

Welding on Rotors for Power Plant Turbo Sets

State of the Art

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Introduction

Turbine and generator rotors undergo high stresses and, from a safety aspect, are the most significant components of a turbine generator system. Depending on the appropriate operating temperatures, the shafts can be fabricated out of low/high alloy heat resistance material or of low alloyed, highly toughened material for low pressure application. **Figure 1** provides a listing of materials used with the customary permissible operating temperatures.

Rotortype	Material	R _{p0,2} N/mm ²	R _m N/mm ²	A5 %	Impact Energy (20°C) J	Working temperature °C
HP, IP	30 CrMoNiV 5 11 21 CrMoNiV 5 9	≥ 550	≤ 850	15	≥ 24	≤ 560
	X 22 CrMoV 12 1	≥ 590	≤ 930	13	≥ 24	≤ 600
	X 12 CrMoWVNbN 10 1 1	≥ 700	≤ 1000	13	≥ 24	≤ 630
HP-LP	23 CrMoNiWV 8 8	≥ 550	≤ 850	15	≥ 80	≤ 530
S-Rotor	26 NiCrMoV 10 10	≥ 580	≤ 820	16	≥ 100	≤ 350
LP, Ge	26 NiCrMoV 11 5	≥ 610 / ≥ 650	≤ 850 / ≤ 900	15	≥ 100	≤ 350
	26 NiCrMoV 14 5	≥ 705	≤ 980	15	≥ 100	≤ 350
LP Disk	26 NiCrMoV 14 5	≥ 750 / ≥ 820	≤ 970	15	≥ 100	≤ 350

HP = High Pressure	S = Saturated Steam	R _{p0,2} = Yield Strength
IP = Intermediate Pressure	Ge = Generator	R _m = Tensile Strength
LP = Low Pressure		A5 = Elongation

Figure 1: Materials for Rotors

The paper will present examples of overlay, shape and joint welding which is performed during the fabrication and repair of operationally stressed rotors at Siemens Power Generation.

In addition to welding processes, applied materials, thermal requirements during welding and post weld heat treatment are also described here. In addition, mechanical and metallurgical properties are outlined.

The welding of highly complex components is also possible, according to experience with operationally stressed rotors which remain bladed during this welding process. One example would be already assembled low pressure turbine shafts which have a high alloy stress corrosion resistant additive, or indeed, high pressure turbines with creep damage indications in the blade securing area. This is providing the welding-specific behaviour of the base material is taken into consideration by selecting the appropriate weld process and heat treatment which meet the specific requirements of the component complexity.

Overlay Welds

It is generally known that rotors made of high CrMoV steels (customary: 9% up to 12%Cr) show bad running behaviour in babbitted bearings. Therefore it is necessary to coat the journal areas of such rotors with materials which prevent the known wire whooling effect and improve the performance. For safety reasons, those materials are normally applied by overlay welding.

Figure 2 shows a pre-machined rotor forging made of 12 % CrMoV steel, for which the journal bearings were overlay welded. A low alloy MnCr weld metal with an approximately 0,2 % carbon content was selected as overlay weld material. To reduce the carbon diffusion, butter layers made of a filler metal similar to 16 Mo 3 were deposited on the 12 % Cr steel rotor prior to depositing the MnCr surfacing electrode. In principle all these welds are performed using the submerged arc welding process. The only exception is axial bearing areas where the buffer layers are performed with an automatic gas-shielded welding unit.

