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Research Article

Comparative Analysis of Different Steel Grades for Francis Turbine Spiral Casing & Modification in Maintenance Strategy for Cavitation Prevention

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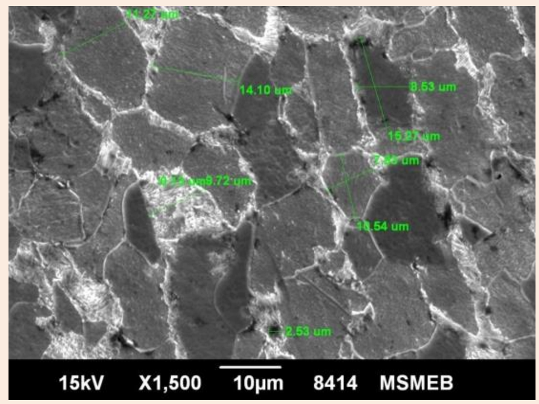
Abstract

The efficiency of hydro turbine depends upon specific shape and contour of spiral casing. Cavitation erosion leaves behind cavities or pits which affect contours of turbine, creating obstacles to smooth flow of water through the turbine & also leads to eddies formation. This leads to a loss of operating efficiency of the turbine. Ultrasonic testing can be used as condition based maintenance tool as measure of advance fault detection In Conventional ultrasonic non-destructive condition monitoring the testing personnel utilize his testing experience to interpret defects by analyzing the ultrasonic echo. Due to the coarse structure of material, the ultrasonic wave attenuate more so sometimes it gives false impression of defect & provides unreliable results. So conventional ultrasonic testing technique is subjective one & has low reliability. This research paper recommends incorporating microstructure analysis with ultrasonic testing so as to assure reliable results. In this paper comparison of pitting resistance properties between two grades of steel MS P355N & MS P275NL1 is also given so as to suggest most suitable material for manufacturing of spiral casing of hydro turbine.



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Introduction

Francis turbines [1] are the most common water turbine in use today. They can operate between large ranges of head heights (60-150m) with high efficiency. The turbine powered generator power output generally ranges from 10 to 750 megawatts as with any equipment, excessive repairs to a turbine can lead to reduction in its performance and useful operating life. Extensive weld repairs can result in runner Blade distortion and possible reduction of turbine efficiency. Also, extensive repair can cause residual stressing in the runner resulting in structural cracking at areas of high stress. So it is better to go towards condition based monitoring so that failure can be detect in earlier stages & corrective action can be taken. Thorough periodic inspection [1] of equipment using condition based maintenance program is a prerequisite to long-term reliability, and routine inspection for cavitation damage is no exception to this concept.

Ultrasonic [2, 3, 4, 5 & 6] is a highly effective non-destructive condition monitoring method which can detect even incipient faults. This will minimize production downtime, improve quality control and safety, and decrease man-hours by improving troubleshooting capabilities. So MTBF increases due to proactiveness & reduce MTTR by improving trouble shooting capabilities.

As with all other techniques ultrasonic testing also have some disadvantages. The predominant factor in attenuation measurement is the relationship between the ultrasonic wavelength and the grain size [7, 8, 9, 10 & 11]. These are related as follows:

High attenuation occurs when $\lambda < D$, Where λ= wavelength, D = grain diameter
Low attenuation occurs when $\lambda > D$
Also high attenuation is associated to high level of damage and low attenuation to low level of damage. It means if wavelength of ultrasonic wave if not properly selected than it give false impression of presence of defect in material. So if we know the grain size (Using SEM) of material to be tested than we can easily fix the suitable wavelength for testing.

Methodology

The whole methodology is divided in three parts –

1. Comparative Analysis of Different Grades of Steel for Pitting Resistance
2. Modified Maintenance Strategy for cavitation Prevention
3. Plant Load Factor Evaluation

Comparative Analysis of Different Grades of Steel for Pitting Resistance [12-15]

Mild Steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel has a relatively low tensile strength but it is cheap and malleable. In P355N the tensile strength is significantly improved by normalizing. So this material is best suited for high pressure applications like spiral casing of turbine. The density of material, $\rho = 8.03*1000\ kg/m^3$
Composition is a fundamental characteristic of stainless steel because it determines the alloy's corrosion resistance, microstructural phase balance, mechanical properties, and physical properties (**Table 1**)

