POWER GENXT

Revised Edition

"India's Mission on Advanced Ultra Supercritical Technology for Thermal Power Plant"

NEED
National Energy Excellence Drive
2018

Engineers' Welfare Forum
WBPDCL
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ENGINEERS' WELFARE FORUM

THE WEST BENGAL POWER DEVELOPMENT CORPORATION LIMITED

7
VOLUME

GO GREEN :: SAVE ENVIRONMENT

7th National Seminar of EWF at Swabhumi, Kolkata on 04.11.2018

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Message

The concept of supercritical technology was first introduced in India by the planning commission in its Integrated Energy Policy Report 2006. Consequently, country adopted the supercritical and then ultra-supercritical technology to improve the efficiency of coal power plants. And recently, the Ministry of Science & Technology announced a National Mission on advanced ultra-supercritical technologies for coal utilization efficiently and greenly.

I am very much glad and proud that *"Engineers' Welfare Forum, WBPDCL"*, one and only one registered (Regd. No. S/1L/74829) under the West Bengal Society Registration Act. 1961 and recognized (by **WBPDCL** Vide their letter No: PDCL/CORP/HR/305/1495 dated: 03-03-2012) association formed by the engineers of West Bengal's Premier Power Generating Company, *"The West Bengal Power Development Corporation Limited"* has organized the 7ᵗʰ National Seminar on **"India's Mission on Advanced Ultra Supercritical Technology for Thermal Power Plants"** on *4ᵗʰ November 2018* at *Swabhumi Rang Manch, Kolkata - 700 054.*

Currently, the estimated carbon dioxide pollution from coal-based power plants in the country is 38%. The AUSC project is estimated to reduce this carbon dioxide emission by 20% at source. Also, the power plant based on AUSC technology will reduce coal consumption by 20% in comparison to a sub-critical plant and by 11 percent compared to super critical plant. Furthermore, the AUSC operating efficiency is expected to be above 50% which is much higher than sub-critical and super critical technology. Hence, the technology would lead to capital cost savings.

This transition is the burning issue for the mankind. As an Indian Citizen, fruitful thinking about this matter and its implementation is the prime task of the Engineers and Technologists attached to the different power sector of India as well as in abroad. This seminar will help to create a platform for knowledge shearing among the well experienced engineers of different power sectors.

On the same auspicious day **Engineers' Welfare Forum, WBPDCL** will publish their annual technical journal **"POWER GENXT, Vol-7"** and Bi-annual Bulletin **"VISION(Vol-4)"** which will also be the knowledge shearing platform for the Engineers.

I extend my best wishes to all the Members i.e. my brothers and sisters, of the forum, the participants of the seminar, the different organizations who helps the forum to organize the seminar, the co-worker and wish the seminar a grand success.

(MANOJIT KUMAR BASAK)

SAVE ENERGY :: PRODUCE GREEN :: SAVE COUNTRY :: SAVE UNIVERSE

Development of Welding Technology for Boiler Tubes and Turbine Rotors of Indian AUSC Thermal Power Plant

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ABSTRACT

As a national mission program, Research Organizations and Industries are working together for the development of new materials, fabrication technology, designing and construction of Indian Advanced Ultra Super Critical (AUSC) thermal power plant of 800 MW capacity with steam parameters 710C/720C/310 bar. Indigenously developed Alloy 617M (a chemistry control variant of Alloy 617) and 304HCu SS are materials of choice for AUSC boiler tubes. The HP and IP rotors for AUSC plant are welded rotors made up of two different materials i.e. 10%Cr ferritic-martensitic steel and nickel-base Alloy 617M. Welding procedure has been developed and qualified for similar and dissimilar metal welding of Alloy 617M and 304HCu SS boiler tubes. For welded turbine rotors, welding procedure and post weld heat treatment has been optimized for dissimilar metal welding of 10%Cr steel to Alloy 617M using hot-wire narrow-gap TIG welding process, and mock-up weld joints are qualified as per ASME Section IX requirements.

KEYWORDS: 10%Cr steel; Alloy 617M; 304HCu SS; TIG Welding; Welded rotor; Boiler Tube.

1. INTRODUCTION

Research and Development on coal-fired thermal power plants with higher thermal efficiency has been taken up by advanced countries for meeting the large requirement of electricity and to reduce the emission of CO_2, SO_x and other environmentally hazardous gases [1]. Towards this, India is aiming to indigenously develop materials and fabrication technologies, and to design and build an 800 MWe capacity Advanced Ultra Supercritical (AUSC) plant with steam parameters of 710°C/720°C/310 bar to achieve high efficiency (~46%). With the promotion of steam parameters to AUSC level, high temperature materials with improved creep strength, steam corrosion and oxidation resistance such as advanced austenitic heat resistant steels and Ni-base superalloys are required. Austenitic stainless steel (SS) 304HCu and nickel-base Alloy 617M (a chemistry control variant of Alloy 617) are the candidate boiler tube materials for AUSC plants. For the first time in India, the indigenous development of 304HCu SS seamless tubes (52 mm OD, 9.5 mm WT) and Alloy 617M

seamless tubes (52 mm OD, 11.9 mm WT) has been successfully developed by IGCAR Kalpakkam in collaboration with industrial partners, MIDHANI Hyderabad and NFC Hyderabad meeting the international standards [2].

Alloy 617M, and 10%Cr ferritic-martensitic steel are candidate rotor materials under consideration for steam turbine of India Advanced Ultra Super Critical (AUSC) coal fired power plants [3-4]. 10% Cr steel is used for section of the rotor subjected to maximum temperature up to 580C. While, Alloy 617M is considered for high temperature section of the rotor above 600C and maximum up to 720C [4]. Hence, there is a dissimilar metal welding (DMW) between 10% Cr steel rotor parts to Alloy 617M rotor parts [4-5]. This DMW will be executed by hot-wire narrow-gap TIG (NG-TIG) welding process using Alloy 617 filler (ERNiCrCoMo-1) wire. Manufacturing of welded rotor meeting the required mechanical properties and joint integrity is a technologically challenging task. Most importantly, optimization of methodologies for welding and post weld heat treatment (PWHT) and any other heat treatment associated in fabrication of welded rotor is very crucial owing to its large size, weight and cost. In-house NG-TIG welding facility has been established at IGCAR, Kalpakkam to develop the welding procedure for joining of thick components for AUSC Project, fission and fusion reactor programs. The present paper discus the welding procedure developed for: (i) DMW of 10Cr steel to Alloy 617M using NG-TIG welding machine at IGCAR, and (ii) similar and dissimilar metal welding of 304HCu SS and Alloy 617M boiler tubes.

2. Narrow-Gap TIG Welding of Turbine Rotor

Narrow-Gap welding also known as narrow-groove welding is an advanced technique for higher productivity in the manufacture of thick-walled components. This welding technique uses joint preparation with small included angle (typically 2-20) which requires less volume of weld metal and hence less welding time and economical. Narrow-Gap technique has been used for various welding processes such as Submerged Arc Welding (SAW), Gas Metal Arc Welding (GMAW), Tungsten Inert Gas (TIG) welding. Because of narrow-groove and limited accessibility to the joint root, specialized equipments are required to carry out the welding. NG-TIG welding process is used in thick section welding of nuclear and thermal power plant components [6-7].

To develop the dissimilar metal welding procedure, a mock-up welding was planned using 400 mm diameter 10Cr steel and Alloy 617M forgings. The welding procedure involves buttering/weld overlaying of 10Cr steel using ERNiCrCoMo-1 followed by post weld heat treatment (PWHT) and subsequent welding of weld overlay deposit with Alloy 617M part by NG-TIG welding process. The chemical composition and mechanical properties of 10Cr steel and Alloy 617M forgings, and Alloy 617 filler wire used are given in Table 1. Figure 1 shows hot wire NG-TIG

welding machine at IGCAR with column and boom arrangement to manipulate the TIG torch for linear welding of plate, and circular welding of pipe using Tilt Table Positioner-Rotator.
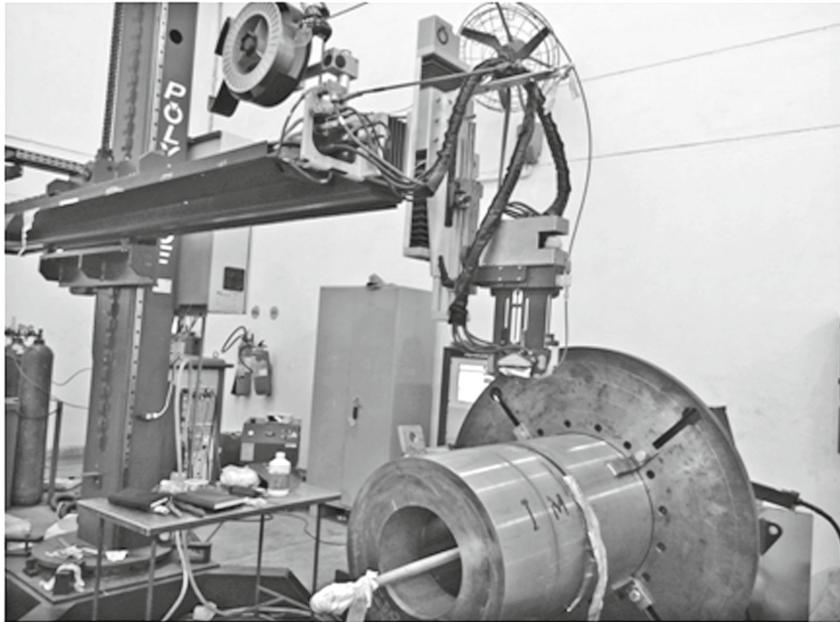

Fig. 1: NG-TIG Welding Machine at IGCAR

Table 1: *Chemical composition and mechanical properties (at RT) of 10Cr steel forging, Alloy 617M forging and Alloy 617 filler wire*

10 % Cr Steel Forging													
Cr	Mo	W	V	Nb	Ni	C	N	Mn	Si	P	S	Al	Fe
10.56	1.07	0.98	0.2	0.02	0.77	0.123	0.046	0.42	0.024	0.005	0.002	0.005	Bal.
0.2% YS (MPa)		UTS (MPa)		% Elongation (5d)			% Reduction in Area				Impact Strength (J)		
770-779		894-902		17-18			59-62				56-61		
Alloy 617M Forging													
Cr	Fe	Mn	Mo	Co	Al	C	Cu	B	Si	S	N	Ti	Ni
22.9	0.38	0.001	8.39	12.32	0.81	0.062	0.019	0.003	0.11	0.002	0.0046	0.428	Bal.
0.2% YS (MPa)			UTS (MPa)				% Elongation (5d)						
414			726				52.6						
Alloy 617 Filler Wire													
Cr	Fe	Mn	Mo	Co	Al	C	Cu	B	Si	S	N	Ti	Ni
22.30	0.8	0.42	8.7	11.30	1.3	0.1	0.1	-	0.32	0.002	-	0.42	Bal.

