# Major Field Repair on Ammonia Converter

A detailed report on the development and execution of a major repair project of an ammonia synthesis converter at the UKF Fertilizers (GB) Ltd. plant

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The UKF ammonia plant is a Chemico, 1,000-short ton/day unit which was commissioned in December, 1970. In March of the following year severe hydrogen damage had occurred to the lower carbon steel outlet forging resulting from the ineffectiveness of the internal insulation canisters.

At that time it was thought that the insulation quality of the canisters could be improved. Therefore it was decided to effect a remedial repair by boring out the hydrogen-damaged material of the existing forging to a depth of 20 mm. and replacing the removed metal with a hydrogen-resistant, 5 Cr - ½ Mo steel, liner seal, welded top and bottom, with the annulus between the back face of the liner and the carbon steel forging vented to the atmosphere.

However, when the ammonia converter was returned to service, the installed skin thermocouple recorded unacceptably high metal temperatures which necessitated the implementation of external forced water cooling.

Repeated efforts during subsequent plant shutdowns to improve the design of the internal insulation canisters did not succeed. And the continuing need to resort to water cooling raised grave concern despite the fact that repeated ultrasonic examinations revealed no evidence of further hydrogen damage. However, a breakdown in the integrity of the 5 Cr - ½ Mo liner did eventually occur at the seal weld between the liner and the 2¼ Cr - 1 Mo outlet nozzle which proved difficult to effect a satisfactory permanent repair.

With the advent of the change in plant ownership from the 100%-owned Shell company Shellstar to UKF Fertilisers Limited, comprising 75% D.S.M. (Dutch State Mins) and 25% Shell, the introduction of a technical audit highlighted the questionable reliability of the converter forging under the operating conditions then current.

Calculations based on the "Manson" theory made by the D.S.M. stress analyst using the actual temperature profiles obtained under service conditions (i.e., during forced water cooling) indicated high cyclic stresses, particularly during start-up and shutdown.

### Decision was to replace with a suitable alloy

The conclusion was that the existing forging was operating under severe adverse conditions and as such was approaching imminent retirement. Therefore the only practicable and reliable alternative was to replace the forging in a suitable alloy steel. This was satisfactorily accomplished during the 1976 turnaround in 42 × 24-hr. days in the field.

As-built design data of the forging were as follows: design pressure, 3,750 lb./sq.in.gauge; design temperature, 300°C; partial hydrogen pressure, 2,200 lb./sq.in.gauge; and hydrogen attack limit for carbon steel 240°C (Nelson Curve).

Stress analyst calculations results were as follows. Calculation No. 1 was based on a temperature gradient of 100°C, assuming an inside forging metal temperature of 200°C and an outside forging metal temperature of 100°C. The calculated stress was 66 kg./sq.mm. and estimated fatigue life 2,000 cycles approximately.

Calculation No. 2 was based on a temperature gradient of 180°C, assuming an inside forging metal temperature of 250°C and with a recorded outside forging metal temperature of 70°C. The calculated stress was 80 kg./sq.mm. and estimated fatigue life 300 cycles approximately.

*Analysis:* In both cases the calculated stress was twice the material's specified yield of 28 kg./sq.mm. and as such was indicative of permanent damage having been sustained by the forging due to plastic deformation occurring in the region of the nozzle area leading to eventual failure by fatigue.

The actual temperature gradient obtained in service ranged between 100-140°C. This, combned with the numerous start-up and shutdown cycles estimated at 300 (i.e., 150 plant stoppages) during five years of service, suggested that conditions approaching the prediction made in Calculation No. 2 existed.

The first requisite was that the replacement forging and outlet nozzle be suitable for the service environment and procured in time for the January 1976 plant turnaround; i.e.:

1. Resistant to hydrogen damage at the corresponding operating partial pressure and temperature.
2. Designed for a temperature 500°C without dependancy on insulation canisters.
3. On-site delivery by December 31, 1975.

To meet the design requirements, the chosen material was 3 Cr - 1 Mo, to specification A.S.T.M. 182-F21, and the wall thickness of the forging was increased from 170 mm. to 220 mm., with a corresponding increase in the strength of the stud bolts securing the end closure which was designed to incorporate a self-energizing Inconel 'O' ring gasket. It is illustrated in Figure 1.

The engineering design and drawings were produced by D.S.M. (Dutch State Mines), who also placed and carried out the expediting of the order through reputable manufacturers in West Germany under the inspection authority of T.U.V. (Technischer Uberwachungs ⅛ Verien e.V) in liaison with National Vulcan Insurance Co. Ltd (N.V.I.), the plant insurers for UKF (GB).

