Quality and design aspects of the pump-turbine runner at the Tehri pumped-storage plant

H.L. Arora[1]	Kunal Kishore[1]	Lalit Kumar[1]	Sanjay Rawat[1]
Ex. Director Technical	Dy. Manager	Manager	Manager

1THDC India Limited, Bypass Road, Pragatipuram, Rishikesh, Uttarakhand-249201, India
Tel: +91 9997190385; Email: srthdc@gmail.com & sanjayrawat@thdc.co.in

Abstract-Pumped-storage hydro plants are flexible, dynamic and efficient means to store and deliver large quantities of electricity by moving water between two reservoirs at different elevations. In a reversible pump-turbine unit, a pump-turbine runner rotates in both the directions under the pump and turbine modes. The flow in the runner is quite different under the pump and turbine modes, which creates a great challenge for the design of a pump-turbine runner. Tehri PSP is the biggest Pump storage project in India, comprising of 04 pump turbine units of 250 MW each. The main feature of the Project is the large variation of head about 90 m, under which the reversible units shall operate. Presently project is under construction and scheduled to be commissioned by June 2022.

The operation of Tehri PSP is based on the concept of recycling of water discharged between upper reservoir (Tehri Dam) to lower reservoir (Koteshwar HEP). There are various parameters which affect the runner's performances of reversible turbine and one parameter might have contrary effects on runner performances under the pump and turbine modes. It is difficult to obtain a runner with optimum performance at both the pump and turbine modes.

During the fabrication of the runner followed by heat treatment various Non destructive tests are done on runner's components. The complexity of the runner blade profile is the biggest challenge to achieve it within the allowed tolerance limits. Static balancing of the runner assembly and the runner blade angle measurement are one of the key challenges during the quality check.

All critical issues were kept in mind at the time of designing to meet out the requisite standards for better quality control & performance. In this paper, we are focusing on the Quality Control aspects of the pump turbine runner of Tehri PSP after complete fabrication and machining during various stages of manufacturing/fabrication. The complete fabrication process of runner and its quality checks are quite stringent from the performance/efficiency point of view of pump turbine unit.

Keywords: Pump storage project, Pump Turbine, Laser Tracking Method, Templates, Coupling Flanges and Static Balancing

1.0 Introduction

Tehri Hydro Power Plant (THPP) is located in District Tehri, Uttrakhand, India. The Tehri Hydro Power Plant has a 260m high Earth and Rock-fill dam. It comprises of 1000 MW (4x250MW) underground power house and consists of 4 synchronous generators coupled with Francis turbines. The live storage of Tehri dam is 2615 MCM.

In first Stage Tehri Hydro Power Plant (THPP) has been constructed and in the second stage of the project a 97 m high concrete dam having 400 MW (4x100 MW) power house (Koteshwar Hydro Electric Project) was further constructed in koteshwar region which act as a downstream reservoir. With the creation of downstream reservoir, the installed capacity of Tehri Hydro Power Complex was further enhanced by construction of a unique Pumped Storage Scheme with the capacity of 1000 MW (4x250MW) under construction, thereby having the total installed capacity of 2400 MW of Tehri Hydro Power Complex.

The Tehri Pump Storage Plant (TPSP) which is located in the vicinity of Tehri Hydro Power Plant (THPP) has four variable speed pump-turbines with asynchronous motor-generator. This plant is planned to operate in generating mode during peak time and in pumping mode during off peak times as required so as to refill the upstream reservoir and reuse the water.

2.0 Description of PSP machine

Rated unit capacity	250 MW
Installed capacity	1000 MW
Number of units	04 nos

Type of Machine	Variable speed vertical Francis type reversible turbine
Gross Head Range in Turbine Mode	127 m to 227 m
Turbine Net Head Range	120.4m to 219.4 m
Pump delivery Head Range	130.5m to 229.5 m
Design Head	188 m
Operating Speed Range	206 rpm-250 rpm (Variable speed)
Distributor axis	approx. EL 568 M
Rated flow at rated head in turbine mode	146.9 m3/sec
Rated flow at rated head in Pump mode	109.5 m3/sec
Rated speed at rated power and head	230.77 rpm
Maximum Reservoir Level	830 m
Minimum Drawdown level of reservoir	740 m
Maximum Tail Water Level	612.5 m
Minimum Tail water level in Turbine mode	603 m

Table 1. Salient features of the Tehri Pump Storage Project

It is known that the impeller of a reversible pump-turbine is mainly designed for pump mode operation. From a practical point of view, this means that a single-stage reversible pump turbine is by nature forced to be operated as a compromise between an optimum pump and an optimum turbine . Attention should be paid to the overall performance in order to obtain the advantages of a simplified and cost-effective pump-storage design concept.