Buttering of 400 mm diameter 10Cr steel was carried out by hot-wire TIG welding process using ERNiCrCoMo-1 filler wire. Preheating and inter-pass temperature of around 200C was maintained during buttering operation using induction heating system. The buttering of 10Cr steel forging using ERNiCrCoMo-1 has been successfully carried out and deposited to the required height of 33 mm towards job centre. Figure 2 shows 10Cr steel forging with weld overlaying of ERNiCrCoMo-1. The weld overlaying was qualified by liquid penetrant test after the final pass and found to be free from surface defects. The 10Cr steel buttering piece was subjected to PWHT at 670C for 10 hrs.

Fig.2: 10Cr steel forging buttering with ERNiCrCoMo-1

For NG-TIG welding, 10Cr steel buttering piece and Alloy 617M solid forging were machine fabricated into hollow forging (400 mm 95 mm wall thickness 200 mm length) and edge prepared for NG-TIG welding with groove angle of 6. NG-TIG welding was carried out between Alloy 617 buttering layer and Alloy 617M part in 1G position using ERNiCrCoMo-1 filler wire of 0.8 mm diameter (Fig.3). During welding, inter-pass temperature was maintained below 150C. Welding of 95 mm thick weld groove was completed by 50 weld passes. After completion of welding, the weld bead was qualified by liquid penetrant test and was found to be acceptable (Fig. 4). The volumetric inspection of the thick dissimilar weld joint by an ultrasonic phased array methodology with beam focusing at different depths confirmed that the weld joint is free from any defect equivalent to or larger than 2 mm side drill hole (SDH) at any location in the buttering layer or weld volume. The weld joints passed side bend test and cross-weld tension test as per ASME Section IX requirement.
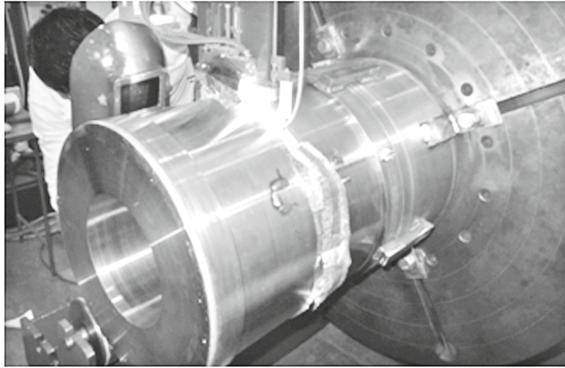
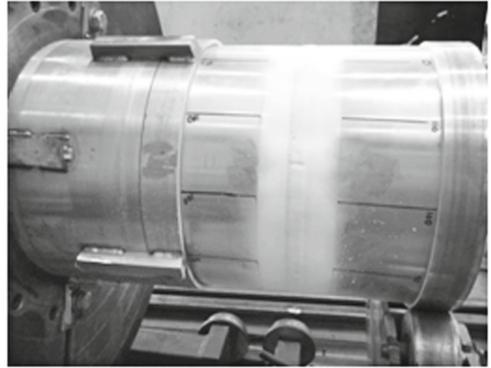**Fig.3**: 10Cr steel/Alloy 617M DMW in progress

Fig.4: LPT after final weld pass of 400 mm diameter 10Cr steel/ Alloy 617M weld joint

3. Similar and Dissimilar Welding of 304HCu SS and Alloy 617M Boiler Tubes

Welding procedures are developed for similar and dissimilar weld joints of 304HCu SS tube (Ø 52 mm 9.5 mm wall thickness) and Alloy 617M tube (Ø 52 mm 11.9 mm wall thickness). Welding of 304HCu SS tube was carried out using matching filler wire ER304HCu SS. The ER304HCu was with higher Ni and Mn compared to 304HCu SS base material. Similar welding of Alloy 617M and dissimilar metal welding of Alloy 617M/304HCu SS was carried out using ERNiCrCoMo-1(Inconel 617). The chemical composition of 304HCu SS and Alloy 617M tube materials and welding consumables is given in Table-2. Multi-pass TIG welding was carried out using single-V joint geometry by a qualified welder in a systematic way and procedures were qualified by carrying out X-ray radiography and mechanical tests (tension and bend) of the weld joints as per ASME Section IX. Lack of fluidity of nickel base filler wires was a challenge to obtain full penetration and crack free joints. Welding parameters and groove angle was optimized by doing few welding trials on mock-up pieces to obtain radiographically qualified joints. Figures 5 & 6 show photograph of Alloy 617M boiler tube weld joint and its bend tested specimens respectively. Table 3 shows cross-weld tensile properties of similar and dissimilar weld joints of 304HCu SS and Alloy 617M tube joints. All the three type of welded tube joints passed bend test and tension test as per ASME Section IX requirements. Based on this approved welding procedures, subsequently, total 125 numbers of similar and dissimilar weld joints (100 nos. similar and 25 nos. dissimilar) were fabricated. All the weld joints were qualified by liquid penetrant examination, X-ray radiography.

Table 2: Chemical composition of 304HCu SS and Alloy 617M tube materials, and welding filler wires (wt. %)

| Elements	Base Metal Tubes		Welding Consumable s	
	304HCu	Alloy 617M	304H Cu	ERNi617 ERNiCrCoMo -1
Carbon	0.07 - 0.13	0.05 - 0.08	0.04 - 0.08	0.05 - 0.15
Chromium	17.0 - 19.0	21.0 - 23.0	19.5 - 22.0	20.0 - 24.0
Nickel	8.0 - 10.0	balance	9.0 - 11.0	balance
Molybdenum	-	8.0 - 10.0	0.5 max	8.0 - 10.0
Manganese	1.0 max	0.3 max	3.0 max	1.0 max
Silicon	0.3 max	0.3 max	0.3 - 0.65	1.0 max
Sulphur	0.01 max	0.008 max	0.03 max	0.015 max
Phosphorous	0.03 max	-	0.03 max	0.03 max
Nitrogen	0.07 - 0.12	0.05 max	0.1 - 0.16	-
Cobalt	-	11.0 - 13.0	-	10.0 - 15.0
Copper	2.5 - 3.5	0.5 max	3.01	0.5 max
Niobium	0.3 - 0.6	-	0.4 max	-
Titanium	-	0.3 - 0.5	-	0.6 max
Aluminium	0.003 - 0.03	0.8 - 1.3	0.03 max	0.8 - 1.5
Boron	0.002 - 0.006	0.002 - 0.005	0.01 max	-
Iron	balance	1.5 max	balance	3.0 max
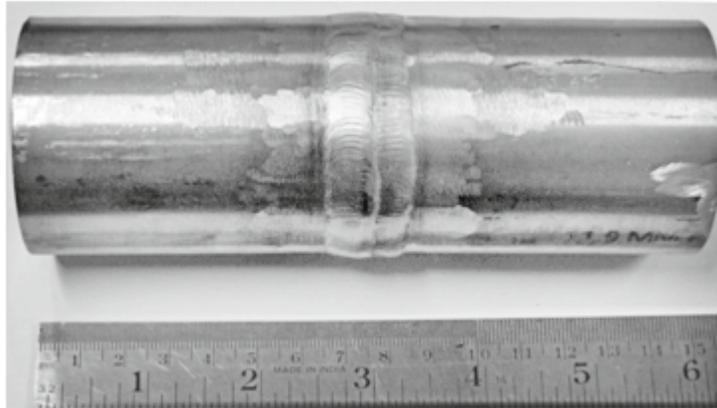
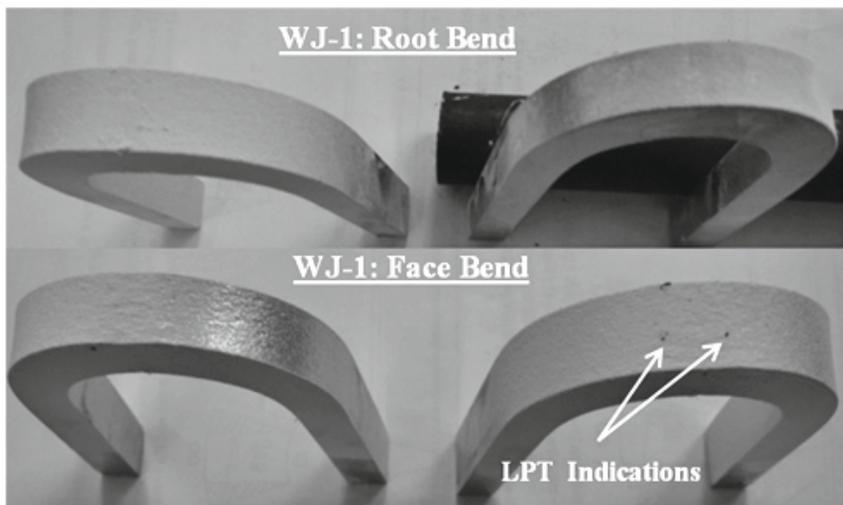**Fig. 4:** Photograph of a typical Alloy 617M welded tube

Fig. 5: Photograph of bend tested specimens of Alloy 617M welded tube

Table 3: Tensile properties cross-weld similar and dissimilar tube joints

Tensile Properties of 304HCu SS & Alloy 617M Weld Joints				
Materials/Weld Joints	Filler wire	UTS(MPa)	Failure Location	Remarks
304HCu SS Weld Joint	ER304HCu	694	Weld	Met ASME section IX and are Acceptable
Alloy 617M Weld Joint	ERNiCrCoMo - 1	798	BM/WM	
304HCu/Alloy 617 M DMW	ERNiCrCoMo - 1	706	304HCu Base Metal	

4. CONCLUSION

1. The dissimilar metal welding of 10%Cr steel to Alloy 617M using ERNiCrCoMo-1 required for Indian AUSC welded rotor application has been successfully demonstrated using hot-wire NG-TIG welding process. Mock-up weld joint of 95 mm weld thickness passed in LPT and UT. The weld joint met the tensile properties and bend test requirement as per ASME Section IX. Welding procedure specification including weld groove design and PWHT is finalised for fabrication of welded turbine rotors for AUSC project.

