

# HEAVY SHELL CASTINGS DESIGN/ OPERATION AND REPAIR CRITERIA

by

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that will eventually determine the reparability of a turbine casting, two are of paramount importance, the percentage of low cycle fatigue strength and/or creep rupture strength remaining at the point of failure and the chemistry/casting quality as originally made.

## PRELIMINARY COST COMPARISON

The as delivered cost of a replacement turbine shell casing for a utility size turbine from a domestic original equipment manufacturer (OEM) has historically run from \$12.00 to \$18.00 per pound with a one to two year delivery cycle. Quotations within the past several years indicate that replacement turbine shell casings, i. e., high pressure, reheat or high pressure/reheat combined are generally in the \$1.5 to \$2.5 million range in cost. These prices and delivery cycles may not, however, reflect current costs and times, as both of the major domestic OEMs have disposed of their capability to produce large castings in house and generally now procure such items offshore.

As a general comparison, a major permanent repair to such a casing will cost between \$400 thousand and \$600 thousand and take approximately six to seven weeks to complete. If there is extensive remachining involved, the cost will go up fractionally i. e., \$50 thousand to \$100 thousand, however, the time required may increase by several weeks or more.

It would indeed solve many of the problems in making decisions relative to repair or replace if turbine casings could be broken down into a finite number of categories and then well defined parameters developed that described a finite set of possible problems for each category. Unfortunately, experience has shown that as far as the individual details of exactly how to address a cracking problem in a turbine casing, each must be treated on a case by case basis. In general, the preheat, welding parameters and post weld heat treatment are standard, however, as will be described later, many other parameters will be dependent upon the individual casing geometry and the extent of the repair required.

## OPTIONS (PREVENTION)

The attack on the problem of cracking of existing casings must, of necessity, be twofold i. e., prevention and then if required, repair. The comment earlier about very gradual heating and cooling cannot be understated and is fairly well understood in the industry, if not always practiced; there is, however, another area of concern in prevention. Historically, since much of the final surface of a turbine casting is used in the ascast state, the assumption has been made that the only surfaces that are critical are those that are a machined fit, i. e., blade ring or diaphragm steam fits, gib and key bearing surfaces and steam sealing flange surfaces. Many castings are filled with very sharp internal radii, obliquely drilled holes that penetrate the casing wall with razor sharp edges, sharp false cuts adjacent to finish machined surfaces, etc., and, in general, a lack of attention to the condition of the surface finish on machined surfaces.

## ABSTRACT

Unless the utility industry is prepared as a whole to commit a very large dollar amount to the purchase of new heavy wall castings for turbine casings and valve chests, the use of the art of repair for existing castings will need to be both understood and used in the near future. Existing equipment, some of it well over 40 years old, will need to be operated and in most cases the older the equipment, the more severe this service duty, i. e., cycling.

## OVERVIEW

Turbine casings or chests that contain sections operating above 750°F are subjected to thermally induced stresses that result in distortion and eventually cracking. The materials used are generally cast alloy steels 0.15 to 0.25 C., 1.0 to 2.25 Cr., 0.75 to 1.0 Mo., 0 to 0.25 V. The calculation routine needed to provide mechanical strength to support the assembled parts and to contain steam up to 3600 psi at 1000°F or 1050°F is relatively straight forward. The detail required to control casting geometry, i. e., elimination of abrupt changes in cross-section, right angle transitions, points of shell penetration, etc. can be and is extremely difficult. Once designed and manufactured, if a turbine casing could be very gradually and uniformly heated to operating conditions and then left that way indefinitely, they would probably never fail. Consideration of operating parameters is absolutely critical to prolonging the life of heavy turbine castings. Once a problem occurs, if it is major, the repair effort can be both very costly and very time consuming. Of the factors

All turbine castings should be examined with the thought in mind that any change from a flat, smooth surface is a potential site for crack initiation as the result of low cycle fatigue from thermal cycling.