## Development work

Early consultation between UKF and N.V.I. was pursued

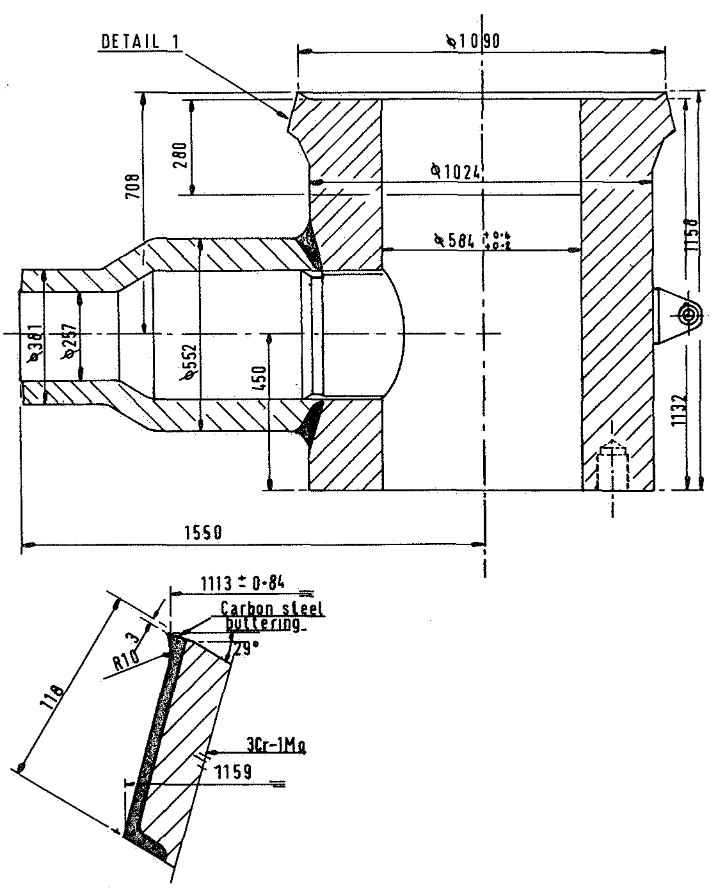


**Figure 1. Dimensional drawing of lower outlet forging.**

to advise the latter of the proposal to replace the bottom forging of the ammonia converter and to acquaint them with envisaged environmental difficulties under which the exercise would by force of circumstances have to executed, viz:

1. With the catalyst remaining undistrubed under a nitrogen blanket, necessitating personnel having to wear respirators.
2. A one-sided overhead weld with none, or at best very limited, access to the weld root or inside of the vessel.
3. On-site cutting and welding under 200°C preheat in a confined space.
4. A high probability of encountering inclement winter weather.

In addition to these restrictions, the completed job could not be pressure tested prior to recommissioning, due to presence of catalyst, in lieu of which 100% non-destructive testing was to be employed.

It was on this point, i.e. the waiving of a hydraulic pressure test that N.V.I. expressed deep concern on the basis that, in the absence of a hydraulic test at 1.5 × design pressure, the weldment was denied the important benefits of "Shakedown," i.e. a degree of plastic flow and strain redistribution. This was an opinion they defended very strongly and were reluctant to waive without sound engineering justification first being demonstrated to warrant their agreement otherwise.

To secure this agreement, UKF Fertilisers instituted with assistance afforded by the technical resources of the D.S.M. central materials testing laboratories in Geleen, Holland, a full procedure evaluation programme, viz: a) full thickness weld procedures; b) theoretical fracture mechanics calculations; c) C.O.D. (crack opening displacement) experiments; and d) N.D.T. (non-destructive testing) techniques in radiography and ultrasonic flaw detection.

A satisfactory weld metallurgy and mchanical testing procedure was achieved using a single vee-weld preparation between materials compatible with those to be welded on site, i.e., 19Mn5 to 3 Cr/Mo. The CrMo side of the speciment was first buttered with carbon steel weld deposit and stress-relieved at 690°C for 4 hr., the weldout being completed under a preheat using carbon steel electrodes "CONARC 54" and stress-relieved at 600°C for 4 hr. There was also intermediate stress relieving at 600°C for 4 hr. after the joing had been filled to approximately 35 mm. Welding position was overhead.

Figure 2 is a sketch showing weld construction. Dimensions of the trial weld are seen. Thickness of the 3 Dr 1 Mo plate was 60 mm., and that of the 19 Mn 5 plate was 90 mm. Plates of equal thickness were not available. The original wall thickness of 120 mm. was therefore simulated by welding strips to one side of each plate, as also shown in Figure 2. The trial weld was tested ultrasonically after stress-relieving had been completed: no defects were observed in this test.