2. Welding procedure is established for similar and dissimilar metal welding of 304HCu SS and Alloy 617M boiler tubes for AUSC program.

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Design and Development of AUSC Steam Turbine Rotor

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Abstract: Power producers across the world are vying for higher steam parameters in fossil fueled power plants to increase efficiency and reduce carbon emissions. Ultra Super Critical power plants operating in the range of 620-650°C, although limited in numbers, cater to this demand of efficiency to a large extent. In pursuit of further efficiency improvement, the latest dream of power equipment manufacturers is to design, develop and operate a power plant with still higher steam parameters above 700°C known as Advanced Ultra Super Critical (AUSC) parameters.

In India, fossil fuel is the mainstay of power sector industry and expected to remain so in future also. Taking lead from the research being pursued world over, India has also joined the League of Nations working towards development of AUSC technology. Three prominent technical organizations of the country Indira Gandhi Center for Atomic Research (IGCAR), Bharat Heavy Electricals Ltd. (BHEL) and National Thermal Power Corporation Ltd. (NTPC) have joined hands to develop AUSC power plant indigenously, partially funded by Govt. of India.

High Pressure (HP) and Intermediate Pressure (IP) turbine rotors are most critical components of AUSC turbine. As these rotors are subjected to elevated temperature conditions more than 700 $^{\circ}$C, use of nickel based alloys become mandatory. The present paper describes the approach adopted by BHEL in design of IP rotor to mitigate different failure modes.

Keywords: AUSC, IP rotor, Steam Turbine

1. Introduction

In a fossil fuel power plant steam turbine rotors are most critical components and are subjected to severe operating conditions under transient and steady state loading. As these rotors operate under dynamic conditions, any failure in these can be catastrophic in nature.

Since, the design codes like ASME, RCC-MR, PD-5500 etc. are directly not applicable for rotating equipment of steam turbines; most of the original equipment manufacturers (OEMs) have their own proprietary design rules.

Indian AUSC program is targeting to design steam turbine of 800MW capacity. The steam parameters are 31MPa/710°C/720°C. Intermediate Pressure (IP) turbine section is subjected to Hot Reheat Steam of 720°C. Hence, IP rotor of AUSC steam turbine is one of the most critical components among others.

Based upon five decades of experience in design and manufacturing of Power Plant equipment, BHEL has made own design rules taking guidance from design codes and existing practices for designing AUSC IP rotor. Advanced FE tools as well as classical formulations were used in combinations to safeguard the design against various failure conditions described further.

2. Material Selection

Conventional thermal power plants using Ferritic steels for turbine components mostly operate up to maximum temperature of 610°C. Above this temperature, High Chrome Ferritic steels loose the requisite mechanical strength. Hence, for AUSC temperature application, candidate materials require superior mechanical properties and stable microstructure around 700°C.

Due to time limitations, for optimizing procurement and development cost and easy material characterization, only coded materials were considered for Indian AUSC program. With these considerations, Alloy 617 (M) having controlled chemical composition of Alloy 617 was selected for IP and HP rotors in the zone of temperature from 560°C to 720°C. Alloy 617 is having fairly good commercial availability and material properties from the standards could be used to start the design process. For temperature lower than 560°C, high Chrome steels would be used as for existing sets.

3. Design Philosophy

The IP rotor for Indian AUSC program is a bimetallic rotor consisting of Alloy 617 (M) and conventional High Chrome Ferritic steels having a weld joint at suitable location in the blade flow path. Experiments are underway to qualify the dissimilar rotor weld design. Hence, mechanical design of weld zone is not a part of this paper. Design of any steam turbine rotor is broadly governed by three kinds of loads onto the rotor:-

    i.   Inertia loads, primarily centrifugal loads and bending loads
    ii.   Torsional loads.
    iii. Thermal loads due to temperature gradients inside the rotor.

Out of the above loading conditions, the first two are primary loads and the last one is secondary in nature. Primary loads are responsible mainly for creep life consumption whereas Thermal loads (secondary) are self-regulating and cause low cycle fatigue (LCF). Both these loads in combination reduce the operating life of the rotor substantially.

These above mentioned loads give rise to different kind of failure mechanisms in steam turbine rotor. The major failure mechanisms in steam turbine rotor include:-

- Gross Section Failure and Burst Excessive Bulk Deformation.
- Creep rupture
- Creep deformation
- Low Cycle Fatigue (LCF),
- Creep-Fatigue Interaction (CFI)
- High Cycle Fatigue (HCF)
- Fatigue and creep crack growth
- Rotordynamics

The generalized procedure of stress characterization using "Design by Analysis

(DBA)" chapter of ASME-BPVC codes was adapted as per need so as to effectively use commercial Finite Element Analysis software ANSYS..

4. Analysis Methodology

The design of IP rotor is based upon blade flow-path and construction requirements The IP rotor for AUSC design is a drum type construction with bi-axial flow having a central groove. Overall length is approximately seven meter. Rotor diameter increases from minimum at inlet groove till the end of flow path (Fig-1). The rotor is evaluated against all the failure criteria as described before.

During FE based thermal analysis of IP rotor, Convective Heat transfer Coefficients (HTC) between steam and rotor play a very crucial role. These HTCs are governed by steam pressure and steam velocity and thus by steam flow. Determination of these HTCs for the flow passage in steam turbines involves CFD analysis and experimentation[1].

Mechanical analysis of IP rotor for AUSC turbine can be divided into two major categories:

I.   Stress analysis for basic failure modes (rotor body stresses)

II. Stress analysis for complex failure modes (LCF, Creep Fatigue Interaction etc.)

Overall analysis of the rotor was based on linear elastic stress analysis methodology. Neuberisation principle was used in conjunction with the elastic stress analysis results for the estimation of total strains wherever necessary.
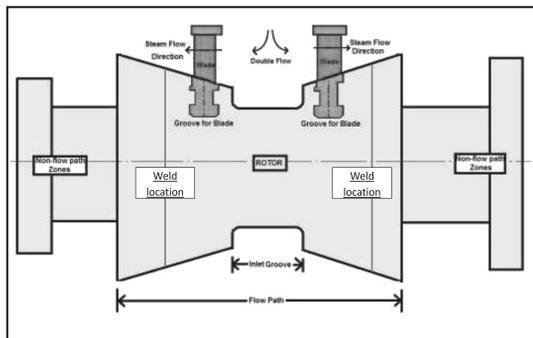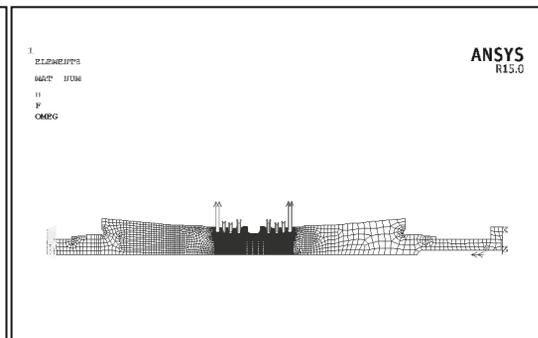

Fig-1: Schematic of IP Rotor

Fig-2: FE Model of IP Rotor

4.1 Rotor Body Stresses

Von Mises failure theory is widely accepted as the failure theory for ductile materials; however certain rotor body stress failure modes are primarily governed by radial and tangential principal stresses.

Overspeed (above rated rpm) events for short duration does take place during operation of steam turbines occasionally. Hence, design for over speeds at elevated temperature is essential.

Keeping in mind the above aspects, several failure criterion were considered. Material allowable is based on legacy design practices, probability of an event occurrence and magnitude of the event.

An axisymmetric model of IP rotor with 8-noded quadratic elements was generated for evaluation of body stresses (Fig-2).

The bulk temperature of steam along with HTCs for steady state operation was used for establishment of steady state temperature distribution in the IP rotor (Fig-3).

Rotor body stresses (Hoop and Radial) under nominal operating conditions were evaluated using steady state temperatures and centrifugal loads due to rotation (Fig-4 & 5). These stresses at 3000 rpm were used for evaluation of stresses at any other rotation speed as they are directly proportional to the square of rotation speed.
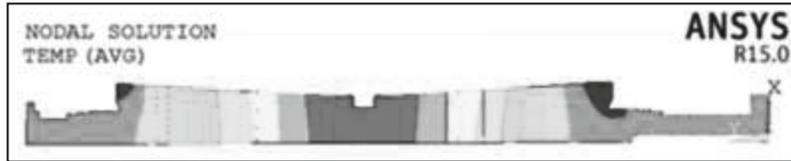
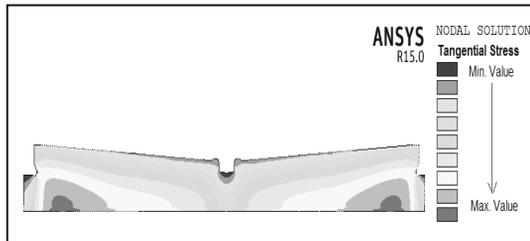
Fig-3: Steady State Temperature Distribution

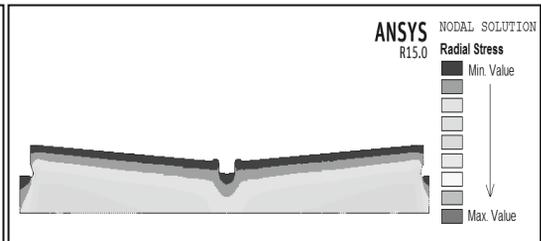Fig-4: Hoop/Tangential Stress Distribution   Fig-5: Radial Stress Distribution

Under abnormal operating conditions due to over speed, to avoid ductile burst in IP rotor the area weighted hoop mean stress and radial stress were considered. These stresses should be sufficiently below the tensile strength of rotor material at elevated temperature at 180% of rated speed [2].

