design and CFD analysis of a kaplan turbine runner wheel blades

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Abstract—Due to recent crises of electricity in the country, it is utmost need for the utilization of renewable energy resources abundantly available like hydropower. To overcome this problem of electricity shortage, hydro-power turbines can be used. Since every hydro site have different site conditions, so design and selection of the proper turbine type and size becomes more important. In this case, it is vital to adopt indigenous design and development of hydropower components. Hydro turbines are the most important part of hydro-power plant. In this research, development of turbines has been focused, mainly of low head turbines. The reason is that small low-head schemes can easily be executed on the run-off-rivers and canals. This paper presents the optimization technique carried out on a complex geometry of blade profile through static and dynamic computational analysis. It is used through change of the blade profile geometry at five different angles in the 3D (Three Dimensional) CAD model. Blade complex geometry and design have been developed by using the coordinates point system on the blade in PRO-E /CREO software. Five different blade models are developed for analysis purpose. Based on the flow rate and heads, blade profiles are analysed using ANSYS software to check and compare the output results for optimization of the blades for improved results which show that by changing blade profile angle and its geometry, different blade sizes and geometry can be optimized using the computational techniques with changes in CAD models. After successful validation, five different blade profiles have been developed. Research results show improvement in the power output of the turbine with 5.43%. Future recommendations were also suggested to pave the way of further improvement in this area of specialization.

keywords: **Low Head, Kaplan Turbine, Runner Blade, CFD, Optimization, Hydropower, Run-of-River.**

1. INTRODUCTION

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. A turbine is a turbo machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Gas, steam and turbines have a casing around the blades that contains and controls the working fluid.

The Kaplan turbine is an outward or inward flow reaction turbine. Here working fluid changes pressure as it moves through the turbine. Power is gained from both the hydrostatic head and from the kinetic energy of flowing water. The Kaplan turbine is an outward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. Power is recovered from both the hydrostatic head and from the kinetic energy of the flowing water. The design combines features of radial and axial turbines.

Demand for increasing the use of renewable energy has risen over the last two decades due to environmental issues. The high emissions of greenhouse gases have led to serious changes in the climate. Although the higher usage of renewable energy would not solve the problems over night, it is an important move in the right direction. Use of water power energy can be very much effective in this regard.

Hydropower remained the most important source of the renewable energies for electrical power production worldwide, providing 19% of the planet's electricity. Small scale hydro is in most cases "run-of-river", and is one of the most cost-effective and environmentally benign energy technologies to be considered both for rural electrification in less developed countries and further hydro-power development worldwide.

Hydropower is a renewable, non-polluting and environment friendly source of energy. It is perhaps the oldest energy technique known to mankind for conversion of mechanical energy into electrical energy. Hydropower represents use of water resources towards inflation free energy due to absence of fuel cost. Hydropower contributes around 22 % of the world electricity supply generated. The total potential of small Hydropower of the whole world is 780,000 MW out of which 50,000 MW has already been utilized.

Small Hydro is also the highest density resources in generation of electricity due to the reason of being it environment friendly, flexibility in operation and suitability in giving support in peak time to the local grid. Due to the small gestation period, small capital investment and quicker return involved, in recent years it has become the point of attraction for private sector. Fiscal incentive announced by the central and state Governments time Finally, to time for investment in this sector have further caused private investor to give attention to this sector. Small hydro power plants (SHP) provide maximum benefits in minimum time. And offers the most fastest economical means to enhance power supply, improve living standards, stimulate industrial growth and enhance agriculture with the least environmental impact and without heavy transmission losses. Due to less transmission losses there is a reduction in distribution cost as well.

2. THEORETICAL CALCULATION

There is lot of scope for investment in small hydropower sector. Very few power plants are under the private sector management. One of such hydroelectric plant, which is working successfully, is Tawa hydroelectric power plant under the efficient management of M/s HEG (Hindustan Electro Graphite Ltd) in Madhya Pradesh (M.P).

- **A CASE STUDY OF A POWER PLANT IN A PRIVATE SECTOR IN MADHYA PRADESH**

Small hydropower plant was setup on left Bank to utilize the tailrace water for irrigation purpose. The tailrace channel from the powerhouse leads to L.B.C. The two units of 2x6.75 MW were setup by M/s HEG Ltd. Mandideep. The Power production in this plant was started in the year 1998. During Kharif and Rabi season the water is supplied through powerhouse tailrace channel to command area for irrigation.

Tawa project is an irrigation project located on River Tawa a tributary of Narmada River .The River Tawa, which is one of major tributaries of River Narmada, rises from the Satpura range of hills at an elevation of 2500 ft. (762.00m).
The head works comprises earthen dam of average height 22.528m and masonry Dam of 57.912m heights with central masonry spillway. 13 Nos. radial gates each of size 15.24mx12.192m are provided with spillway crest at a R.L. 343.205. The M.W.L. of the Dam is 356.692m.

The right bank canal has a cultural command area of 98079 ha and an annual irrigation of 75878 ha. (Kharif, Rabi and Summer crops) The Left Bank irrigation canal has cultural command area 1,86,162 ha and an annual irrigation area of 2,56,904ha (kharif, Rabi, and Summer crops)

Technical Highlights

- Canal head project.
- Catchments area spreads over approximately 6000 Sq Km.
- Full reservoir level (FRL) 335.397 m.
- Head range 7 to 21 m and discharge varying from 25 to54 Cumecs.
- Two turbo generators 6.75 Mw Rated Capacity (20% Over load).

- **Theoretical design**

  Procedures followed in the theoretical design process are discussed in the followings.

