

REPAIR SEVERELY DAMAGED ROTORS BY SUBMERGED ARC WELDING

by

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From 1971 to 1978, Mr. Heeter was on active duty with the U.S. Air Force as a Weapon Systems Officer flying the F-4 Phantom fighter aircraft. From 1978 to 1990, he flew the Phantom on a part-time basis with the Hawaii and Texas Air National Guard units, and although he no longer flies, he is still active as the Intelligence Officer for the 147th Fighter Interceptor Group of the Texas Air National Guard.

ABSTRACT

Severely damaged rotors often can be rebuilt even when damage has occurred to the shaft/rotor forging. Such shop repair returns what would have been a scrapped or degraded rotor to original equipment standards.

The repair procedure is to:

- Remove damaged areas of the rotor by machining.
- Build up metal with metallurgically compatible weld wire and fluxes, using submerged arc welding in sequences as dictated by repair design.
- Thoroughly inspect the welded/machined area by magnetic particle, ultrasonic, and dye check procedures after each sequence.
- Stress relieve the welded area after each sequence, using computer controlled heating of the desired area so as to control hardness in the heat affected zone (HAZ) and assure adequate metallurgical properties in the weld metal.
- Repeat these sequences until the repaired area conforms to the design required by welding engineering, mechanical engineering, insurance specialists, and/or consulting metallurgical laboratories. These procedures can often provide metallurgical properties superior to those of the original material, move the heat affected zone (HAZ) out of the steam path, strengthen the repaired area, compensate for anticipated problems, and/or improve the original design of the rotor.

Such repairs involve use of special jigs, equipment, techniques, and procedures.

A detailed description of the turbine rim weld repair is given, including use of supplementary pictures, drawings and techniques.

Cracks were discovered in the body of a nominal 22 in diameter, first stage Curtis wheel of a forged turbine rotor. Laboratory analysis indicated the cracks were due to stress corrosion, believed to have been caused by caustic introduced accidentally with inlet steam.

The damaged portion of the wheel was removed by machining at a point well into the unaffected portion of the wheel. The remaining rim was welded to build up, heat treated, finish machined to accept blades, and rebladed. The finished rotor was dynamically balanced at operating speed, installed in its casing, and returned to service. The reinstalled rotor has operated without trouble at up to design conditions for a number of months.

These welding procedures were evolved and improved through experience gained over the past eight years in the repair of about 80 damaged turbine rims. Similar repairs have also been performed on centrifugal compressor rotor wheels and shafting. Monitoring and periodic shop inspection of these welded rotors has shown no degradation in the repaired areas. Repair costs have been well below those that would have been incurred by replacement with original vendor equipment and, most often, in significantly less time than it would have taken if a new rotor was provided from the original equipment manufacturer.

INTRODUCTION

As late as 10 years ago, it was unthinkable to weld on any portion of high performance turbomachinery rotors. Consequently, many quite expensive turbine and compressor rotors were scrapped for relatively minor damage.

The demands for production combined with the long lead time of replacement rotors led to the gradual development of welding procedures for rotor repair. At first, only coupling hub fits, journal surface, and seal surface repairs were attempted.

The success of these initial repairs, along with the perfection of metallurgically sound metal deposition techniques, evolved into the weld buildup and remachining of turbine blade fastening rims. Over the past eight years, the author's company has put more than 80 damaged rims back into service. Monitoring and periodical shop inspection of these welded rotors has shown no degradation in the repaired areas.

A very dramatic repair recently completed is described in which the complete first stage wheel, down to the rotor body, was removed and rebuilt to include the blade attachment rim. This unit is now in service and valuable operating time is being accumulated to provide confidence for future similar projects.

CASE STUDY

The following case study involves a rotor from a four stage steam turbine (Figure 1). The rotor is forged with integral wheels (monorotor). After some months of operation, during a routine inspection, cracks were discovered in the outer radial faces of the first stage Curtis wheel. Surface inspection indicated that the

cracks were possibly due to stress corrosion believed to have been caused by caustic introduced accidentally with inlet steam. The laboratory analysis required the machining off of the outer rim in full cross section segments.

