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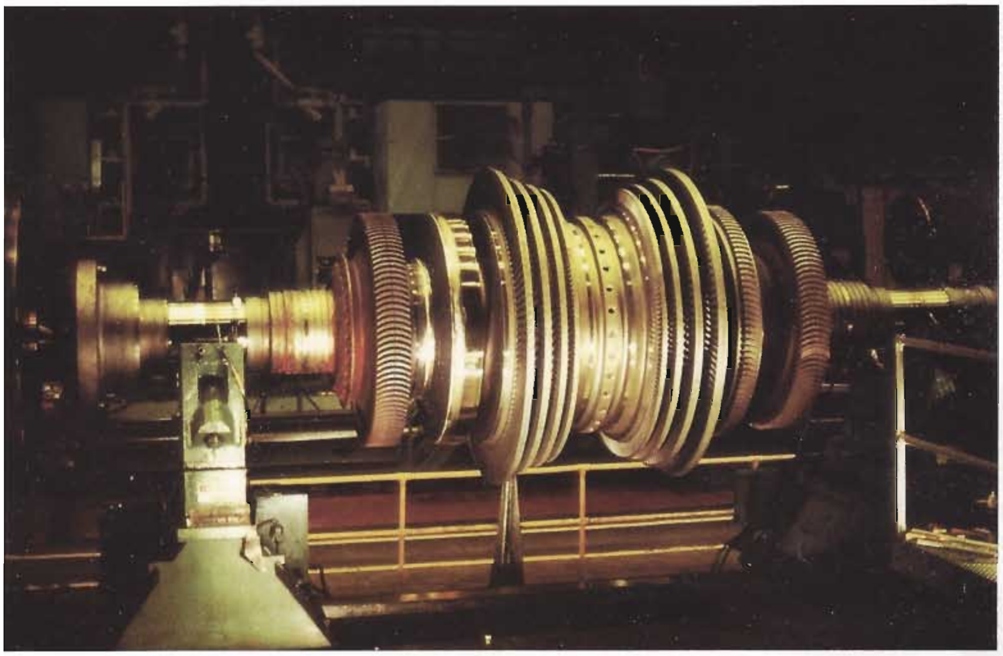

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REFURBISHMENT AND UPGRADING OF STEAM TURBINE ROTOR BLADE ATTACHMENTS BY WELDING

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Abstract

The actual service lives and/or operating capacities of steam turbine rotors in some cases are adversely affected by service-induced distress in the blade attachment areas. The causes for this distress have included stress corrosion cracking, hard particle erosion, rubbing contact between rotor and stationary parts and fatigue cracking.

In recent years, advanced methods have been used to rebuild the blade attachment areas of rotor forgings with high-integrity weld deposits which meet or exceed the material properties of the base metal [1]. This has provided a lower-cost, shorter lead-time alternative to rotor replacement or reduced turbine capabilities.

Topics including applications to high- and low-pressure rotors, verification testing, actual experience with weld restorations, and process improvements are described.

Introduction

Previous papers (2, 3, 4, 5) have described our initial qualification procedure, fabrication sequences, and weld properties for both low-pressure (NiCrMoV) and high-pressure (CrMoV) rotor repair welds. Since these papers were issued, a significant number of low-pressure and high-pressure rotor repair welds were made to correct in-service distress and to accommodate new blade designs where the blade attachment changed. The various blade designs require different amounts of weld metal to be deposited. This can result in a significant volume of weld metal. All welds have been made by the automatic gas tungsten arc weld process.

Several development programs have been completed in the low-pressure and high-pressure rotor welding programs, and several more are in progress. The recent programs are directed toward increasing the weld deposition rate with no increase in weld properties or weld quality. Other programs are aimed at improving in-process control and monitoring of the weld process.

The rotor weld repair program design specifications require that the developed weldment properties are equivalent to rotor properties and/or rotor design allowable stresses to help avoid weld concerns over the life of the weld-repaired rotor. For low-pressure rotors, the weldment concerns are: stress corrosion cracking; high-cycle fatigue; fracture toughness; and temper embrittlement. For high-pressure rotors, the weldment concerns are: creep-rupture; low-cycle fatigue; high-cycle fatigue; fracture toughness; and temper embrittlement. These concerns have all been thoroughly evaluated and are discussed herein.

History Of The Rotor Weld Program

A significant number of weld repairs have been made to areas of steam turbine rotors and discs. To date, our repair welds on high-pressure rotors have been made predominantly on blade attachments in the control stage area. For 360° weld build-up replacement of the blade attachments, we have made the following number of repair welds:

Type Repair Weld	Number of Rows
LP - 360°	86
LP - ruggedized - 360°	26
HP - control stage - 360°	20

The cross-section configurations for typical welds are shown in Figure 1.