- **Flow parameters**

  The rotational speed N of the turbine is given by
  We know that **= characteristic factor**

$$\sigma = \frac{2N\sqrt{\pi Q}}{[2gH]^{3/4}}$$

$$N = \frac{\sigma[2gH]^{3/4}}{2\sqrt{\pi Q}} \quad N = \frac{1.45[2*9.81*10]^{3/4}}{2\sqrt{\pi*72}} = [2.527]s^{-1}$$

Then the specific speed(N_s)

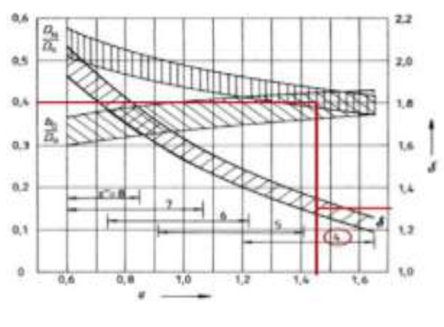


Figure 2.1 illustrates the relationship between hub (inner) and outer diameters of the wheel (D_o, D_i), σ, diameter number (δ), ratio of (D_i/D_o) .

$$N_s = \frac{N\sqrt{Q}}{[H]^{3/4}} = \frac{151.62\sqrt{72}}{[10]^{3/4}} = [168.79]s^{-1}$$

The outer diameter of the runner can be defined with Eq.

$$D_o = \frac{2\delta}{\sqrt{\pi}} * \sqrt[4]{\frac{Q^2}{2gH}}$$

$$D_o = \frac{2*1.3}{\sqrt{\pi}} * \sqrt[4]{\frac{(72)^2}{2*9.81*10}} = 1.662 \text{ m}$$

The diameter number (δ) of 1.3 is related to σ = 1.45 and diameter ratio (D_i/D_o) of 0.4. Thus, the hub diameter (D_i) can be calculated as below

$D_I = D_o \times 0.4 = 1.662 \times 0.4 = 0.665$ m

The number of blades (z'') are related to σ and can be read out from Figure2.1 . The suction head (H_{Smax}) is defined by Eq.

$$H_{Smax} = \frac{\text{patm}}{\rho g} - \frac{\text{pv}}{\rho g} - \sigma H$$

$$H_{Smax} = \frac{101300}{1000*9.81} - \frac{1279}{1000*9.81} - 0.8*10 = 2.196 \text{ m} = 2 \text{ m taken}$$

Where $p_{atm}$is the atmospheric pressure, p_v is the vapor pressure of water, σ is the cavitation coefficient, and is the density of the water. For this work, the water temperature and vapor pressure were chosen as 15 °C and 1279 Pa, respectively. Usually, σ is obtained by the turbine manufacturer through model testing. A maximum suction head (H_{Smax}) of 2.396 m was given by Eq. as the maximum possible head to avoid cavitation and hence the suction head (H_S) of 2 m was chosen for the case study.

- **Turbine blade design**

The tangential velocity of the blade (u) can be given by Eq.

$u = \pi D n = \pi \times 1.662 \times 2.527 = (13.19)\text{ms}^{-1}$

The relative velocity in meridian direction w_m depends on the discharge and area of the fluid flow in the runner and this would be the same for whole runner section. Hence, the inlet velocity C_O would also be similar to w_m.

$$w_m = co = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}(D^2_O - D^2_I)}$$

$$= \frac{Q}{A} = \frac{72}{\frac{\pi}{4}(1.6622 - 06652)} = [39.51]\text{ms}^{-1}$$

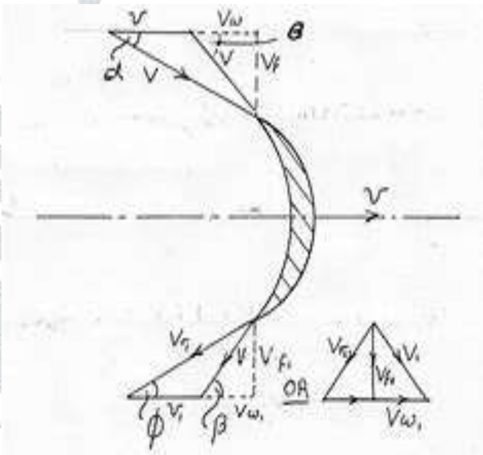


Fig.2.2 Velocity triangle diagram

The tangential velocity of the fluid flow (cu_∞) depends on the head and blade's tangential velocity, defined by Eq.

$$cu_\infty = \frac{(H - Hs)g}{u} = \frac{(10.-2)*9.81}{13.19} = [\mathbf{5.98}]\text{ms}^{-1}$$

The difference of the tangential velocity (Δwu) depends on the head and tangential velocity of the blades. The efficiency of the runner is assumed to be the highest possible efficiency for Kaplan runners, 94%

$$\Delta w_u = w_{u1} - w_{u2} = \frac{Hg\eta e}{u} = \frac{10*9.81*.94}{13.19} = [\mathbf{6.99}]\text{ms}^{-1}$$

$wu_\infty = cu_\infty - u = 5.98 - 13.19 = [\mathbf{-7.21}]\text{ms}^{-1}$

The relative velocity at the middle of the blade w_∞ = is :

$$w_\infty = \sqrt{W_{um}^2 + W_m^2} = \sqrt{(-7.21)^2 + (39.51)^2} = [\mathbf{40.16}]\text{ms}^{-1}$$

The angle at the middle of the blade with horizontal (β_∞) is defined by

$\beta_\infty = 90^0 - tan^{-1}\left(\frac{wu\infty}{wm}\right) = 90^{\,0} - \tan^{-1}\left(\frac{-7.21}{39.51}\right) = 100.34^0$

The above presented theoretical calculations can be evaluated by checking the expected and resulting efficiency. As was mentioned, the expected efficiency ηe of the runner was selected as 94%. For a comparison, the resulting efficiency can be calculated with the provided and actual output powers of the runner wheel. The provided power by the water to the runner can be calculated by Eq.