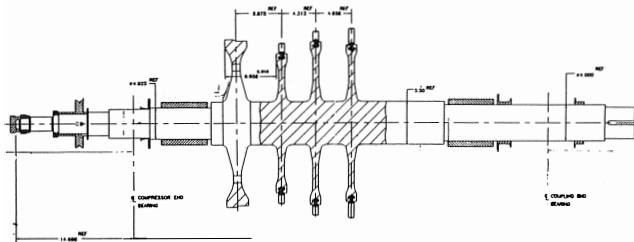


Figure 1. Diagram of the Rotor Assembly for the Nominal 22 In Forged Turbine.

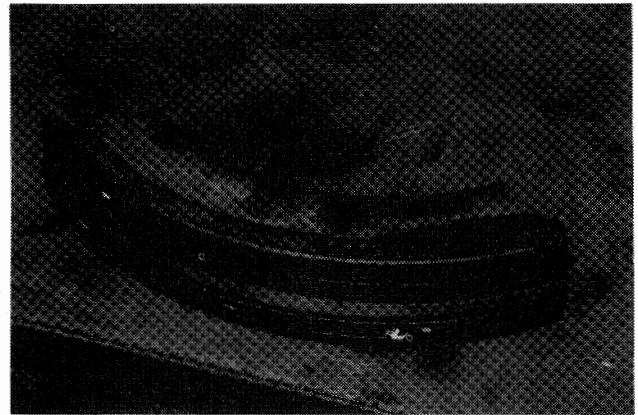


Figure 2. Segment Removed from the Rim of the Curtis Wheel.

Prior to the destructive sampling of the rotor, it was important that engineering drawings be prepared to enable the reestablishment of finish dimensions after the final repair.

Metallurgical analysis confirmed that the cracks were due to stress corrosion. The possibility of another accidental introduction of caustic into the steam left doubt in the owner's mind concerning the integrity of the spare rotor which had just been put into service.

The time required and the expense of a new replacement rotor was felt to be prohibitive. Therefore, a decision was made to proceed with a weld repair of the existing rotor. A weld repair plan was established:

- Further machine the first stage wheel and extend the welded area down to the shaft. This would place the exposed heat affected zone (HAZ) in a low stress area on the shaft and outside of the steam path where it would be unaffected by caustic in the steam.

- Agreement was reached between the owners, insurance technical personnel, and the repair shop welding experts as to weld procedures, filler metal, flux, stress relief temperatures, weld sequencing and nondestructive testing (NDT) for quality acceptance. Fortunately, the welders and the agreed upon weld procedures for the material involved had previously been qualified with the proper engineering and insurance officials. This qualification procedure had required extensive metallurgical and mechanical testing of specially prepared weld coupons and could have significantly delayed the repair if a new procedure/material required qualification.

- In general, the rotor was built up in a series of procedural sequences or steps. After each step, the weld area was machined, magnetic particle inspected, ultrasonically tested and dye checked to ensure conformance to stringent acceptance criteria. After the first step and the last step, the weld area was stress relieved using blanket electric heaters with time/temperature computer control. Proper techniques are required to achieve preset levels of hardness and other critical metallurgical and physical properties.

The rotor was delivered to the repair facility with the damaged part of the wheel removed (Figures 2 and 3). Discussions that followed caused the planners to recommend removal of more of the rim (Figures 4 and 5) in order to assure that all the damaged material had been eliminated, and to facilitate welding from the shaft upward, which would place the HAZ out of the steam path.

Repair shop engineering personnel recommended adding additional cross sections to the rim at the juncture with the shaft, and for a few inches outward to eliminate any concern for adequate strength at that part of the design (Figure 6). They also chose a generous radius at the connection of the rim to the shaft to reduce the possibility of stress corrosion cracking and to provide more than adequate strength.