At over speed condition of 120%, it is ensured that excessive bulk yielding should be avoided. For this purpose, the failure criterion is weighted average hoop stress should be below the allowable based on min. yield strength at operating temperature [3].

The rotor is balanced at 125% over speed conditions at manufacturing works. To avoid yielding during balancing, the stresses were evaluated at 125% over speed at room temperature and compared with the allowable limit based on min yield strength [3].

Sustained long term operation of rotor at rated speed and elevated temperature for life more than 100,000 hours requires design for creep. For design against creep failure it is necessary to avoid average tangential stress or stage wise average radial stress at any radius exceeding the creep rupture strength based material allowable. Appropriate design modifications had to be made to satisfy this criterion [3].

Torsional shear stresses at rated power also need to be evaluated. The most critical location for torsional shear stress to avoid creep failure is inlet zone of the IP rotor. Here, from the rated torque conditions, torsional shear stress is calculated. Equivalent Von Mises stress based upon shear stress is then compared against creep rupture based allowable. Similarly torsional stresses due to transient electrical fault condition like short circuiting, out of phase synchronization etc. were calculated and compared with allowable stress based upon shear yield or shear strength [3].

We were able to successfully design the rotor for all the above mentioned failure modes for time-dependent and time-independent material allowable limits.

4.2 High Cycle Fatigue

Steam turbine rotors are heavy weight components supported on bearings during operation at 3000 rpm. Gravity sag of these rotors cause alternating stresses with each rotation. These stresses combined with steady state stress (mean stress) result in high cycle fatigue (HCF). AUSC IP rotor is evaluated for HCF using Modified Goodman Criterion at critical locations like inlet groove, step change in diameter outside flow path where stress concentration effects are present.

Von Mises steady stress is calculated from principal stresses at critical location, which forms the mean stress component. At the same location alternating component stress which is bending in nature is also evaluated. Stress concentration factors in shafts are calculated using Peterson's formulations [4].

Nickel based alloys like Alloy 617 (M), do not have clearly defined endurance limit as in the case of Ferritic steels. Hence, fatigue limit corresponding to 10^8 cycles was taken as the endurance limit for Alloy 617 (M) [5]. Endurance limit modification factors were applied as appropriate. Fillets were designed and validated using the above procedure.

4.3 Low Cycle Fatigue (LCF):

Steam temperatures inside the turbine vary when there is a change in the operating condition such as start-up, loading, shut down etc., and fluctuations in inlet steam parameters.

Change in steam temperature cause change in metal temperature of the turbine components. This, in turn, produces free or constrained thermal expansion. Free thermal expansion shows itself as a change in length and distortion, whereas constrained thermal expansion causes thermal stressing.

Transient thermal stresses depend heavily upon material properties along with the HTCs. Alloy617 (M) is having low thermal diffusivity and high coefficient of thermal expansion compared to Ferritic Steels (Fig 6&7). This result in relatively high thermal gradients and hence high thermal stress in IP rotor of AUSC design compared to existing Ferritic rotors.

Not only are the physical properties of Alloy617 (M) material inferior but also Low Cycle Fatigue properties i.e. strain range vs. number of cycles to failure are inferior compared to Ferritic Steels (Fig-8). Hence, start-up is modified accordingly.
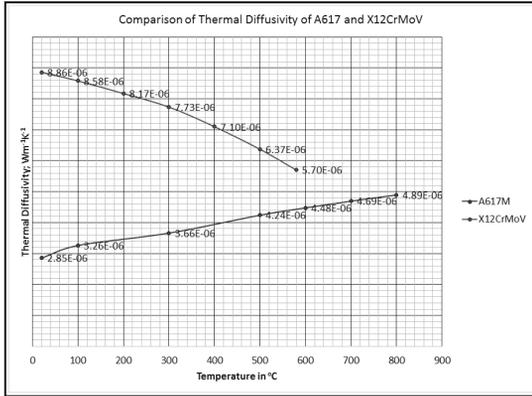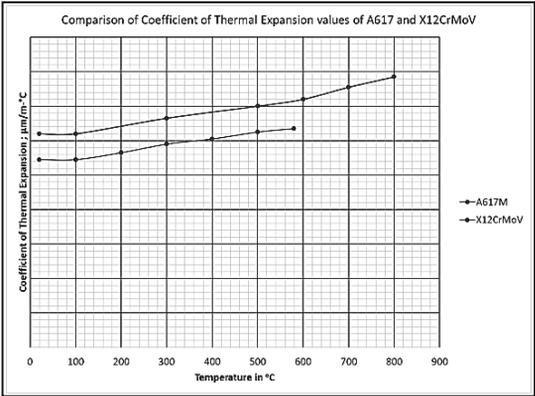
Fig-6: Thermal Diffusivity Chart   Fig-7: Coefficient of Thermal Exp. Chart

LCF analysis of IP rotor was carried out using Transient Thermo Mechanical Finite Element analysis. An eight node 2-D axisymmetric model was used for this analysis (Fig-9). Blade centrifugal loads were directly applied at the load bearing faces of blade grooves. Only the most severely loaded blade grooves were considered for analysis purpose. The results at the surface and core were studied at these critical locations along with inlet groove.

Time history of stresses at all the critical locations during start-up process was studied. Von Mises equivalent strains were used to take care of multi axial loading. Linear elastic analysis was carried out and plastic strains were evaluated using Neuberisation process. Fig-10 shows the result of peak Von Mises transient equivalent stresses during the cold start using the above approach. This analysis was performed for all the three kind of start-up viz. Cold, Warm and Hot starts. LCF design curve of Alloy 617 given in the draft code case of ASME at maximum temperature point in the transient cycle was used for life evaluation [6].

Cumulative LCF damage was then assessed for total number of cycles during the entire life of turbine. The results were found satisfactory
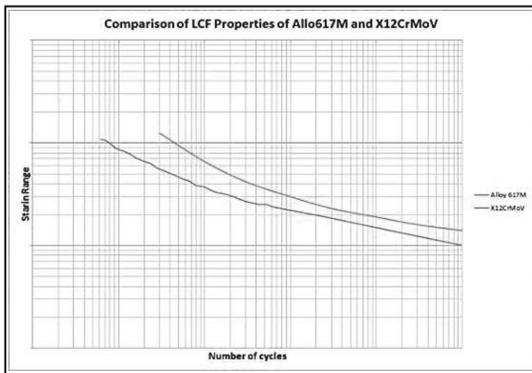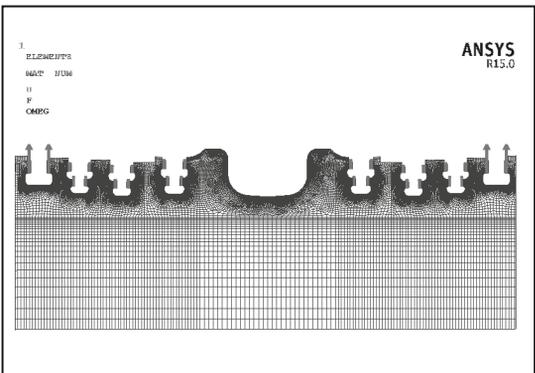

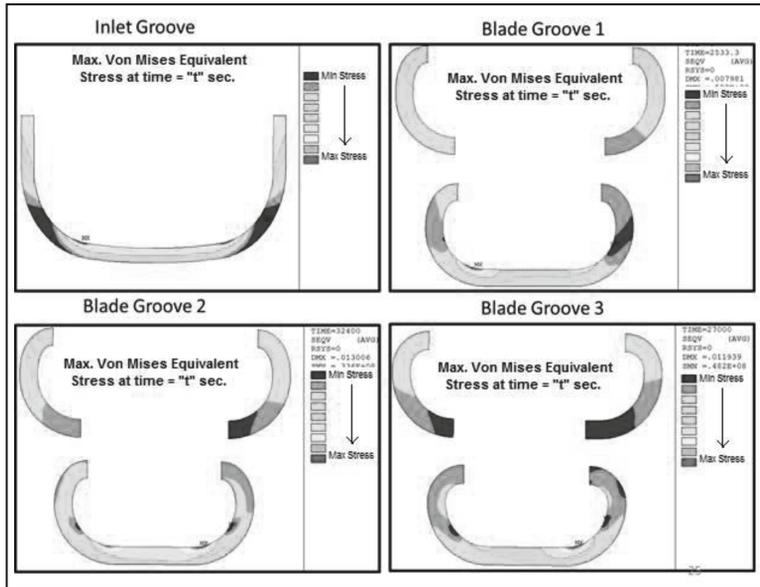Fig-8: LCF Curve   Fig-9: FE Model for LCF Evaluation

Fig-10: Von Mises Stress Distribution at Critical Locations

4.4. Creep Fatigue Interaction and Cumulative Damage:

Life of steam turbine rotor is consumed both by creep damage as well as Low Cycle Fatigue damage. Linear Damage Accumulation (LDA) rule is used for combining creep and fatigue damage

Cumulative Fatigue damage is evaluated as per modified Miner and Palmgren's rule whereas creep damage is evaluated as per Robinson's rule. Linear damage accumulation under combined creep and fatigue is given as below:

$$M = M_{creep} + M_{fatigue}$$

M_{creep} = Cumulative damage fraction due to creep
$M_{fatigue}$ = Cumulative damage fraction due to LCF

Creep Fatigue interaction diagram with 0.3-0.3 envelope is used to find out the safety of rotor due to both creep and low cycle fatigue acting simultaneously.