A view is shown in Figure 1 of the seat area of a control valve. Note the sharp corner left in the casting surface just outboard of the valve seat on the left hand side. Later, NDT identified a crack in this location. In grinding out the crack, the size of the radius in the corner and the general surface finish were improved, however, had the crack been deep it would not have been possible to improve upon the geometry.

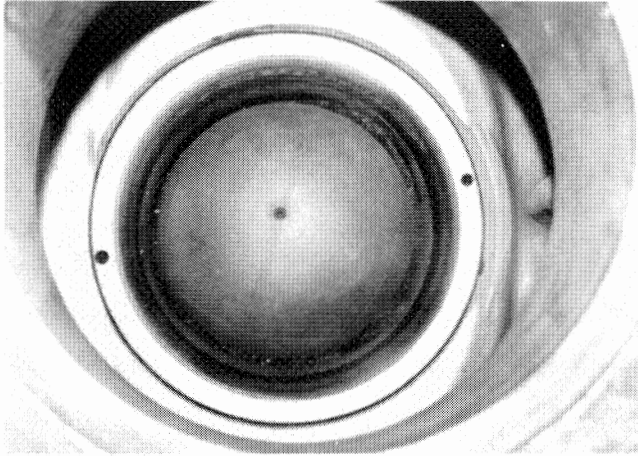


Figure 1. View of Turbine Control Valve Seat with Sharp Internal Corner in Casing Body.

The opening or ledge in a lower half, high pressure shell that contains a nozzle plate is shown in Figure 2. The circled area is an original casting defect that has led to cracking and to the left is a sharp corner that is also cracked. The very same corner in the upper half of the same turbine shell is shown in Figure 3. Note the very poor condition of the machined surface in the area of the crack.

A view is shown in Figure 4 of a similar high pressure casing with its nozzle plate assembled to the left in the photograph. Note the sharp corners in the recess in the casing for the nozzle and the groove with its small radius at the corner of the opening or ledge for the second stage stationary steam path.

It is not too difficult for an individual experienced in turbine inspection to be able to pinpoint the future location of the first crack in a new heavy turbine casing.

#### OPTIONS (REPAIRS)

Once a turbine casting has cracked, there are a number of items that should be considered, such as:

- The projected future for the turbine, i. e., under the framework of power requirements for the particular utility—is the turbine expected to run only five more years or 20 or more years? The answer to this question will usually dictate the method and extent of repair.
- The history of both the turbine duty cycle and any problems through the years with the casting in question—a casing that has had numerous minor temporary repairs through its life that have resulted in scattered heavy cracking in a number of locations is a poor candidate for an extensive repair with the expectation of a reasonable extension of life. On the other hand, a casing that may have deep, serious cracking, but only in one general area, is usually a good candidate for a successful repair.