3.0 Design Perspectives

In Tehri dam water can be stored upto max elevation of EL 830 mtr. The stored water is released as per peak demand of grid besides fulfilling the irrigation requirements and is bought down to MDDL EL 740 meter before onset of monsoon of next season i.e. by end of June. During monsoon season (July to September) reservoir level increases rapidly to reach its maximum in September end. Thus, during a year the level variation in reservoir from El. 740 to El. 830 Mtr. During the DPR stage of Tehri PSP following option were envisaged to select the optimum option in terms of the technical and economic point of view of the project.

3.1 CONVENTIONAL DESIGN

To design a pump-turbine, it is needed to work on the pump characteristics first. The optimum pumping power is generally set between the yearly averaged head and the lower head, in order to find a compromise between efficiency, cavitation and instability zone of the pump.

The Tehri PSP selected dimensioning criteria for Tehri (110 m3/s under a 212.5 metre delivery net head and cavitation curve centered within the discharge range) have led to the selection of following values for hydraulic parameters:

Synchronous speed : n sync=272.7 rpm

Outlet pump runner diameter : D1e = 4.92 m

No higher rotational speed has been studied, because it would have implied much higher submergence and important risks in terms of sensitivity of the machine to vibrations of the structures and of the shaft line. Single speed and adjustable speed pump/turbine units operate in a similar manner during generation mode. In generation mode, single speed units are able to operate down to 50% of the rated capacity and adjustable speed units are able to operate down to 30% of the rated capacity. The other possible design could have been set up by decreasing the rotational speed, but it would have cause larger diameter, larger motor and higher input power at lower submergence.

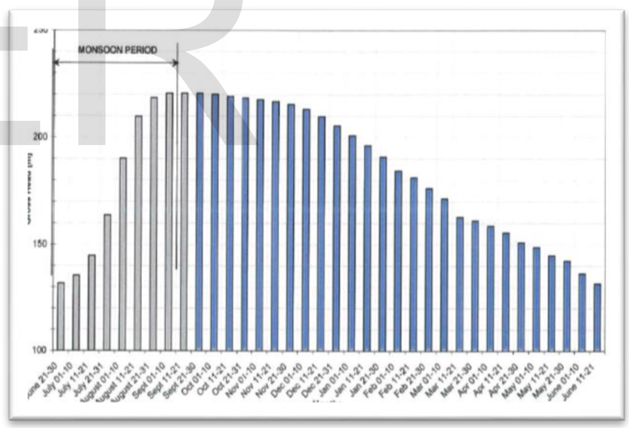

Fig.1 Estimated gross head evaluation through one averaged year

In Conventional turbine mode the best efficiency point found outside the operating range. Further it has certain drawbacks:

1. The efficiency deteriorates sharply as soon as the head is far away from the rated head, particularly in case of low delivery head in pumping.
2. The submergence -150 mtr. is extremely far from usual value and to ensure to avoid the risk of cavitation.

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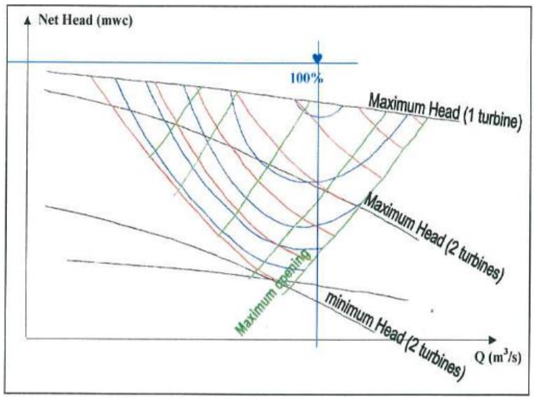

Fig.2 Best efficiency point in conventional option

3.2 TWO SPEED SOLUTION

In two speed solution, the pump works from the maximum to medium head range at one speed and from medium to minimum head range at the second speed, the pump performance shall be better in terms of efficiency and Cavitation limits than conventional solution.

In this case, single stage Francis pump turbine coupled with a special synchronous motor generator, motor generator presents two distinct statoric windings installed in the same core and frame and special rotor with wide and narrow poles, the rotational speed either 214.30 rpm or 250 rpm. 250 rpm with a pump running from 229.5 m to medium heads around 171.5 m and from this medium head range to lower head 130.5 m. 214.3 rpm, In two speed solution, the runner outlet diameter is 5.32 mtr. However issues with this option were significant increase in cost of the machine which can mainly be attributed to appreciable increase in weight of the machine's rotor which would substantially affect other aspects of the plant such as load bearing capacity of thrust bearings, increase in capacity of crane at power house etc.

