"Welding of critical coolant pump Component — An Experience"

By : J.V. DAKSHINAMURTY

I. INTRODUCTION

Common man normally attaches atomic energy to the nuclear arms race and fears the holocaust it can cause. Little he realises its capabilities for peaceful purposes which can indirectly bring about a sea change in his daily life. Even for peaceful uses, very few people are aware of its applications in the fields of medical therapy, agriculture etc. Nevertheless, the greatest potential in nuclear energy undoubtedly lies in generation of electrical power through nuclear reactors.

Welding plays vital role in nuclear engineering. The progress achieved in the nuclear field of the world is unthinkable without reliable welds. This factor is of great significance in nuclear reactors as few of the critical welds are inaccessible for periodic inspection. Hence the quality of workmanship demanded is of highest order and extremely stringent. From experiences gained in construction, operation and maintenance of nuclear reactors all around the world, established practices and guidance is available for use on the above factors in the form of codes/standards, for example as given by ASME Boiler and Pressure Vessel Code Section-III Nuclear Power Plant components etc. India's achievements in construction and operation of conventional reactors of such nature are creditable. Though she had its more than fair share of teething problems, a stage is reached now from where she can launch her ambitious programme of 10,000 megawatts nuclear power by turn of the century which will be around 10% of total generating capacity of electrical energy by all sources put together.

Apart from these conventional nuclear programmes, keeping in view of the future requirements and raw material resources, India is planning to venture into new and challenging branches of nuclear science. In this context, India has commissioned pilot plant facilties to develop the necessary expertise on all aspects of the high technology. Needless to say that the existing international norms and standards leave much to be desired to directly adopt such high technology with confidence, largely due to the non-availability of recorded data of performance for the new nuclear technologies. Hence it becomes imperative to formulate separate specifications-tailor made to suit the specific critical application. To ensure trouble-free functioning of such "tailored to measure" components, it will be but natural to expect the most stringent quality conditions in construction. The welds in construction of components are required to pass various quality control tests almost ensuring zero defect level and also the weldment as a whole has to meet the critical dimensional requirements.

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Welding of one such component which is a coolant pump shaft is discussed here to share the experience with all.

II. ABOUT THE COMPONENT

The component is the shaft of a pump that circulates liquid metal which is radio active to conduct heat away from the reactor and transfer it to the secondary circuit. The shaft is vertically mounted in the pump casing with Impeller fixed at the lower end. On rotation, it generates radial suction and axial discharge for the pump. The rotational speed varies from 200 to 1450 r.p.m. with normal operating speed of 1390 r.p.m. Also, service temperature ranges from 150°C to 520°C and the normal service temperature will be 380°C. At any given instant, temperature gradient also exists along the longitudinal axis of the shaft.

Unlike the conventional single piece solid shafts for pumps, the subject shaft is a three piece construction with a central hollow tube having two solid end pieces welded together. Fig.1 shows the geometry of the shaft with approximate dimensions. As can be seen from Fig.1, there are two circumferential welds. There are also two centering back up rings, one at each weld to facilitate fit up in assembling the shaft for welding and control weld distortion to certain extent.

The top, bottom end pieces are rough machined with 2mm over thickness and with half the anticipated shrinkage of single weld on each end piece. The central tube will be finish machined with extra length of half the shrinkage allowance at either end.

A small tube is attached to the top end piece to provide shielding gas at the root side of the welds. The hollow space in intermediate tube and end pieces is filled with Argon at atmospheric pressure and the small tube is seal welded with a plug before the shaft is put into service.

A special post weld stress relieving heat treatment is necessary before final machining to facilitate trouble-free service. The finish machined shaft with its rotating assembly undergoes dynamic balancing to close limits.

To meet the critical and demanding service conditions, a special French Refractory forged stainless steel material is selected for the shaft. The specification details are given in Table - 1.

III. WELDING ASPECTS OF THE SHAFT :

Quality, both with respect to weld defect level and dimensional tolerance of the weldment is the watch word for the shaft. The importance lies in the fact that the manufacturer has to take special efforts to work under the specific conditions imposed by the customer which are different from his regular practices and still meet the required quality.

General practice of most of the fabricators/erectors for full penetration circumferential pipe welds is that some opening at root of the joint is given to facilitate penetration for obtaining radiographic quality deposit. Also the configuration of weld edges and fit-up etc., are allowed to be changed to suit the shop practices for obtaining the required quality. However, in this case, it is insisted by the customer that zero root opening has to be observed and also the weld edge should conform only to the details given in Fig.2. Fig. 2 also gives the weld runs sequence which was also insisted by the customer to be adhered to. So the manufacturer has to allign himself to these special impositions by the customer by giving special training and practice to the personnel to work under such conditions. From the sequence of depositing the runs, it is noteworthy that though run number 4 and 5 are in the form of multirun layer, the subsequent run numbers 6 and 7 are single run layers.