## Background to development of welding procedure

A welding procedure was drawn up for the repair work to

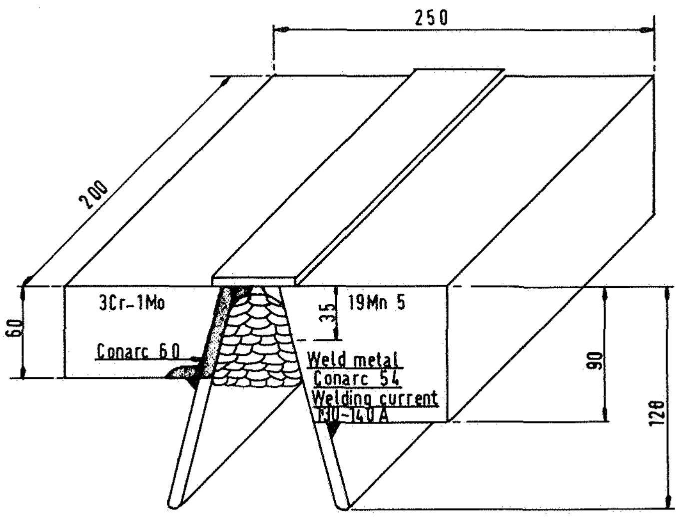

**Figure 2. Construction of the trial weld.**

be done on the ammonia converter. In conformity with this procedure, an experimental weld was made to gain an insight into the mechanical strength of the ultimate weld. The microscopic and mechanical examinations have yielded values proving that the weld was of good quality. It may therefore be concluded that as far as mechanical strength of the weld is concerned, the welding procedure may without any objection be applied to the ammonia converter.

After consultation between National Vulcan Insurance and DSM/U.K.F., the welding procedure has been modified slightly. It was decided to omit the backing strip and to deposit the root layer as specified in the "Broken Arc Technique."

Based on the Neuber, Irwin, Wells, and Dugdate theory, an acceptable critical crack length of 10 × 20 mm. was calculated. However, it was thought for added security this dimension should be halved and detectable defects in excess of 5 × 10 mm. should be repaired.

Fracture toughness values measured on test specimens taken out of the stress-relieved weld procedure test plate, showed that the admissable size defect under the most unfavorable conditions equalled 17 mm. This was better than the theoretical value and furthermore demonstrated that the material was fully ductile. The test was conducted in accordance with the Draft British Standard B.S. DD19.

The C.O.D. test was executed on a test bar containing a manufactured fatigue crack initiated from Chevron notch machined into the test bars. The critical crack opening value ($c$) was related to the crack initiation from the fatigue crack.

The requirements of the fracture mechanic calculations and the C.O.D. tests demanded that defects of 10 × 5 mm. must not only be detectable by applied N.D.T. techniques but sized and located accurately to allow their correct analytical interpretation by fracture mechanics. This requirement was to be applicable throughout the welding cycle by employing magnetic particle inspection (M.P.I.) radiography and ultrasonics in that order, each technique being able to complement the other in ensuring complete integrity of the finished weldment.

The following procedures were developed, demonstrated, and approved for implementation:

1. M.P.I. root run and subsequent weld layer under 150°C preheat using dry magnetic powders and 800-amp. coil-induced magnetic field of 35-40 oersteds for the detection of circumferential cracking, for transverse weld crack detection use a 10,000-amp. turn solenoid electromagnet at 18 oersteds. Followed by M.P.I. of the first 35 mm. of weld deposits using aluminium prods at 150-mm. spacing, producing 40 oersteds. These different techniques were limited by the available access dictated by the geometry of the weld preparation.
2. Gamma radiography, in accordance with British Standards B.S. 2600 the first 35 mm. of weld deposit using Iridium 192 with a maximum physical source size of 2 × 2 mm. at a source-to-film distance of 450 mm. to produce a film density of 2.5 with a sensitivity of 2% for interpretation to ASME VIII - Div. 2. 1975.
3. Ultrasonically examine (essentially in accordance with ASME Article 9-3) the completed weld before and after stress relief, using a "KrautKramer USM 2" flaw detector/4-mHz. normal probe and a 2 and 4-mHz. twin crystal angle probe. Employing the tandem probe technique as applicable for the detection of planar type defects along the fusion face. All indications producing a response greater than 20% of the reference level to be plotted and recorded. A reference level with a length exceeding 15 mm. to be sized and evaluated in conjunction with the available fracture mechanics data.

### Contractor was used to do job specification

Having demonstrated to the satisfaction of N.V.I. sufficient and convincing engineering evaluation to justify the omission of a full hydraulic test, the next step was to select and engage a competent contractor to implement the plan of action, namely the job specification. The principle architect of this was UKF (GB).

