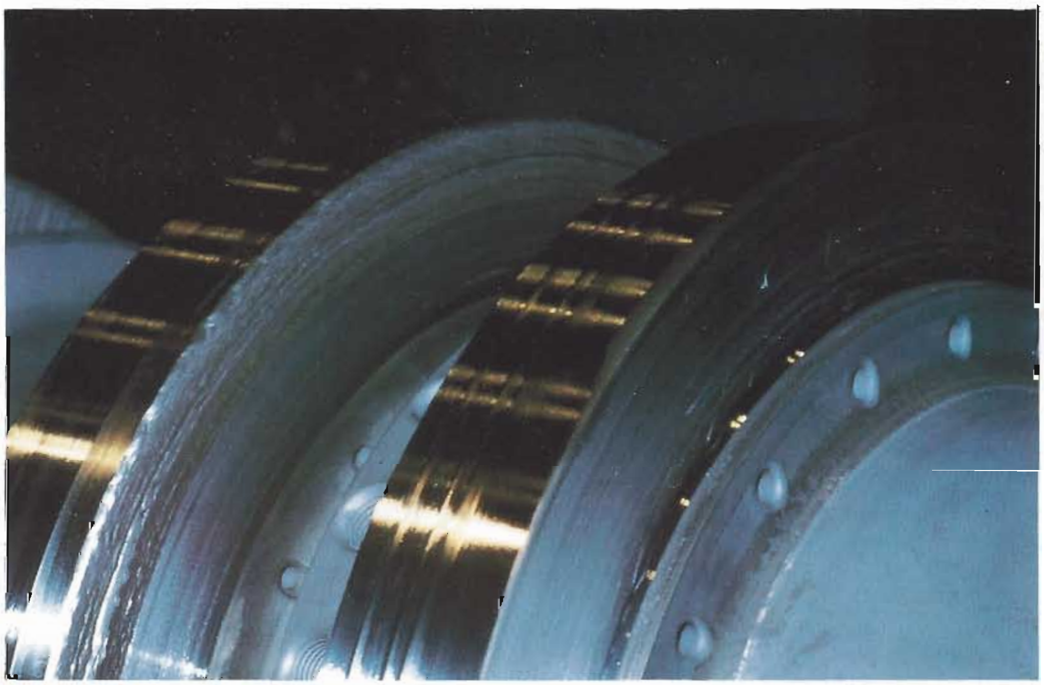
WELD REPAIR HP TURBINE

HOUSTON LIGHTING & POWER CEDAR BAYOU #1



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Abstract

Severely damaged root attachments for the control stages of an HP turbine were repaired by Gas Tungsten Arc Welding (GTAW). The old side entry roots were machined off and a "weld build-up" replaced the metal and allowed for installation of new triple pin blades. A procedure for weld repairing an HP rotor was developed by Westinghouse (Ref #1) and approved by the Hartford Steam Boiler Inspection and Insurance Company and utilized on Houston Lighting & Power's Cedar Bayou Unit #1. The entire process was witnessed and photographed by the author. This paper will chronolog all significant events. Technical information not considered preferential by Westinghouse will also be discussed.

Introduction

On July 1, 1987, extreme turbine vibration resulted in the shutdown of Houston Lighting & Power Company's Cedar Bayou #1 unit. This is a 770 MW unit with turbine inlet conditions of 3,650 PSI, 1,000°F. Inspection of the High-Pressure Turbine revealed that the inlet flow guide had broken loose and was rubbing against both control stages of the disc. The flow guide had rubbed the control stage blading (governor end) to the point where the blade root was cut. When sufficient blade root was removed, the blades broke just above the platform; 12 blades broke. Since July and August are peak months, the turbine was expeditiously repaired so it could be returned to service. The flow guide was replaced and the HP inner cylinder was repaired. However, extensive damage to the root area of both control stages did not allow for replacement of the control stage blading at this time. Both rows of control stage blading were machined down to the top of the root platform. The unit was returned to service, without control stage blades, with a 70 MW reduction in unit output. Unit outage time was 18 days.