$p_{water} = \rho g H Q = 1000 * 9.81 * 10 * 72 = 7063200$ W

By Euler formula given in Eq.and the values of the power of the turbine runner wheel can be calculated:

$p_{runner} = \dot{m}(u_1c_{u1} - u_2c_{u2}) = \dot{m}u\ \Delta w_u$

$\dot{m} = \rho Ac_0 = \rho\frac{\pi}{4}(D^2_O\text{-}D^2_I)c_0$

$p_{runner} = \rho\frac{\pi}{4}(D^2_O\text{-}D^2_I)c_0\ u\ \Delta w_u$

$p_{runner} = 1000 * \frac{\pi}{4}(1.6622 - 0.6652) * 39.51 * 13.19 * 6.99$

$= 6637590.018$ W

Now the theoretical efficiency is given be:

$\eta r = \frac{pwater}{prunner} * 100 = \frac{7063200}{6637590.018} * 100 = 93.97\ \%$

This proves the accuracy of theoretical results and another check will be carried out to compare the theory with CFD.

3. DESIGN AND DEVELOPMENT OF THE RUNNER BLADE

The Keeping in view the previous research on optimization in water turbine runner blades, area of design and development/optimization through geometrical changes in the blade runner profile was focused for new research. The same is illustrated in the next sections. Water turbines are the most important part for hydro-power generation in the country. For different range of heads and flow rates, different types of turbines are used. Kaplan turbines are used for low head applications. The main characteristics of design are the data on which the design of the runner is based.

From the localization and topology of the power station in which the turbine is going to operate, the fundamental design parameters for any turbine design can be determined. Head and the amount of water flow give not only information of how much energy that can be produced but also to determine the type of turbine, the basic design parameters.

Turbine basic data was obtained from the tawa Hydro Power Plant hoshangabad, Madhya Pradesh , and based on site data like design flow rate of 2554 cusecs (72 m^3/sec), gross head of 10 meters and hydraulic efficiency of around 94%, technical characteristics of the turbine are:

Maximum power output = 6.75 MW, Runner diameter=1.662m, and Hub diameter=0.665m.

For optimization of the turbine runner blades using the latest computational techniques, it is essential to develop the complex 3D model of the blade. For this purpose, actual blade sample is used to create the model in CAD. Blade geometry was then obtained through x-axis, y-axis and z-axis coordinates by assuming the test bed level as the datum line reference. Based on this data, development of the complex blade geometry for initial design, have been carried out using AutoCAD and ProE/Creo.

In Table 3.1, coordinates for inner side and outer side of the blade geometry are shown and similarly in Table 3.2, coordinates for the development of right hand side and left hand side are shown. CMM machine and 3D scanner are now-a-days commonly used for the development of complex CAD models in the industry as well as in the academic institutes. In this study, Pro-E/Creo have been utilized to develop CAD models of turbine runner blade with the help of coordinate points system. Through this procedure, different CAD models of blade profiles with required geometries were possible to be developed.

TABLE 3.1. COORDINATE POINTS FOR BLADE DEVELOPMENT (FOR INNER AND OUTER SIDE)

INNER UPPER SIDE													
X(mm)	643	600	500	400	300	200	100	0	-100	-200	-300	-400	-457
Y(mm)	-1519	-1476	-1396	-1336	-1293	-1263	-1246	-1240	-1246	-1263	-1293	-1336	-1368
Z(mm)	13	32	74	117	159	215	266	311	348	381	409	439	456
INNER LOWER SIDE													
X(mm)	643	600	500	400	300	200	100	0	-100	-2000	-300	-400	-457
Y(mm)	-1519	-1476	-1396	-1336	-1293	-1263	-1246	-1240	-1246	-1263	-1293	-1336	-1368
Z(mm)	0	6	21	36	50	68	94	131	178	238	310	383	425

OUTER SIDE LOWER		
X(mm)	Y(mm)	Z(mm)
-100	-2	215
-200	-10	217
-300	-21	218
-400	-38	222
-500	-60	224
-600	-87	226
-700	-119	236
-750	-140	245
-775	-158	249
-800	-185	261
-825	-229	271
0	-0	223
100	-2	221
200	-10	224
300	-21	232
400	-38	236
500	-60	240
600	-87	244
700	-119	247
800	-157	249
900	-201	253
1000	-251	254
1100	-308	253
1200	-379	247
1250	-447	243
1270	-497	242
1281	-569	241

OUTER SIDE UPPER		
X(mm)	Y(mm)	Z(mm)
-100	-2	287
-200	-10	284
-300	-21	281
-400	-38	280
-500	-60	280
-600	-87	282
-700	-119	287
-750	-140	290
-775	-158	292
-800	-185	296
-825	-229	301
0	-0	291
100	-2	293
200	-10	295
300	-21	297
400	-38	298
500	-60	298
600	-87	298
700	-119	298
800	-157	296
900	-201	294
1000	-251	290
1100	-308	283
1200	-379	275
1250	-447	269
1270	-497	265
1281	-569	257

were measured physically from the runner blade on test bench i.e. surface table by using the well calibrated measuring instruments like height gauges to ensure the accuracy of the measurements taken by qualified quality personnel. True levelled surface of the test bench was taken as reference for these measurements.

In this procedure, runner blade was placed and levelled on the test bench/surface table. Blade upper and lower surfaces were properly cleaned before marking of points. Outer periphery of the blade on upper and lower sides was measured by using calibrated measuring tape. At start, initial reference point was marked as coordinate (0,0,0) and from this reference point, next point was marked on the periphery line at an interval of 100mm with the help of divider. This point was then measured with respect to initial point by measuring the dimensions along x-axis, y-axis and z-axis. Dimensions along x and y-axis were measured with the help of calibrated Vernier calipers, whereas dimension along z-axis was measured by using the calibrated height gauge.