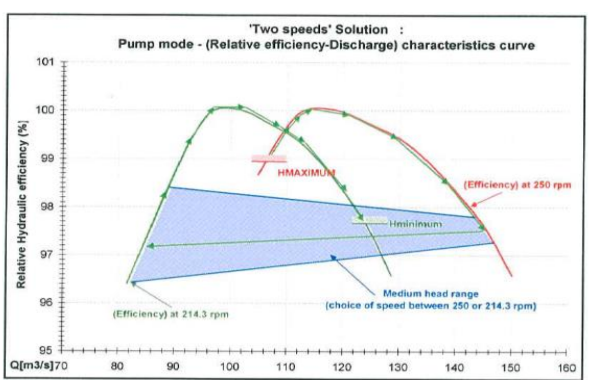

Fig.3 Relative efficiency V/s Discharge in '2 speed solution' option

3.3 VARIABLE SPEED OPTION

In variable speed option, pump can work from maximum to minimum head by in adjusting the speed continuously with the delivery head and optimizing the machine performance in terms of the efficiency and cavitation limits. This option enables to adjust the required input power, which is not possible in other solutions, the possibility to run at minimum speed for reaching the best efficiency point within the operating range.

Variable speed reversible units deployment in Tehri PSP also offer other extremely interesting features such as usage of modern VSI based excitation circuit which in conjunction with SPMax speed governor , optimizes the speed-power output. Power converters fed rotor circuitry enables power exchange from two sides i.e stator & rotor hence named as Doubly fed asynchronous machine (DFAM). DFAM machine based PSP facilitates variable speed operation, smooth starting, braking (regenerative & dynamic), reactive power compensation and also acts as a active power filters. Moreover, the VSI system and SPMaX system are also responsible for achieving speed, real power, reactive power control in both pump & turbine mode. Due to change in machine technology from two speed to variable speed, the submergence required for the pump turbine reduces from 57mtr to 40 mtr without compromising in efficiency and other performance parameter of the machine resulting in reduction of cost of civil excavation that cannot be ignored.

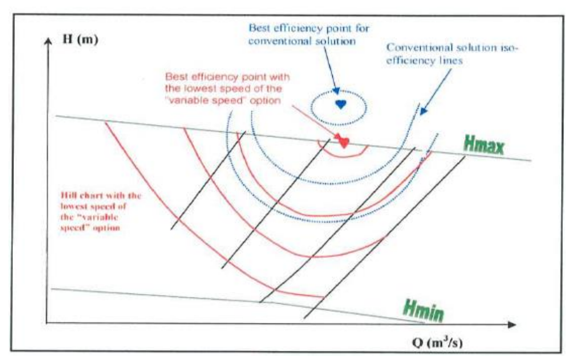

Fig.4 Best efficiency point comparison in variable and conventional speed option

3.4 COMPARISON OF THREE SOLUTIONS

The two speed solution and variable speed solution have heavier weight of rotating parts than conventional solution. The comparisons of

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dimensional parameters of different solutions are under:

Sl. no.	Parameter	Conventional solution	2 speed solution	Variable speed solution
1	Outlet pump runner diameter (m)	4.92	5.32	3.413
2	Maximum spiral casing width (m)	13	14	14
3	Depth of the draft tube (m)	11	12	12
4	Core Length (m)	3	3.5	3.01
5	Stator Weight (tons)	240	400	320
6	Rotor Weight (tons)	360	750	490

Table 2. comparison of three solutions

3.5 Global pumping/Turbining cycle efficiency comparison

Tehri PSP can be operated and this takes into account various hypothesis as defined the following points:

i. Outside the monsoon period (270 days)7 hours of pumping have been estimated by off peak hours.
ii. During monsoon extra discharge of rain falls is brought, no pumping is required.

Sl. no.	Machine Characteristics	Conventional solution	2 speed solution	Variable speed solution
1	Submergence under the TWL (m)	-150	-57	-40
2	Speed value (rpm)	272.8	214.3 /250	206- >250
3	Energy absorbed in pumping in 1 year/1 unit (GWh)	495.2	437.2	424.2
4	Energy produced in turbining in 1 year/1 unit (GWh)	291.5	350.1	332.7
5	Turbining/ pumping energy ration (%)	77.3	80.1	78.4

Table 3. comparison of machine characteristics

The main characteristics of Tehri PSP project is the wide operating head range (from 127m to 227m), which means that standard solution with single-speed reversible unit would lead to major drawbacks:

a) High loss in pump-turbine efficiency in large portion of the head range
b) High Cavitations risk
c) High submergence

These main three parameters may increase the cost of project and ultimately increase the cost of per unit generation i.e. tariff.

On the basis of comparison elaborated above between three alternatives and above characteristics, variable speed machines has more advantage compared to other two alternatives therefore for Tehri PSP variable speed reversible pump-turbine machine has been selected which can operate at better efficiency in large portion of head range with less cavitations risk. It also gives an overall increase of 5-6% in energy generation for whole year.

4.0 Components of Pump turbine runner

Runner is one of the vital components of the Power plant. A typical runner assembly comprising of Crown, Band, Blades and hub. In Tehri PSP there are 9 nos of blades in the runner. These parts are made of cast steel and welded together. A stainless steel cone is welded to the runner to guide the water as it leaves the blades.