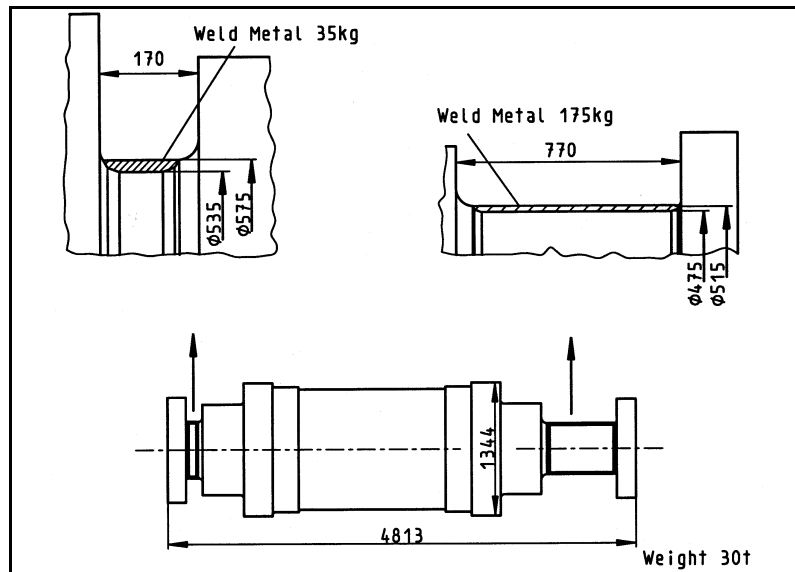


Figure 2: Journal Overlay Weld on Turbine Rotor

Saturated steam turbine rotors, normally made of NiCrMoV steel are susceptible to erosion corrosion especially in the area of the shaft seal section. Due to the high steam flow rates, a material which is strongly resistant to erosion corrosion is necessary. The standard rotor material does not fulfil these requirements.

Overlay welding with filler material 13%Cr 4%Ni is a feasible choice. At temperatures exceeding 550°C the stress relieve temperature of the overlay weld material is at a level similar to that of the rotor heat treatment temperature. To reduce the carbide band, the rotor is buttered with low carbon weld material. The overlay welding of the butter passes and the final overlay welds were performed using the SAW process with wire electrodes.



Figure 3: Overlay Weld in the Shaft Seal Area for a Nuclear Power Plant

Figure 3 shows the seal area welding on a rotor forging for a nuclear power plant. The customary built furnaces at both ends of the forging are used for preheating, for heat control during welding as well as the subsequent post weld heat treatment process.

In addition to the overlay weld properties (such as good running performance in babitted bearings or erosion / corrosion resistance in wet steam), as they differ from those of the rotor base material, it had to be taken into account whether overlay welding affects the structural strength of the whole component. The measured values from pre production performed welding procedure specification tests meet expectations. Meanwhile, several rotors are in operation for more than 200.000 hours, with overlay welded journal areas as well as overlay welded shaft seal sections, without experiencing any problems.

Shape welding

The objective of shape welding is to manufacture one complete component out of melted down filler material, customarily by using the multi-wire SAW process. Due to economic and technical problems this process has thus far not been feasible. The following examples exceed the scope of customary build-up welding, because they modify the shape of the forging. More specifically, restore the use of the component for the application. Consequently, this process is referred to as “shape welding”.

For the purpose of inter changeability, shape welds were performed at the couplings on both journal ends of a fully bladed LP rotor made of 3,5% NiCrMoV steel with a weight of approximately 70 tons. The amount of weld metal to be deposited was between 500kg and 600 kg, **Figure 4**.