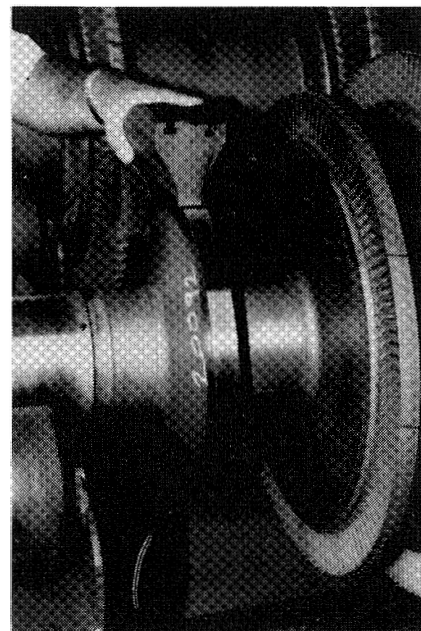


Figure 3. Relationship of the Removed Segment to the Remaining Rim of the Curtis Wheel.

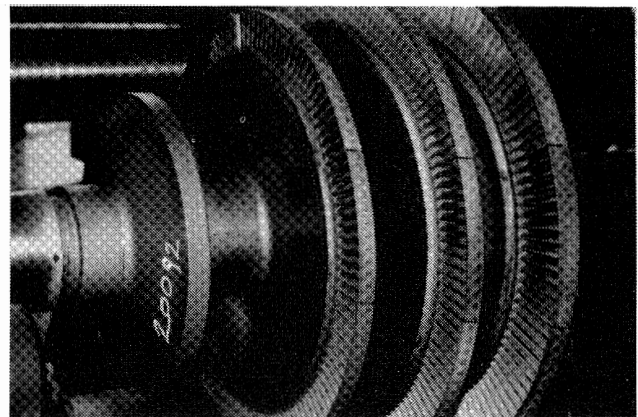


Figure 4. The Remaining Portion of the Rim of the Curtis Wheel as Received at the Shop.

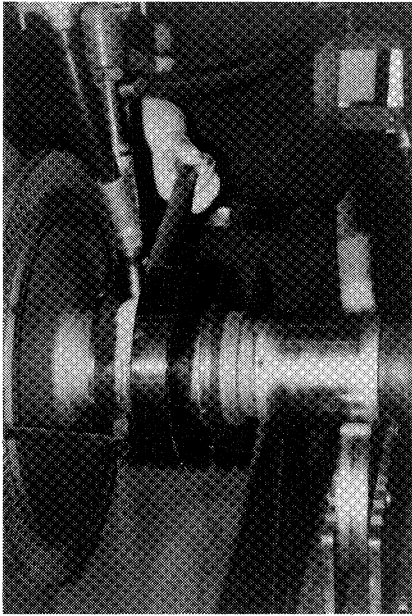


Figure 10. Weld Metal Was Laid Down by Submerged Arc Welding on First One Side Then the Other.

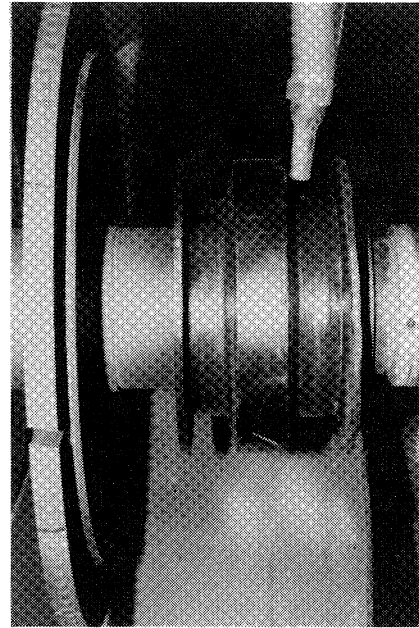


Figure 12. The Total Width of the Buildup Area Was Almost Twice the Thickness of the Remaining Rim.