4.1 Material and other specifications

Runner Blade	ASTM A743 Grade CA6NM
Runner Crown & Band	ASTM A743 Grade CA6NM
Runner Cone	ASTM A240 UNS 41500
Nos of blades	09 nos
Runner Weight	57.83 Ton
Inertia	676 TM2

Table 4. Material specification of runner components

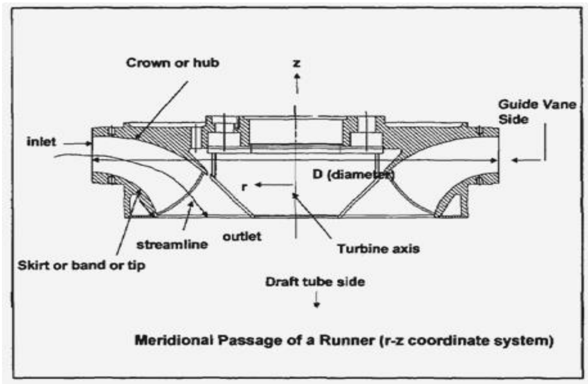

Fig.5 Components of Pump turbine Runner

4.2 Runner Blade, Crown and Band

Since the casting material of Blade, Crown and Band is quite similar, therefore the quality checks are more or less similar. However, as per the criticality of dimension and thickness of casting of blade, crown and band checks (non destructive test) at different part may be differed. Here we are considering a case of Unit#5 (It is Unit#1 of PSP, however in terminology as it is extension of Tehri HPP unit) of Tehri PSP.

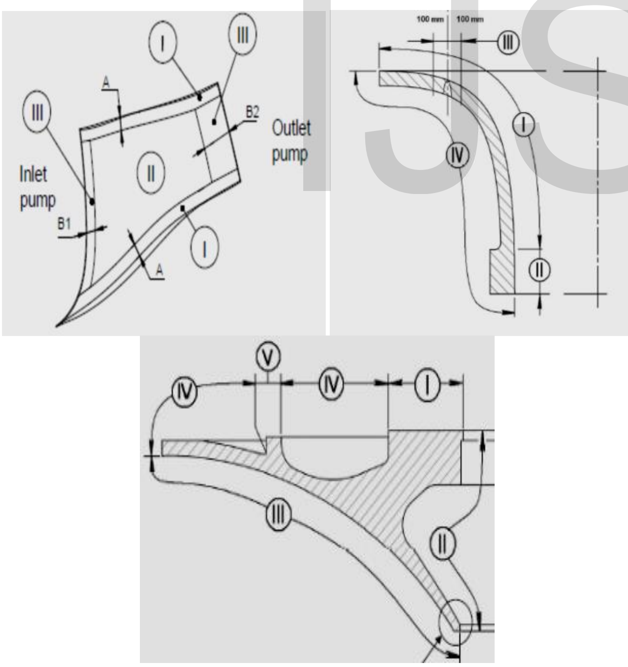

Fig-6: Runner Blade, Runner Band and Runner Crown

5.0 QUALITY Checks for the Assembled Runner after complete Fabrication and Heat Treatment Process

The following quality checks were carried out after runner fabrication (Refer Fig.7) :

NDT of weld joints after heat treatment

Dimensional inspection

Blade Pitch

- Outlet opening
- Blade Inlet and outlet angle(variation Δβ)

1. Static balancing of runner
2. Checking of coupling holes and hole positioning with templates and Surface Roughness

5.1 Non Destructive test after complete Fabrication:

Sketch Area	I		II		III
Inspection at	F	M	F	M	F
VT: Visual Test		(a)		(a)	
MT: Magnetic Particle				(b)	
UT: Ultrasonic test					
PT: Penetrant		3			

Table 5. NDT testing schedule for the fabricated runners **M: Manufacturer workshop F: Foundry Shop**

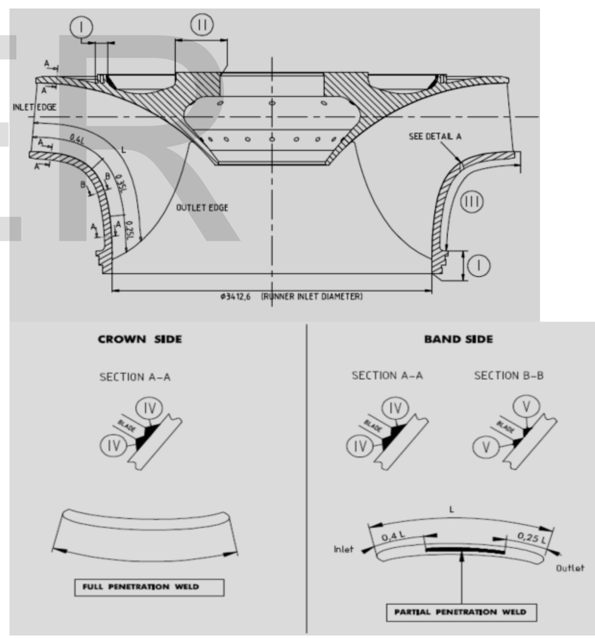

Fig-7: Pump Turbine Runner after Fabrication

5.1 Non Destructive test after complete Fabrication:

Sketch Area	I		II		III
Inspection at	F	M	F	M	F
VT: Visual Test		(a)		(a)	
MT: Magnetic Particle				(b)	
UT: Ultrasonic test					
PT: Penetrant		3			