One of the rotor repair welding requirements for each family of repair welds is a full-size mock-up that is welded, nondestructively examined, postweld heat-treated and mechanically tested prior to welding an actual component. In addition to the three types of repair welds listed above, full-size mock-ups have been made on a variety of other configurations.

Welding Of Low-Pressure Rotors

Design Considerations For Low-Pressure Rotor Welds

Low-pressure rotor welds are made on all parts of the rotor forging and various disc forgings. Properties such as stress corrosion cracking, high-cycle fatigue, toughness, and fracture mechanics are controlled by the filler material and the welding process. The filler material is matched to the particular rotor being welded. A detailed description of the testing

Low-pressure rotor welds are made on all parts of the rotor forging and various disc forgings. Properties such as stress corrosion cracking, high-cycle fatigue, toughness, and fracture mechanics are controlled by the filler material and the welding process. The filler material is matched to the particular rotor being welded. A detailed description of the testing and results of these properties is discussed in a later section. Table 1 gives a complete listing of all properties that have been evaluated and tested.

When designing a weld repair for a typical low-pressure (LP) rotor, the following three areas are given special attention for each individual rotor:

- High-cycle fatigue
- Stress corrosion cracking
- Geometry of the Weldment.

High-Cycle Fatigue

High-cycle vibration occurs from both normal operation and from untuned modes of the blades. This requires that the weldment must retain the fatigue characteristics of the rotor material. For a weld to have the necessary fatigue life, it must exhibit the proper grain structure and ultrasonic soundness. Testing has confirmed that the right choice of filler metal will yield properties equal to or better than the rotor material. All welds are inspected to the same ultrasonic calibration level that is used for the rotor forging. Multiple inspections are performed to verify the soundness of the weld deposit and heat-affected zone (HAZ).

Stress Corrosion Cracking

Another primary concern for many of the LP rotor weld repairs is stress corrosion cracking (SCC). Many of these welds are located on the last two rows of the turbine, where SCC is most common. While SCC may exhibit preferential attack on areas of high hardness and high stress, two techniques are utilized to address this concern. In welds on the LP rotor alloy, the HAZ is considerably harder than the weld or rotor material. This problem is treated two ways. First, the HAZ is located at a position below the bottom of the attachment grooves to lower the stress level, since SCC is aggravated by higher stresses. Second, although the HAZ is still harder than the rotor material following postweld heat treatment, its extremely fine-grain structure resists SCC.

Geometry Of The Weldment

Many of the weldments made on LP rotors are in excess of 600 pounds. These large volumes require that we consider how to shape the weld build-up to reduce high stress concentrations. These concentrations could initiate a crack due to the high residual stress of the multiple weld passes that are deposited. Some designs have required an intermediate machining operation to blend weld fusion lines to reduce stress concentration points. The geometry of the weldment must also allow for contact ultrasonic testing. Weld surfaces must be machined flat to allow for inspection with .50" and 1.00" diameter ultrasonic transducers. The machining of the weld just prior to heat treatment must eliminate sharp edges at the weld fusion lines to properly evaluate fluorescent magnetic particle inspection results. Distortion is also allowed for in the placement of the weld beads on the rotor. Finite element analyses are used to model the behavior of the weldment during welding and stress relief.

Low-Pressure Rotor Materials

The materials shown in Table 2 are suitable for repair welding using the automatic gas tungsten arc weld process (cold wire). The low-pressure alloys are the complete range of commercial NiMoV and NiCrMoV alloys. We have successfully

The materials shown in Table 2 are suitable for repair welding using the automatic gas tungsten arc weld process (cold wire). The low-pressure alloys are the complete range of commercial NiMoV and NiCrMoV alloys. We have successfully made various repair welds on most of these compositions.

Testing of Filler Metals For LP Rotor Welding

For every weld wire heat that is applied to a rotor, tensile and Charpy V-notch tests are conducted. Tensile tests are conducted over a range of postweld heat treatments. Thus, each heat of filler wire is categorized in its yield strength response to various postweld heat treatments. The weld yield strength for each particular rotor repair weld can be predicted before welding by selecting a particular weld wire heat, review of the rotor final tempering temperature and selection of the postweld heat treatment. Weld wire heats that meet the weld wire material specification limits cover a yield strength range of 90 to 125 ksi when using various heat treatments. The yield strength for the various postweld heat treatments can also be quickly estimated from the chemistry and postweld heat treatment temperature by use of a regression analysis developed from empirical data on numerous filler wire heats.

Welding Of High-Pressure Rotors

Design Considerations For High-Pressure Rotor Welds

The majority of weld repairs that have been made on high-pressure rotor alloys have been to the control stage to facilitate a design change from side entry to triple pin configuration. This row is the first to accept steam, which results in operating environments of the highest temperature and the highest stress. Only rotors that do not suffer from severe temper embrittlement, fatigue damage, or other irreversible damage are considered for weld repair or modification.