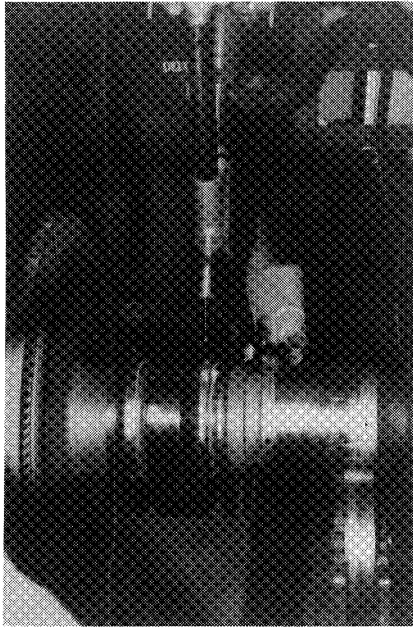


Figure 11. Complete Weld Passes Were Laid Down from Side to Side.

At completion of this first welding sequence, the weld width control rings were machined off, and the welded area was rough machined to required dimensions such that the first buildup area looked as shown in Figure 14.

Next, the welded area was dye checked, ultrasonically tested and magnetic particle inspected for defects and/or inclusions. This was done to make certain that the weld metal of this first stage was sound. The acceptance criteria for these inspections is extremely stringent, sometimes exceeding the specifications for the original forging. Valuable time and effort would be lost if the entire buildup

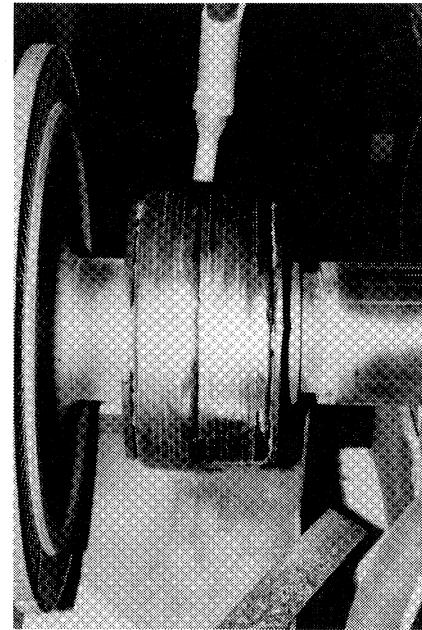


Figure 13. The Remaining Wheel Disk Was Completely Covered with Weld Metal at This Point.

was accomplished in one step and subsequent inspection revealed a detrimental flaw in the lower portion of the weld, which would have to be removed. Therefore, a three step buildup procedure is used on a weld of this magnitude.

Stress relieving was accomplished using adaptable resistance heaters and insulating blankets (Figure 15). The temperature rise rate, soak time, temperature and cool down rate are computer controlled to ensure compliance with stress relief specifications. The computer controller system setup utilizes redundant thermo-

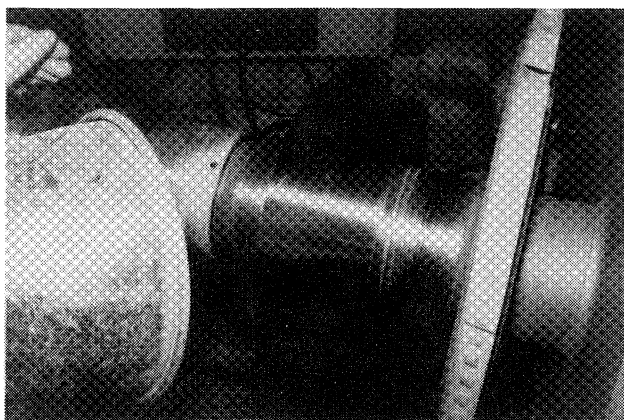


Figure 14. At the Completion of this Buildup Sequence, the Blank Was Machined to Rough Dimensions and Prepared for NDT Testing to Assure Quality Welding.

couples with a maximum temperature alarm system to prevent damage from thermocouple burnout and subsequent temperature run away. The stress relief of the first lay up was done at a slightly higher temperature than subsequent treatments so as to control hardness in the HAZ.