In this way, all the points/coordinates were measured and plotted on the drawing.

TABLE. 3.2 COORDINATE POINTS FOR BLADE DEVELOPMENT (FOR LEFT AND RIGHT SIDE)

LEFT HAND UPPER SIDE										
X(mm)	-837	-825	-800	-775	-750	-700	-650	-600	-550	-500
Y(mm)	-295	-364	-452	-536	-616	-766	-905	-1035	-1158	-1274
Z(mm)	300	309	320	330	341	361	382	401	421	440

LEFT HAND LOWER SIDE										
X(mm)	-837	-825	-800	-775	-750	-700	-650	-600	-550	-500
Y(mm)	-295	-364	-452	-536	-616	-766	-905	-1035	-1158	-1274
Z(mm)	268	276	287	298	308	329	349	369	388	407

RIGHT HAND UPPER SIDE								
X(mm)	1270	1250	1200	1100	1000	900	800	700
Y(mm)	-650	-700	-773	-907	-1041	-1175	-1308	-1442
Z(mm)	237	224	205	170	136	102	67	33

RIGHT HAND LOWER SIDE								
X(mm)	1270	1250	1200	1100	1000	900	800	700
Y(mm)	-650	-700	-773	-907	-1041	-1175	-1308	-1442
Z(mm)	223	211	191	157	123	88	54	20

Blade geometries are developed with utilization of the point's coordinate system. Sequence of the working on drawings to finally develop CAD 3D model is as shown in Fig 3.1.

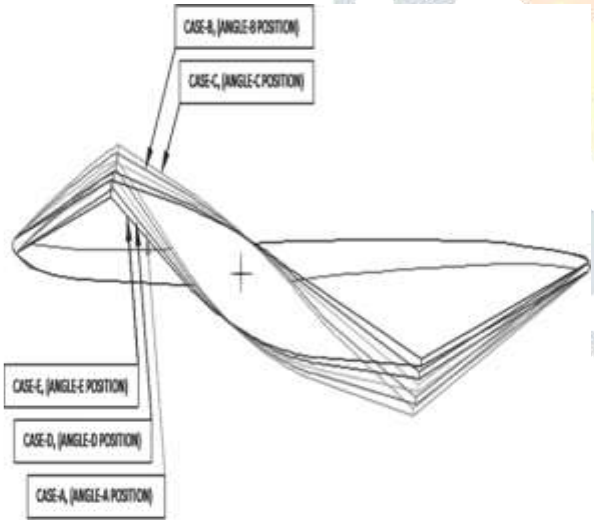


Fig 3.1. 3D model of blade

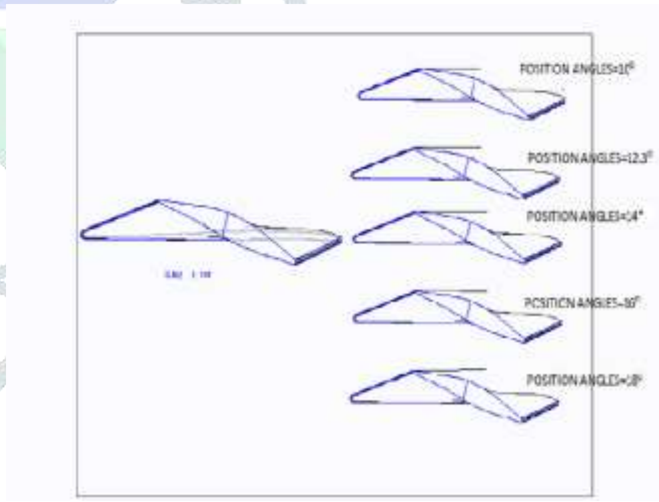
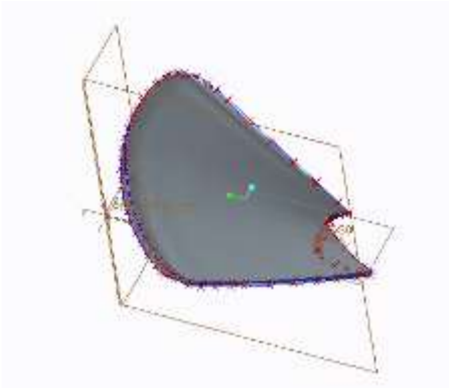