The two most important criteria considered when a weld repair to a high-pressure rotor is proposed are: (1) stress in the heat-affected zone (HAZ) and (2) operating temperature. These criteria have been accepted as the limiting factors because the main failure mechanism in the blade attachment areas is creep. Other factors such as low- and high-cycle fatigue, fracture toughness, and temper embrittlement are considered when designing the exact configuration of the repair to the blade attachment areas.

Before a weld can be placed on the rotor, a stress analysis of the control stage area is performed to determine the location of the lowest stresses in relation to the actual blade attachment area. This analysis takes into account that the welded rotor is at its lowest point of the residual stress when it is at soak temperature during the postweld heat treatment cycle. As the weld cools down, residual stresses are induced due to the differences in thermal expansion between the weld and the rotor. Some of these stresses are reduced when the rotor is elevated to the operating temperature in service. These residual stresses are then added to the other stresses that are common to normal control stage areas.

Because the HAZ of the weld is the weakest point in high-pressure rotor welds, it is placed in the zone that would receive the lowest stresses (in the control stage area) in service. This area is usually .50" to 1.00" below the attachment point of the blades and from fillets and other high-stress concentration areas. If the in-service operating temperature is above a predetermined value, a special weld layering technique is specified to optimize the HAZ properties. Qualification tests for the high-pressure rotor welding program were conducted on specimens through thickness across the weld, HAZ and base metal.

Low-cycle and high-cycle fatigue life are not normally calculated for each repair, provided the weld metal tests for that particular heat fall into the normal range for this alloy. If any flaws are discovered by ultrasonic testing, they are treated the same as in new rotors and are evaluated against crack growth rate studies and tests that have been performed. Unacceptable indications are removed according to our normal repair methods.

High-Pressure Rotor Materials

The high-pressure rotor composition listed in Table 2 is typical of rotors made since the early 1950s. This alloy is more difficult to weld and requires careful attention to details.[4]

Testing Of Filler Metals For HP Rotor Welding

For high-pressure rotor filler metal, we perform several all-weld stress-rupture and tensile tests to confirm that the heat will meet strength requirements following the postweld heat treatment.

Verification Testing Of Low- And High-Pressure Rotor Welds

A variety of tests were conducted on welded plates and full-size component mock-ups to verify that the mechanical properties of the weldments would meet low-pressure and high-pressure rotor design allowable stresses. Weld test plates were generally 2 to 3 inches wide by 2 inches thick by 8 to 12 inches long. A 2–3 inch thick weld build-up was made on the plates. Full-size mock-ups were made of each type weld configuration to confirm test plate properties. Typical tensile and Charpy V-notch impact properties for low-pressure (NiCrMoV) rotor welds and high-pressure (CrMoV) rotor welds using gas tungsten arc welding are shown in Table 3. Data shows the welds to be equivalent or better than the base metal for these properties. Specimens were oriented to test all-weld and through thickness weld directions to evaluate both areas of the weld.

High-Cycle Fatigue

High-cycle fatigue tests were conducted transverse to the weld for both low-pressure and high-pressure weldments. Tests were run with the test gauge centered at the fusion zone (to test weld, fusion zone and base metal) and with the test gauge being all weld metal. Test conditions were as follows:

	Low Pressure	High Pressure
Mean stress (ksi)	0 and 40	0 and 30
Environment	Air at 75°F Low O_2 steam*	Air at 75°F Air at 950°F
Run-out	Air 10^7 cycles Low O_2 steam* 10^8 cycles	Air at 75°F 10^7 cycles Air at 950°F 10^8 cycles

*20 ppb Oxygen at 212°F

Test results are shown in Table 4, where they are normalized to the base metal. Yield strengths for the low-pressure weld and base metals are equivalent, and for high-pressure, the weld yield strength is 105 ksi and the CrMoV rotor yield strength is 95 ksi. Data shows the low-pressure material and weld metal have equivalent fatigue limits. Tests were also taken transverse to the weld with the fusion zone and heat-affected zone at the specimen gauge mid-length. These tests all failed in the weld; thus, the fusion zone and heat-affected zone were not the weak link in the LP weldment.

For the high-pressure weld, the high-cycle fatigue tests showed a slightly lower fatigue limit. This lower fatigue limit occurs as the heat-affected zone is slightly overtempered during the weld process. A slight, overtempered HAZ is preferred over insufficient tempering, which can cause stress relief or reheat cracking.

Low-Cycle Fatigue

All-weld and transverse-weld low-cycle fatigue tests were conducted at 75°F, 800°F and 1,000°F on high-pressure rotor weldments. Results show:

- All-Weld. Properties exceed base metal over the entire strain range tested.
- Transverse-Weld. Properties are equivalent at low-strain ranges, and the transverse weld is about 10% lower at high-strain ranges.