5. Conclusion:

"Design by Analysis" has been used as guidelines for stress characterization and successfully leveraged for preliminary design of AUSC IP rotor. Allowable stresses adapted from design codes were customized to suit the internal design criteria for steam turbine rotors.

All the requirements for preliminary design of IP rotor such as ductile burst, excessive yielding, creep rupture, HCF and LCF were met. Future scope could include detailed and advanced analyses for example crack growth studies etc.

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Recent Advances in the Field of Insulation Diagnosis Using Time Domain Spectroscopy Data

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ABSTRACT : This paper presents a review of recent developments made in the field of power transformer insulation diagnosis and dielectric response function modeling. The paper starts by describing insulation model that is available for modeling dielectric response function along with its short comings. Thereafter, advancements made in the field of insulation diagnosis using newer model is discussed. This paper also reports various problems (and their mitigation) that are commonly faced during field measurements. Finally, some recent developments like influence of de-trapped charge on insulation response and its impact on diagnosis results are presented.

Keywords: Paper moisture; Field measurement, Remaining Life, Activation energy; Non-invasive measurement

1. INTRODUCTION :

Insulation materials in transformers degrade at higher operating temperatures in the presence of oxygen and moisture. Degradation from thermal stress affects electrical, chemical, and mechanical properties of insulation materials. Utility providers use a number of diagnostic techniques to assess insulation condition of aged transformers. Among them, moisture analysis in transformer oil, dissolved gas analysis DGA. [1], degree of polymerization (DP) measurement and furan analysis are frequently used. Solid insulation used in transformers are made from vegetable cellulose. The number of monomer units present in a polymer is known as Degree of Polymerization (DP). New Kraft paper has an average chain length of 1000 to 1500 which eventually decreases to 200 after a long period of service at high temperature with high content of water and oxygen. For Kraft paper with DP value of 150 to 200 the mechanical strength of paper reduces to 20% of its initial strength. This point is generally regarded as the end of life criterion for transformer insulation [3]. According to reference [2] the strength of the paper decreases in direct proportion to DP once DP reaches a range of 500 to 200. Paper sampling followed by analysis of DP is perhaps the most reliable method of assessing condition of oil-paper insulation. Though DP can also be indirectly measured from viscosity oil samples, given the volume of oil used in

a power transformer; it is less reliable than analysis of paper samples. Conducting such destructive testing is not a practically feasible option for in-service high voltage power equipment.

Degradation of insulation is always accompanied by associated alteration in its molecular structure [4]. This in turn influences the chemical, electrical and dielectric properties of the insulation system. Consequently, techniques like measurement of Insulation Resistance (IR), dielectric loss factor (DLF), dissolved gas analysis (DGA) have been extensively used in the past for performing non-destructive condition monitoring of transformer insulation. Emsley et al. [5] reported that in the case of a healthy transformer, 100 ml of oil should contain negligible amount of higher hydrocarbon gases and less than 0.05 ml of combustible gases (including short chain hydrocarbons). Duval and De Pablo [6] discussed the interpretation of gas-in-oil analysis using new IEC 60599 (which considers five different fault types) and IEC TC 10 databases. However, results obtained using above reported techniques may not always provide adequate and definitive information about the condition of insulation. Interpretation of DGA result often become difficult due to gas fluctuation and gas migration between oil and paper. Available literature shows that Insulation resistance can also be used for condition assessment. However, the value of IR is sensitive to measurement temperature. Thus, maintaining temperature of the insulation constant is an important issue when measuring IR. An increase in temperature of $10^{\circ}C$ reduces the IR approximately by half. In addition, low value of IR is usually unreliable for performing insulation diagnosis.

Newer technique like analysis of time domain spectroscopy data like Polarization and Depolarization Current (PDC), measurement is gaining popularity owing to its simplicity and because it can provide large amount of information regarding the condition of insulation [4]. Time domain measurements are conducted by application of a step voltage across the insulation object. Time domain measurements based on polarization depolarization current measurement and return voltage measurements have gained significant attention over the last few years for their potential in identifying condition of transformer insulation. Polarization-depolarization current measurement has been recently suggested as an effective alternative to RV method. A brief introduction about the overall PDC measurement process is presented first in the paper. Then, findings related to interpretation of the recorded PDC data in discussed.

The polarization and depolarization currents (PDC) measurement procedure consists of applying a dc charging voltage (U_c) of considerable magnitude to the test object for a long time (usually 10,000 s). During this time, the polarization current that passes through the test object is measured. This current arises due to activation of the polarization processes of dipoles corresponding to different insulation materials

present in the object, (which has been previously carefully discharged). The charging voltage is then removed and the object is short-circuited at $t=t_c$, enabling the measurement of the depolarization current (or discharging, or de-sorption) in the opposite direction, without contribution of the conductivity. The polarization current measurement is usually stopped once the current becomes either stable or very low. The overall principle of PDC measurement is pictorially represented in Figure 1. On the other hand, Figure 2 shows a typical shape of PDC data. In order to improve readability, the voltage profile is also included in Figure 2.
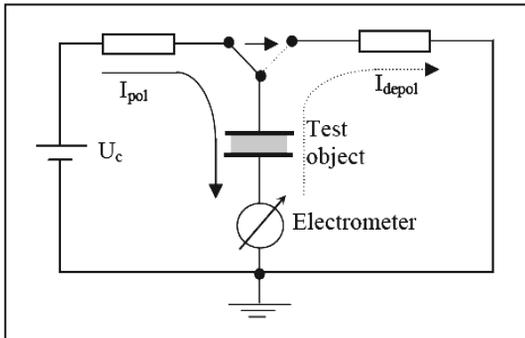

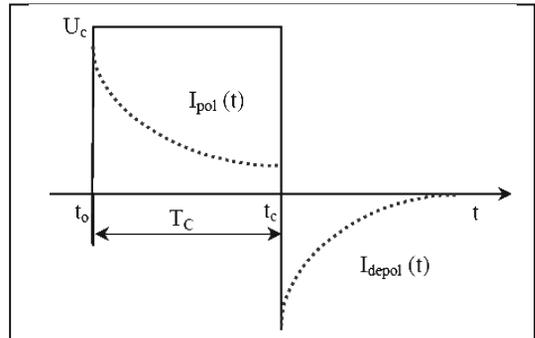**Figure 1.** principle of PDC measurement   **Figure 2.** Typical profile of PDC data

Diagnosis of HV equipment using time domain spectroscopy is usually carried out in two major steps: First the parameters of the insulation model are identified from the recorded dielectric response. Next, performance parameters are evaluated using the identified insulation model parameters. It is understandable that properties of oil-paper insulation are influenced to a significant extent by physical dimension of actual insulation. As a result, performance parameters evaluated from insulation models of two different units cannot be readily compared for insulation condition prediction purposes.

2. RECENT DEVELOPMENTS

Oil impregnated paper insulation contains several dipole groups having dissimilar relaxation times [4], [7]. This property makes structures like CDM well suited for analysis of such insulation systems, which by design has a monotonically decreasing response to a dc excitation function. In fact, research findings reported in last few years show that use of CDM has been quite common for condition assessment of insulation used in high voltage equipment [8-10]. The primary problem associated with the structure of CDM is that it assumes that a specific dipole group undergoes uniform aging irrespective of its location in the actual insulation and hence can be represented by a specific branch of the insulation model. Figure 3 shows the structure of the well-known CDM circuit.
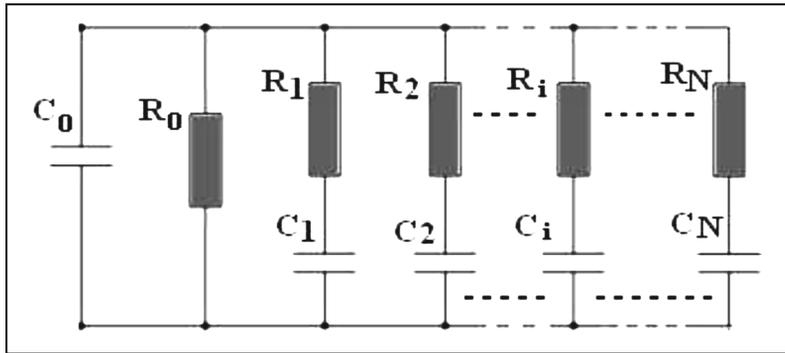
Figure 3. Conventional Debye Model (CDM).

In Figure 3, C_0, R_0 represent the insulation geometry related parameters while series R_i-C_i branch model the response of different dipole groups present in the insulation. It is understood that during normal operation of real life HV equipment, temperature of live parts are maintained at a considerably higher level than that of the ambient. As deterioration and associated change in dielectric properties of HV insulation are significantly influenced by temperature [11], thermal gradient across any oil-paper insulation makes the characteristic of a specific dipole group a function of its physical location. Hence, in order to satisfactorily model HV insulation, containing non-uniform aging, the branches of CDM needs to be suitably altered so that the relaxation process of a specific dipole group can be expressed as a resultant of multiple elements, each representing different degree of aging. It is shown by the authors of the present paper that CDM can be suitably modified to a new insulation structure called Modified Debye Model (MDM).

It is shown by the authors of the paper that MDM can effectively consider the influence of non-uniform aging. The steps involving identification of *MDM* branch parameters are detailed in [12]. It is understood that information regarding severity of aging in various isothermal sections can be obtained by inspecting the sub-elements present in a particular branch. Comparison presented in [12] show that use of CDM, which does not consider the effect of non-uniform aging, leads to inaccurate identification of branch parameters. It is reported by the author of this paper that it is possible to find performance parameters that are less sensitive to geometry using insulation model parameters [12]. However, such analysis necessitates accurate modeling of dielectric response function and analysis using an insulation model that is formulated while keeping in mind the effect of radial temperature gradient. CDM does not consider the effect of non-uniform aging caused by the radial temperature gradient and hence is not suited for determining such performance parameters. However,

identification of MDM significantly depends on accuracy of PDC recorded from in-service transformers. Sometimes during field measurement, it becomes practically impossible to reduce residual dipole energy of the insulation to zero prior to PDC measurement. Such residual energy (which gets introduced due to incomplete polarization or operator error) affects recorded PDC data and its subsequent interpretation. In order to address this issue, the authors reported a MDM based methodology [13] to detect and compensate the effect of such residual energy in the insulation. It is further shown by the authors that MDM can be effectively used for obtaining information regarding value of dielectric loss factors that exists in different regions of a non-uniformly aged transformer insulation [14].