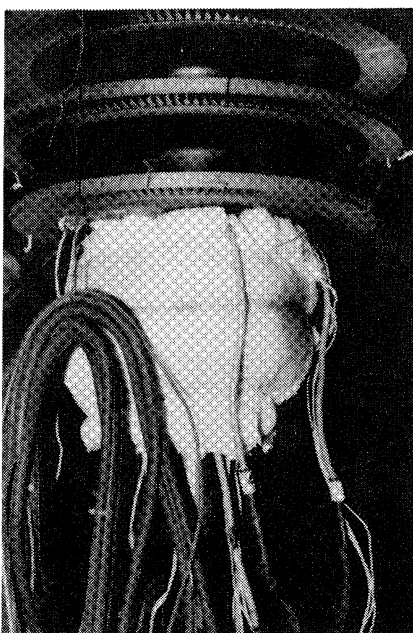


Figure 15. The Machined Built up Area Was Stress Relieved Using a Computer Programmed Heating and Cooling Schedule Designed to Develop the Required Physical Properties.

The next lay up of weld metal required use of copper welding dams as shown in Figure 16. A simple arrangement was used consisting of two copper faces that rode against the buildup area on either side of the weld point, so as to maintain the flux around the weld puddle until it solidified (Figure 17).

The second buildup area is easily seen compared with the machined area of the first buildup area (Figures 18 and 19). After rough machining, the two areas were as shown in Figure 20. As with the first sequence, the second buildup was nondestructive test (NDT) inspected to ensure an acceptable weld before proceeding with the final sequence.

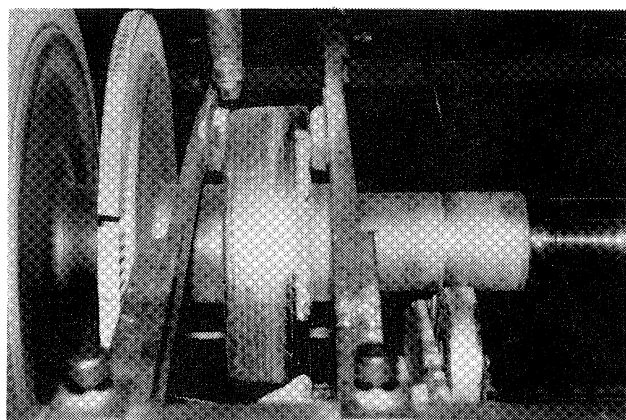


Figure 16. Copper Welding Dams Were Used to Retain the Weld Metal in the Next Buildup Sequence.

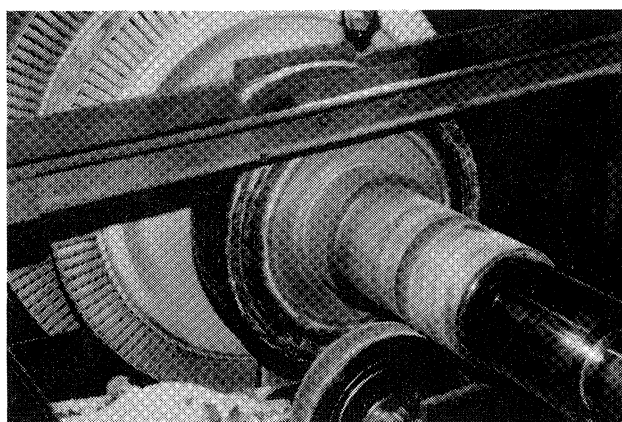


Figure 17. The Welding Dams Were Designed Such That They Could Be Adjusted for Height As the Buildup Grew.