In November 1987, the HP turbine wheel for Cedar Bayou #1 unit was again removed from service and was shipped to the Westinghouse facility in Charlotte, North Carolina for a weld repair of the HP rotor. This represents the first weld repair of this type in the world. Installation of new triple-pin control stage blading was also to be performed. Some turbine rotors have been weld repaired using a submerged arc for the buildup, but this is the first time that Gas Tungsten Arc Welding (GTAW) has been used for the entire process.

Procedure Development

Since the area of the weld build-up is subject to the most extreme turbine inlet conditions (1,000°F, 3,650 PSIG), it was imperative that proper metallurgical conditions be maintained. Extensive testing of the GTAW process was completed (Reference #1). Parameters tested included stress rupture, low-cycle fatigue, high-cycle fatigue, impact, and high-temperature tension. The results of the test program indicated a weldment that had higher toughness and stress rupture resistance than the original rotor. It took the manufacturer three years to develop the HP rotor weld procedure.

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The main advantage of the GTAW process is the resulting small grain size of the weldment. GTAW results in a grain size of approximately 1/10 the size of other welding processes. The fine-grained weldment has significantly better properties than the base rotor material, specifically toughness. In fact, stress analysis performed by both Westinghouse and Southwest Research indicated that any failure would occur in the rotor base material, not the weldment. The smaller grain size is the result of the process developed by Westinghouse.

A method of overlapping weld beads was utilized to minimize the number of heat-affected zones. Proper preheat temperatures is also essential. The weld wire was another factor influencing the procedure. The combinations of temperature, filler metal amperage, and rotor base material all interact and must be considered during development of a weld procedure.

The chemical composition of the original rotor material is:

Cr — 0.99	Mn — 0.84
Mo — 1.12	S — 0.006
Ni — 0.20	Si — 0.26
C — 0.31	Sn — 0.012
V — 0.28	P — 0.012

The composition of the weld metal is considered confidential. However, it can be said that it contains more chromium than the rotor.

The design of the new triple pin blade grooves was established and a procedure for rough machining of the existing blade roots was also completed. The idea was to put the "transition zone" (line between the rotor base material and the weldment) at a minimum stress point on the rotor.

Work Scope

The estimated schedule for the repair indicated that it would take Westinghouse 15 weeks to complete the entire repair of the rotor. This included:

Receive rotor at Charlotte Plant and visual inspect. Truth check. Remove control stage steeples. Clean rotor, remove center plugs, stargage and hone bore. Magnetic particle and UT inspect bore. Magnetic particle rotor OD. Evaluate bore results.	3 weeks
Set up rotor for weld repair. Preheat and clad rotor. Weld buildup of rotor. Cool down.	5 weeks
Pre-post weld heat treatment machining. UT welded areas. Evaluate results. Set up and postweld heat treat. Clean rotor and install center plugs.	2 weeks

UT welded areas.
Evaluate results.
Set up and postweld heat treat. 2 weeks
Clean rotor and install center plugs.

Finish machine blade grooves. Deburr and NDE again. Install control stage blades. (Triple pin) Turn shroud, polish journals, tune up.	1 week
Hi speed balance. Final inspection. Ship rotor.	3 weeks

The actual repair took 14 weeks and 2 days.

The weld repair was completed in the following five steps:

1) Machine roots and finish machine to preweld dimensions. (Figure #1)
2) Build up rotor and weldment. (Figure #2, 6, 7)
3) Rough machine for NDE, then postweld heat treatment. (Figure #3)
4) Final machining of "fingers" for triple pin blades. (Figure #4)
5) Install triple pin "blade blocks." (Figure #5)

Preweld Work

The rotor was received by Westinghouse at Charlotte, NC on November 13, 1987. The first task was to thoroughly inspect the existing rotor and verify its integrity. A complete NDE inspection was performed. Both ultrasonic and magnetic particle inspection of the bore was completed as well as magnetic particle inspection and truth checks of the external portions of the rotor. All testing results concluded that this was a weldable rotor. A visual inspection of the bore revealed one small dimple that was "dressed" and removed. The dimple was not significant and was of no concern. The entire bore was "polished' after inspection to remove surface scratches created during the bore inspection.