MDM is observed to be a truly versatile model. Research carried out by the author suggests that it is possible to use the branch parameters of in MDM to identify performance parameters that less sensitive to insulation geometry. Such parameters include system poles [15], parameters computed from Transfer Function of insulation model [16-17]. Research carried out by the authors show that several aging sensitive performance parameters like dielectric dissipation factor, paper moisture can be estimated using system poles [15] and Transfer function zeros [16]. Recently, the authors have reported another method [18] using which it is possible to have an accurate estimation of paper moisture. This method comes to the conclusion about paper moisture by effectively combining information related to transfer function zero and loss factor (measured at power frequency). Polarization De-polarization Current (PDC) measurement is carried out offline after the oil-paper insulation of the equipment reaches thermal equilibrium. The total measurement time of PDC data is dependent on the condition of insulation and may range from several minutes to few hours. It is understood that thermal equilibrium of the equipment concerned is dependent on atmospheric conditions which controls the value of ambient temperature. During field measurement, the ambient temperature may not remain constant throughout the PDC recording process. Situation may arise where variation in ambient temperature disturbs the thermal equilibrium that the equipment may have attained prior to the start of the PDC measurement procedure. In such a case the recorded dielectric response data gets invariably affected. In one of the papers the authors reported a method based on MDM that is capable of eliminating such effect of temperature variation [19]. Furthermore, related analysis carried out by the authors suggested that the above method is observed to be independent of the value of the equilibrium temperature. Research initiatives undertaken by the authors in recent times has also led to improvement/modification of available, FDS based, techniques of moisture estimation [20]. The improved relation is shown to be capable of handling significant variation in measurement temperature.

The role of activation function in the field of insulation diagnosis cannot be ignored. Besides assessment of insulation condition, estimation of a transformer's remaining life is also equally important to ensure the reliable and uninterrupted power supply for a longer period of time. However, in order to estimate the remaining life of transformer insulation, information regarding its activation energy must be known. It is a known fact that the life estimation methods are likely to perform better if the value of E_a is known beforehand. Information regarding activation energy can be obtained either by carrying out invasive testing (like analysis of paper sample) or by testing dc insulation resistance of the transformer at different temperatures. It can be understood that both these methods are not practically feasible for in-service, in-situ units where ambient temperature is decided by atmospheric conditions. Hence, the authors developed a reliable, non-invasive, PDC analysis-based method for estimate activation energy for in-service transformers [21]. It is reported in [21] that application of the above-mentioned method leads to accurate estimation of Remaining Life for a given transformer.

Utilities usually prefer to minimize shutdown time of large power equipment to ensure continuity of service. Prior to PDC measurement, the concerned transformer needs to be disconnected from the grid and allowed sufficient cooling time to attain thermal equilibrium within oil-paper composite insulation. Moreover, PDC measurement is a time consuming process because it involves measurement of current until it settles down to a constant value. This may take large time as the dipole relaxation time depends on the conditions of concerned insulation. During field measurement, PDC measurement time can continue from several thousand seconds to few hours [1-3]. During measurement, environmental condition (like ambient temperature) may change and this can affect the thermodynamic equilibrium of the insulation. This in turn hence may lead to recording of erroneous response data. In such cases, multiple recording may be used for accurate measurement. However, for utilities it is difficult to afford such high measurement time due to involvement of economic factors. In addition, at larger value of time, the magnitude of PDC becomes substantially small and hence become prone to low frequency noise. Figure 4 shows the profile of such a noise affected polarization current profile obtained from an in-service transformer. The authors have shown that such low frequency noise can be effectively removed using Wavelet Transform [22]. However, such method is computationally intensive and requires knowledge about signal processing. Hence in order to address these issues, the authors devised an Artificial Neural Network (ANN) based methodology using which the overall PDC measurement time can be reduced from thousands of seconds to mere few hundred seconds [23].
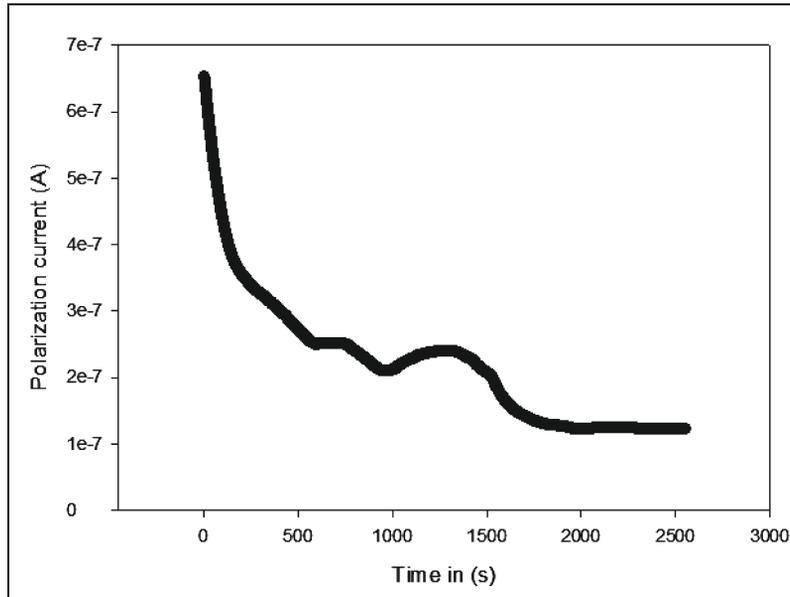
Figure 4. Low frequency noise affected polarization current [22]

Recent initiatives undertaken by the authors have shown that depolarization current data get influenced by ionic trapped charges present in the insulation [24]. This is primarily responsible for making the profile of polarization (without the dc conduction current) and depolarization current dissimilar. As the PDC profile gets affected due to the influence of trapped charge, analysis of PDC data without paying attention to the effect of trapped charge leads to inaccurate analysis. Research findings reported by the authors show that important information (relevant to insulation diagnosis) can be obtained once information about this trapped charge is obtained [25]. The authors in their communication [25] have reported a simple but elegant method of separating current due to de-trapped charge from the recorded PDC data.

3 CONCLUSIONS :

An attempt has been made in this paper to review different diagnostic methods that are available in the literature. Emphasize is given to non-invasive electrical (time domain) measurement based diagnosis techniques. Among available time domain measurement based techniques, interpretation of PDC data is particularly popular. A number of researchers also proposed PDC measurement as the superior tool because this can monitor oil and paper conditions separately. Certain aspects like influence of ionic trapped charge on recorded PDC data is only recently reported and it can be expected that more research is required to fully understand the effect of such factors on insulation response. Our experience suggests that interpretation of PDC data can be used effectively to obtain reliable information regarding insulation health. It is shown

by researchers that crucial aging sensitive information (like paper moisture, loss factor) can be obtained from PDC data. A number of attempts have been made by the authors of this paper to formulate new interpretation technique of PDC data and also to solve common problems encountered during field measurements and this research is still ongoing.

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Discussion on Ash deposition in Ultra-Supercritical Coal based Thermal Power Plants

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Deposition of Ash on the heating surfaces in a Ultra-Supercritical coal-fired boiler is a most troublesome operational problem. There are two forms of ash deposition; namely, slagging and fouling. Slagging is the ash deposition in the radiant section of the boiler, which consists of burners and water-walls, where the heat transfer surfaces are subjected to radiant heat exchange. Fouling is the ash deposition in the convection section of the boiler, where the superheater, reheater tubes as well as economiser and air heater are subjected to convective heat exchange.

Slagging and fouling are the main causes for major maintenance requirements, reduction in heat transfer coefficient, increase in fuel consumption and, in extreme cases, unplanned shutdown of the plant for ash deposition removal and boiler repair. Mainly Ash deposition problems are related to the mineral matter in the coal and the operating conditions of the boiler. Coals from different regions are likely to have different compositions of mineral matter and the mode of occurrence of the mineral matter may also vary. Depending on the nature of the mineral matter in coal, the various chemical and physical transformations occurs during combustion. In fact coal ash is formed from the minerals and inorganic matter after the coal is burnt. The major inorganic elements found in coal are Si, Al, Ca and Fe, while the minor inorganic elements include K, Mg, Na, Ti, S and P. Trace inorganic elements that may be present include Hg and Sn. The physical state and size of the ash particles as well as the gas velocity, gas flow patterns and temperature in the system will influence the movement of the ash particles.

Other important factors influencing mineral matter transformation and ash deposition, are the operating conditions of the boiler, such as the boiler load, air to fuel ratio, gas temperature and soot blowing patterns. The degree of slagging and fouling varies throughout the boiler, depending upon the local combustion environment, which influences the characteristics of the ash deposits formed on the heat transfer metals.

Once the ash particles are transported to the heat transfer metal surfaces, they will stick and remain on the surfaces forming a thin layer of deposit. The adhesion and growth of these ash deposits depend upon the ability of these particles to form strong bonds with the metal surfaces. The characteristics of the reacted layers on the steel surface, temperature of the steel surface, melting behaviour of the ash particles and the thermal and chemical compatibility of the deposit and steel surface are factors that

influence the formation of these bonds.

Mostly the deposits are so strong that reduces the effectiveness of soot blowing. Moreover, the growth of ash deposits will also lead to the worst operating conditions within the boiler, such as the gas flow and temperature, which may increase the ash deposition problems. In some boilers, the deposits are routinely removed using soot blowers, which utilise high pressure jets of air, steam or water. However, this cleaning method may not be effective enough to remove the deposits that are strongly bonded to the wall, as well as the deposits that form in areas that are inaccessible to the cleaning devices. Excessive soot blowing is not recommended as these activities cause erosion damages to boiler tubes.