Fig 3.2. These five blade models are developed at five different angles



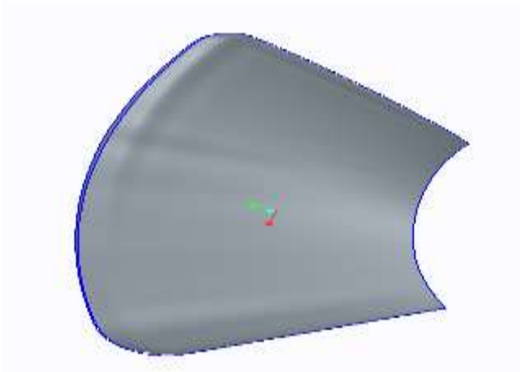


Fig. 3.3 design of blade

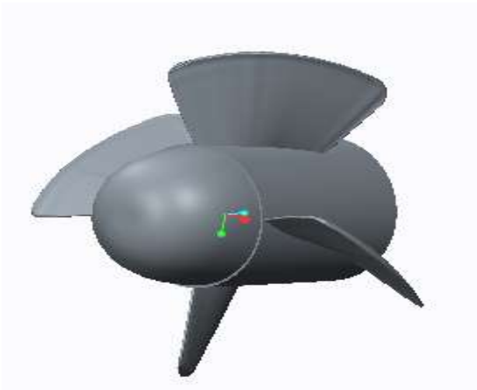


Fig 3.4 design of Impeller

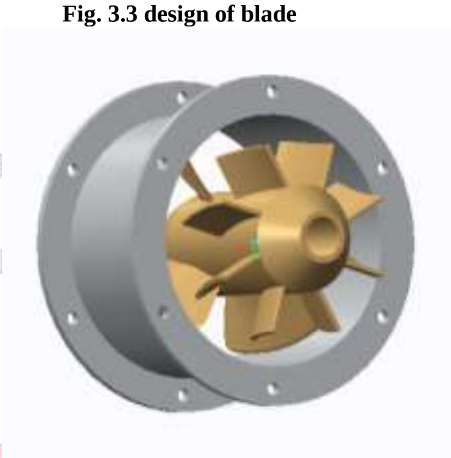


Fig. 3.5 design of impeller and casing mesh

4. CFD ANALYSIS AND RESULT OF TURBINE RUNNER BLADE

Computers are used to perform the millions of calculations required to simulate the interaction of fluids with the complex surfaces used in engineering. More accurate codes that can accurately and quickly simulate even complex scenarios such as supersonic or turbulent flows are an ongoing area of research.

CFD provides a qualitative as well as quantitative prediction of fluid flows by means of mathematical modeling (partial differential equations) and numerical methods (discretization and solution techniques). Computational Fluid Dynamics (CFD) is computer-based simulation to analyze systems involving fluid flow, heat transfer and associated phenomena. A numerical model is first constructed using a set of mathematical equations that describe the flow. These equations are then solved using a computer programmed in order to obtain the flow variables throughout the flow domain.

The experimental approach of evaluating the performance of Kaplan turbine is costly as well as time consuming. Conversely CFD approach is faster and large amount of results can be produced at virtually no added cost. Computational fluid dynamics study has been carried out using ANSYS on the original geometry and results obtained were compared to validate with the theoretical data as illustrated in next sections.