The "as-received" rotor was then placed in a lathe for final machine prior to welding (Figure #1). The blade roots were machined past the bottom of the root to the point of least stress on that area of the rotor. Most weld failures occur in the heat-affected zone, so it was prudent to put the heat-affected zone in the lowest-stressed area. The machined surface was then tested with UT and MT inspection with no recordable indications being found.

It had been determined that this was a weldable rotor. Not all rotors are weldable. The amount of residuals remaining after manufacturing can influence the decision of whether a rotor is weldable. Weldability studies (Ref. #2) have shown that impurities such as sulphur, phosphorous, tin and antimony have segregated at the grain boundaries, affecting embrittlement, creep ductability and toughness. Vanadium and Carbon content also influence the affecting embrittlement, creep ductability and toughness.

Welding

After preweld NDE, the rotor was set up in the weld shop. It was placed on powered rollers and began rotating. It was pre-heated before welding. The rotor body temperature was slowly raised to a specified temperature, held, then changed to the required welding temperature. Temperature monitoring throughout the entire welding process was intense, redundant and accurate. Temperatures were recorded every 15 minutes and taken with two pyrometers. The rotor body was heated with resistance heaters placed adjacent to the weld areas and were automatically controlled by timed cycling. There are plans to automate the entire heating sequence.

Welding was delayed for two days because Westinghouse felt that this was the first HP rotor to be commercially welded and it was imperative that all procedures be verified. Procedures were checked an rechecked. Welding test coupons were repeated to verify certification of the welders and their procedures.

The welding was completed in two steps. The first eight layers were completed with one process and the remaining 78 layers with a second process. Both processes use GTAW. The first process, called "the Overlay," is performed at extremely low amperage and is undulated. The pass size is small (20 passes per layer). The second pass is called the "build-up." The amperage is high and weld bead is larger (14 passes per layer). There were 1,321 total passes on the governor and 1,361 total passes on the generator end. Both processes used the same gases with some change in percentages and pressure. The gas used was extremely clean and presented no problems during welding. Temperatures were constantly recorded and the tungsten tips were replaced periodically to avoid tungsten contamination. There were no tungsten problems either. The welding was uneventful except for two incidents which created some confusion and slowed the repair process, but did not affect the integrity of the repair. One incident occurred when a "magnetic flux" congregated on one edge of the governor end. The magnetism affected the arc and less than a desirable weld bead was created for two passes on the edge. This proved to be a source of the only recordable indication, which will be discussed in detail later in this paper.

The welding was completed January 1, 1988, two days ahead of schedule. A planned cool-down period was established. The temperature would be changed from the welding temperature, held a short time, then cooled at a predetermined rate. Again, extensive attention was given to temperature recording.

Postweld Activities

The next process completed after welding and cool-down was the rough machining of welded areas (Figure #1). The weld material was machined to the rough dimensions without incident. In fact, the only problems with **any** machining was "normal tool breakage." Both control stages (governor end, generator end) were rough-machined, then polished for NDE.

NDE after welding consisted of magnetic particle and ultrasonic inspection. No linear flaws were allowed and internal defects were considered "reportable" if the ultrasonic signal showed 50% intensity of a returned signal when compared to a 1/16-inch diameter flat bottom hole. There was one reportable indication found during UT with a 65% intensity of a 1/16-inch flat bottom hole. The indication was extensively evaluated by Westinghouse. Since the size of the indication was extremely small and was located at a minimum stress point on the rotor, it was considered to be an acceptable indication and would not be repaired. Houston Lighting & Power Company concurred. The rotor was then postweld heat treated. It took 10 days to perform the entire postweld heat treatment (PWHT) process. The rotor was heated by resistance and some induction heaters. The entire rotor was wrapped with insulation during the heat treat process. There was nothing new or exciting about the postweld heat treatment. The rotor is suspended in a vertical position and heated. The heat was automatically controlled by computer.