The boiler efficiency is also influenced by the properties of the deposits formed on the heat transfer metal surfaces, such as the effective thermal conductivity, micro-structure and thickness of the ash deposits. Coal blending is another way to reduce transportation problems, fuel cost, reducing slagging and SOx emission.

Several researches have also been made to develop and/or improve engineering and analytical techniques for the investigations of the thermal behaviour of the mineral matter in coal as well as to enhance the capability of predictive tools or models to predict the slagging and fouling property of coal.

The results obtained from the analysis of the ash deposits formed in a laboratory or pilot-scale combustor never represent the actual ash deposition mechanism in a full-scale boiler without considering the actual configurations, aerodynamics of the system and the operating ash particles conditions in the boiler firing the coal. Therefore, to fully understand the ash deposition problems in a boiler firing a particular coal sample, a systematic investigation considering both the coal properties and the boiler operating conditions in the full scale boiler must be carried out.

In supercritical and ultra-supercritical coal-fired boilers, due to the increased in steam temperature ash fouling and slagging increases. This kind of problem must be taken care in design stage by understanding the complex combination of organic and inorganic matter of Coal (mainly of carbon, hydrogen and oxygen, with some water and traces of inorganic matter) how the different types of mineral matter transform during combustion, how the ash deposits and grows on the heat transfer surfaces and how the ash deposits affect the performance of the boiler.

Materials Issue in AUSC Power Plant

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https://scholar.google.co.in/citations?user=OaaDwzwAAAAJ&hl=en

The increase in power generation efficiency of fossil fuel power plants, to contain the CO_2 emission to atmosphere (greenhouse effect) as well as to decrease coal consumption, depends critically on material selection. Efficiency is increased with increase in steam temperature and pressure (Fig.1). Indian AUSC power plant is envisaged to work with maximum steam temperature of $710\,^{\circ}C$ at 310 bar as against the USC plant with steam at $600\,^{\circ}C$ and 247 bar, increasing the efficiency by around 3 % with the reduction in coal consumption and flue gas emission by around 10 % (Fig.2). This calls for selection of materials capable of withstanding the high temperature and pressure in the flue gas and steam environments. The required properties of material at high temperature are creep deformation and rupture strength, fatigue strength, notch sensitivity, stress relaxation, microstructure stability, steam oxidation and fireside corrosion resistances, erosion etc. Creep deformation and rupture strength of materials is the basis of design of such high temperature plant. Creep resistance materials for engineering structures are commonly grouped as precipitate hardened tempered-martensite ferritic steel, precipitated hardened austenitic stainless steel and and hardened nickel base superalloys. Today's creep resistance material developments restrict the usage of ferritic steel upto about $620\,^{\circ}C$, austenite steel at around $675\,^{\circ}C$ and beyond this temperature nickel base superalloys are the only option (Fig.3). The discontinuous or flexible operation mode in A-USC power plants, including daily start-up in the morning and shut-down at night to account for energy from renewable power sources, needs to have good thermal flexibility for thick section components, namely, low thermal expansion, high thermal conductivity, and enough resistance to creep-fatigue damage.

Fireside corrosion results from the presence of molten sodium-potassium-iron trisulfates. The corrosion rate is low at lower temperature ($<600\,^{\circ}C$) as the trisulfates remains in solid state and again low at temperature higher than $750\,^{\circ}C$ as the trisulfates evaporate. The worst corrosion problem in the range $600 - 750\,^{\circ}C$, temperatures of interest in AUSC. Oxidation/corrosion resistance of materials depends critically on the chromium content (Fig.4). 9-12% chromium in ferritic steels restricts their usage to around $600\,^{\circ}C$ and calls for overlay coating or cladding with high chromium alloys for prolonged service in the fire side corrosion environment at high temperatures, if economical. Around 20 % chromium content in austenitic stainless steels makes it suitable for usages at temperature around $650\,^{\circ}C$. More than 20% chromium in nickel

base superalloys makes it suitable for application around 700 °C. Following is the ranking of alloys in increasing order of corrosion resistance: T91, HCM12, type 347 SS, Inconel 800 and Inconel 617 and 740.
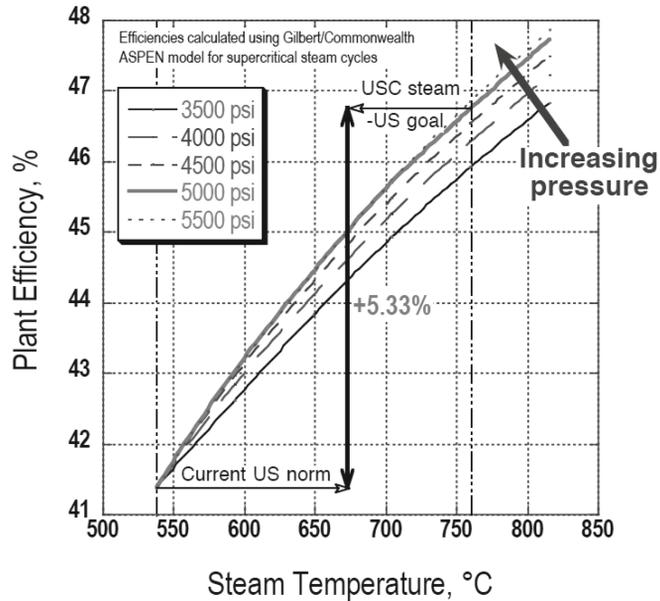

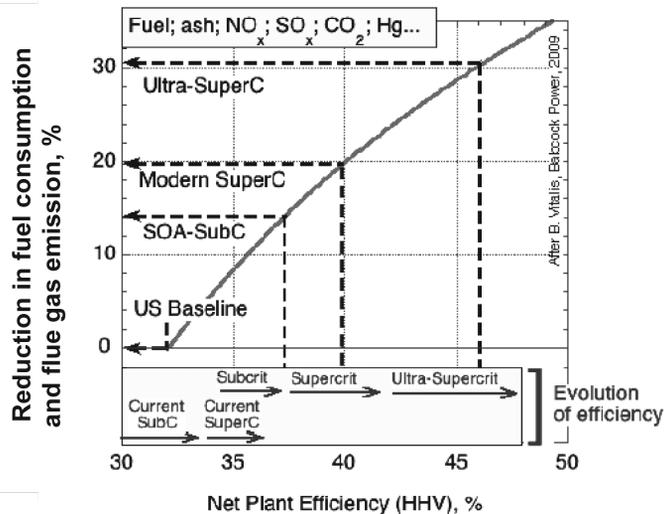Fig.1 Effect of steam temperature and pressure on efficiency of power generation

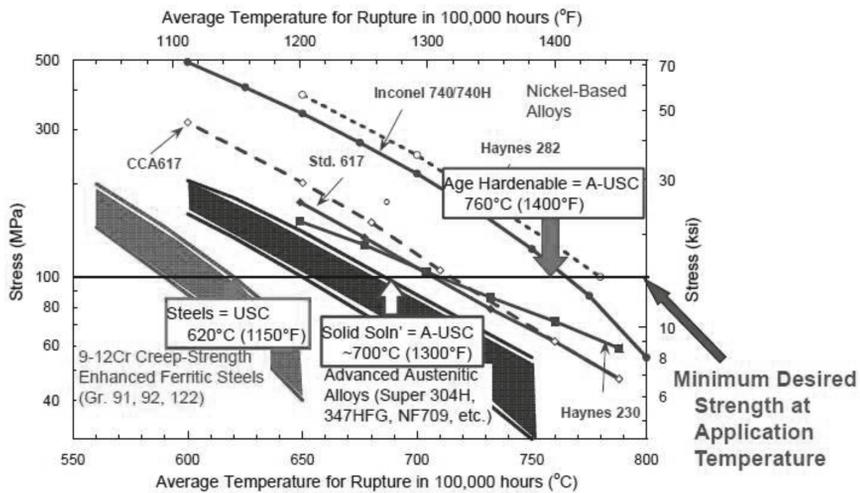Fig.2 Effect of plat efficiency on coal consumption flu gas emission.

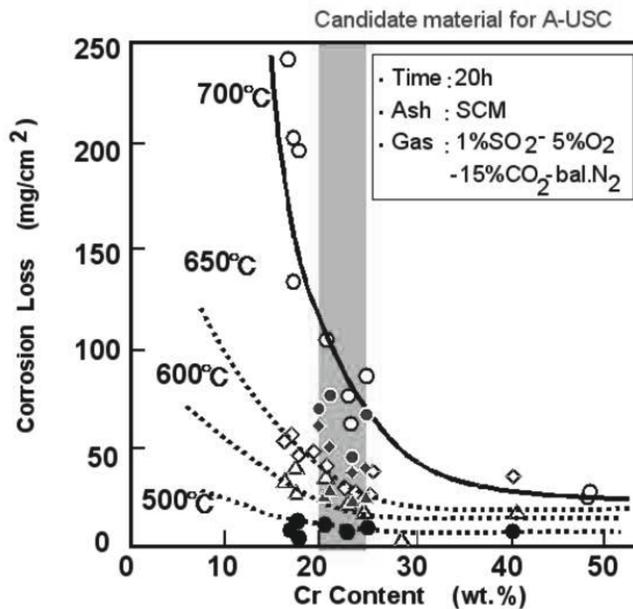Fig.3 Creep rupture strength of various alloys and steels.

Fig.4 Corrosion resistance of alloys and steels as a function of chromium content

Boilers:

Different components of USC power plant work at different temperature and pressure conditions. As far as up gradation of existing USC power plant technology to AUSC is considered, the materials of boiler and turbine components are needed to

change to withstand the enhance temperature and pressure. Major components of power plant along with others is boiler and turbine. Boiler is a steam generator which supplies high temperature and pressure steam to turbine. Critical components of boiler, apart from many others, are waterwall panels, superheater and reheater coil assembles, headers, pipes and valves etc. Feed water is converted into steam in waterwall. In AUSC, high supercritical pressure coupled with the required high heat release furnaces makes the commonly used T11 (1.25Cr-0.5Mo) and T22 (2.25Cr-1Mo) steels in USC power plants not suitable from both creep strength and corrosion points of view. T91 tube having higher creep strength and corrosion resistance is used in AUSC as waterwall tubing. Both cold bending and fusion welding processes are used to fabrication the waterwall. The post fabrication heat treatments at subcritical temperatures are required to relieve the welding and cold bend stresses as well as tempering the HAZ in welding. Reduction in creep strength due to the fabrication processes is needed to account for in the design. Corrosion still remains an issue to be addressed by overlay coating or cladding with high chromium cladding.