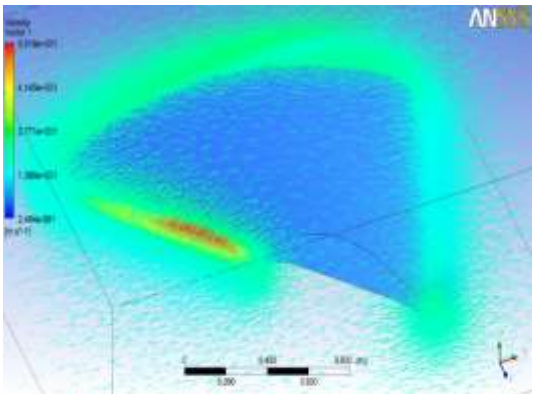


Fig 4.1 Velocity vector at 10^0 angle

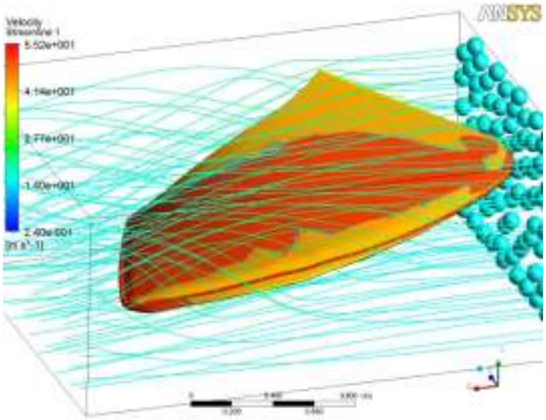


Fig 4.2 10^0 streamline flow diagram

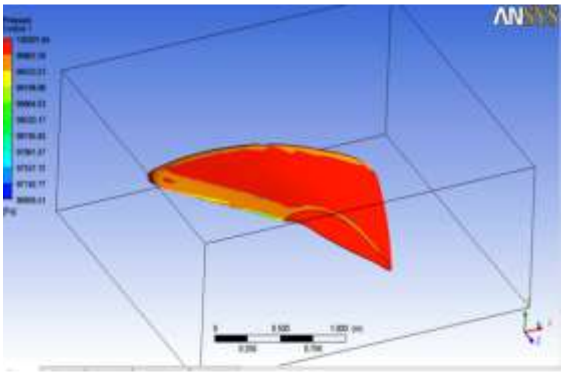


Fig 4.3 Pressure at 12.3^0 angle

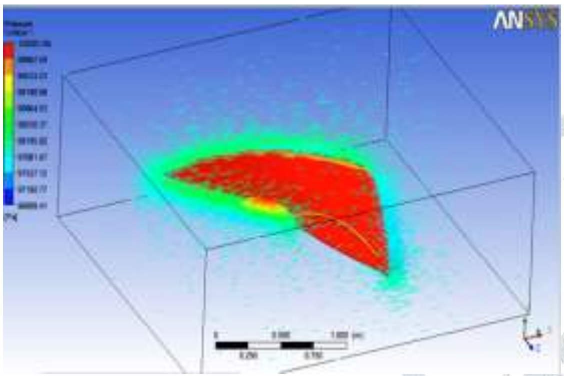


Fig 4.4 Velocity vector and pressure at 12.3^0 angle

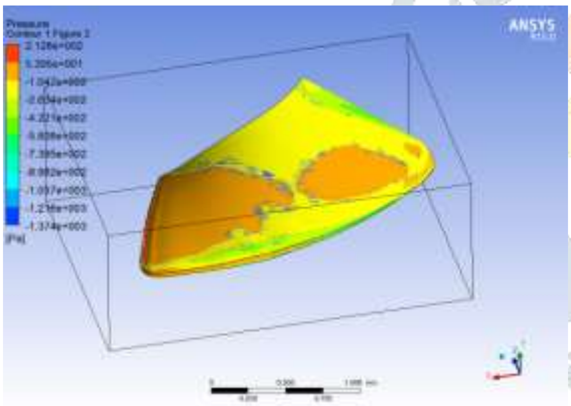


Fig 4.5 Pressure at at 14^0 angle

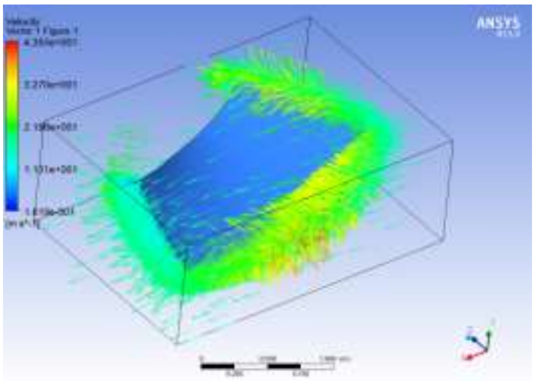


Fig 4.6 Velocity vector and pressure at 14^0 angle

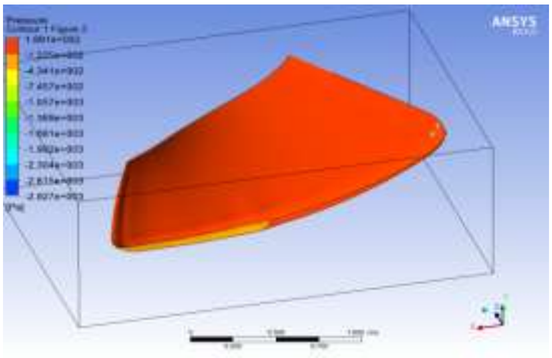


Fig 4.7 Pressure at 16^0 angle

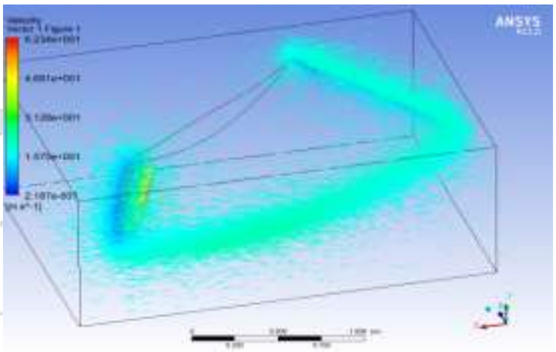


Fig 4.8 Velocity vector and pressure at 16^0 angle

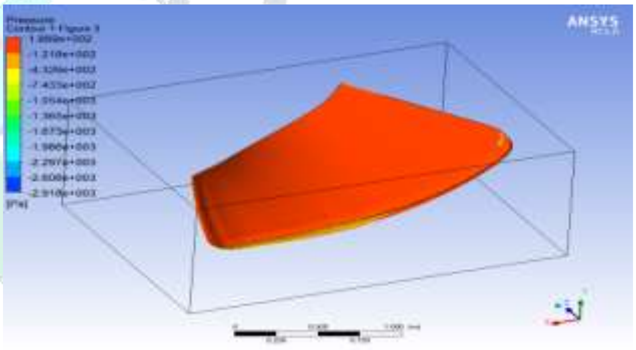


Fig 4.9 Pressure at 18^0 angle

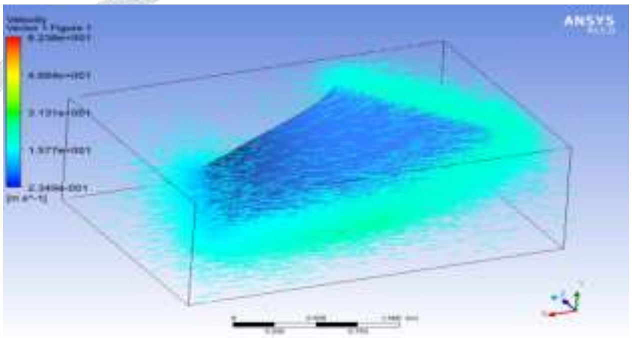


Fig 4.10 Velocity vector and pressure at 18^0 angle

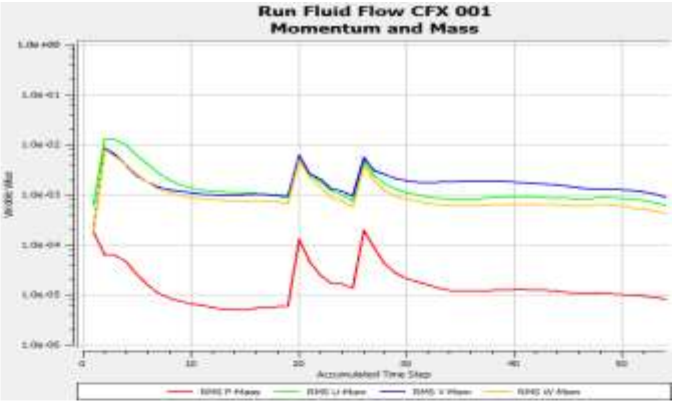


Fig.4.11 momentum and mass graphically represented for 12.3^0 angle

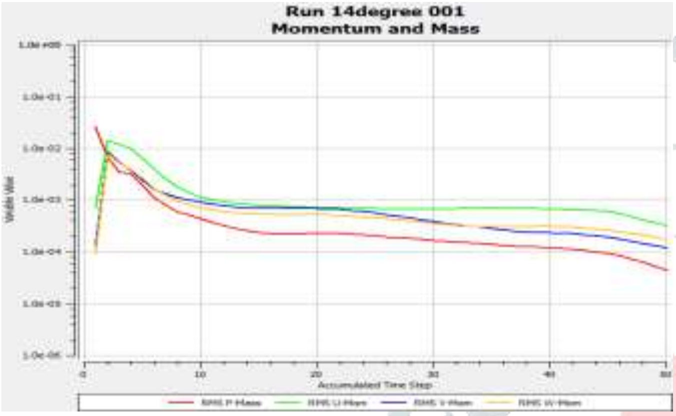


Fig. 4.12 momentum and mass graphically represented for 14^0angle

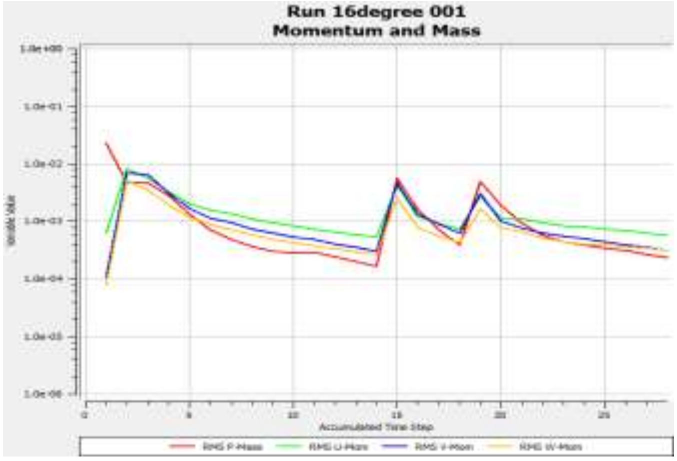


Fig. 4.13 momentum and mass graphically represented for 16^0angle

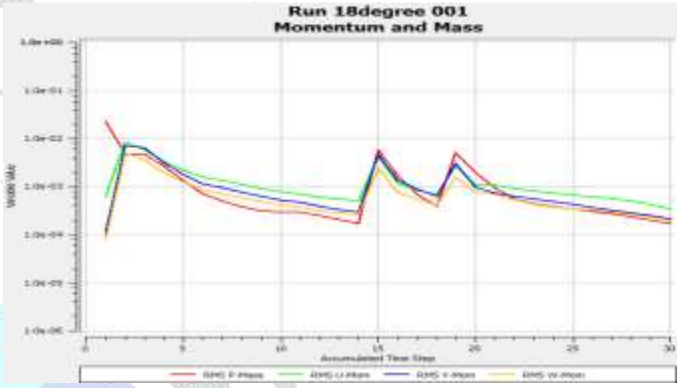


Fig. 4.14 momentum and mass graphically represented for18^0angle

4.1 BLADE PROFILE OPTIMIZATION

If to achieve the improved design characteristics and to optimize the blade profile, blade profile geometry was modeled and developed for five different cases i-e case-A, case-B, case-C case-D and case-E at five different positions /inclinations on hub side.