Stress Corrosion Cracking

Stress corrosion cracking tests were conduced on low-pressure weldments. These tests were as follows:

(a) r_{SCC} tensile tests - to determine long-time stress dependence of cracking and the relative SCC ranking between the various weldment zones;

(b) U-bend tests - to screen long-term cracking susceptibility of weld materials under high-strain conditions; and
(c) K_{ISCC} tests - to analyze the rate of SCC crack growth in the various weldment zones at several initial stress intensity levels.

Environments consisted of:

(a) de-aerated 230°F, 28% NaOH + 3.5% NaCl;
(b) 350° pure water; and
(c) 350°F water + 3.5% NaCl.

The result of the initiation-type SCC tests are as follows:

- The HAZ was little affected by stress corrosion initiation. This is probably a reflection of a very fine-grain size in this zone.
- The K_{ISCC} tests in pure water indicate that the weld is about the same or slightly inferior to the base, and the heat-affected zone is inferior to the base in stress corrosion resistance. However, all three locations exhibit crack growth rates well below the minimum crack growth rate measured on new materials. This crack growth rate is used for determining acceptable turbine life.
- The K_{ISCC} tests in a caustic environment indicate that the weld and heat-affected zone have somewhat better stress corrosion resistance than the base metal.
- The overall indication of the K_{ISCC} tests is that the weldment is very acceptable in terms of stress corrosion resistance. This is based on the fact that there are not large differences in crack growth rates between locations, and more importantly, that the growth rates in water at all three locations are very low in the context of turbine life, and compared to existing data, on the NiCrMoV steel.
- The weldment exhibits relatively little galvanic corrosion.

The result of the crack growth rate SCC tests for low-pressure weldments are as follows:

- The K_{ISCC} tests for the weldment in pure water indicate that the weld is about the same or slightly inferior to the base, and the HAZ is inferior to the base in stress corrosion resistance. However, all three locations exhibit crack growth rates well below the minimum crack growth rate measured on new materials. This crack growth rate is used for determining acceptable turbine life.
- The K_{ISCC} tests for the weldment in caustic indicate that the weld and HAZ have somewhat better stress corrosion resistance than the base.
- The overall indication of the K_{ISCC} tests is that the weldment is very acceptable in terms of stress corrosion resistance. This is based on the fact that there are not large differences in crack growth rates between locations, and more importantly, the growth rates in water at all three locations are very low in the context of turbine life, and compared to existing data, on NiCrMoV steel.

Fatigue Crack Growth Rate

We have conducted an in-depth study of the fatigue crack growth rate properties of both the low-pressure and high-pressure weldments, including heat-affected zone and weld, and compared them to base metal properties. Environments used were:

(a) Air at 230°F and 75°F;
(b) pressurized water at 350°F; and
(c) 28% NaOH + 3.5% NaCl at 230°F.

Compact-type specimens were machined to test the weld, HAZ and base metal. For low-pressure weldments, the results are as follows:

- Fatigue crack growth rates of the base, weld, and heat-affected zone materials in the air and water environments were found to be essentially comparable, irrespective of test temperature and R-ratio.

- In the caustic solution at R = 0.1, the crack growth rates were nearly identical in the three materials. At R = 0.8, the near-threshold crack propagation rates in the base material were the fastest, while those in the heat-affected zone were the slowest.

- In the air and caustic environments, increasing the R-ratio from 0.1 to 0.8 increased the rates of crack propagation. Decreasing DK increased the effect of R-ratio on crack growth rates. Interestingly, the R-ratio effect is minimal in the water environment.

- Increasing the temperature from 75°F to 230°F generally increased the air-environment crack growth rates. Decreasing DK increased the influence of temperature on crack propagation rates.

- The crack growth rates in the air and water environments were comparable regardless of the test material. In each material, the rates of near-threshold crack propagation in the caustic environment were slower than those in the air or water environment.

For high-pressure weldments, the results are as follows:

- The air-environment, near-threshold crack propagation rates of the base material were found to be generally slower than those of the weld or HAZ material. Decreasing DK increased the influence of material on crack propagation rates.

- Increasing the R-ratio from 0.1 to 0.8 increased the rates of air-environment, near-threshold crack propagation regardless of test material. Decreasing DK increased the effect of R-ratio on crack growth rates.

Creep Rupture

Creep- and stress-rupture tests were conducted on high-pressure rotor weldments in the all-weld and transverse-weld test directions. Test durations exceeded 40,000 hours for the all-weld tests, and 20,000 hours for the transverse-weld test direction. Results of the tests are plotted in Figures 2 and 3. The data shows:

- All-Weld. The rupture strength is on the high side or well above the data base for CrMoV rotors.
- Transverse-Weld. The rupture strength is slightly below the lower data band for CrMoV rotors. All failures

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occurred in the heat-affected zone.