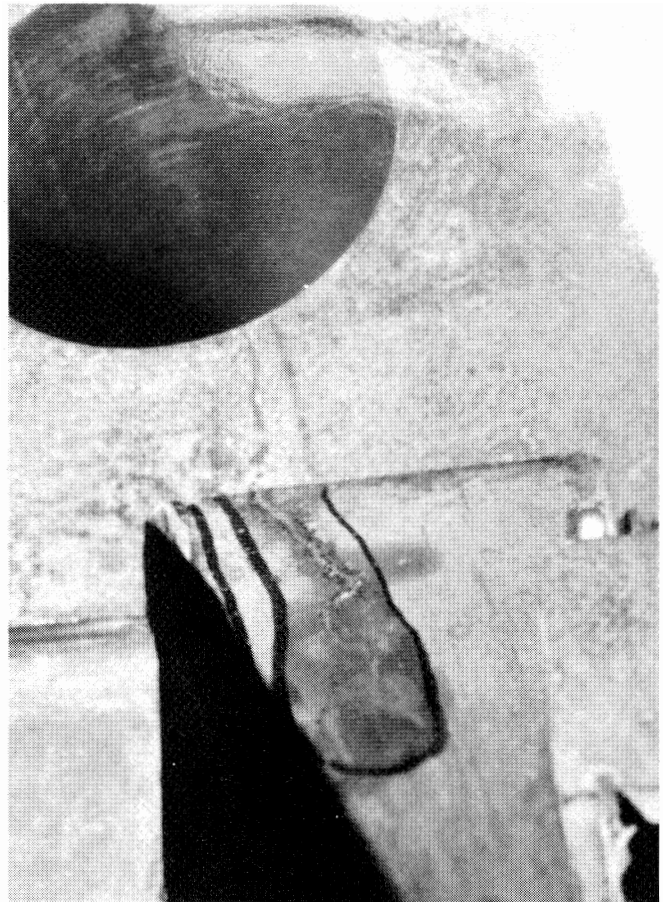


Figure 2. View of Turbine Shell Casting Illustrating Both Old Casing Defects and Sharp Internal Radii.

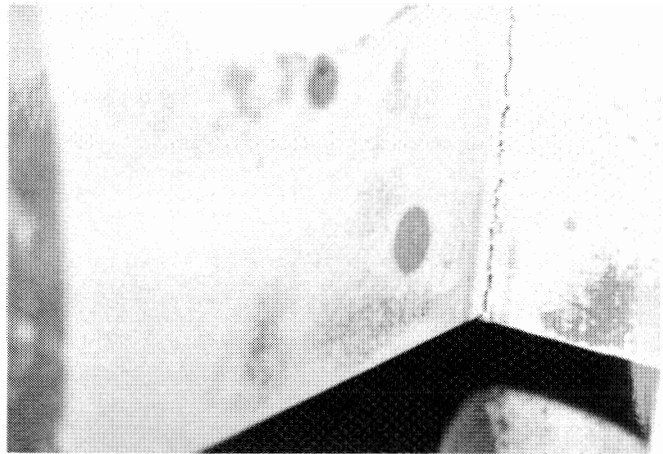


Figure 3. View of Turbine Shell Casting Illustrating Sharp Internal Radius.

- The general condition of the casting in question, i. e., extent of cracking, probable remaining life of whole casting, chemistry, etc. This item is an extension of the second option above and is extremely important. Normally, less than ten percent and in many cases less than five percent of the overall volume of a particular casing is in deep trouble. However, every bit of that five or ten percent may be unusable. The use of surface replication and “boat” samples is a must in determining how