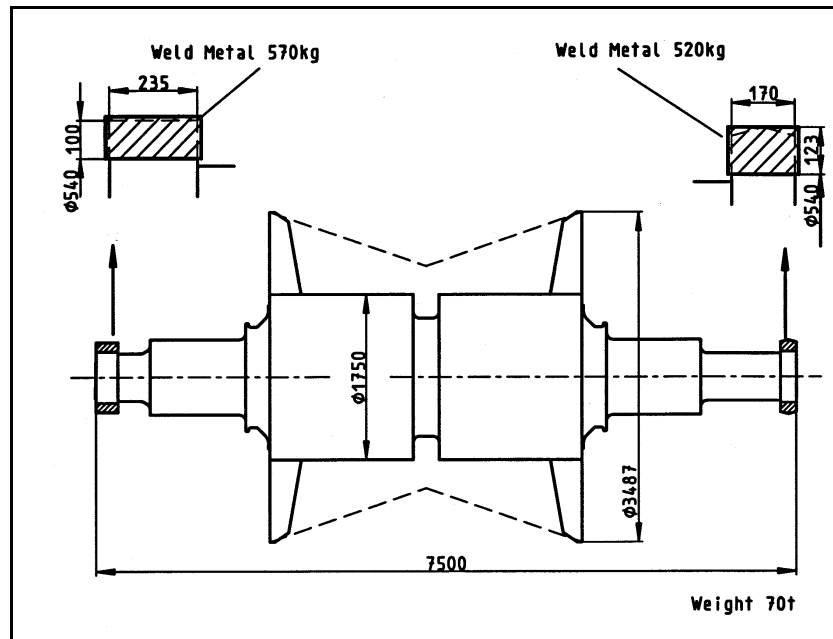


Figure 4: Coupling Replacement by Build-up Weld on a Completely Bladed Rotor

In addition, shape welded couplings were attached to both ends of several spare rotors (material also 3,5% NiCrMoV steel) that had been stored as pre-machined forgings. In their pre-machined, unmodified condition, the weight of these rotors was approximately 40 tons. The weight of each build-up weld was nearly 800kg. The mechanical properties of the filler metal were similar to those of the forging base metal.

This build-up technique used in new manufacturing is also widely used for repair work on turbine and generator rotors in the coupling and journal areas as well as in the rotor body. Extremely high demands are placed on the process technology when blade attachments have to be rebuilt.

Siemens Power Generation has already qualified such rotor weld repair processes for the case of stress corrosion cracking indications (first example) and creep damaged rotor blade grooves (second example).

1. Stress Corrosion Cracking (SCC) is the result of three interacting factors. The steam environment must have a corrosive effect, rotor material is susceptible to corrosion and high level stresses must occur at the surface of the blade attachment. Power Plant experience shows the 3,5 NiCrMoV material, customarily used for low pressure steam turbine rotors, is susceptible to SCC if the other two factors are given.

Based on this knowledge, a Type 410 stainless steel filler material (13%Cr, 4%Ni) was developed for the welding of fir tree blade attachments to the rotor 3,5 NiCrMoV base material. Submerged arc welding has become the suitable choice for the welding process, because of its high guarantee against lack of fusion and the enormous efficiency of this technique.

Numerous welding tests were evaluated to find acceptable yield strength, toughness and corrosion resistance using a post weld heat treatment at an acceptable temperature level for the rotor base material. High cycle fatigue testing was also performed in simulated steam environments. The complete process was successfully qualified in an extensive test program.

Figure 5 shows build-up welding of a complete 360° stage of fir tree blade attachments which had SCC indications, here using double head submerged arc welding.

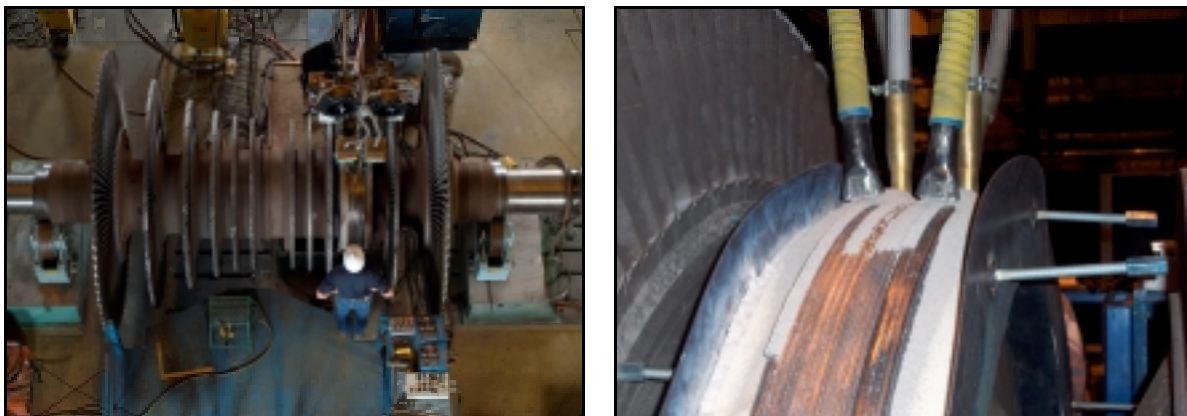


Figure 5: Build-up Weld on Fir Tree Blade Attachments after SCC Indications

2. Creep Damaged Rotor Blade Grooves: In some old combination IP/LP impulse stage rotors, made of 1,25% CrMoNiV steel, material creep damage caused unacceptable deformation in the blade securing area of one specific blade row (operating temperature of approximately 500°C). According to life expectancy calculations the rotors still had adequate service life remaining, so the affected row of blades was removed, the creep damaged rotor blade groove was cut off and replaced by a build-up weld, **Figure 6**.