The second UT of the welded areas took place after postweld heat treatment. It verified the initial findings and showed that the indication did not change in size. The indication was re-examined by the Hartford Steam Boiler and Westinghouse using both shear wave and T-wave transducers. Hartford Steam Boiler felt that the indication was much larger than what Westinghouse had originally said and that repair of the flawed area should be considered. EPRI technical services in Charlotte was contacted and asked to evaluate the indication. While they would not issue a report or write any formal communication on their findings, EPRI indicated that because of the geometry of the area, T-wave transducers should be used for sizing instead of the shear wave transducers. The EPRI inspector thought the indication was smaller than indicated by either Hartford, Westinghouse or HL&P. Since EPRI would not issue a report, HL&P contacted Southwest Research Institute to examine the indication and also to perform fracture mechanic calculations for determining flaw growth. A meeting was held at HL&P between all parties concerned — Westinghouse, Hartford Steam Boiler and Insurance Company, Radian Corporation, and Southwest Research Institute. The Southwest Research Institute study reported findings that the indication size and geometry was such that the flaw would extend no
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more than .01" in 50 years. These findings agreed in principal with both Westinghouse and HL&P's conclusions. Based on the date presented, Hartford Steam Boiler concurred with the conclusion not to repair.

Install Triple Pins

Completion of the NDE and clearance to proceed allowed the next process to begin. Final machining of the "fingers" in the rotor was completed without incident (Figure #4). Nothing was special about machining the weldment. The weld material appeared to machine easily.

The next major task was installation of the new Triple Pin Blades (Figure #5). The blades are in groups of three and machined from one "block." There were 90 blades and 30 blade groups. There are three pins per blade group. All the groups are placed on the rotor at one time for the drilling and pinning operation. The pins have a shrink fit and are staked once. After pinning, the integral shrouds are final machined. The rotor was then high-speed balanced.

Conclusions

There is no doubt that Westinghouse has proven their ability to successfully weld repair High-Pressure steam turbine rotors. The procedure development, planning, implementation and execution of the repair demonstrated the ability of Westinghouse to weld repair high-pressure turbine rotors. HL&P believes the Gas Tungsten Arc Welding process produces the best possible weldment, and that the Charlotte Plant has the "art" necessary to perform such marvelous welding feats. While this welding process is a little slower, we feel the time is well spent. The improved creep properties and toughness of the weld metal over the base rotor metal will increase the life of this rotor significantly. Welding of low-pressure rotors is now considered routine compared to weld repair of high-pressure rotors.

Weld repairing of turbine rotors is an extremely cost-effective maintenance tool with minimum risk. I would expect to see a dramatic increase in the number of rotors weld-repaired. Weld repairing of turbine rotors will allow for redesign of blading and for upgrading rotor metal at blade attachment areas.

Operating experience will be monitored. The first inspection of the repaired rotor is to be completed after one year of operation, with a second inspection three years later. Replicas of the heat-affected zone will be taken to monitor any creep.

Acknowledgment

Houston Lighting & Power Company and the author wishes to acknowledge and thank the Westinghouse Plant, Charlotte, North Carolina, for their trust and assistance in allowing the author to witness and photograph the entire repair. Furthermore, we acknowledge the dedication of all persons involved in the repair.

Reference #1 R.E. Clark, R.L. Novak, D.R. Amos, *Development of the Techniques for High-Pressure Rotor Weld Repair.* EPRI seminar on Turbine Rotor Welding, San Francisco, December 1987.