Manual Gas Tungsten Arc Welding (GTAW) process was selected for the reasons of obtaining the required weld defect level and controlling distortion alongwith availability of welding consumables. The filler rods for GTAW also conform to the specification given in Table-1 and were imported from France along with parent materials.

Control of weld defect level was one of the major aspects of welding quality. X-Ray radiography was the non-destructive testing method selected for inspecting the welded joints. Considerable efforts were put in, to develop and establish special techniques for double walled radio graphy with centering ring in position. Though separate acceptable limits were fixed up for defects in radiographs, in reality it was almost nil defect level and clear radiograph was only acceptable. Radiography was specified both in as welded condition and after post weld heat treatment. The weld was also to pass Helium leak test under vacuum.

Mechanical properties of the welds were to be ensured by welding mock up of similar pieces and physically conducting the testing. The specification limits of parent material were specified as limits for the welds in mechanical testing.

Another major aspect of weld quality was control of weldment distortion to meet the dimensional requirements of the job. The two ends of the shaft, which were approximately 1500 mm. and 600 mm. away from respective welds, had to be controlled in such a way during welding that there would be sufficient machining allowance left at both ends. The ends were also to be concentric within close limits. As the stress relieving treatment may also contribute to the as welded distortion, deflection of ends should be controlled within half the allowable levels. It was also the condition laid down by the customer that "In no case, straightening of the shaft to correct the verticality shall be allowed", hence the need to evolve, develop and establish fool proof welding technology which involves no physical straightening operation.

IV. DEVELOPMENT AND QUALIFICATION OF WELDING TECHNOLOGY

Keeping in view of the criticality of the job, a Welding Technician was selected, who not only possesses the necessary skill but also understands the importance of technology and readily adopts to the new methods, different from the established regular shop practices, and also his own working methods.

In the beginning, as the first step, few flat test plates were welded with carbon steel and later with stainless steel with the weld edge preparation and fit up in line with regular shop practices and also with the geometry fit up of the job weld. The technological differences between the two were studied and the extra effort in meeting the requirement was put in.

As a second step, few more flat test plates of stainless steel were welded using the sizes of Filler Rods like that of the job weld to set the welding parameters. These plates were inspected radiographically to ensure proper fusion. Since no grinding of excessive reinforcement would be allowed, special care was given during training to keep a little weld reinforcement with good bead finish.

Welding procedure was qualified as per the tailor made specification supplied by the customer. Pipe pieces were used for welding the mock-up for qualification with materials, weld geometry and fit-up as per job. Welding was carried out by GTAW in down hand position by rotating the pipe and welding from top. Table 2 gives the details of welding conditions observed on the mock-up piece. Table 3 gives the non-destructive and destructive tests conducted and results of the same. It is interesting to note that elongation was measured on Transverse Tensile Test specimen The special features of the qualification were Radiography, Microscopic examination and Texture test which are extra tests compared to the conventional procedure qualification. Although on job, radiography was possible only with centering ring in position, for qualification, radiography was also taken after removing the centering ring to doubly ensure the quality. Microscopic examination was primarily to observe the distribution pattern of delta ferrite. Inter-run temperature of welding was maintained below 125°C to control ferrite. Texture test was to reveal weld defects, if any, by senctioning a piece along the longitudinal weld axis.

Another important factor of the development and training programme was the distortion and shrinkage control techniques. Since the acceptable distortion was very small, special techniques were devised to get the requisite distortion control. For shafts of this nature, distortion in the form of transverse angular distortion is of most importance. Being forgings, the components do not show much ovality. Misalignment at weld does not pose problem as the centering ring at joint location takes care of it.

Correct application of the necessary welding heat input at the required location was the technique essentially utilised in controlling weld distortion and shrinkage. The emphasis was to allow the components to deviate freely on welding without restraining them, so that the amount of locked in stresses would be low and relief of the same would not unduly affect the dimensional stability. By this technique, controlled amount of distortion was introduced to get the desired result. A few mock ups were welded to perfect the technique.

It may be added that the welding technician employed picked up techniques very fast and readily adopted himself to the conditions new to him.