The contract was awarded to a well-known reputable British company, who having been supplied with detailed drawings and job specification developed this into a workable undertaking by fabricating and procuring the site equipment as well as carrying out their own evaluation tests. In particular, they perfected the welding skills required to ensure a defect free root pass i.e., the "broken arc technique."

The contractor chose 24 of their best welders and sent them to their own welding school for intensified job training. After several weeks training, 18 were selected on quality of performance for further simulation training and welder qualification testing. To achieve this a "mock up" of the bottom of the converter was built. It is shown in Figure 3.

This afforded the purpose of subjecting the welders during their qualification testing to the same conditions they would experience in the field i.e., overhead welding in a confined space, under preheat wearing a respirator. All the 18 welders were eventually qualified to B.S. 1515 by N.V.I.

The "mock up" was also used in other aspects of the job

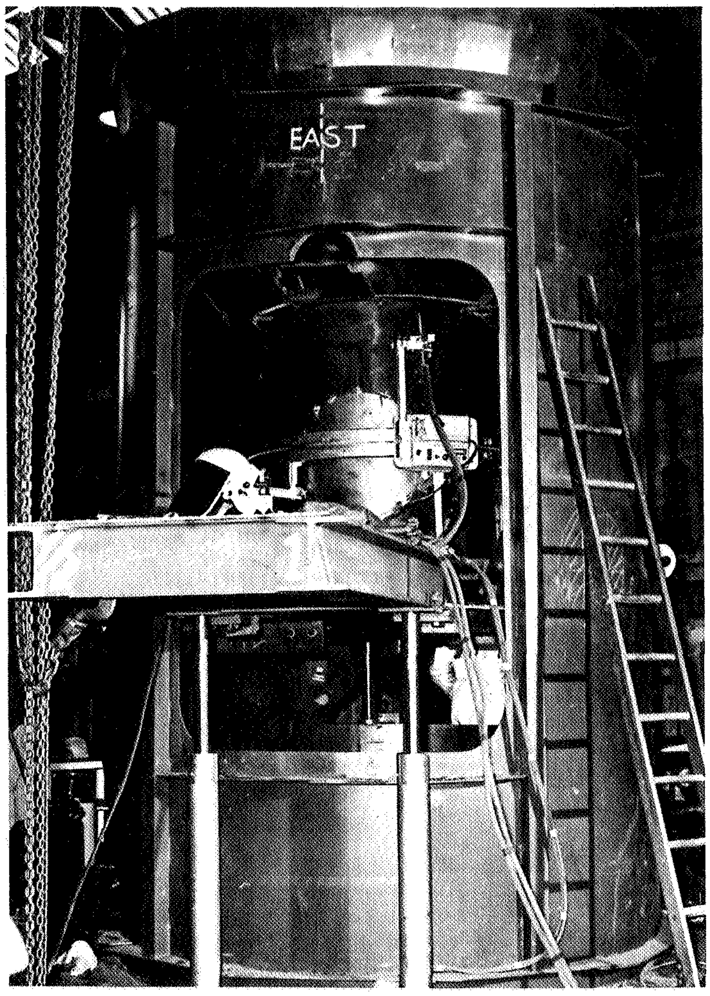


**Figure 3. Mock-up of converter bottom, showing "Katring" and burner head setup, also hydraulically adjustable platform and sledge.**

development and proved invaluable in demonstrating:

1. The setting up and trials of the flame-cutting and boring machine apparatus to be used in removing the forging.
2. Installing and improving the design of the hydraulically adjustable platform and sledge for use in handling the forging in and out of the vessel skirt.
3. The feasibility of carrying out the M.P.I. technique to be used in evaluating the root pass of the replacement forging.
4. Preparing the design and layout of the pre and post weld heating elements.

To minimize the risk of on-the-job work in a nitrogen-enriched atmosphere, all contractor personnel were briefed on the safety hazards and given instruction on the use of respirators in organized training sessions conducted by UKF (GB) safety officers. In addition they were also acquainted with the company's existing job safety and clearance certificate system.

As a further precaution and to control the flow of free nitrogen from any one opening as the job progressed, a bunging or sealing sequence was drawn up. To facilitate this special bungs had to be designed.

## Field work was early in 1976

Execution in the field started Jan. 5, 1976; and total completion was dated Feb. 15, 1976. A prefabricated asbestos-sheeted shelter was erected to embrace the whole of the working area around the bottom of the converter as a protection against the weather and to act as a barrier to prevent access of unauthorized personnel. The area was also provided with independent lighting, power supply for the pre- and post-weld heat treatment, welding current, and compressed air.

After the initial preparation work of dismantling the quench lines, removing the bottom cover and forging internals, the basic sequence of events was as detailed in the following. In addition, each event necessitated a quality control "check-out" by nominated personnel from UKF and the contractor before proceeding to the next event.