Reference #2 G.S. Kim, J.E. Indacochea, *Weldability Studies in HP, and IP Turbine Rotor Steels.* EPRI seminar on Turbine Rotor Welding, San Francisco, December 1987.

Reference #3 T.D. Spry, D.J. Graves, G. Kohnen, G. Faber, H. Bartsch, *Weld Repair of HP & IP Turbine Rotors Having Extensive High-Temperature Service.* American Power Conference, Chicago, April 1987.

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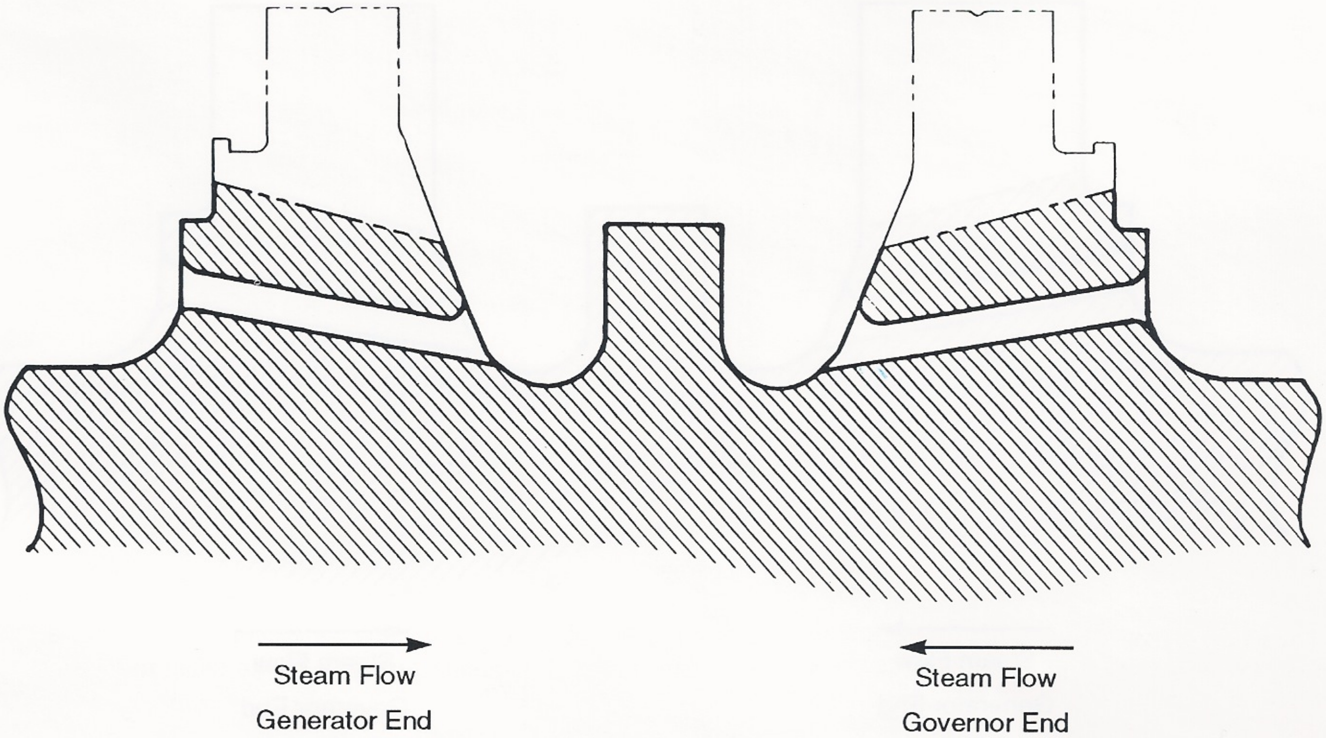