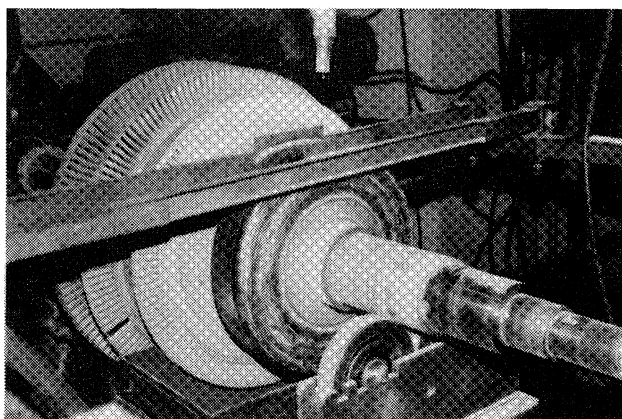


Figure 18. The Second Pass Buildup Was Deeper Than the First.

Lay up of the third and final weld area was accomplished in a similar fashion, using copper welding dams adjusted to the new weld elevation (Figures 21 and 22). Post weld rough machining of the wheel blank was as shown in Figure 23. The final weld buildup was again NDT inspected, and the blank was then further rough machined prior to stress relieving as shown in Figure 24.

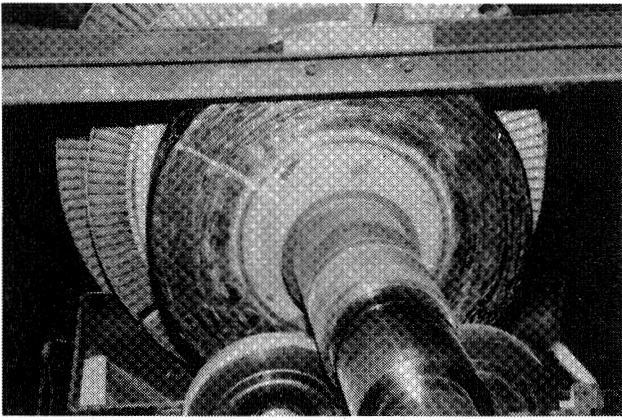


Figure 19. Closeup View of the Buildup Showing the First and Second Sequences.

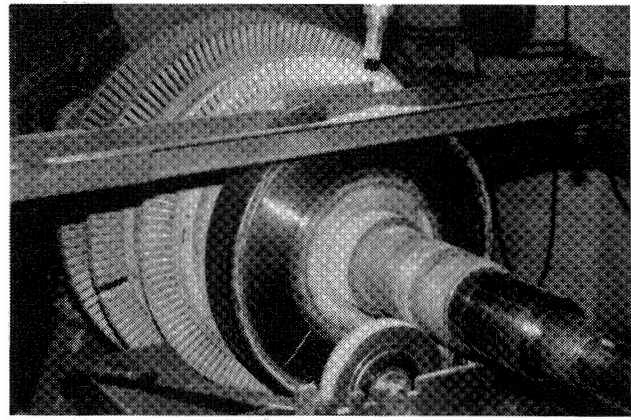


Figure 22. End View of the Added Buildup after a Few Passes of the Third Sequence.

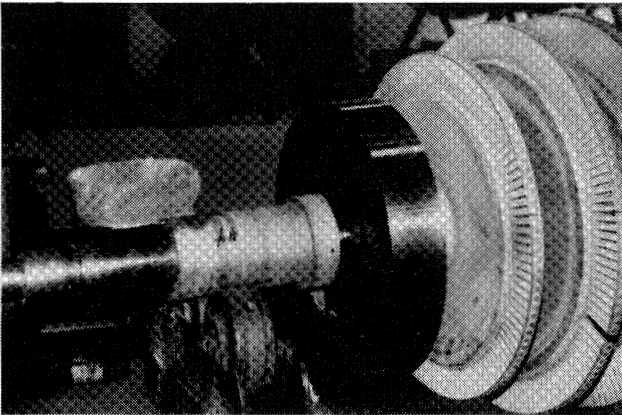


Figure 20. The Blank after Machining the Second Sequence of Buildup.