M: Manufacturer workshop F: Foundry Shop

(a) VT: Machine surface all areas : No linear discontinuity

(b) **Area II:** MT-No linear discontinuity>1.6 mm and no nonlinear indication>3.2 mm

(c) **Area III:** MT-No linear discontinuity>3.2 mm and no nonlinear indication>4.8 mm

(d) **Area IV:** Full penetration weld section A-A (Crown Side)

100% UT as per ASME-V Article 4, Acceptance criteria: ASME VIII-Div-I- art. 12
The selection of probe shall be as per the blade thickness and geometry of weld joint
100% PT as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8

(e) **Area IV:** Partial penetration weld section A-A (Band Side)

100% PT after first pass in 316 L as per as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8
100% PT on finish joint as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8

(f) **Area V:** Partial penetration weld section B-B

100% PT after first pass as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8
100% PT on finish joint as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8
No UT

(g) **Area VI:** If necessary Band can be cut for welding access, the band will be then rebuilt with heterogeneous weld 316 L, the weld will be controlled as follows:

100% PT after first pass as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8
100% PT after 3 filling layers as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8
100% PT after end of welding as per ASME-V Article 6, Acceptance criteria: ASME VIII-Div-I- art. 8
No UT

The ultrasonic testing of weld joint (blade to crown and blade to band) was performed by using angle probe of 45, 60 and 70 degree and no recordable indication was observed .

Further, after welding the in area –IV, V and VI the PT was performed and no discontinuity was observed.

5.2 Dimensional checks after machining

Being a very complex geometry and vital component it is required to measure all the key dimension of the runner.

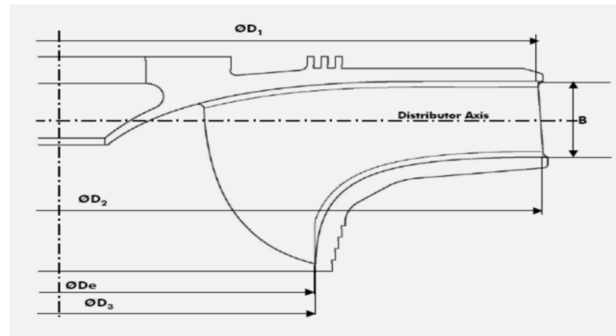

Fig-8: Machining Dimensions of Pump Turbine Runner

	Theoretical Value mm	**Average Value measured mm**	*Deviation mm*	**Average allowance**	**Individual allowance**
D_1	5026.3	5031.7	*+4.9*	+/- 8.5 mm	+/- 8.5 mm
D_2	5152.4	5155.9	*+3.5*	+/- 8.5 mm	+/- 8.5 mm
D_3	3413.2	3416.3	*+3.1*	+/- 8.5 mm	+/- 8.5 mm
B	760.6	759.7	*-0.9*	+/- 1.5 mm	+/- 2.3 mm
D_e	3412.6	3416.5	*+3.9*	+/- 8.5 mm	+/- 8.5 mm

Table 6. Measured machining dimensions of runner

D_1, D_2 and D_3 should be checked and measured before radius welding.

5.3 Hydraulic Profile Checking

Cord	Values(mm)
C1	253.5
C2	0
C3	253.5
S4	487.5
S5	780.0

Fig-9: Section of runner for the templates for hydraulic profile measurement

5.3.1 TEMPLATE METHOD

The entire templates were checked on 1:1 drawing, keeping template on the top of approved drawings and adjusting the template and it should be noted that both the template and its drawings lines shall be coincide perfectly. After template verification from the approved drawings, Pump – Turbine runner profile shall be checked by putting the template on EC1, EC2, EC3 location (outside) already marked on the runner on first day of dimensional inspection carried out on the machine. The diameters inlet and outlet pumps rae tangent to the edges of blade section (Refer Fig. 7). The templates were adjusted on the runner blade profile and shall be supported by small jack and properly leveled with help of spirit level. Check the gap between blade and template at 5 equidistance points marked on template. In case of Tehri PSP Pump-Turbine inspection the values recorded were tabulated in the below table in P1, P2…..S4, S5 columns. As per IEC recommendation maximum gap between profile and template shall be +/- 0.1% D3 i.e +/-3.4 mm.

5.3.2 LASER TRACKING METHOD

When it comes to validation of engineering values on a runner, either for single dimensions or complex profiles, the laser tracker is often useful. Measurements can be taken during and after machining for validation. The laser tracker brings accuracy measurement of complex components to an accessible level. The laser tracker also increases the capabilities of measuring various components in ways that were not possible without it, as for example checking the complex profile of a runner blade, or checking flatness of a surface on the field with great accuracy. More points can be measured than with traditional methods and scans can be performed.