The welds were performed using the SAW process and depending on the stress, selecting either a 2,25% CrMo filler material, or a 1% CrMoV wire - similar to that of the shaft. By

raising the carbon content to approximately 0.10% - 0.12%, the latter filler metal reaches strength values that correspond to the lower limit value of the scatter range for the 1% CrMoV shaft material, **Figure 7.**

The welding preheat temperature was in the range of 200°C - 250°C and the post weld heat treatment was performed at a temperature range of 680°C - 690°C.

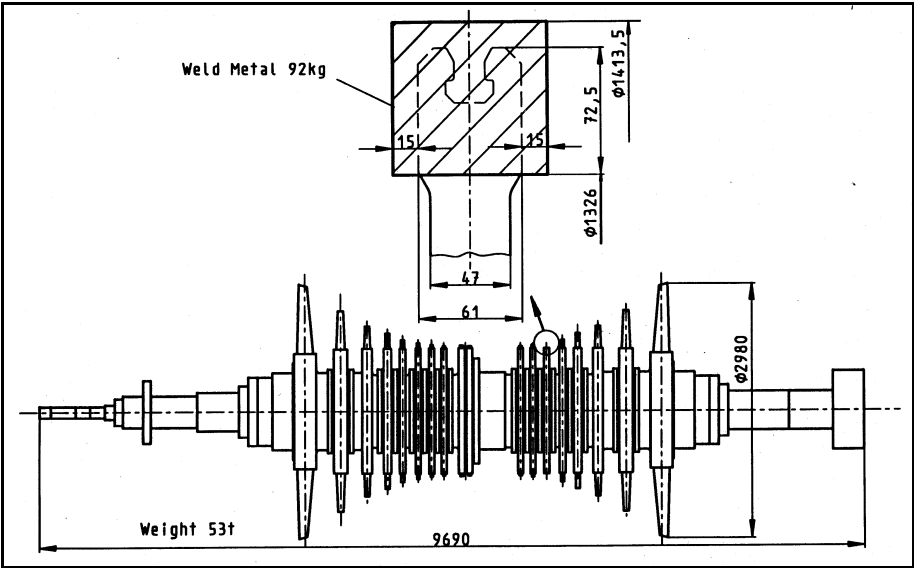


Figure 6: Replacement of Blade Root Groove after Creep Damage

Build-up welds were performed with 9% CrMoVNb steel for applications where even the creep rupture strength of 1% CrMoV filler metal is not adequate. Creep rupture strength of this material is even higher than that of the customary used 12% CrMoV steel.



Figure 7: Build-up Weld Repair of Creep Damaged Stage

Joint Welding

The combined IP / LP turbine rotor design is based on the premise that steam pressure and temperature vary along its length, as do the amounts of stresses. Thus, mechanical properties which meet or exceed these exacting demands are needed. There is currently no known forging alloy which meets all of the necessary material properties ideally.

At the IP inlet, steam temperatures of 565°C require a high heat resistant material such as the industry standard of CrMoV, **Figure 8**. Thousands of creep resistant forgings with 1,25% Cr, 1,25% Mo ,0,25% V steel are used around the world with an excellent service history.