The Heat-Affected Zone

Test data obtained during all phases of the low-pressure rotor development program show the heat-affected zone has properties equal to the base metal.

For the high-pressure rotor weld program, all transverse-weld tests failed in the heat-affected zone; thus, this zone is the low-strength area of the weldment. Only the Charpy V-notch impact properties were improved over the base metal, perhaps because of its lower yield strength. A weld development program was conducted to improve the heat-affected zone strength and has resulted in a significant improvement in the transverse-weld, heat-affected zone stress-rupture properties. This program consists in varying the weld parameters over the first 12 layers of weld.

Recent Weld Process Improvements And Techniques

Several improvements to the original rotor repair process have been made over the last four years and have resulted in lower cost and cycle times. These improvements enable the utility to return their rotor to service in a shorter amount of time without paying a premium for a compressed schedule.

The Gas Tungsten Arc Welding (GTAW) process, while producing a high-quality weld, has very low deposition rates and resultant long lead times and high labor cost. Three separate programs were initiated to address these problems:

- Continuous high-purity gas supply
- Increased feed rates
- Dual torch.

During a typical rotor repair process, hundreds of bottles of welding gas were used. This frequent changing of gas bottles increased labor costs and provided an opportunity for contamination in the gas lines each time the lines were disconnected and reconnected to the bottles. A bulk Argon and bulk Helium gas system was installed, which produced the benefits of continuous gas supply and consistent research grade gas without the lines being disconnected. Gas supply problems are now nonexistent.

The low deposition rates of the GTAW process were addressed in two ways. First, a program to increase the wire feed rate to almost double the qualified rate was initiated. After testing the higher deposition welds to the same stringent criteria as the original qualification welds, the process was determined to produce weld equal to the original process in every respect. The deposition rates for production welding increased 94%, resulting in almost a 50% reduction in cycle time. The second program developed a method to have two torches acting on the weld with two separate arcs controlled by one operator. Presently operators are being trained with the new equipment that should be on-line in early 1992. This program promises a 40% further reduction in cycle time on many of the L-0 and L-1 row repairs.

In addition to lower cost and improved cycle time, three other programs were initiated, specifically aimed at statistical process control (SPC) and in-process inspection.

The rotor repair business is not a high-volume, assembly-line environment and, thus, does not lend itself to typical SPC methods. The first program was a statistical-designed experiment where each of the variables of the welding process was evaluated to determine which one(s) had the most effect on the welding process. The results of this program were then used in a second program that installed real-time sensors on the key variables to monitor the inputs into the welding process. Ranges can then be set based on statistical analysis of the data collected, and alarms can trigger the operator to an out-of-limit (out-of-control) condition.

then used in a second program that installed real-time sensors on the key variables to monitor the inputs into the welding process. Ranges can then be set based on statistical analysis of the data collected, and alarms can trigger the operator to an out-of-limit (out-of-control) condition.

The third program is a new immersion ultrasonic testing system that has been developed and which is able to inspect the weld in the as-welded condition with only a very brief delay in the welding operation and is performed on location in the rotor welding area. Many inspections can be completed during the time the rotor is in the area, thus verifying that no deep indications will be found at final inspection. Investigation is underway to determine if the system can be adapted for real-time ultrasonic inspection.

Nondestructive Examination

Nondestructive examination of the repair welds is used to verify the absence of indications that degrade the quality of the weldment. It is required that the weld nondestructive examination quality be equal to the rotor forging. Two nondestructive examination techniques are used to evaluate the weld and heat-affected zone. Inspections prior to postweld heat treatment are used to detect porosity, lack of fusion, and cracking which could result from the welding process. The inspections following heat treatment are used to verify the absence of indications that may occur due to delayed cracking or stress-relief effects. A summary of the techniques is as follows:

- Ultrasonic. Used both before and after postweld heat treatment to the rotor acceptance standards.
- Fluorescent Magnetic Particle Inspection. Used before and after postweld heat treatment (after final machining) and is evaluated to the original forging acceptance standards.

The results of the Ultrasonic testing are recorded and charted to track welder performance. For each weld repair, all passes deposited on the rotor are assigned to the welders for that job as applicable. Indications, if found, are charged to the welder who is welding at the time the indication occurred. Welders must weld over 1,300 pounds without two point indications and over 4,000 pounds without two linear indications being charged against them. Welders who fail to meet these criteria are placed into a welder requalification program.

The rotor welding group as a whole is monitored for their collective performance. A chart is kept of how many pounds of weld metal are deposited among the various jobs without an indication that requires repair. In 1991, the chart reached a point of over 25,000 pounds of weld metal deposited without an indication that had to be repaired.