1. Establish reference levels and datum points, as shown in Figure 4.
2. Reinforce additional openings into the skirt to facilitate the installation of the adjustable platform mounted sledge for easy handling of the 7½-ton forging.
3. Cut and remove transfer line and forging outlet nozzle.
4. Set up the "Katring" track and mounting the oxy-acetylene cutting head, shown in the photograph in Figure 5.
5. Set and recheck angle of oxy-acetylene burner before commencing flame cutting through the 115-mm. thick dished head carefully, following the previously circumscribed cut line. (This was a critical stage demanding

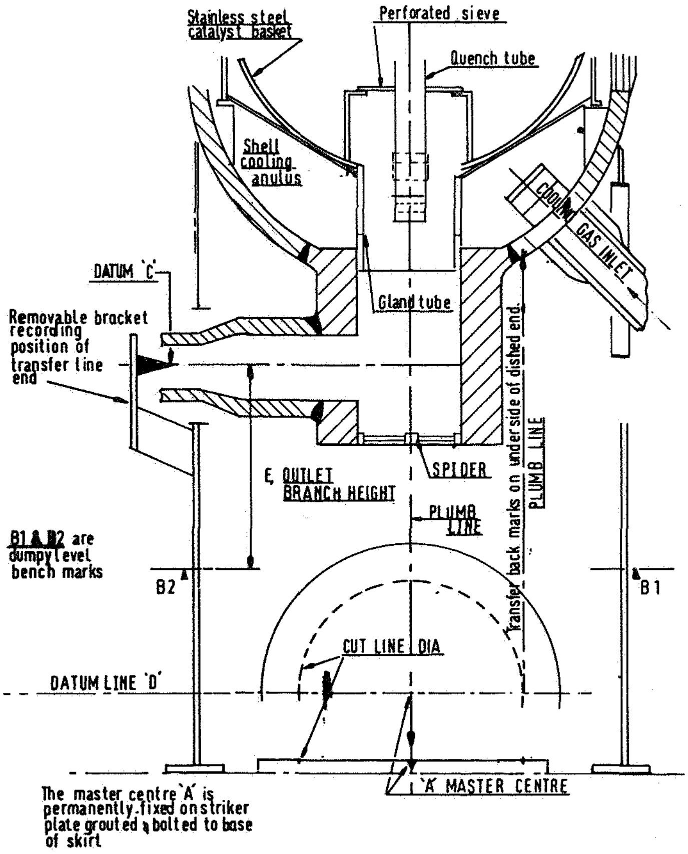


**Figure 4. Reference levels and datum points.**

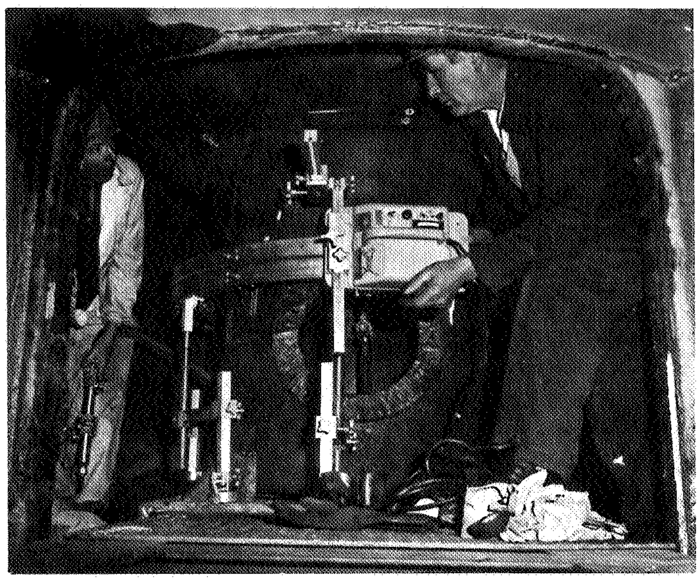

**Figure 5. Setting up B.O.C. "Katring" and cutting head. Note the cut off outlet nozzle.**

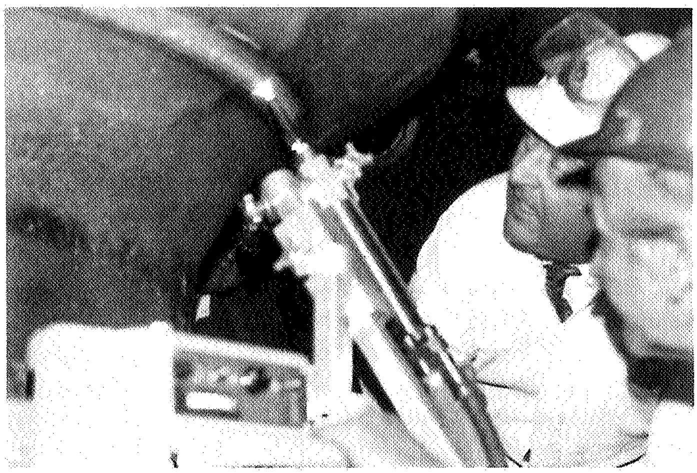

**Figure 6. Final check of flame-cutting geometry.**

infinite accuracy in geometry, for a cutting error at this time would have resulted in serious and far reaching consequences). Figure 6 shows a final check being made of flame-cut geometry. The total time for a once-round through-cut with a circumferential travel of 3.52 meters was 30 mins.