Figure 1. Original Blades and Roots Machined Off

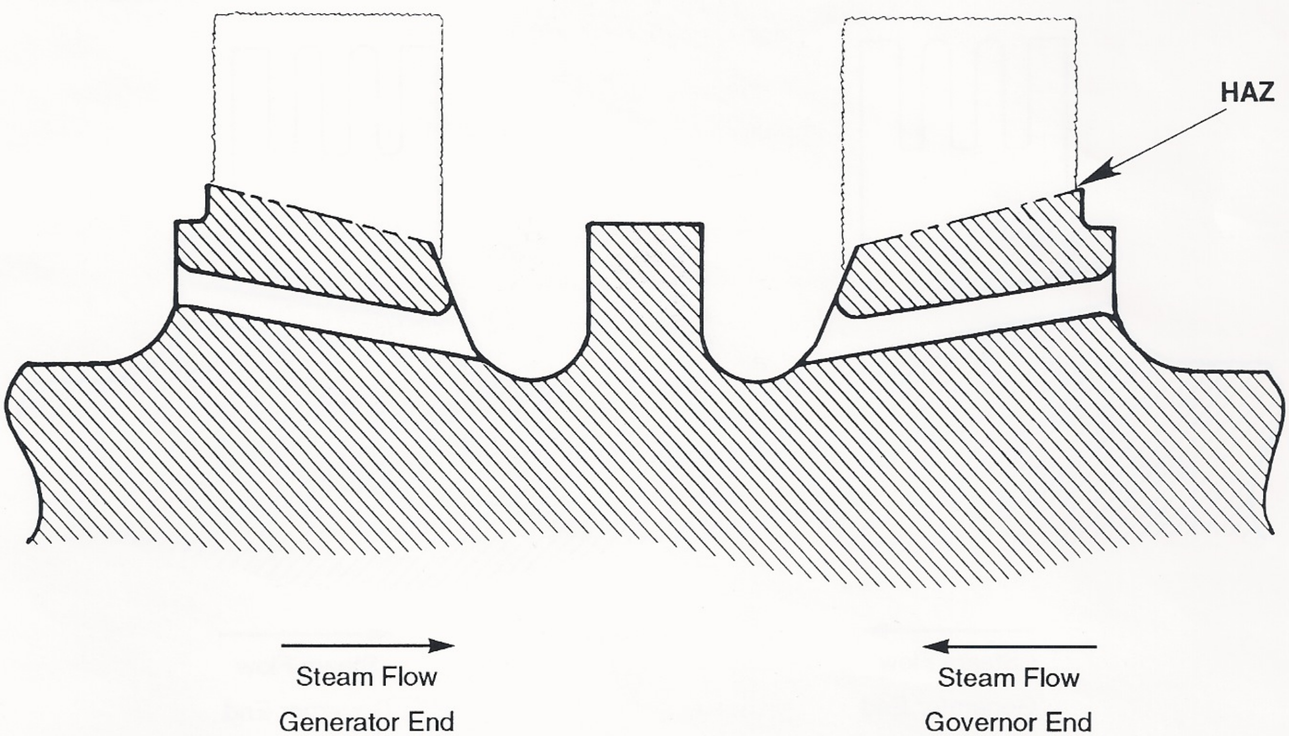

Figure 2. Welded Area