These blade models were developed in Pro-E / Creo. Case-B and case-C developments were made at a position of angle 12.3^0 and 14^0respectively. Whereas other two developments case-D and case-E were made at a position of angle 16^0 and 18^0 respectively. An average increment of2^0 was considered for the angular displacement in clockwise and anticlockwise direction. CFD analysis was carried on the five different blade geometries consideration the same topology and boundary conditions taken in the earlier analysis.

From graphical representation shown in the figure4.1.1, it is clearly indicated that CFD analysis on the developed blade profiles have improved the turbine power output. Results comparison have shown that blades used in the assembly for case-E have improved the power output of the turbine.

Table 4.1.1 Output result obtained with difference Discharge

S. NO.	DISCHARGE (m^3/sec)	THEORITICAL	POWER OUTPUT (MW)				
			10^0	12.3^0	14^0	16^0	18^0
1	35	3.22	3.2	3.15	3.7	3.9	3.17
2	42	3.69	3.6	3.65	3.60	3.75	3.70
3	50	4.2	4.15	4.2	4.25	4.17	4.29
4	56	5.35	5.3	5.4	5.11	5.23	5.50
5	62	6.2	6.2	6.15	6.19	6.27	6.33
6	72	6.63	6.59	6.55	6.50	6.57	6.60
7	80	6.67	6.65	6.62	6.62	6.69	6.7
8	90	6.7	6.73	6.71	6.72	6.79	6.79
9	97	6.72	6.7	6.72	6.67	6.70	6.72

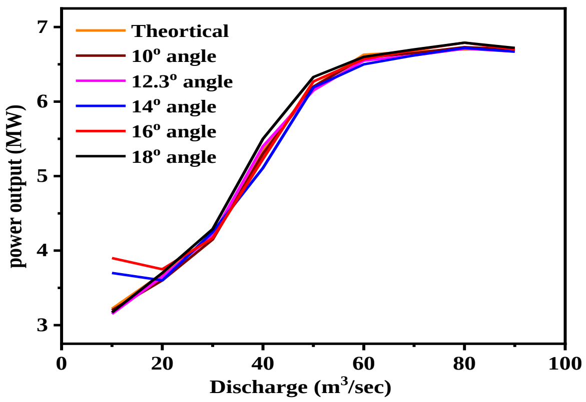


Fig.4.1.1 Theoretical data and CFD results for all cases

4.2 VALIDATION OF THE CFD MODEL

After CFD analysis it becomes very important to validate the results achieved. Validation is required for the assessment of the accuracy of computational model. Validation is achieved by comparing CFD results with available theoretical data.