6. On completion of the cut, lower the platform and withdraw cut-off forging on the sledge, as seen in Figure 7.

7. Plasma arc cut internal 25-mm. thick, stainless steel gland tube.

8. Set up boring maching and machine the dished head weld preparation within the accuracy of 1 mm. on a finished diameter of 1120 mm., shown in Figure 8.

9. M.P.I. and ultrasonically examine finished weld preparation.

10. Install the new, already hydraulically and ultrasonically tested at works forging. Carry out alignment checks against those established at Stage 1, seen in Figure 9.

11. Fix preheat elements and attach thermocouples to the inside and outside of the forging and dished head. The thermocouples were attached by a capacitor discharge gun to avoid tack-welding on the alloy steel forging.

12. Raise preheat to 300°C and hold for 3 hr. to release

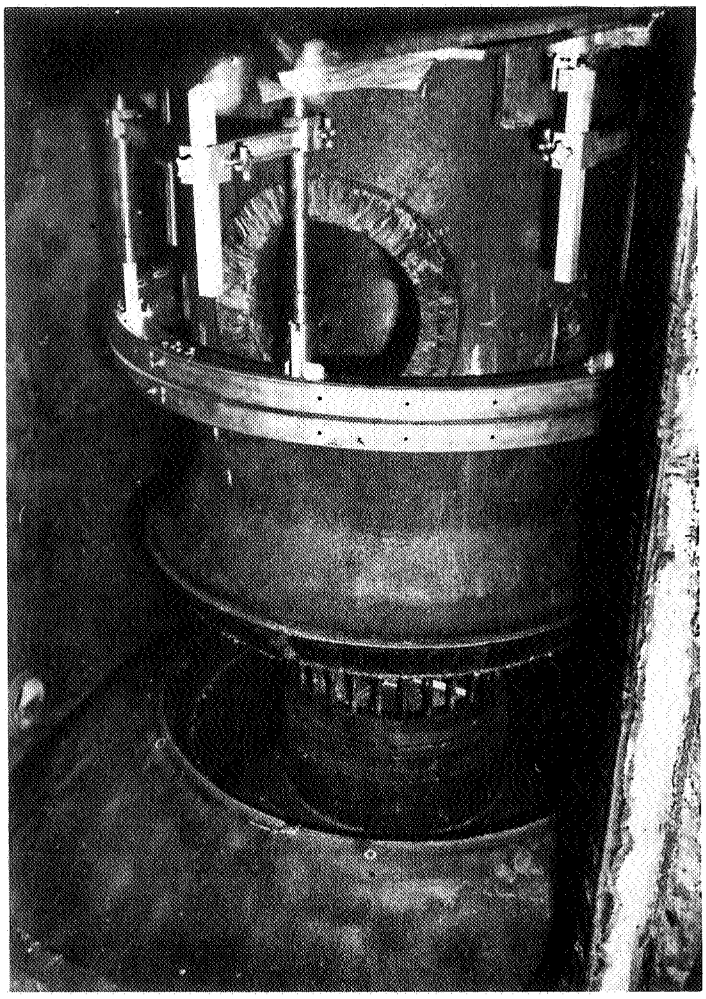

**Figure 7. Lowering the flame-cut carbon steel forging, exposing gland tube and the bottom of the internal catalyst basket. Note the chaffing of gland tube, indicating expansion travel.**