Superheater and reheater (SR/RH) tubing application calls for high creep strength, thermal fatigue strength, weldability, bendability, resistance to fireside corrosion/erosion and resistance steamside oxidation and oxide spallation. High temperature and pressure (710 $^{\circ}$C, 310 bar in SH outlet and 720 $^{\circ}$C, 45 bar in RH outlet) in AUSC plant needs better creep resistance material than the ferritic steels (T91 and T92) used in USC power plant. It may be mentioned that the metal temperature is more than the steam temperature. Tube mid wall temperature is arrived at by adding appropriate allowances to steam temperature prescribed by codes. In general, allowance is 50 $^{\circ}$C for heat transfer surface situated in the radiant heat transfer zone, 39 $^{\circ}$C for heat transfer surface situated in convective zone and 11 $^{\circ}$C for economizer heating surface which is situated at the end of flue gas path in the boiler boundary. For headers situated in the convective zone of boiler the allowance is 28 $^{\circ}$C. Austenitic stainless steel (Sanicro 25) and nickel base superalloys (Inconel 740) are considered for superheater and reheater tubes for Indian AUSC. Selection of the material among the different alternative (Super 304H and Inconel 617) are based on detailed creep strength and economy. Reduction in tonnage requirement due to decrease in tube wall thickness resulting from higher creep rupture strength, favours the usage of Sanicro 25 austenitic steel against and Inconel 740 against Inconel 617 as superheater and reheater tubing. However, cold bending of Inconel 740 tube in access of 5% strain decreases the creep rupture strength and calls for heat treatment as subjected to the parent tube (solution treatment at 1100 $^{\circ}$C for 1 hour followed by ageing at 760-816 $^{\circ}$C for 4 hours minimum), which is very stringent. Higher creep strength in Inconel 740 is accompanied by higher fatigue strength than the Inconel 617. The use of Inconel 740 tubes in superheater and reheater brings more flexibility in operation because of

superior thermal fatigue resistance. Inconel 617 suffers from stress relieving cracking in weld joint and must be post weld heat treated at 980 °C for 1 hour to avoid stress relieve cracking. Stress relieve cracking susceptibility is much less in Inconel 740 and the mandatory post weld heat treatment is between 760-815 °C for 4 hours.

Material property requirement for headers and steam pipes are likely to be similar and hence they are grouped together. However, steam temperature is likely to be more uniform in steam pipes but in headers time dependent and local dependent temperature exist. Hence, the requirement of fatigue resistance is more for headers than in pipes. One of the most important differences is that headers have many welded attachments to inlet stub tubes from superheater and reheater and intersections of outlet nozzles connecting pipework. Depending on the selection of materials for the superheater/reheater tubes and the header piping, dissimilar metal welded joint may be required. Inconel 617 and 740 both are qualify for headers and main pipes. Inconel 740 is preferred over Inconel 617 because of it has higher creep rupture strength coupled with higher fatigue strength than the Inconel 617. Induction bending process is used fabrication. In the open literature, very little is known about the bending process particularly for Inconel 740, requires extensive research for crack/defect free bending. Unlike Inconel 617, Inconel 740 suffers from weld strength reduction. Weld strength reduction factor is to be considered for design of longitudinally welded Inconel 740 pipes and headers.

Turbine:

Three different types turbine depending on the steam temperature and pressure are used in USC/AUSC power plants. They are High Pressure (HP) turbine with inlet steam at 710 °C, 310 bar and outlet 63.7 bar, 443 °C; Intermediate Pressure (IP) turbine with inlet steam at 720 °C, 59 bar and outlet at 340 °C, 5.2 bar; and Low Pressure (LP) turbine with steam inlet 340 °C, 5.2 bar and outlet at 38 °C, 0.06 bar. Accordingly, different materials will be used based on the temperature and stress.

Key components of turbine are: Casing (both inner and outer) to contain the steam and to regulate the steam flow, Bolts to integrate both halves of casings and Rotor and Blade to extract the steam energy to convert into mechanical energy. In AUSC, both the casing and rotor of HP and IP turbine will be welded one, from economy and availability points of view. Complicated structure of the casing is produced by casting processes. Inherent defects of casting make this component more prone to failure at high temperature and pressure. Mechanical properties of the cast product are scarcely available and needs detailed research and property evaluation. For inner casing, Inconel 625 alloy superalloy along with ferritic steel (G911) will be used in AUSC against only G911 ferritic steel in USC. Detail casting technology along with mechanical properties evaluation are on progress in different national laboratories (IGCAR, BHEL and NTPC). Welding technology for the dissimilar weld joint

between alloy 625 and G911 is also in progress. The outer casing in both HP and IP turbine will be fabricated from G911 ferritic steel casting. Bolts for integrity of both halves of the casing for HP and IP casing of AUSC turbine will be Inconel 718 against alloy X9 for USC, for the high stress relaxation resistance requirement at higher temperature in AUSC.

As in casing, the rotor of both HP and IP turbine of AUSC will be welded one. The rotor will be fabricated out on forged Inconel alloy 617 and E911 ferritic steel against E911 steel in USC. Large diameter ($\approx$1 meter) rotor will produced by forging process, bringing grain size inhomogeneity (higher grain size at the core than at the periphery) and hence mechanical properties variation across the diameter. Welding process development of the dissimilar (625/E911) rotor is a key technology and is in the process of development. Blade materials (both for stationary and moving blade) will be different at different location of HP and IP turbines. At the initial stages (at the steam inlet) Inconel 617 blade (both stationary and moving) will be used in both HP and IP turbines. At later stage close to outlet steam X19CrMoNbVN11-1, a ferritic steel (10Cr-0.5Mo-0.4Nb-0.1V-0.4Ni-0.2C-0.1N) will be used for stationary blade and GX12CrMoWVNbN10-1-1 (10Cr–0.6 Ni–1Mo–1W–0.2V–0.06Nb–0.05 Cu–0.05 N-0.1 C) (grade 911) in moving blade in both HP and IP turbine.

The valves will be made of Inconel 617. Instead of cast, forged and welded valve casing is considered for better mechanical properties. To deal with impact and rubbing effects, the valve spindle, guide bush and valve seating will be made of Nimonic 90 having very high hardness at high temperature, instead of hardfacing of X10CrMoVNB 9 steel seating by Satellite 21.

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ADMINISTRATIVE OFFICE:	PADMABATI BHAWAN, KAKDIHI, MECHEDA, PURBA MEDINIPUR, 721137

SITE OFFICES

KTPS: Kolaghat Thermal Power Station, P.O.: Mecheda, Purba Medinipur.

BKTPP: Bakreswar Thermal Power Project, P.O.: Bk.T.P.P, Birbhum.

SgTPP: Sagardighi Thermal Power Project, P.O.: Monigram, Murshidabad.

BTPS: Bandel Thermal Power Station, P.O.: Tribeni, Hooghly.

STPS: Santaldih Thermal Power Station, P.O.: Santaldih, Purulia.

IISCO: Steel Authority of India Ltd., P.O.: ISP, Burnpur, Burdwan.

CPL: Crescent Power Limited, CESC P.O. - Madanpur, Asansol, Burdwan.

IOCL: Indian Oil Corporation Limited, Haldia Refinery, Purba Medinipur.

HPL: Haldia Petrochemicals Limited, Haldia, Purba Medinipur.

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- AMC / ARC OF BOILER AND BOILER AUXILIARY (UP TO 500 MW).
- AMC FOR ELECTRICAL MAINTENANCE OF SWITCHYARD 400 KV/220 KV/132 KV/33 KV.
- AMC FOR ELECTRICAL MAINTENANCE OF ESP AND TOTAL DRY ASH SYSTEM.
- ANNUAL CONTRACT FOR AMMONIA DOSING SYSTEM AND CHLORINATION PLANT.
- OVERHAULING OF BOILER PRESSURE AND NON PRESSURE PARTS, UP TO 500 MW.
- OVERHAULING AND MAINTENANCE OF ESP & OTHER ALLIED WORK.
- REPLACEMENT OF ECONOMIZER COIL, RE-HEATER COIL & PRIMARY SUPER HEATER AND HEADERS.
- OVERHAULING MAINTENANCE AND RECTIFICATION WITH OIL FILTRATION OF TRANSFORMER.
- ERECTION & COMMISSIONING OF COAL HANDLING PLANT (CHP).
- ERECTION & COMMISSIONING OF AMMONIA FLUE GAS CONDITIONING SYSTEM (AFGC).
- ERECTION & COMMISSIONING OF DRY FLY ASH HANDLING SYSTEM.
- ERECTION & COMMISSIONING OF HIGH PRESSURE & LOW PRESSURE PIPELINE.
- FABRICATION, ERECTION & COMMISSIONING OF STRUCTURAL AND IBR PIPING JOB.
- RATE CONTRACT FOR SERVICING & IBR INSPECTION OF WASTE HEAT BOILERS.

REGISTRATION DETAILS

IBR LICENSE NO.	: 73 / Dated – 18.07.2016 [Govt. of W.B., Directorate of Boilers]
ELECTRICAL LICENSE NO.	: 20070104350.
FIRM REGN. NO.	: L78984
PAN No.	: AAJFT3026G
TAN NO.	: CALT06838G
E.P.F.CODE NO.	: WB / CAL / 0033668.
ESIC CODE No.	: 74000260470001001,
PROFESSION TAX NO.	:192002162296 / 191000266271
GST REGN. NO.	:19AAJFT3026G1Z5
POLLUTION REGN. NO.	: 4880-hl-co-0/15/0214 Dated – 06.11.2015
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SSI UNIT REGN. NO.	: 19-019-22-00106E (PART-II)

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