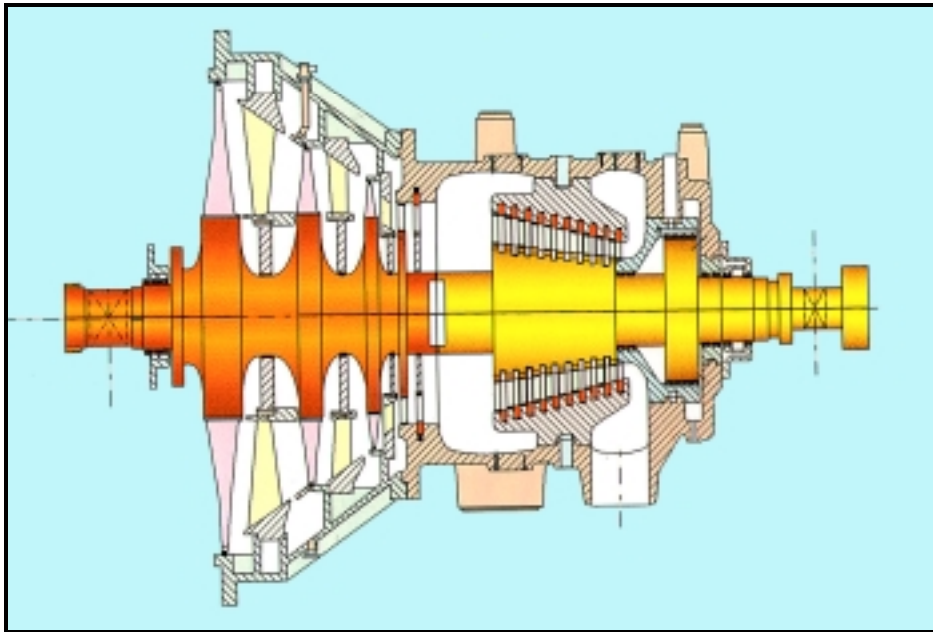


Figure 8: Sketch of Welded IP / LP Turbine Rotor

For the LP end of the rotor, creep is not a problem. However, due to very long blade lengths, particularly at the back end, a material is needed that exhibits excellent yield strength. Most designs for the last stage blades root require a minimum 750MPa, with an extraordinarily high ductility and low FATT behaviour. For these demanding requirements NiCrMoV forging is an excellent choice. The 3.5%Ni steel forging is the standard in industry for low pressure applications.

Due to differences in alloy content, one post weld heat treatment is not effective for both. Therefore it is necessary to use a different post weld heat treatment to optimise the heat affected zones of each, without degrading the strength of either base metal.

This is accomplished by buttering the CrMoV steel and applying the first PWHT with a time and temperature well suited to the alloy. After welding of the connection joint, PWHT is performed at a much lower temperature adapted to the NiCrMoV steel.

In contrast to the previous described welding activities where the SAW process is used, all joint welds are performed with the Gas Tungsten Arc Welding process in narrow gap version (GTAW - NG).

This technique is a variation of the conventional GTAW process, where the low weld metal deposition is offset by an extremely narrow gap. Even up to a wall thickness of 180 mm the gap width in the root area is in the range of 9mm and at the top only 11mm, which is only a fraction of the gap used for conventional high deposition processes. Particularly in joining thick walled components, GTAW - NG is very cost effective as compared to other welding processes due to the very high depth-to-width ratio. Reductions are made in weld preparation time, filler wire consumption, and inspection time with virtual straight side walls.

There are other advantages to GTAW-NG, such as low distortion, low residual stresses, and excellent weld quality. Furthermore, superior mechanical properties can be the primary reason for using the GTAW process. For some steels and engineering requirements, GTAW is the only alternative. These are only some of the reasons why the application of this process is growing in many different fields.

These two rotor forgings are welded in down-hand position to maximise productivity. Each rotor part is installed in a lathe which provides the necessary accuracy to greatly reduce unnecessary machine stock. After tack welding, the gap is continuously filled by turning the rotor, **Figure 9**.