Table 1 Comparison of Chemical Composition [12-14]

Material Name/ Composition	P275NL1 (1.0488)	P355N (1.0562)
C	0.16	0.18
Si	0.4	0.5
Mn	1.1	1.3
Ni	0.5	0.5
P	0.025	0.025
S	0.015	0.015
Cr	0.2	0.3
Mo	0.06	0.08
N	0.010	0.012
Nb	0.05	0.05
Ti	0.03	0.03
Al	0.02	0.02
Cu	0.3	0.3
-	Nb+Ti+V < 0.05	Nb+Ti+V < 0.12

As in case of turbine casing manufacturing large amount of material with better properties is required. Here it is clear from above tables that the material P355N has better properties comparative at lower price to MS P275NL1

Pitting Resistance Equivalent Numbers (PREN) [16-18]

Pitting resistance equivalent numbers (PREN) are a theoretical way of comparing the pitting corrosion resistance of various types of stainless steels, based on their chemical compositions. Higher PREN values indicate greater corrosion resistance. The formula for PREN is:

$$PREN = \%Cr + 3.3*\%Mo + 16*\%N \quad (1)$$

This formula suggests that molybdenum is 3.3 times more effective than chromium at improving pitting resistance, which is true within limits. Chromium must always be present in stainless steel to provide basic corrosion resistance. Molybdenum cannot provide this basic resistance, but it significantly enhances a stainless steels corrosion resistance.

Table 2 Composition & Effect [14]

Material /Composition	Effect
C	Iron is alloyed with carbon to make steel and has the effect of increasing the hardness and strength of iron.
Mn	Improve strength toughness and hardenability.
Cr	The corrosion resistance is due to the formation of a self-repairing passive layer of Chromium Oxide on the surface of the stainless steel
Mo	Improves resistance to pitting and crevice corrosion especially in chlorides and sulphur containing environments.
N	Yield strength is greatly improved when nitrogen is added to stainless steels, as is resistance to pitting corrosion.

From above tables it is clear that due to higher chromium, molybdenum & nitrogen content the material MS P355N has better pitting resistance properties as compared to MS P275NL1

Table 3 Comparison of Material Properties [12-14]

Material Name/ Properties	P275NL1	P355N
Tensile strength (MPa)	390-510	490-630
Minimum yield strength (MPa)	255	335
Min. elongation at fracture (%)	24	22
Impact energy (J) transverse (at 20 °C)	47-60	39-50
Impact energy (J) longitudinal (at 20 °C)	70-80	55-75
Density (×1000 kg/m3) (at 25 °C)	7.7-8.03	7.7-8.03
Poisson's Ratio	0.27-0.30	0.27-0.30
Elastic Modulus (GPa)	190-210	190-210

Table 4 Comparison of Cost [12 & 13]

P355N	US $650 - 1,200 / Ton
P275NL1	US $600 - 1,500 / Ton

Table 5 PREN Evaluation

Steel Grade	Cr	Mo	N	PREN
P355N	0.3	0.08	0.012	0.756
P275NL1	0.2	0.06	0.010	0.558

So it is clear from above discussion that P355N has greater pitting resistance than P275NL1.

Modified Maintenance Strategy for cavitation Prevention

For successful implementation of any maintenance strategy a suitable planning is needed. This section of paper covers a modified approach of maintenance planning so as to achieve high MTBF & low MTTR.