CFD analysis have been carried out on the original blade geometry at different flow rate conditions. theoretical data was taken from the site of the hydro-power turbine unit located at Tawa project is an irrigation project located on River Tawa a tributary of Narmada River. The River Tawa, which is one of major tributaries of River Narmada, rises from the Satpura range of hills at an elevation of 2500 ft. (762.00m).
theoretical data and CFD results obtained from the analysis carried on the original blade assembly i.e. case-E (18^0angle) are tabulated in Table 4.1.2

To compare the closeness of CFD simulation results to the theoretical data, two measures, the percentage root mean square error and the percentage mean absolute error are used.

$$\%RMSE = \sqrt{\frac{\sum(P_{theo} - P_{cfd})^2}{n}} \text{ x } \frac{100*n}{\Sigma(P_{cfd})}$$

$$\%MAE = \frac{\Sigma(P_{theo} - P_{cfd})}{\Sigma(P_{cfd})} \text{ x } 100$$

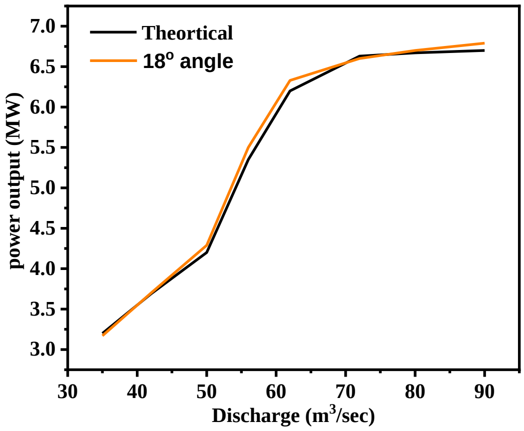
Where P_{exp} is the experimental data, P_{cfd} is the CFD simulation result data and n is the number of operations.
The errors of the CFD simulation results with the experimental ones are found as 4.3% and 4% respectively. It shows that the CFD simulation results are in the sufficient agreement with experimental data and therefore validating the results.

S. NO.	**DISCHARGE (m^3/sec)**	**THEORITICAL**	**POWER OUTPUT (MW) 18^0angle**
1	**35**	3.2	3.17
2	**42**	3.69	3.70
3	**50**	4.2	4.29
4	**56**	5.35	5.50
5	**62**	6.2	6.33
6	**72**	6.63	6.60
7	**80**	6.67	6.7
8	**90**	6.7	6.79
9	**97**	6.72	6.72

Table 4.1.2 Comparison between theoretical data and CFD analysis

Comparison between the theoretical data and CFD results have been graphically represented in Figure 4.1.2 . From results comparison, it is evident that power output of the turbine is close enough to be validated.

Fig. 4.1.2 Comparison between the theoretical data and CFD results have been graphically represented



5. CONCLUSION AND RECOMMENDATIONS

CONCLUSION

Equalize An optimization methodology is developed for the design and development of Kaplan turbine runner blade using computational fluid dynamics tools. 3DCAD model of the original runner blade is generated from as-built physical measurements. Complex geometrical profile of the blade is developed using Pro-E/Creo for the purpose to analyze using CFD. Based on this geometry, five other modified profiles are developed to carry CFD analysis for optimum solution.
CFD simulation results are compared with the experimental site data to validate the CFD analysis. Results after comparison were found close enough to validate the CFD analysis.
The developed Kaplan turbine runner blade is manufactured locally in india and after successful completion three more blades were casted for a complete unit.
The developed methodology is applied for the Kaplan turbine runner blade design of an actual hydropower project. Small hydropower plant was setup on left Bank to utilize the tailrace water for irrigation purpose. The tailrace channel from the powerhouse leads to L.B.C. The two units of 2x6.75 MW were setup by M/s HEG Ltd. Mandideep.
overall turbine efficiency of 94.3%.Results of the research study carried out on the CAD model of original blade and modified blade profiles have shown improvement in the turbine power output, resulting in the power output increase from 6.50 MW to 6.63 MW (5.43%)increase. The same improved output of 6.60MW have also been verified at site. It resulted an increase of around 6000 kwh units per day or180,000 kwh per month, having financial impact of worth Rs. 1.8 million or18,000 US Dollar (i.e. equivalent @ Rs. 100/- equal to one US Dollar) per month saving for 4.6 MW turbine unit.
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RECOMMENDATIONS

In future research, CFD study can be conducted on the hydro-mechanical components of water turbines for improvement to obtain optimum solutions.
This study can be based on many aspects like component material behaviors, structural stability, economical measures, indigenization criteria, standardization in the design.
Furthermore, following recommendation can be addressed for future research work in the research field of hydro-power development in the developing countries;

- Study on the use of composite material as replacement to the conventionally used materials on blades for the cost effectiveness and better and better performance.
- To carry research for improvement in the turbine efficiencies depending on the blade tip clearance criteria using CFD techniques.
- To carry research work on the turbine balancing techniques using latest computational techniques.
- Research work in the area of hydraulic structures need more attention. Use of CFD can lead to improved and optimum design of hydraulic structures like gates, stop logs, trash racks etc.
- To investigate the criteria for optimum design and development of penstock, bifurcation and expansion joints through dynamic analysis.

ACKNOWLEDGEMENTS

I express my sincere gratitude to my project guide, **Mr. Om Prakesh Sondhiya**, Department of Mechanical Engineering Institute of Engineering & technology, Devi Ahilya Vishva Vidyalaya, Indore for this valuable guidance, careful reviews with proper advice and constant encouragement during the course of this work.

I am highly thankful to **Dr. Ashesh Tiwari,** Head of the Mechanical Engineering Department, at IET, DAVV indore for providing an opportunity and moral support during my project work.

I do not find enough word with which I can express my feelings of thanks to all my teachers and friends at IET, DAVVindore for their help, inspiration and moral support which went a long way in my work.

I am also thankful to the referred authors whose research work have been consulted and quoted in this project work. I also extend my thanks to all labs incharges, librarians and all the another members of the mechanical engineering department ,IET,DAVV indore, for their direct and indirect help and cooperation.

In the end I extend my gratitude to my **parents** and other **family members** for cooperation and moral support.

PINKESH BHURLEKAR

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