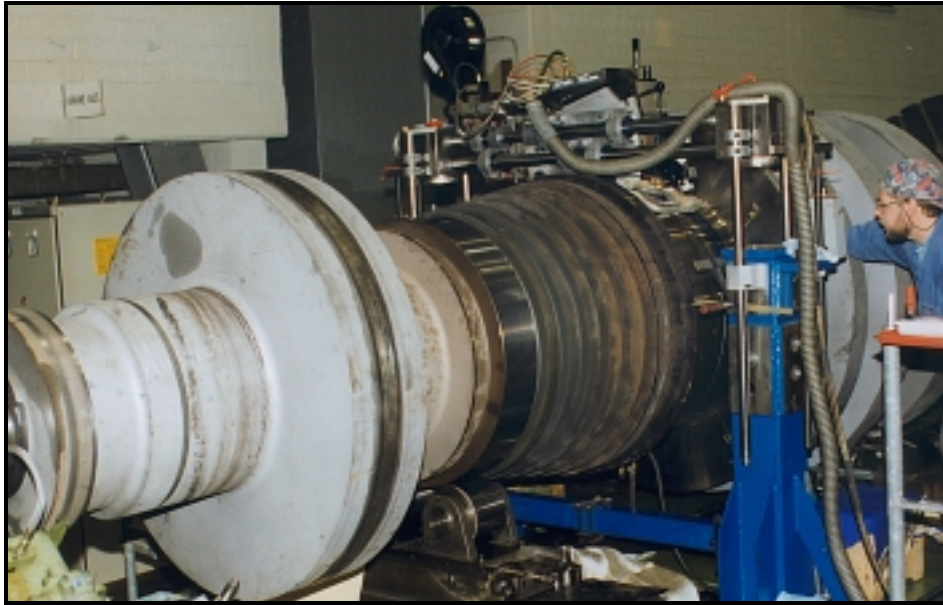


Figure 9: IP / LP Turbine Rotor during Welding

Figure 10 shows the CCD camera which is part of the welding head and gives an impression of the geometrical conditions in the gap (right side of the picture). The width of the gap is only 9 mm. The torch in the middle of the gap is completely water-cooled and isolated with ceramics. The width of the torch is about 6,5mm. The tungsten electrode at the bottom is oscillating during operation to guarantee a faultless connection to the side walls.

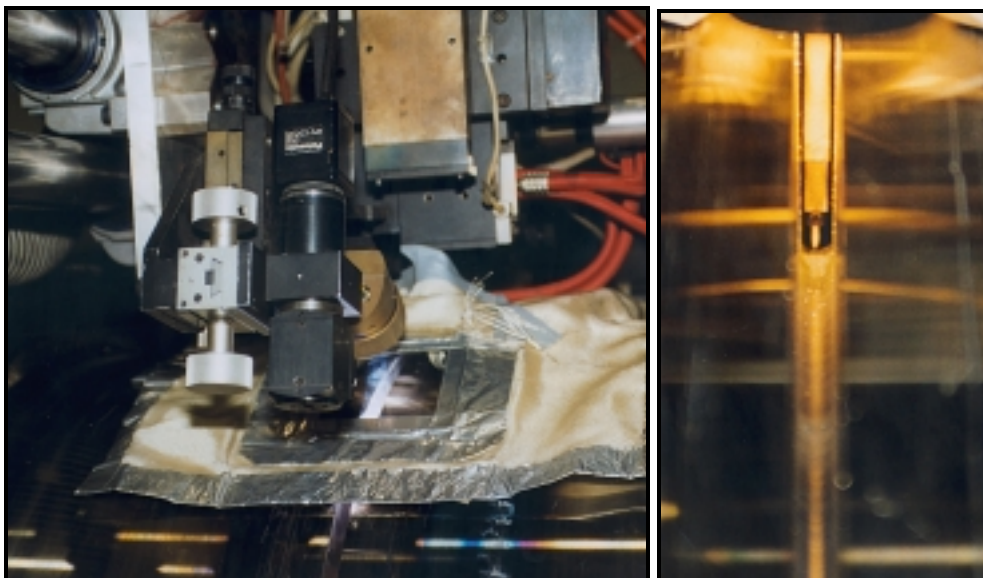


Figure 10: Camera Monitoring during Welding and Geometrical Conditions in the Gap

High material stresses caused by weight and centrifugal forces, load moments and thermal stresses require an excellent weld quality.

This applies particularly for the root of the weld, because no post weld treatment such as cleaning or grinding of the root is possible - each end is a “no bore” or “blind bore” forging.

This places high demands on the welding process, as well as on the non-destructive testing after welding, particularly in the root area. In addition to quality control in the form of ND – testing, a video of the complete weld process is stored on tape to have visual documentation of the process. To be independent from welders’ actual daily condition and concentration, the process is connected to a fully online process control system which supervises the observance of parameters. Material properties as tensile, fatigue, toughness and others which have to be used as basis for design, have been determined from full scale model welds.