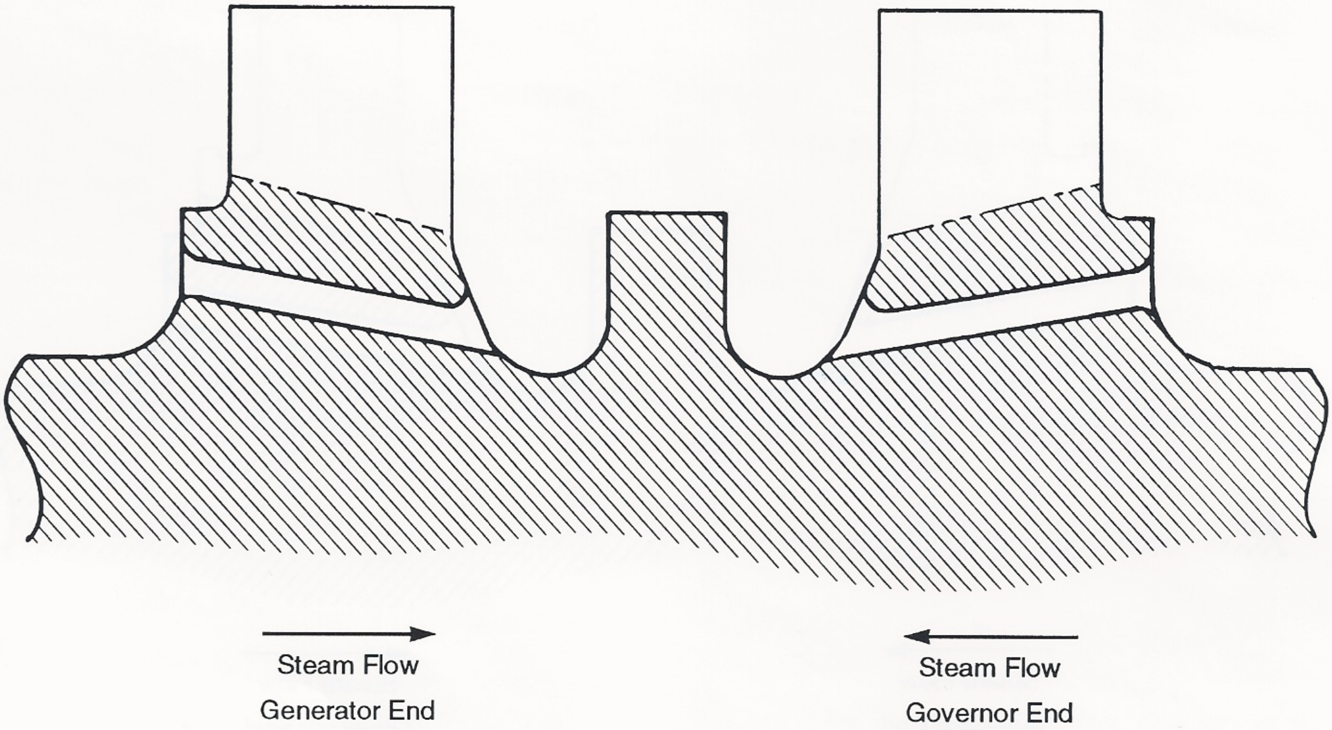

Figure 3. Rough Machine After Welding

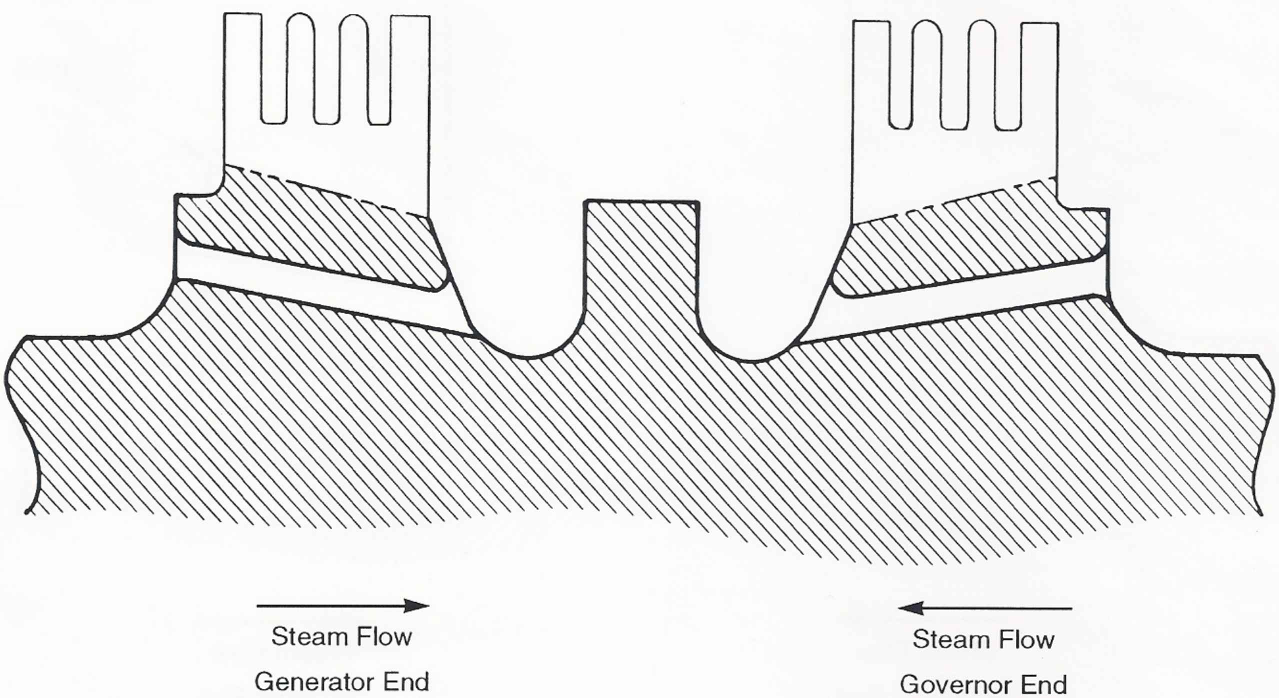