By using the above nondestructive examination procedures, complete volumetric coverage to highly-restrictive acceptance criteria verifies the highest quality in the restored areas.

References

1. United States Patents 4,897,519 (dated January 30, 1990), 4,903,888 (dated February 27, 1990), 4,893,388 (dated January 16, 1990), 4,940,390 (dated July 10, 1990, and 4,958,431 (dated September 29, 1990).

2. R.E. Clark, D.R. Amos and L.D. Kramer. *Weld Repair of Low-Pressure Rotors for Increased Availability.* Presented before the Power Division of the ASME Joint Power Conference, September 30–October 4, 1984, Toronto, Canada.

3. R.E. Clark, J.M. Schmerling, D.R. Amos and L.D. Kramer. *Experiences with Weld Repair of Low-Pressure Steam Turbine Rotors.* Proceedings of the American Power Conference. Volume 47, 1985.

4. E.P. Payson — Allegheny Power Service Corp., Dr. R.L. Novak — Westinghouse Electric Corporation. *Weld Repair Option for Destressed LP Rotors.* Presented at the Pennsylvania Electric Association, 1986.

5. R.E. Clark, R.L. Novak and D.R. Amos. *Developments of the Techniques for High-Pressure Rotor Weld Repair.* Proceedings: Weld Repair of High- and Intermediate-Pressure Turbine Rotors for Life Extension. Electric Power Research Institute GS-6233, Proceedings April 1989 (pp. 2-1–2-15).

5. R.E. Clark, R.L. Novak and D.R. Amos. *Developments of the Techniques for High-Pressure Rotor Weld Repair.* Proceedings: Weld Repair of High- and Intermediate-Pressure Turbine Rotors for Life Extension. Electric Power Research Institute GS-6233, Proceedings April 1989 (pp. 2-1–2-15).