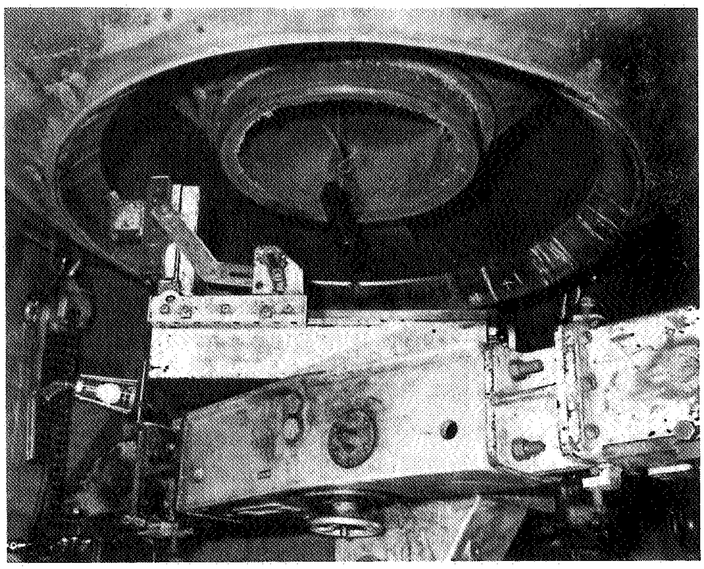

**Figure 8. Setting the boring machine. Note the excellent finish of the flame cut, also the plasma arc cut off gland tube.**

any entrapped service hydrogen.

13. Reduce temperature to welding preheat of 200°C, rechecking concentricity and alignment of the root-gap set at 3 to 4.5 mm. The correct gap was important in achieving a

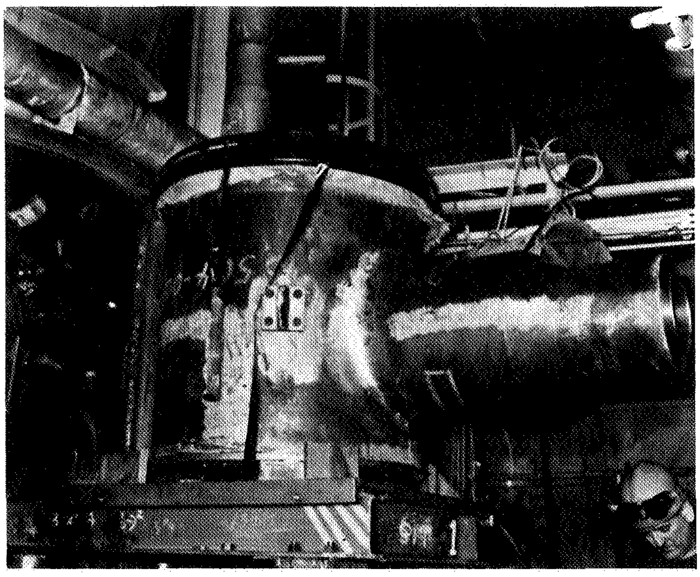

**Figure 9. Replacement 3 Cr 1 Mo forging, positioned on sledge and ready for installation. Note personnel inside the skirt wearing respirator.**

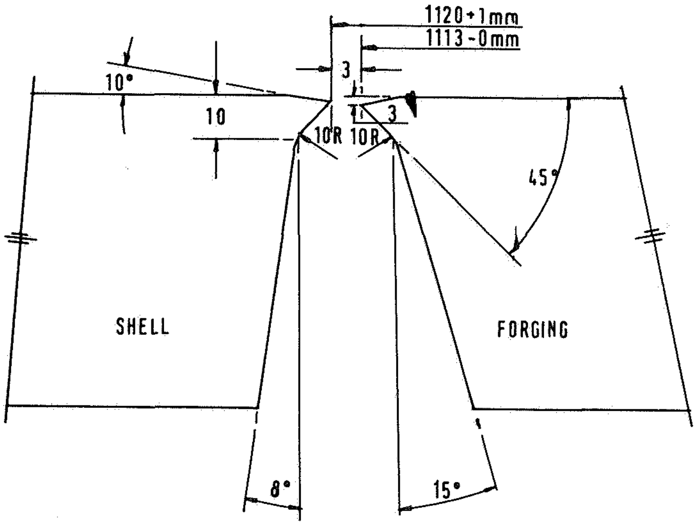


**Figure 10. Welding procedure.**

**Figure 11. Commencement of root run.**

satisfactory root run with the broken arc technique. At this stage, 24-hr. inspection coverage was initiated by N.V.I. for continuous monitoring of the welding technique, issuing of electrodes, preheat recorders and to carry out the N.D.T.

14. Commence balanced welding in accordance with the contractors procedure, shown in Figure 10, using three welders simultaneously, as seen in Figure 11. On completion of the root run it was ground externally and M.P.I. checked while maintaining preheat. The next weld layer was similarly checked, after which the adjustable support platform was lowered to allow free expansion of the forging during weldout.

15. The next stage inspection was on completion of the first 35-mm. depth of weld deposit, following an intermediate stress relief of 600°C for 1½ hr. On cool-down, a 100% radiographic examination was made using a 35-curie source with fine grain film, followed by a surface M.P.I. check, and found to be defect free.