5.3.3 VARIATION IN INLET AND OUTLET BLADE ANGLE

As per IEC 60193 Clause 2.2.2.2.5

Permissible maximum deviations in geometrical similarity between prototype and model pumps/pump-turbines are as-

Principal dimensions of hydraulic Passages	Prototype average value to scaled model average value
Radial impellers/runners Blade profile:	
inlet and outlet edges	±0,1 % D
remaining part of the surface	±0,2 % D
Inlet angle β2	±1°
Outlet angle β1	±1°
Inlet and outlet width	+3 % to -1 %
Maximum blade thickness	+3 % to -6 %
Inlet and outlet diameters and other impeller/runner dimensions	±0,25 % D

Table 7. Allowable tolerance in dimension of the pump turbine runner

With comparison to IEC tolerance criteria, THDCIL approved tolerance criteria, were more stringent for better quality control.

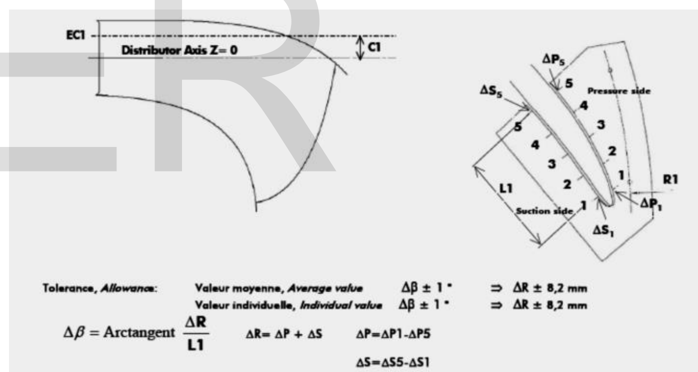

Fig-10: Measurement of outlet side pump mode section EC1

Blade no.	ΔP	ΔS	Δ*R* +/-	Δβ +/- degree	**P1**	**P2**	**P3**	**P4**	**P5**	**S1**	**S2**	**S3**	**S4**	**S5**
					Allowance +/- 0.1% D3 i.e +/-3.4 mm					Allowance +/- 0.1% D3 i.e +/-3.4 mm				
1	0	0	*0*	0	4.5	3.5	4	4	4.5	5	5	5	5	5
2	0	-0.5	*-0.5*	-0.06	5	4.5	4	4.5	5	5	5	4.5	4	4.5
3	0	0	*0*	0	5	5	5	5	5	4.5	4.5	4.5	4.5	4.5
4	-0.5	0	*-0.5*	-0.06	4.5	5	5	5	5	5	5	5	5	5
5	1	0.5	*1.5*	0.18	5	4	4	4	4	4.5	5	5	5	5
6	10	0	*0*	0	4.5	4.5	4.5	4.5	4.5	5	5	5	5	5
7	1	0	*1*	0.12	5	4	4	4	4	5.5	5	5	5.5	5.5
8	0	-0.5	*-0.5*	-0.06	5	5	5	5	5	4	4	4	4	3.5
9	-0.5	-0.5	*-1.0*	-0.12	5	5	5	5	5.5	4	4	4	3.5	3.5

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Table 8. Dimension measured in different position of the templates

In the similar manner, the Δβ can be measured at EC2, EC3 (outlet side pump mode), SC4, SC5 (Inlet side pump mode).

5.3.4 OUTLET PUMP PITCH BETWEEN TWO BLADES

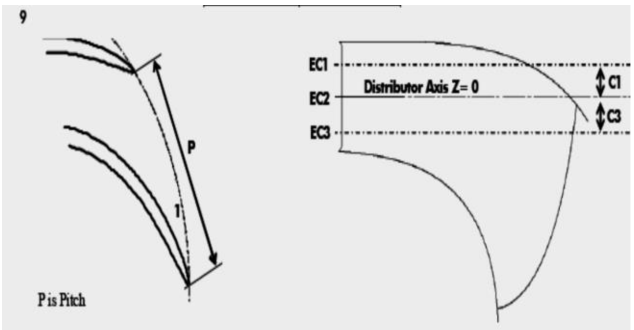
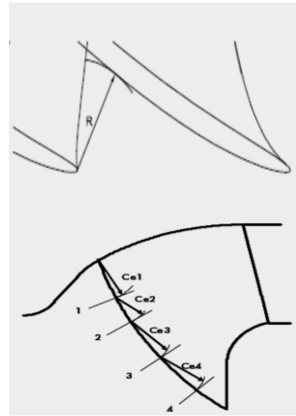


Fig-11: Measurement of Pitch of runner

Blade no.	Diameter EC1	Diameter EC2	Diameter EC3	tolerance
1/2	1727.0	1745.1	1753.7	Individual Outlet pitch +/- 17.1 mm
2/3	1729.1	1739.2	1755.3	
3/4	1728.2	1745.0	1754.7	
4/5	1722.9	1739.3	1752.1	
5/6	1727.9	1742.5	1758.5	
6/7	1735.2	1744.7	1759.4	
7/8	1724.2	1742.6	1755.2	
8/9	1724.9	1736.4	1754.8	
9/1	1723.3	1737.2	1755.7	
Average	1727.0	1741.3	1755.5	Average Outlet pitch +/-6.8 mm
Theoretical	1726.4	1740.7	1755.0	
Δmm	***0.6***	***0.6***	***0.5***	