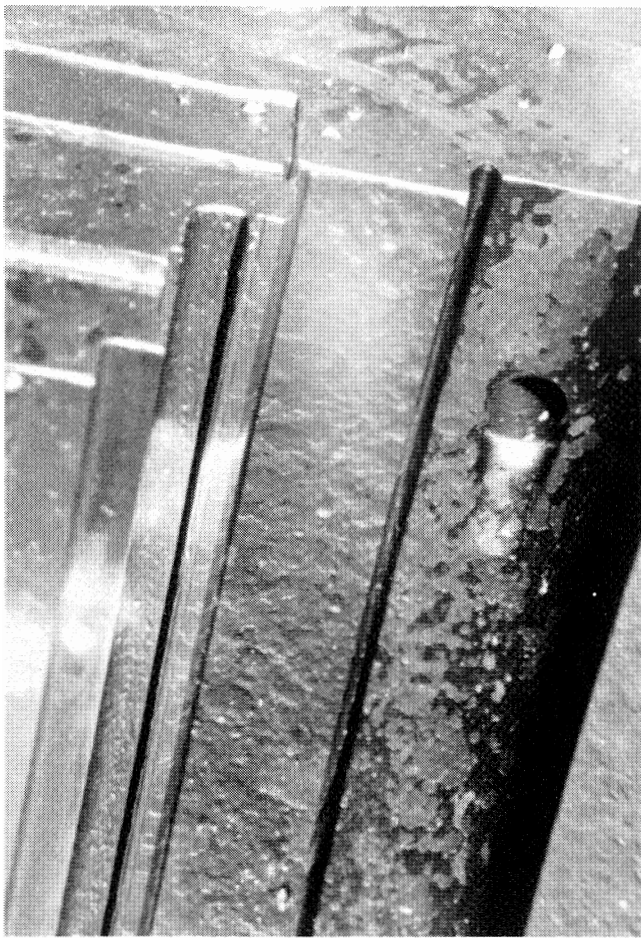


Figure 4. View of Turbine Shell Casting Illustrating Sharp Internal Radii.

much of an existing casting is no longer usable. These methods of investigation can give an accurate picture of the extent of loss of creep rupture strength in particular areas of a casing. It is not practical to attempt major weld repairs on material that exhibits evidence of creep damage. It is possible, however, to remove fairly large areas of damaged material and replace it with either a stress relieved weld deposit or new welded sections. A view is shown in Figure 5 of the internal surface of a high pressure shell casing that is in the process of being surface replicated for evidence of creep damage.

Advances over the last several years in the technique of surface replication have provided a readily available, effective and relatively inexpensive method of evaluating the material properties of castings in question. The material properties of a casting in service as a turbine casing or a turbine valve body will normally deteriorate first at the site of a change in cross sectional geometry, i. e., a relatively thin cross section adjacent to a relatively thick cross-section. Older turbine castings can and do suffer from a number of abnormalities that would not usually be found in a modern "state of the art" casting such as:

- Inattention to geometry which often leads to excessive shrinkage.
- Unfused or unmelted chills, nuts, bolts, etc.
- Higher than desirable carbon content.

As one experienced casting engineer explained, if the casing is old enough, do not be surprised to find part of the refractory wall buried in it.

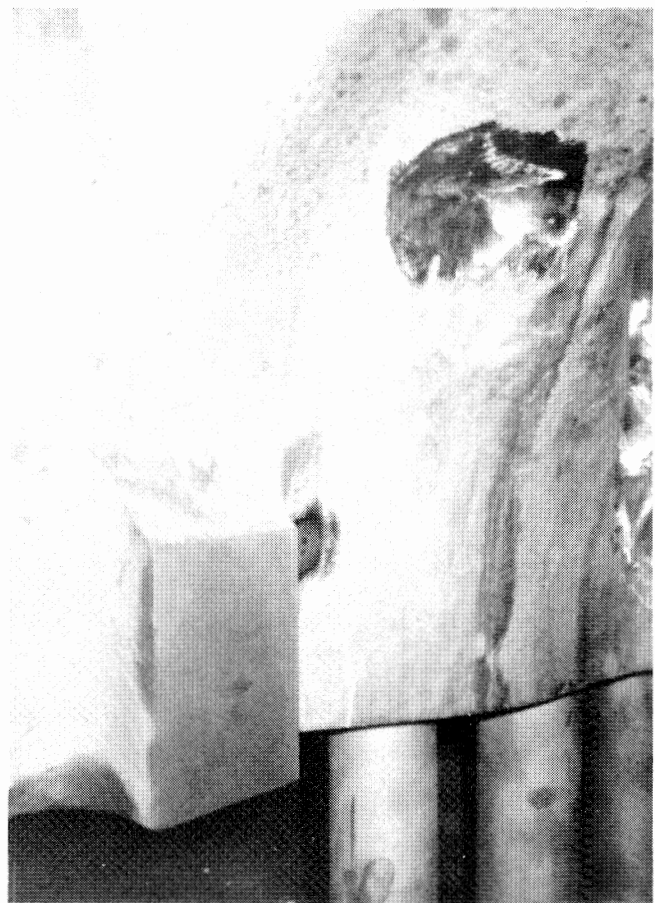


Figure 5. View of Internal Surface of Turbine Shell Casting During Process of Surface Replication.