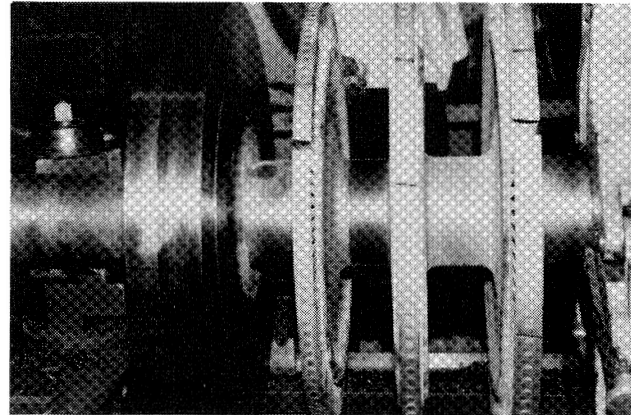


Figure 23. View of the Buildup after Rough Machining the Third Sequence.

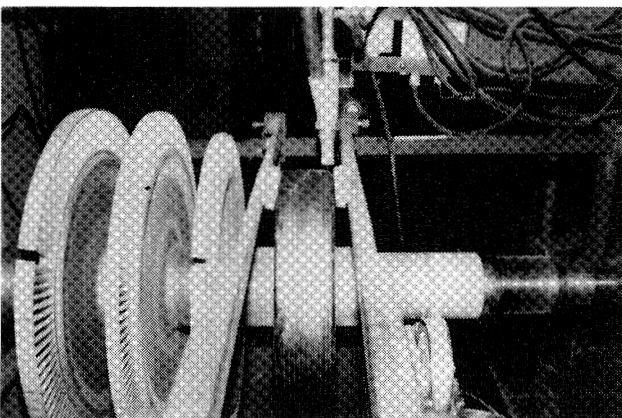


Figure 21. Cross Section View of the Buildup at a Complete Pass on the Third Sequence of Buildup.

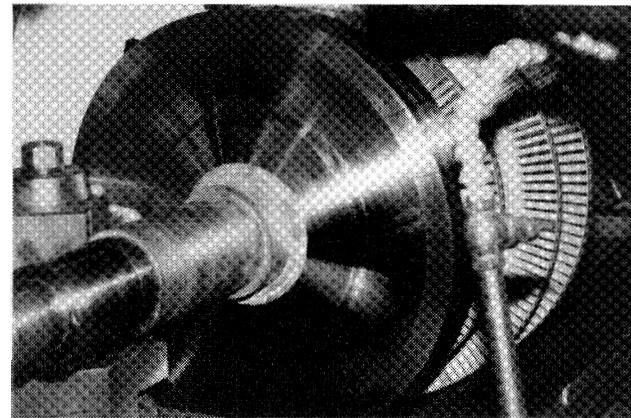


Figure 24. The Blank after the Third Sequence of Buildup As It Was Ready for Stress Relieving.

After stress relieving, the wheel blank is ready for machining to the proper cross sectional dimensions, after which it appeared as shown in Figure 25. Note the curvature of the side walls.

After all machining was completed, the repaired and machined wheel was shot peened to provide additional surface stress control.

This process places the surface in compression to help offset the future possibility of stress corrosion cracking.

The blades were loaded into the Curtis wheel (Figure 26), the shrouds installed, and the tenons peened, using controlled induction heating and an automatic orbital tenon forming machine (Figure 27).

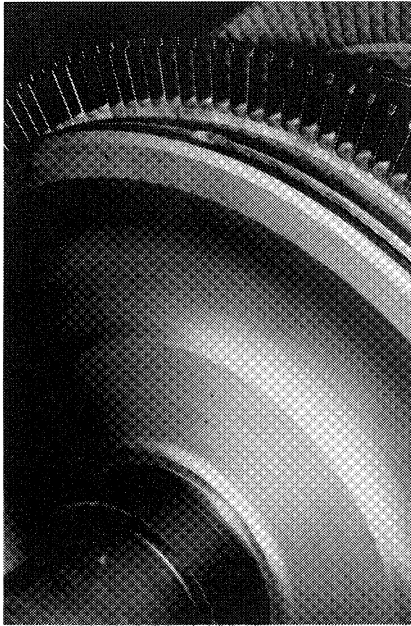


Figure 25. End View of the Buildup Rim after Final Machining, including Slot Machining.