Table 9. Dimensions of pitch measured between two blades

5.3.5 OPENING AT INLET OF THE PUMP



Cord	Values(mm)
Ce1	163.3
Ce2	375.3
Ce3	374.8
Ce4	390.2

Fig-12 Checking opening inlet pump side mode

Blade no.	1	2	3	4	Average by water passage	Tolerance
1/2	271	290	334	385	320	Individual Outlet width +5% -3%
2/3	270	290	334	385	319.8	
3/4	272	293	335	385	321.3	
4/5	272	290	334	383	319.8	
5/6	270	291	334	385	320.0	
6/7	275	294	335	386	322.5	
7/8	272	291	335	385	320.8	
8/9	273	294	336	385	321.8	
9/1	270	290	333	381	318.5	
Average	271.7	291.4	334.4	384.4		Outlet width Avg. crown +3% to -1% Outlet width Avg. Band +3% to -1%
Theoretical	271.7	291.9	333.3	382.6		
Δmm	***0***	***-0.5***	***1.1***	***1.8***		

Table 10 Dimensions of the inlet of the pump

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5.3.6 INLET PUMP THICKNESS:

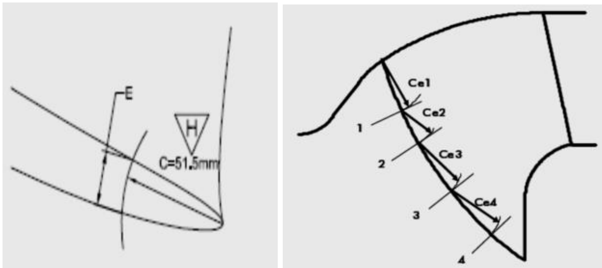

Fig-13 Measurement of Thickness inlet side pump mode

Blade no.	1	2	3	4	Average by water passage	Tolerance
1	25.7	29.4	31.0	34.2	30.1	Individual Thickness +/- 7.5%
2	26.5	28.8	32.0	34.2	30.4	
3	25.6	28.9	32.0	34.6	30.3	
4	25.3	29.4	32.0	35.1	30.5	
5	25.1	28.8	32.0	35.2	30.3	
6	26.0	29.2	31.5	33.8	30.1	
7	26.0	29.2	31.6	34.8	30.4	
8	26.0	28.4	34.8	34.8	31.0	
9	26.0	29.0	34.0	34.2	30.8	
Average	25.8	29.0	32.3	34.5		Thickness Avg. +/-7.5%
Theoretical	24.8	28.4	31.5	34.4		
∆mm	***1.0***	***0.6***	***0.8***	***0.1***		

Table 11. Inlet pump thickness

6.0 STATIC BALANCING OF RUNNER

For runner balancing, a gravity balancing machine, consists of a ball and socket system centered in the coupling bore of the runner to be balanced, is used.

A pump is injecting oil between the male and female ball and sockets in order to create an oil film enabling the part/male ball and socket assembly to swivel over the stationary female ball and socket.

A slow rotation motion is then manually imparted to the part (1 to 3 rpm). A comparator located at a machined face or diameter records the amplitude of the deviation and allows indexing of initial unbalance. The injurious moment is determined by placing a corrective mass at the highest point and on a given radius to counterbalance the deviation.

After a corrective action has been taken by removing or adding material, a new static balancing is carried out to check residual unbalance is acceptable.

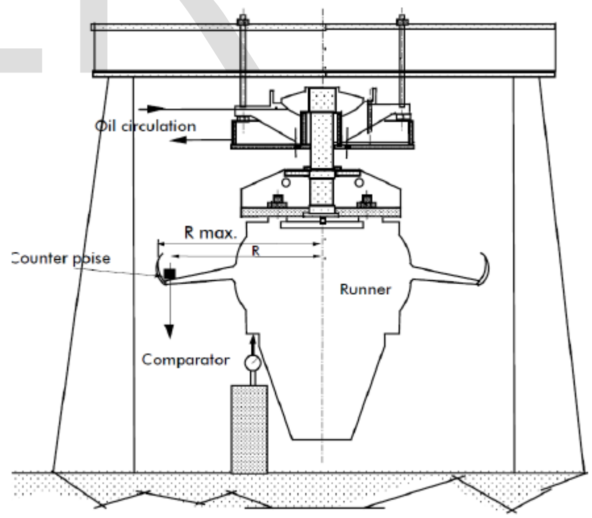

Fig-14 Static Balancing of runner

In case of Tehri PSP Pump –turbine runner, 800 gram unbalance weight was found, Runner was kept on the balancing machine with slight rotation it should move freely, there after reading of dial was checked keeping at one position but at four location during movement, reading was in points, then unbalance weight 800 g kept and again checked found very little deviation. AS per ISO 1940-1:2003(E) Guidance for balance quality grades for rotors in a constant (rigid) state for water turbine Magnitude e per. Admissible balance is 14 m.kg, whereas the residual out of balance is 1.94 m.kg. for the runner unit#5.