16. On restoration of the preheat, the weldout was completed. Monitored throughout by hot grinding and visual inspection of each weld layer. The welders were relieved at frequent intervals to combat fatigue/cramp, with no more than three welding at any one time.

17. The forging preheat was increased to 250-300°C and held for 3 hr. for hydrogen diffusion, then cooled down under controlled conditions. The weld was then ultrasonically scanned using normal and tandem shear wave techniques in both the circumferential and transverse directions. The results of the scan were plotted. No significant defects were detected.

18. Having established that no repairs were needed, the forging was taken through its final heat treatment of 600°C at 4 hr. in accordance with the agreed post-weld heat treatment specification based on B.S. 1515, (and described in the Appendix) then controlled down to ambient before being stripped of its insulation. A final ultrasonic and M.P.I. examination and weld hardness check confirmed the complete integrity of the weld.

19. Subsequent alignment checks were found to be correct within the accuracy of 1 mm. with the original bench marks. Perpendicular alignment was essential in maintaining the required clearance of approximately 3 mm. on diameter between the bore of the forging and the outside diameter of internal gland tube, to allow free expansion of the internal stainless steel catalyst baskets. It was equally essential that rotational accuracy be also achieved, because any resultant error in the outlet nozzle orientation would have affected the alignment of the closing butt welds in new replacement 5 meter long by 257-mm.ID × 67-mm. wall thickness, 5 Cr ½ Mo (ASTM 355 - P5) transfer line.

20. Both of the transfer line weld preparations having been accurately machined for TIG root, they were satisfactorily jig-clamped and welded under pre- and post-heat treatment, and in accordance with the contractor's weld procedure and finally accepted.

21. The job was now essentially and satisfactorily completed, with the exception of reinstalling the internals which included the recharged insulation cannisters, these were re-

quired to achieve an acceptable temperature gradient across the forging to dished head weld zone.

## Conclusion

The critical path plan for renewing the forging spanned 52 days, although it was satisfactorily completed in 42 days.

This demonstrated that a well-engineered job, thoroughly planned and executed without deviation from the previously written specification by trained and disciplined personnel, and controlled throughout to a high quality assurance standard, rewarded the high financial commitment with the security and confidence of a job well done.

In the absence of a hydraulic test, the built in integrity qualified by the N.D.T. results, met the highest degree of safety demanded by UKF and the insurance authorities.

After 2,150 hr. of operation the opportunity was afforded to carry out a post service ultrasonic/M.P.I. integrity check. The results confirmed the welds to be sound. Thus providing further endorsement of the quality of workmanship and the company's attitude towards safe plant operations. #

## APPENDIX

### EXTENT AND GENERAL PRINCIPLES OF STRESS RELIEF

1.1 The weld zone requiring heat treatment is situated at the bottom dome end to nozzle welds. The vessel dimensions are assumed as follows:

Inside diameter - 2,286 mm.
Wall thickness (shell) - 100 mm.

1.2 The heat treatment has been considered as taking place in the field, with the vessel positioned vertically. The method proposed is by electrical external heating to meet specification BS.1515 in principle.

1.3 The temperature specification is as follows:

(a) Rate of temperature rise from ambient to 400°C at 100°C/hr. maximum.

(b) Rate of temperature rise above 400°C at 50°C/hr. maximum.

(c) The soak condition shall be 600°C ∓ 20°C, held for a period of 4 hr. at the nozzle/shell weld position with a gradual temperature gradient condition of 300°C ∓ 20°C being maintained at the /2.5 rt. position (610 mm. from the weld edge), the temperature at the shell-to-skirt weld being kept to a maximum of 300°C.

(d) The cooling rate shall be limited to 50°C/hr. maximum, down to a temperature of 380°C.

(e) Thereafter, cool under undisturbed insulation to 100°C, after which insulation can be removed.

1.4 The heat treatment will be effected essentially by the use of "Cooperheat 240V FCP" elements of individual rating 12 kW at 240 volts. These elements will be mounted externally in fine discrete zones. The total installed power in the zone is in the order of 324 kW. The element connections will be brought to the vessel base by means of cables to the distribution/control boards.

1.5 The insulation which will be utilized throughout will be mineral wool of density 100 kg/cu.m., 50 mm. thick. Two layers will be applied externally to the vessel in the heated zone, and up to the shell/skirt weld, and two layers internally to the same position.

1.6 Consideration has been given to the nozzle, where low voltage ceramic pad elements will be applied locally for the control of any adverse thermal gradients during the stress relief cycle.

1.7 Temperature recording will be acheived by the fixing of 16 nickel-chromium/nickel-aluminium thermocouples. 12 thermocouples ar proposed within the weld zone, and the balance fitted for gradient information, and purpose of temperature control at the nozzles.

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