The actual replication process should involve enough of the casing surface in the general area of all cracking that all areas of deteriorated material properties are identified. In areas of deep cracking, an edge of the crack should be removed in the form of a boat sample that can provide both chemistry and material properties. In addition, nearby areas should also have boat samples removed to obtain information for comparison with the information obtained near or at the cracks. These additional boat samples can be removed from the corners of ledges in the casing or from smooth areas of the casing wall where removal will not encroach upon casing wall thickness.

Once these questions have been addressed, there are a number of differing options available:

- Based upon location and geometry, there are some cracks that are better left alone and neither ground nor weld repaired. These will normally occur in an area where there is no mechanical loading, and the only real stress is induced by thermal gradients at the internal surface of the casting. Cracks that are the result of low cycle fatigue tend to initiate quickly but propagate slowly. The cracked material at the surface of the casting can actually protect or shield the subsurface material from the thermal gradients present at the casting surface. The high thermal stresses on the surface of a freshly ground out crack may be higher than the concentrated stresses at the tip of the crack were it not ground out. It should also be recognized that most cracks will occur at a transition from a smooth surface, i. e., an internal radius and when such a radius cracks, it is seldom possible to make the final radius, after grinding the crack out, anywhere

near as large as the original radius. Views of the inside surfaces are shown in Figures 6 and 7 of a large high pressure casing in the area of the first stage nozzle box inlet openings and support recesses. Most of the internal radii contain surface cracks that are best left alone. A nozzle box support pad location in the same casing is shown in Figure 8. The crack at the back of the support pad shelf is best left alone. A radius in the corner of a stationary blade ring fit that has been sporadically ground in the past to remove cracking (Figure 9). The present cracking is centered in the middle of the old grinding marks. Because of the obvious poor present surface condition, this crack may benefit from blending a generous radius at the bottom of the fit to remove all evidence of cracking. However, when cracking reoccurs, and it will, it should be left alone.

- Localized cracks at abrupt changes in geometry can usually be ground over a series of outages until they become so deep as to present a substantial stress concentration in and of themselves, or they encroach upon the minimum required wall thickness.

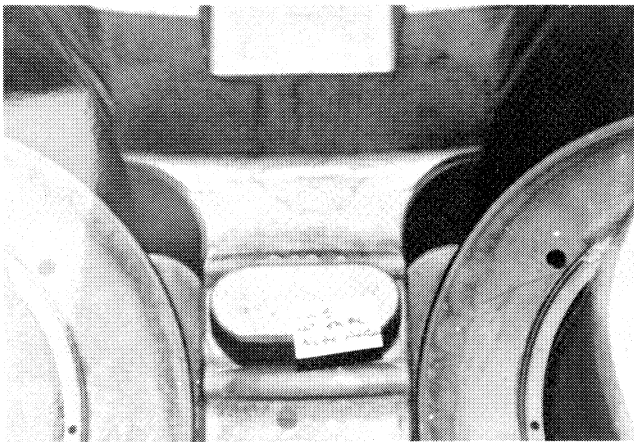


Figure 6. View of Internal Surfaces of Turbine Shell Casting Illustrating Multiple Cracking at Internal Radii.

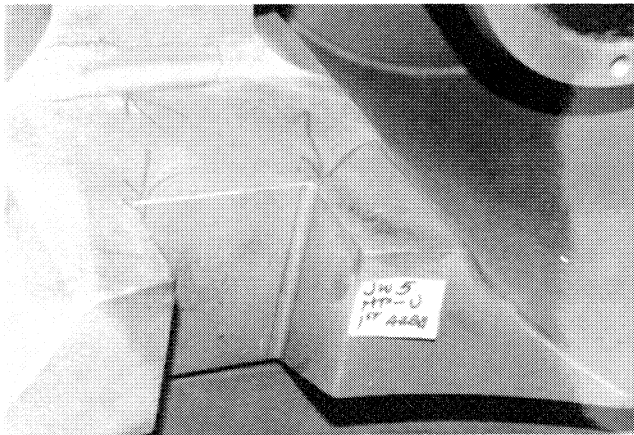


Figure 7. View of Internal Surfaces of Turbine Shell Casting Illustrating Multiple Cracking at Internal Radii.