Figure 4. Machine Fingers

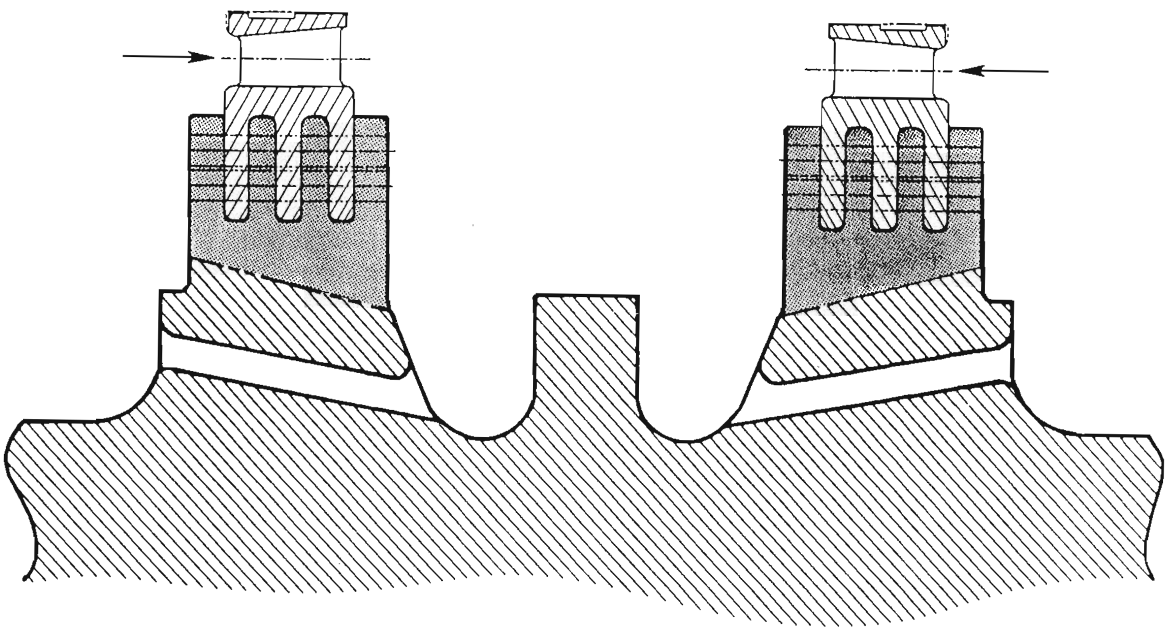

Figure 5. Installation of the new Triple-Pin Blades