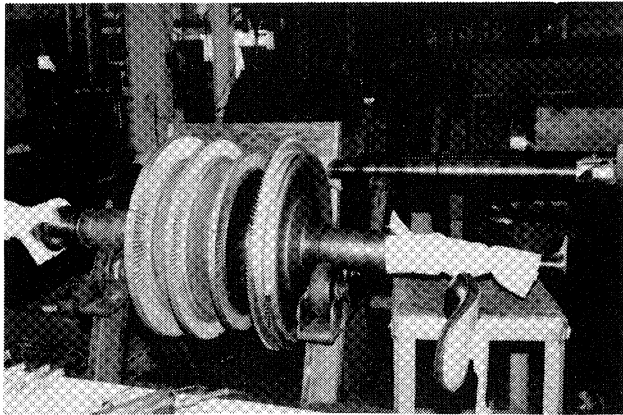


Figure 26. The Rim with Part of One Row of Blades Installed. Note the different thicknesses in the rim.

The completed rotor was then dynamically balanced at operating speed and spin tested up to the designed overspeed trip, setting rpm (Figure 28), after which it was made ready for shipment to the plant site and installed into the turbine case.

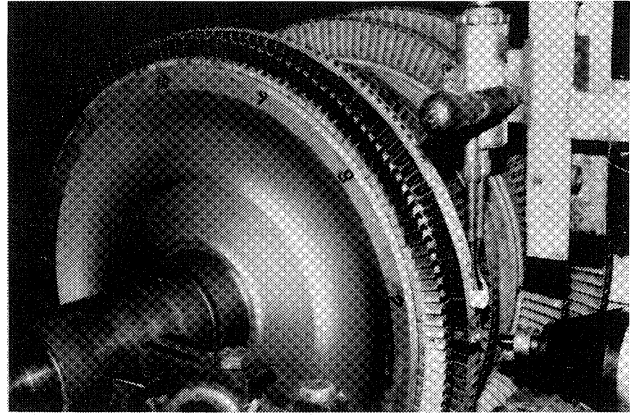


Figure 27. End View of the Rim with Both Rows of Blades Installed and One Row in the Process of Tenon Forming Using Induction Heating and the Orbital Tenon Forming Machine. Note the heater connections hanging down with the ceramic heater head attached.

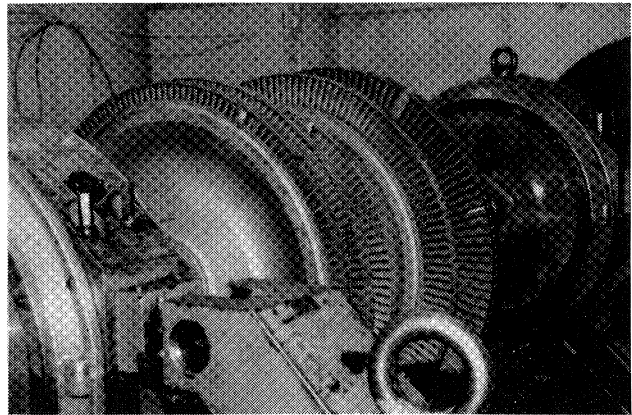


Figure 28. Finished Rotor Installed in the Operating Speed Balance Vacuum Bunker.

This repair returned the rotor to a dimensional and metallurgical condition that is equal to original, with the weld repair heat affected zone located outside of the possibly corrosive steam path. The repair was accomplished in a much shorter time period than the fastest delivery of a new rotor and at a fraction of the cost. At this writing, the rotor has been in operation for seven months with no indications of any problems.