- Extensive, deep cracking almost always requires weld repair which is normally either an unstress relieved, temporary repair or a stress relieved permanent repair. The unstress relieved temporary repair is usually a locally preheated, high nickel weld deposit of Inconel. There are a number of methods of reducing

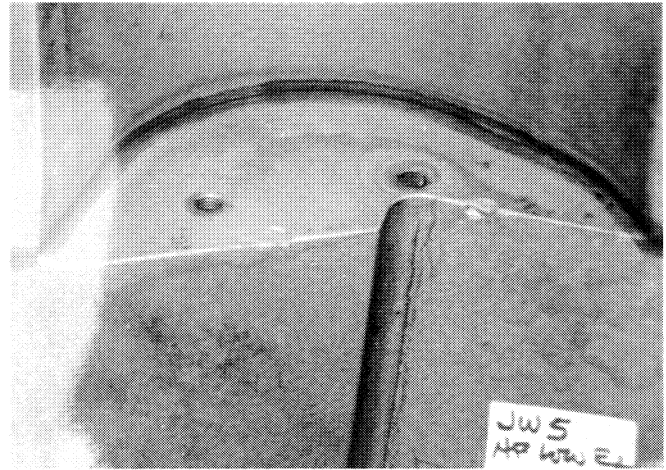


Figure 8. View of Support Pad Recess in Turbine Shell Casting Illustrating Cracking at Internal Radius.

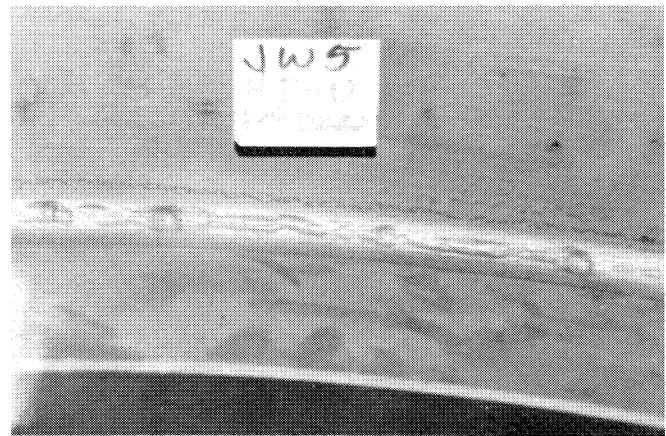


Figure 9. View of Blade Ring Recess in Turbine Shell Casting Illustrating Cracking in Internal Radius.

the final locked in stresses in such a weld, i. e., peening, weld technique, etc. However, there is no procedure/technique to replace the benefits of stress relieving, and as such, these repairs usually result in subsequent cracking at the edges of the weld deposit with time in service. Some of the techniques commonly used to reduce both the likelihood of cracking and the effects of cracks when they occur are spreading the top third of the weld deposit over a wide area or bridging the defect with a welded in plate. The half bead weld technique can be of benefit if properly used. This basically involves laying down all final edge beads at least half bead away from the base metal. To some degree, the heat of the final pass will then hopefully relieve some of the stresses in the edges of the base metal of the casting. A fully stress relieved weld can usually be considered a permanent repair provided the overall quality of the casting is reasonably sound away from the area of repair. When a major repair is warranted on a turbine casing, serious thought should be given to a complete stress relief of the complete casing before attempting the repair and a possible interim stress relief half way through the repair. Both of these stress relief cycles are an attempt to control distortion, and in addition the first stress relief serves to prevent further cracking during the crack removal operation. There are locked up stresses in all turbine shells/casings due to the steady state thermal stresses from turbine operation. Typically there is a 300°F to 500°F thermal gradient over the length of the casing

from inlet to exhaust. The final stress relief will both relieve the stresses of welding and temper both the weld and surrounding heat affect-zone. The basic steps of a major weld repair are quite detailed and each one should receive careful attention for a successful repair.