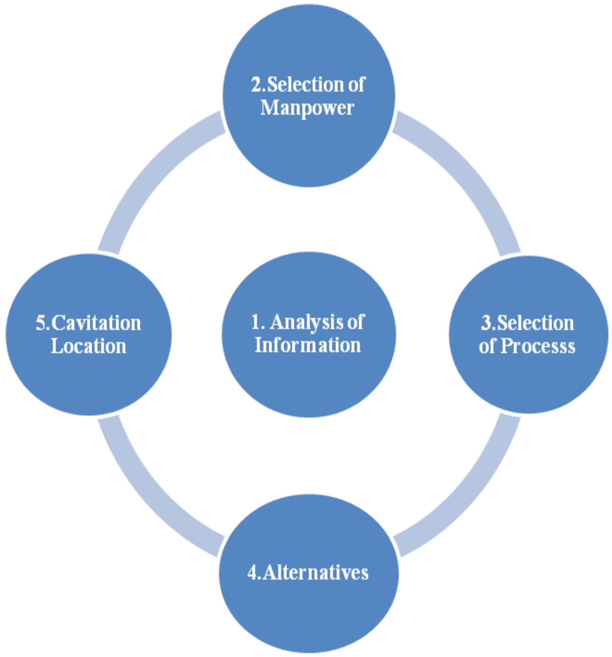

Figure 1 Maintenance Planning Approach

1. Analysis of Information: It is recommended that checklist should be filled by planner so as to ensure success of preparation of maintenance plan. If repairs are made on a more frequent basis, they may be completed within the time frame required for other maintenance work on the unit. If repairs are delayed, an extended outage or a specific outage for cavitation repairs may be necessary, resulting in reduced availability and of possible lost generation or capacity benefits.

The first decision which must be made is whether to complete repairs during the current outage or to delay repairs for a future inspection period. Repairs should not be delayed if:

- Further delay will result in added repair costs because of the accelerating rate of cavitation pitting.
- Availability of maintenance personnel

The demand to return the unit to service in as short a time as possible may make it possible to repair only areas of severe damage, leaving areas of frosting and minimal damage for the next inspection outage. Temporary repairs may also be made using non-fused materials.

2. Cavitation Location: For identifying the location of cavitation following modified approach is suggested -

a) Microstructural Images- For this sample of diameter 10 mm & length 25 mm is prepared after mirror finishing microstructural images are taken These images will be helpful in determining the size of grains.

b) Ultrasonic Evaluation- As per the grain size (D)obtained from SEM images it is recommended to decide the wavelength (λ) of ultrasonic wave so that :

$$\lambda > D$$

3. Selection of Men Power- Choose a person who is having deep & thorough knowledge in the specific field. So that quick & accurate solution of the problem can be found. If maintenance action is performed on the turbine using this modified approach than use the previous details about maintenance operation document for selecting most suitable maintenance crew.

4. Selection of Process- Choose the right process for solving problem. It would depend on the decision situation. Making a high quality decision doesn't have to be time consuming. The repair cost per kg of weld material will decrease as the amount of material increases because of fixed set-up time. This favors a longer period between repairs i.e. higher MTTR.

5. Alternatives: The more options mean greater chance of finding an excellent one. Stop generating more options when the cost and delay of further search are likely to exceed the benefit. It is recommended to identify the alternatives for unavailable spare part & back up maintenance crew. These alternatives help in replacing the some persons in existing maintenance crew & replacement of unavailable or damaged spare part so to avoid unnecessary delay.

Plant Load Factor Evaluation [19]

Plant productivity directly relies on equipment availability for production which further depends upon high MTBF & low MTTR. These two things depend upon maintenance strategy & condition of equipment. The plant productivity is measured in terms of Plant Load Factor (PLF). In the power sector load factor is a measure of the output of a power plant compared to the maximum output it could produce.

PLF = [Energy Generated during the period * 1000 * 100] / [Installed Capacity * 365 * 24] (2)

The research work reports last three year data about installed capacity & actual generation is gathered from central electricity board in period between April to March (2010 to 2013). After that PLF is evaluated for last three years.

Results & Discussions

The SEM image of specimen provides following information's-
1. It also clear from these images that the specimen is free from defects.
2. The SEM image clearly shows that the material contains pearlite & ferrite. The presence of pearlite is shown by dark areas and light regions shows presence of ferrite.
3. After carburizing the microstructural images shows presence of eutectoid carbide shown by light region & secondary carbide by dark region. Carbide formation indicates that the hardness of the material increases.
4. These images help in predicting grain size.

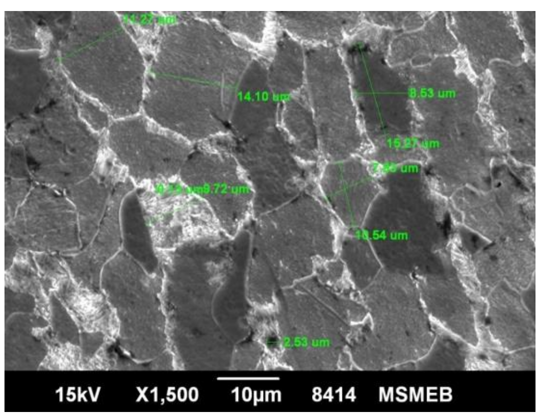

Figure 2 SEM Image of Specimen

The research work reports last three year data about installed capacity & actual generation is gathered from central electricity board in period between Aprils to March. After that PLF is evaluated for last three years.