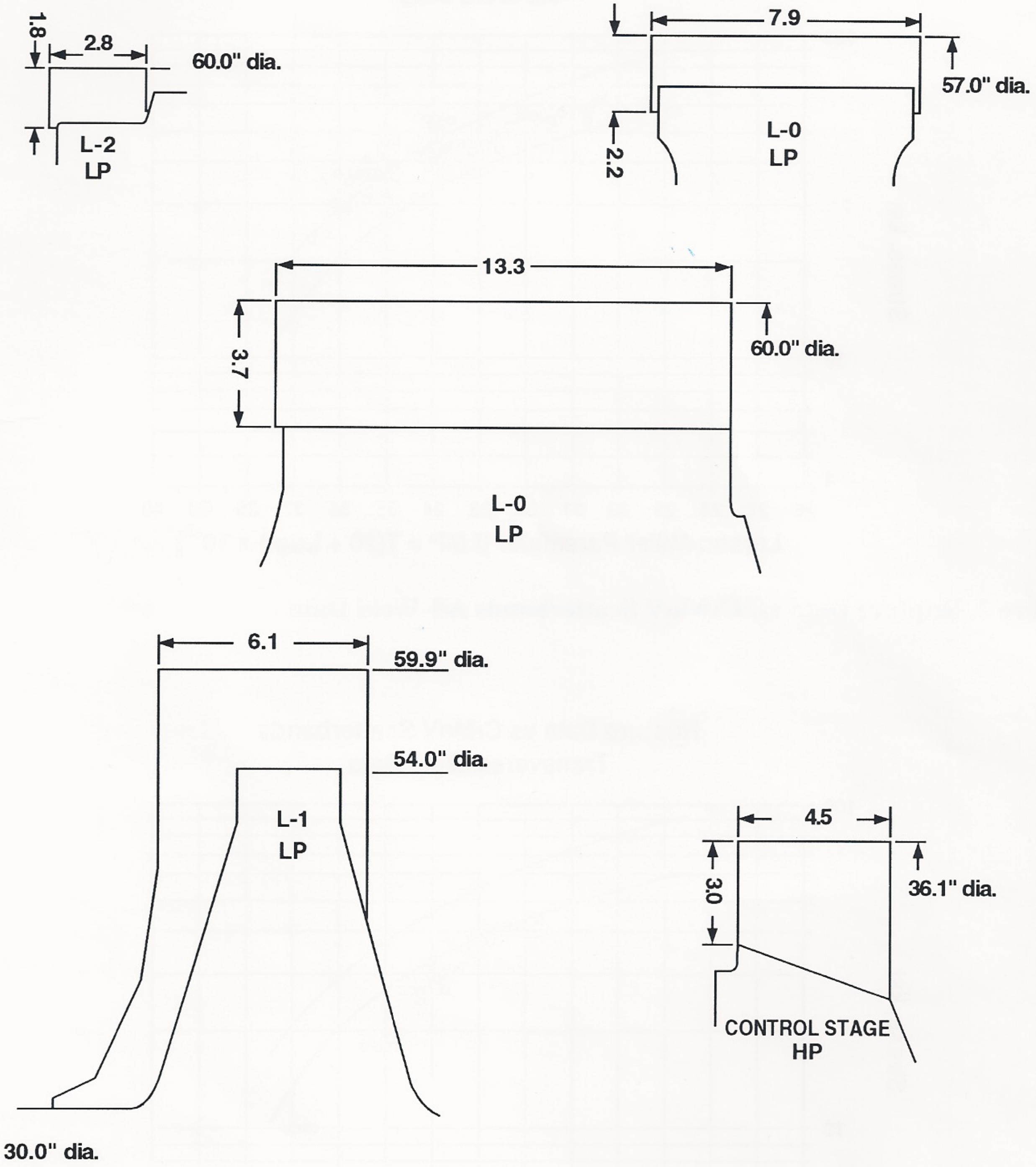

Figure 1. Configuration of Typical LP and HP 360 Blade Attachment Area Repairs

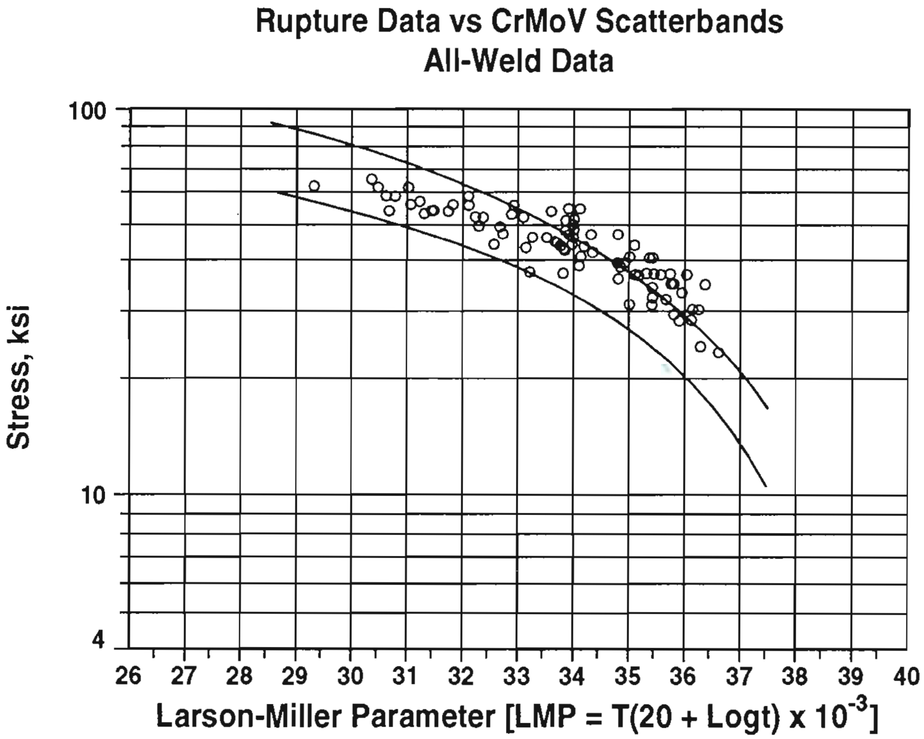

Figure 2. Rupture Data vs. CrMoV Scatterbands All-Weld Data

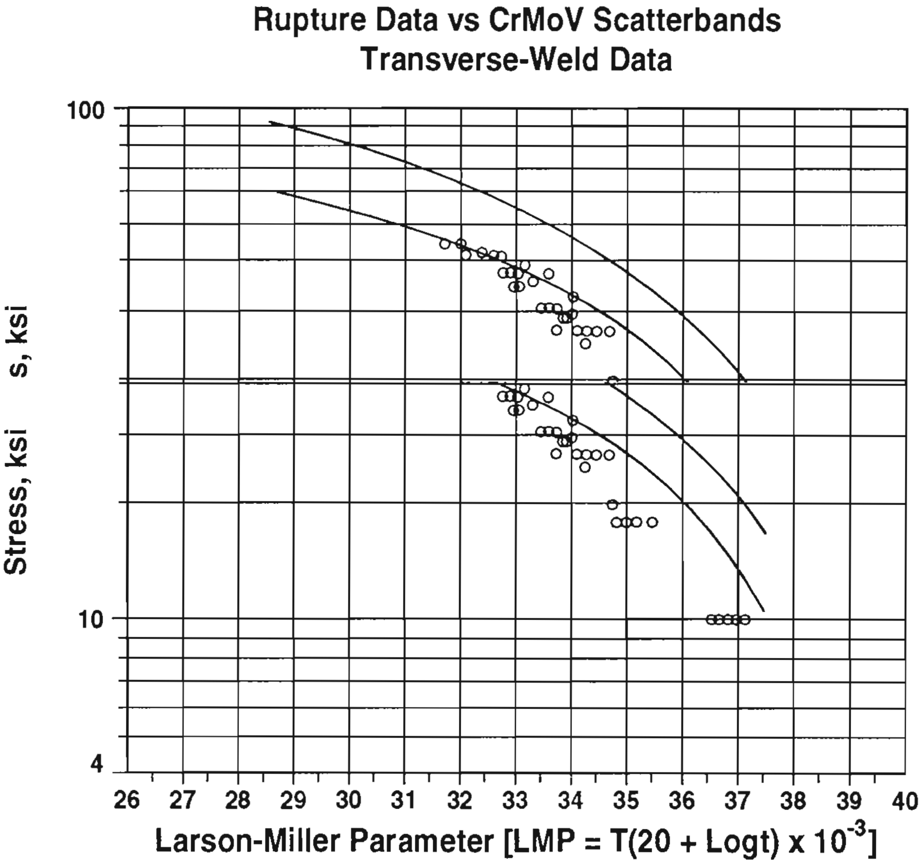

Figure 3. Rupture Data vs. CrMoV Scatterbands Transverse-Weld Data

Area	Engineering Properties Evaluated	LP	HP
Weld	Tensile, Yield Strength	X	X
	Impact Toughness	X	X
	High-Cycle Fatigue	X	X
	Low-Cycle Fatigue	X	X
	Fretting Fatigue	X	X
	Wear	X	X
	Stress Corrosion Cracking	X	X
	Fracture Mechanics	X	X
	Residual Stress Measurement	X	X
	Hardness	X	X
	Microstructure	X	X
	Creep		X
	Stress Rupture		X
HAZ	Impact/Toughness	X	X
	Stress Corrosion	X	X
	Fracture Mechanics	X	X
	Residual Stress	X	X
	Hardness	X	X
	Microstructure	X	X
	Stress Rupture		X
	Creep		X

Table 1.

Comparison Of Properties Evaluated For Low-Pressure And High-Pressure Rotor Materials And Location Of Test

Component Identifications	Generic Alloy Name	ASTM
LP Rotor	2.5 NiMoV	A470, Class 2
LP Rotor	2.5 NiMoV	A470, Classes 3 & 4

Identifications	Generic Alloy Name	ASTM
LP Rotor	2.5 NiMoV	A470, Class 2
LP Rotor	2.5 NiMoV	A470, Classes 3 & 4
LP Rotor	3.5 NiCrMoV	A470, Classes 5, 6, 7
LP Rotor	2.0 NiMoV	A293, Classes 2 & 3
LP Rotor	2.5 NiMoV	A293, Classes 4 & 5
LP Disc	2.8 NiMoV	A294, Classes 2, 3, 4, 5, 6 Grades B & C