- Removal of the casing from the turbine means, in the case of an outer shell, cutting the casing free from all pipes. There is no foolproof way to accurately assess the stresses or loads imposed on a casing from permanently attached pipes and to attempt a major repair with pipes still attached is counterproductive.

- Based upon either analysis of boat samples and/or surface replication, the areas to be removed should be carefully laid out.

- Based upon the location of the area to be removed and the volume of material to be removed, an assessment should be made by an experienced turbine casing welding specialist as to the probable distortion of critical fits and surfaces as the result of the weld repair, i. e., casing joints, stationary blade ring fits, valve seating areas, etc. Provisions should be incorporated into the overall plan to weld build up and remachine, or just remachine critical areas that will be adversely affected.

- The casing must be instrumented with multiple thermocouples to monitor the preweld stress relief, the preheat for welding and the post weld stress relief.

- The casing in question should receive a full stress relief before attempting a major repair to eliminate the locked up stresses that will be present from operation. The basic stress relief cycle for these materials is a ramp rate up of 75°F to 100°F per hour max to 1275°F ± 25°F and a hold at temperature of eight hours. The ramp rate down is 75°F to 100°F per hour max., however, this ramp rate will probably be much slower below 900°F, because of inability to dissipate heat from such a large insulated body.

- The material to be removed can be taken out in a variety of ways, i. e., air arc, chipping hammers (guns), grinding, etc. However, air arcing should always be followed by heavy grinding as the air arced surface may contain a high carbon content that will play havoc with the weld deposit.

- The casing must be solidly braced in every direction in which it would be expected to move as the result of a heavy weld deposit. Once again, there is need of an experienced casing welding engineer to assist in selecting the location of bracing. If possible, main turbine casings should be bolted together for as much of the work as possible. *Note*, this may require up to a complete set of replacement turbine casing bolts.

- The complete casing should be wrapped with insulation and preheated to 450°F minimum.

- Once the casing has been preheated, a complete set of dimensional references should be taken as baseline data, to track distortion as the weld repair progresses. Once again, an experienced casing welding specialist is needed for selecting the points of measurement. As multiple passes of weld are deposited, heavy interpass peening can often be very helpful in controlling distortion.

Of all of the weld deposit techniques/procedures available, sub-arc is by far the most effective and efficient. Sub-arc is:

- Relatively easy to control.
- Does not require that a welder perform critical hand welding in a hostile environment.
- Has a very high deposit rate.

Flux core and/or metal inert gas (MIG) welding are very operator dependent in what can only be described as a hostile environment and both processes are often subject to lack of fusion/penetration. Straight shielded metal arc welding

(SMAW) welding is extremely time consuming, and once again requires that the welder be in a hostile environment.

- At the mid point of the weld deposit, based both upon the total volume of weld required and the distortion up to that point, an interim full stress relief must be considered. At this point, welding would stop with preheat maintained and the casing would be allowed to sit at reheat temperature for 2 to 3 hours to allow the recent weld deposit to drop to preheat temperature and then the complete casing would be stress relieved.

- When the casing has cooled to preheat temperature, the welding should continue, keeping close track of the distortion by comparing mechanical measurements taken between passes with the original measurements taken on the preheated casing.

- When all welding has been completed, including any surfaces that require welding to compensate for distortion, the casing should be allowed to soak at preheat temperature for two to three hours, to allow the most recent weld deposit to drop to preheat temperature and then a full stress relief cycle should be begun and completed on the whole casing.