The advantage of this welded rotor concept, in comparison to the mono block solution, is the optimised materials according to required mechanical properties, cost effective design solution and an increased supplier base for the forged material.

In addition, this technique is used in the field of repair and service work for joining completely new rotor parts to old rotors which have been partly destroyed during operation.

Heat Treatment

The heat treatments related to welding that are performed on rotors, consist of preheating and subsequent post weld heat treatment appropriate for the base and weld material at a temperature ranging from 590°C to 720°C.

Rotors forgings at the foundry are typically heat-treated completely in a furnace. For welded rotors, especially repairs performed on bladed rotors or shape welded rotors described above, a partial heat treatment is preferred. For this application a custom built furnace, equipped with resistance heater elements, is constructed for each rotor with the required heating capacity.

The mandatory heating and cooling transients and gradients (partial heat treatment particularly for already bladed rotors) along with the resulting thermal stresses must be

correlated with the temperature dependent hot yield strength of the material. This avoids plastic deformation, subsequent distortion and reduces the residual stresses. Both axial and radial gradients and suitable temperature transients have been previously determined with a finite element analysis program that is used to calculate the unstable temperature and thermal stress distribution. A separate computer controlled system employing 20 independent heater circuits serves to fulfil the specification and procedure control.

To avoid plastic deformation per mass and to guarantee constant temperature distribution, the rotor is rotated during the entire heat treatment process, **Figure 11**.

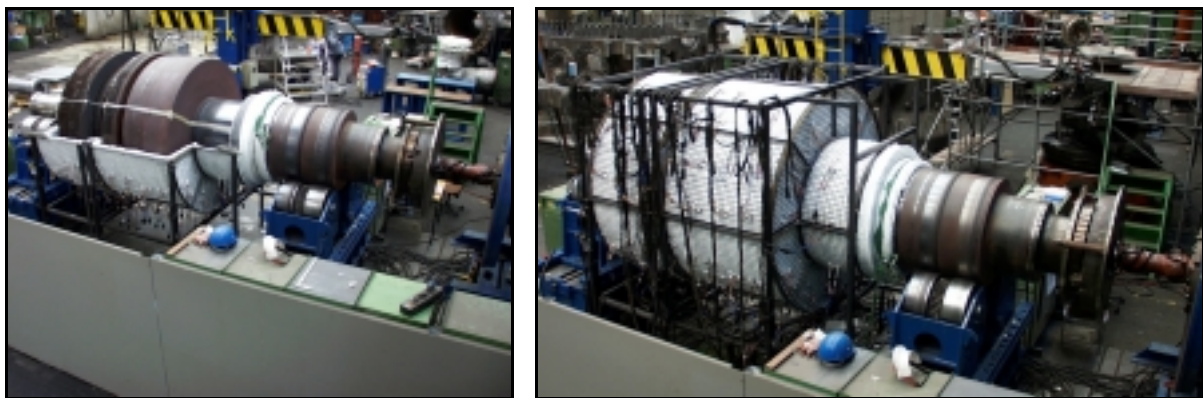


Figure 11: Post Weld Heat Treatment of Welded Rotor in Local Furnace

Conclusion

The examples described give an overview of the wide range of different kinds of weld necessities and possibilities for turbine and generator rotors in new manufacturing as well as in the service and repair business. Each welding technology to be used within the global SPG Network has been extensively qualified in pre production welding procedure specification tests. All properties which are relevant for faultless operation are determined in corresponding mock up welds. The reproducibility of each weld is secured by a semi or fully mechanised process, where online process control systems supervise the observance of parameters.

Under these conditions, process quality is no longer a parameter of the welders actual physical condition. Needless to say, that each weld is being thoroughly tested non destructively with mechanised ultra sonic systems.

For the past twenty years Siemens Power Generation has developed and successfully applied welding for refurbishment and upgrade of a large range of high temperature and low pressure turbine rotors and generator rotors. The simple repair function has been successfully developed to one that involves major interaction with plant designers and operators for the development of repair and upgrade strategies.

This approach not only ensures the swift repair and reinstallation of the turbine rotor but also ensures that there is no recurrence of the original problem by addressing its root causes and providing material and design solutions for long term operation.