7.0 INSPECTION OF COUPLING FLANGES WITH TEMPLATES

In order to ascertain the Turbine shaft assembly with the Runner it is required to check the coupling bolt with the template of coupling flanges. Since runner in itself a huge assembly, therefore the proper matching of holes is necessary for the compliance of the inspection.
Position the template and put the two pins opposite side in the templates. Then we insert the third pin in any other hole. The whole assembly is checked for any clearance.

Fig-15Measurement of coupling flange with template

8.0 SURFACE FINISH

As per IEC 60193, recommended prototype surface roughness Ra (finished surfaces, eventual painting included) shall be as specified below in the Table-13

Type of machine	Component	Ra (mm)
Reaction machine	Runner/impeller blades Guide and diffuser vanes Spiral case	6.3
	stay ring (including return vanes for multi-stage machines)	12.5
	facing plates and draft tube cone	25.0

Table 12. Surface Roughness Allowances

The required surface finish of 3.2 micron was achieved at pump inlet and pump outlet portion.

9.0 CONCLUSION

Pumped storage hydropower is a proven technology that allows for better integration of renewable energy into the grid, as it enables storage of excess energy in the form of water for later use. With the technical advancements in the field of semiconductors now the fixed speed, two speeds or variable speed machines can be selected as per the requirement. The type of pump/turbine units as single speed, two speed or adjustable speed should be evaluated carefully as part of the design process, because such selection ultimately affects the size and configuration of the powerhouse and hence the overall cost of the project. Further, Pump turbine runner plays a vital role in the machine performance, as it ultimately affects the hydraulic profile at machine shaft and hence efficiency of the operation, therefore, all critical factors should be kept in mind at the time of approval of the drawings and Quality plans etc. for better quality control & performance.

However in case of large head variation over the year, the variable speed machines prove to be advantageous in overall energy generation throughout the year. As mentioned above, with variable speed machines around 5-6% of extra energy per year can be generated as compared to similar single speed machines.

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AUTHOR(S)

1. **Mr. H L Arora** is Ex.Director Technical of THDC India Ltd. He is a civil engineering graduate from Thaper Institute of Engineering & Technology and has an illustrative career spanning nearly 36 Years in the Power Sector. Out of his 36 Years of service, he spent 32 years in Himalayan Region of Uttarakhand in the execution and O&M of Hydro Projects and associated with various project activities of Hydro & Wind projects from their concept to commissioning. He has a strong background in planning, monitoring, rehabilitation, execution of large civil structures including underground works, O&M of Tehri HPP and Koteshwar HEP and has a rich experience of Quality Assurance & Dam Safety.

2. **Mr. Kunal Kishore** graduated in Mechanical Engineering from CIT, Ranchi in year 2010. He joined THDC India Limited as an Engineer Trainee in year 2012. He started his carrier from Qulaity Assurance Deptt. , Rishikesh, India where he was assigned the work of quality control aspects of electro-mechanical equipment of Tehri PSP (1000 MW), Vishnugad Pipalkoti Hydro Project (444 MW) and Dhukwan Small Hydro Project (24 MW), . He was also associated with the inspection of the Runner of (4x250MW) of Pump storage plant at GE India, Vadodara. Presently is working as a Dy. Manager.

3. **Mr. Lalit Kumar** graduated in Mechanical Engineering from G.B. Pant Engineering College, Pauri(Garhwal), India in year 2007. He has Joined THDC India Limited as an Engineer Trainee in year 2007. He started his carrier from Electro-mechanical Design Deptt. , Rishikesh, where he was assigned the work of Design and engineering aspects of electro-mechanical equipment of Koteshwar and Tehri PSP Project. In Year 2014, he was also associated with O&M work of Koetshwar HEP. In year 2016, he was also associated with the inspection of the Runner of (4x250MW) of Pump storage plant at Grenoble, France. Presently is working as a Manager in Corporate Contracts Department.

4. **Mr. Sanjay Rawat** graduated in Mechanical Engineering from G.B. Pant Engineering College, Pauri(Garhwal), India in year 2007. He has Joined THDC India Limited as an Engineer Trainee in year 2007. He started his carrier from OMS, QA & Safety Deptt. , Rishikesh, where he was assigned the work of O&M services to the Tehri and Koteshwar Project. In Year 2012, he was also associated with the commissioning work of Unit 3 and 4 of Koetshwar HEP. In year 2012, he was also associated with the Model Testing of the (4x250MW) of Pump storage plant of Tehri at Grenoble France. Presently is working as a Manager in Director (Technical) Secretariat Rishikesh