- When the repaired casing has cooled after stress relief, all welds and adjacent areas should be ground and polished smooth and any critical fit surfaces that have distorted should be machined.

- The complete casing should be either shot or grit blasted and NDT tested for defects.

Cross sections of the high pressure/reheat sections of turbines are shown in Figures 10 and 11. As shown in Figure 10, the weld deposit in the center of the control valve body often exhibits deep cracking from the inside as do the stationary blade ring fits in the inner casings for the first several stages of both the high pressure and reheat sections. As shown in Figure 11, the corners in both the inner and outer casing containing the ring sealed inlet pipe to the first stage high pressure, will often develop deep cracking as will the inner casing fits for the first several stages in both the high pressure and reheat sections. Properly approached, these casings are repairable.

## FINAL COST CONSIDERATION

Normally, the deterioration of a turbine casing to the point where a major decision is required takes place over a reasonably long cycle of operation, i. e., several inspection cycles. The relative repair cost and cycle times can usually be reasonably determined well ahead of the point of no return for the casing. The

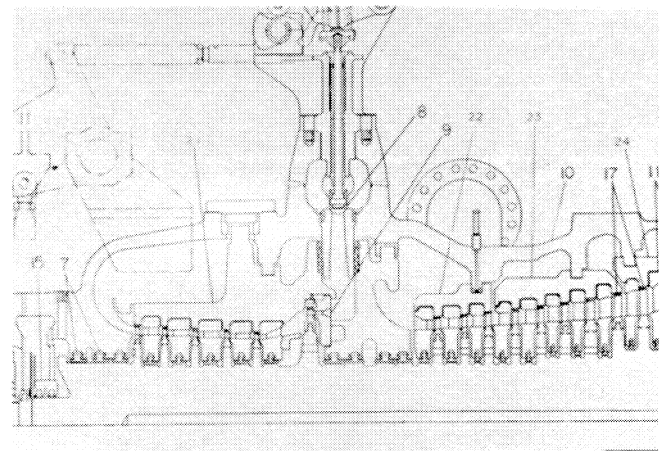
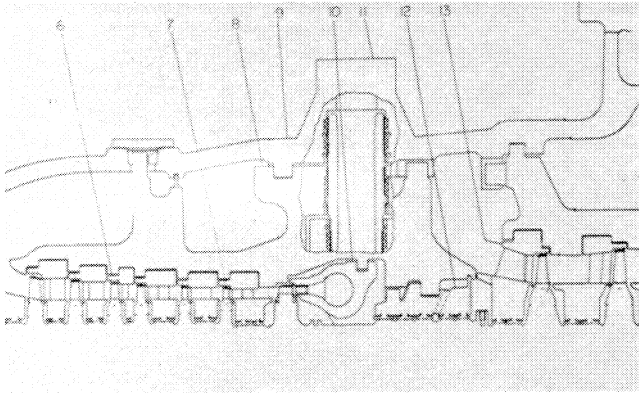


Figure 10. Cross Section Through High Pressure Section of Turbine Illustrating Control Valve Chest Welds and General Internal Geometry of Turbine Casings.



*Figure 11. Cross Section Through High Pressure Section of Turbine Illustrating General Internal Geometry of Turbine Casings.*

one cost that is separate from actual cost of repair, but in some cases overshadows this cost, is the value of the turbine in terms of lost generation. The normal turbine outage is usually shorter than the time required to perform a major shell repair, especially if a casing with permanently welded pipes is involved. Once a casing has been properly repaired, the problems in integrating it back into the turbine in terms of alignment should not be any greater than those encountered in installing a new casing, i. e., they both require a complete alignment.

The need to run older units in cycling duty will surely result in an increasing number of casings with problems. From a cost standpoint, the utility industry cannot afford not to explore the concept of casing repair to its ultimate.