LP Disc	3.5 NiCrMoV	A471, Classes 1, 2, 3
HP Rotor	CrMoV	A470, Class 8

Table 2.

Rotor Forging Alloys Suitable For Repair Welding

Low-Pressure Tension	Rotor 1	Rotor 2	Weld	HAZ
0.2% YS, ksi	102	103	100	*
UTS, ksi	118	121	110	*
EL, %	24	21	27	*
RA, %	74	68	74	*
Impact				
75°F, ft. lb.	158	111	150	125
FATT_{50}, °F	-170	-51	-100	-140
High-Pressure Tension				
0.2% YS, ksi	94	101	105	86
UTS, ksi	117	122	125	110
EL, %	16	17	26	15
RA, %	40	46	75	65
Impact				
75°F, ft. lb.	8	10	130	130
FATT_{50}, °F	210	200	-25	-50

*All tests failed in the weld.

Table 3.

Comparison Of Low-Pressure And High-Pressure Weld Tensile And Impact Properties

Low-Pressure (Yield Strength: Weld At 100 ksi; Rotor At 100 ksi)

Test Description	Environment	Mean Stress, ksi	Normalized* Fatigue Limit, ksi
All-weld	Air = 75°F	0	.93
All-weld	Low oxygen steam	0	1.00
All-weld	Air = 75°F	40	1.07
All-weld	Low oxygen steam	40	.92
High-Pressure (Yield Strength: Weld — 105 ksi; Rotor — 95 ksi)			
All-weld	Air = 75°F	0	.96
All-weld	Air = 950°F	0	1.05
All-weld	Air = 75°F	30	1.08
All-weld	Air = 950°F	30	1.22
Trans-weld	Air = 75°F	0	.95
Trans-weld	Air = 950°F	0	.87
Trans-weld	Air = 75°F	30	1.00
Trans-weld	Air = 950°F	30	.87

*These results are normalized in respect to the base metal properties.

Table 4.

Summary Of High-Cycle Fatigue Tests