Table 6 PLF Evaluation

S.No	Year (Apr to Mar)	Installed Capacity (MW)	Actual Generation (MU)	Average PLF % PLF = [Energy Generated during the period * 1000 * 100] / [Installed Capacity * 365 * 24]
1	2012-2013	39623.40	122263	35.22
2	2011-2012	37291.83	130400	39.91
3	2010-2011	36203.32	114300	36.04

After evaluating the PLF from above formula this PLF is utilized to convert total loss in MW to total loss in MU, then after loss in terms of evaluated.

Table 7 Productive Loss Evaluation

Year (Apr-Mar)	Planned Outage (MW)	Unplanned Outage (MW)	Total Loss (MW)	Ave PLF %	Total Loss MU= MW x 24(hrs) x 365days) x PLF/1000 x100	Avg. Cost (Paise/Kwh)	Total Loss (Crores Rs) = {Total loss in MU x Avg Cost x 10^6} / 100
2012-2013	3186.35	1028.05	4214.4	35.22	13002.5	560	72.81
2011-2012	609.2	466.25	1075.45	39.91	3759.9	548	20.60
2010-2011	615	244	859	36.04	2711.9	530	14.37
Total	4410.55	1783.3	6148.8	111.17	19474.3	1638	107.78

*1 MU = 1000000 kWh, 1 unit = 1 kWh

Total Productive Loss in MU due to cavitation (30%) = 3900.75 (2012-13) + 1127.97 (2011-12) + 813.57 (2010-11)

Total Loss in terms of rupees = {[3900.75 *560 + 1127.97 *548 + 813.57 * 530]*10^6} / 100
= Rs 32.33 Crores

If modified approach reduces the cavitation to 15 % Total Loss in terms of rupees = 1950.37 (2012-13) + 563.98 (2011-12) + 406.78 (2010-11)
= {[1950.37 *560 + 563.98 *548 + 406.78 * 530]*10^6} / 100
= Rs 16.16 Crores

Cost of Francis turbine (110MW) = Rs 11.88 Crores

Cost of Spiral Casing = Rs 1.20 Crores

From analysis of historical data from last three years for the given Francis turbine with rated power. It is very clear that total productive losses amounts to Rs 32.33 Crores due to cavitation (Maximum 30% of the total outage). This productive loss is almost equivalent to cost of three new Francis turbines of 110 MWs. This indicates the significance of early detection of cavitation & its subsequent prevention benefits.

Cost Analysis

(a) **Table 8** Cost of Testing

Testing/Equipment	Cost of Testing (Rs) / Sample in MANIT
Clock Finishing	400
Imaging Microscope	1000
SEM	3371
Ultrasonic Testing	500
Total	5271

(b) Sample Preparation Cost - Rs 400
(c) Total Cost - Rs 5371

Using modified strategy the total expenses in performing proactive maintenance task amount to Rs 5671. Expenses carried out on maintenance activities head ensures safe & reliable working maintaining the net productivity. Therefore proposed modified strategy, using ultrasonic testing as a condition based maintenance tool has immense potential in saving productive losses amounting Rs 32.329 Crores.

Conclusion

In traditional ultrasonic non-destructive testing (NDT), according to the ultrasonic echo, the testing personnel can only judge internal defects by native experience. Due to the material coarse structure, this produces qualitative assessment as well as, in occasions, unreliable results. The traditional inspection method is too subjective, the inspection reliability and efficiency are low. So to enhance the reliability of ultrasonic testing it is necessary to decide the appropriate ultrasonic wavelength by using grain size.

It is clear that material MS P355N is better choice than MS P275NL1 in terms pitting resistance for turbine spiral casing manufacturing. It is also clear that if cavitation is detected at early stages than it will save lot of money.

In proposed modified strategy expenses for proactive maintenance task amounts to Rs 5371 ensuring early detection of cavitation which if occurs amounts 30 % of total outage productive losses (Rs 32.33 Crores).

The proposed modified strategy has immense potential in reducing the productivity losses equivalent to cost of three new Francis turbine of 110 MW.

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