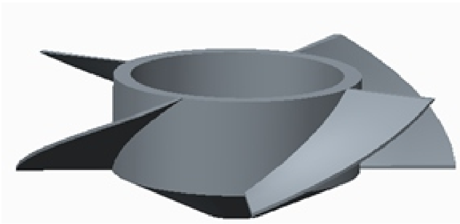
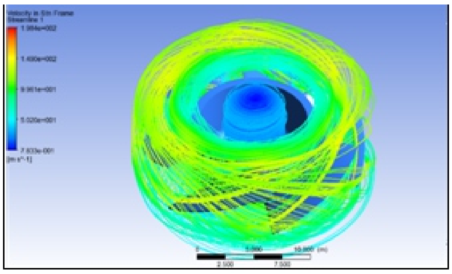


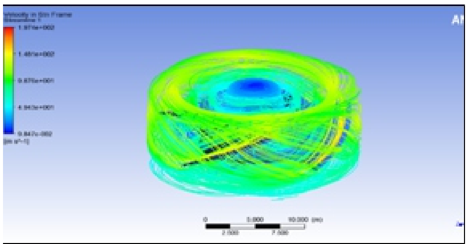
6 blade Vane Impeller



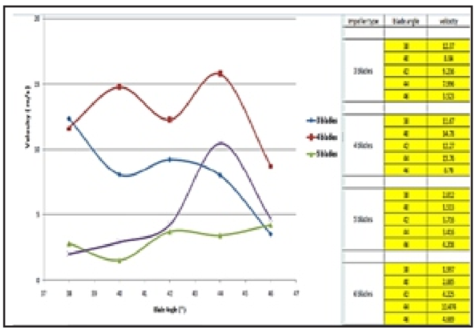
5 blade Vane Impeller



Stream Lines in 6 Vane 42º Impeller

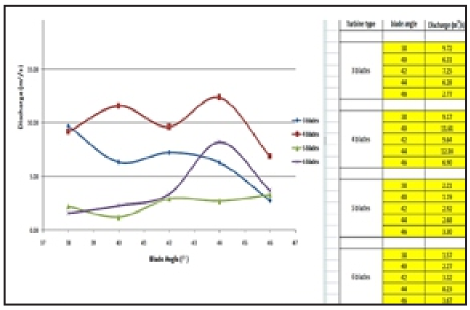


Flow Characteristics Result for 4 Vane 44º Impeller



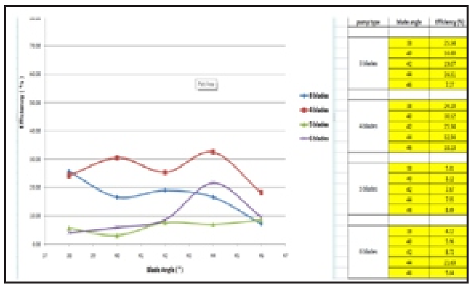
Performance Curve 1: Blade Angle Vs. Velocity

The performance curve is an indication of variation of velocity with blade angles of different configurations. While analyzing this curve, it observed that the existing 6 blade -42º degree impeller has very less velocity as compared with other configurations. At the same time results shows a promising number for 4 blade- 44 º configurations.From the second performance curve(blade angle vs. discharge), an effective correlation between discharge, blade angles and number of blades can be estimated. The ultimate aim is to maximize the discharge. The existing 6 vane 42º impeller gives a discharge of 3.32 m3/s, while a 4 vane 44º impeller would provide a discharge much higher than that of 6 vane configuration (12.38 m3/s). In this waya 4 vane 44º impeller seems more efficient than existing impeller.



Performance Curve 2: Blade Angle Vs. Discharge

From the third performance curve, a picture of blade angle and efficiency can be plotted. The maximum efficiency is 32.54% and the concerned configuration isa 4 vane 44º impeller. The existing model, i.e. 6 vane 42º impeller has an efficiency of only 8.72%. It is worth noting that a whopping 272% increase in efficiency can be achieved if one of the key component is replaced.



Performance Curve 3: Blade Angle Vs. Efficiency

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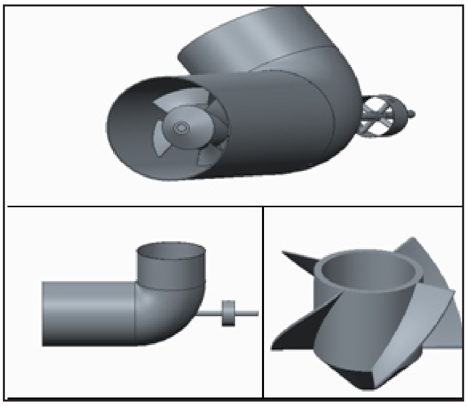
NUMBER OF BLADES	BLADE ANGLES	POWER OUTPUT ρgQH W	POWER INPUT W	EFFICIENCY	% EFFICIENCY
3	38	9527.52	37300	0.2554	25.54
	40	6192.50	37300	0.1660	16.60
	42	7113.68	37300	0.1907	19.07
	44	6158.61	37300	0.1651	16.51
	46	2713.45	37300	0.0727	7.27
4	38	8988.37	37300	0.2409	24.09
	40	11383.74	37300	0.3051	30.51
	42	9450.50	37300	0.2533	25.33
	44	**12138.54**	**37300**	**0.3254**	**32.54**
	46	6762.46	37300	0.1812	18.12
5	38	2165.83	37300	0.0580	5.80
	40	1165.33	37300	0.0312	3.12
	42	2862.10	37300	0.0767	7.67
	44	2631.04	37300	0.0705	7.05
	46	3241.05	37300	0.0868	8.68
6	38	1538.11	37300	0.0412	4.12
	40	2222.06	37300	0.0595	5.95
	42	**3254.14**	**37300**	**0.0872**	**8.72**
	44	8067.20	37300	0.2162	21.62
	46	3596.12	37300	0.0964	9.64

The above table represents the various efficiencies at different vane angles and number of vanes during simulation. From the table itself it is very clear that the existing impeller has very low efficiency as compared to other types. Because of this reason we have to adopt a new model of impeller which gives more efficiency. The 4 vane 44º impeller have more efficiency than that of all other types.

6.Conclusion:

The aim of project is a comparison between various design of impeller with different number of vanes and vane angle. The number of vanes are varied from 3 to 6 and vane angles from 38 to 46 in steps of 2.



Proposed Design:

The simulation results concluded that 4 vane impeller with 44° vane angle gives maximum discharge for same power input hence performance of pump is optimized with this configuration of impeller .The new configuration of impeller can be recommended to manufacturer. In order to compensate the huge amount of impeller losses, suitable modification in the vane shape is appropriate. The weight of the pulley too can be considerably reduced by better design. CFD involves iterative process and solving 1st order 3D equation.

	EXISTING CONFIGURATION 6 VANE 42°	OPTIMIZED CONFIGURATION 4 VANE 44°
Ideal Discharge Q (m^3/s)	3.32	12.38
Area Cleared (Taking Head As 1 m) (Acres)	600	600
Time Taken Hrs. (Days)	**203.15 (8.46)**	**54.48 (2.27)**
Savings In Time = 146.67 Hrs. = 6.19 Days		

Saving in pumping period

From the table it is clear that there is a saving of 6.19 days if the optimized configuration is employed for clearing 600 acres of plot having 1 m height of water there by saving energy and money.

7. References:

#-The Petty and Para (Local language: Malayalam)is an old term used because of its shape.

Para (Suction duct)sucks the water from Paddy .Petty (Discharge duct)discharges the water. The minimum length of Petty is 15 feet. The system needs to be reassembled for any further modification.

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