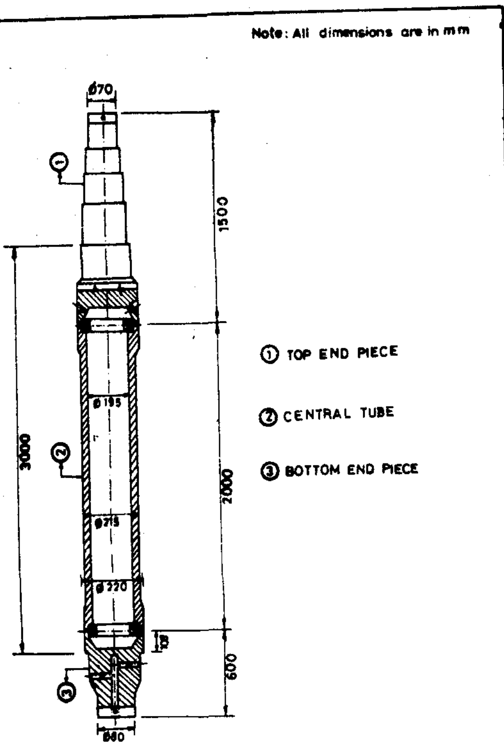


Fig-1 GEOMETRY OF PUMP SHAFT

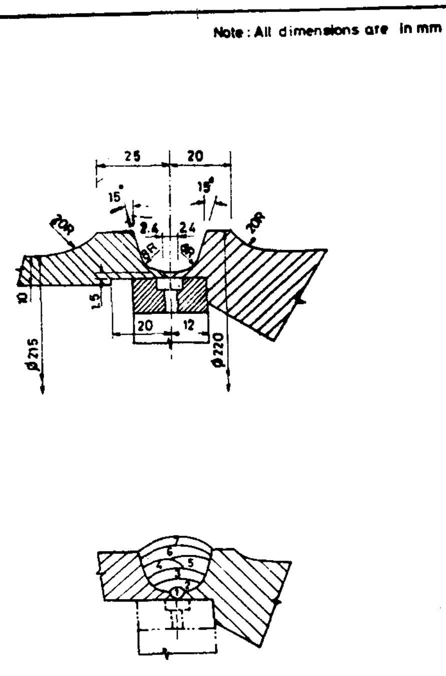


Fig.2 WELD JOINT DETAILS & RUNS SEQUENCE

V. ACTUAL JOB WELDING

Before the set up for welding was made, following work was carried out on individual components.

Purging tube of 14 mm outside diameter was seal welded from inside of top end piece at the hole drilled as shown in Fig. 1. Centering ring which had appropriate fit up with the inside diameter of end piece at the weld was located in each end piece as shown in Fig.2. It was tack welded at three equidistant locations, to the end piece.

Assembling and welding was carried out on a lathe. For assembling before welding, the bottom end piece was inserted in the four-jaw chuck and outside diameter was trued. A steady rest was clamped on the lathe bed and the intermediate piece was kept in position by sliding it on the centering ring of bottom end piece. The top end piece was located in such a way that its centering ring slides into the other end of the intermediate piece. The tail stock was kept in position and tightened such that zero root gap was obtained at both the joints. The trustees and straightness of the shaft was found to be satisfactory at this stage. No tack welding was done in the main weld grooves. A 10mm outside diameter copper tube was inserted through the purging tube and fixed at the location. With the help of flexible hose, shielding gas could be introduced at the root side through the copper tube and the annular space between copper and purging tube provided the outlet for the gas.

Fig. -3 shows assembly of shaft for welding with positions of dial gauges to indicate distortion.

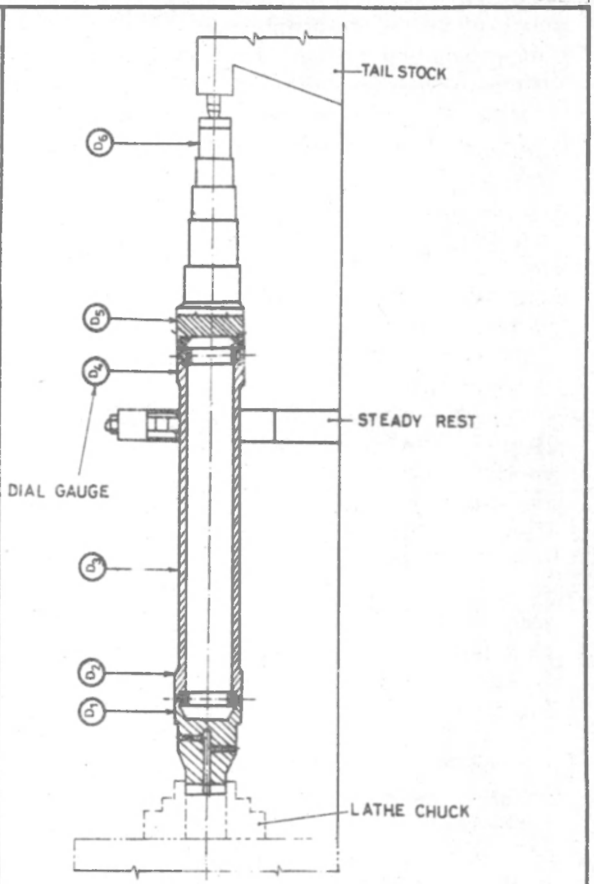


Fig-3 ARRANGEMENT FOR WELDING WITH DIAL GAUGES

The inside air of tne shaft assembly was scavenged with Argon at a flow rate of 15 litres/min. for 30 minutes to fulfil the requirement of scavenging atleast with six times the volume. Later the flow rate was adjusted to the root side shielding rate. For welding, the shaft assembly was rotated by hand. Table 4 and Table 5 give the welding conditions observed for the joints separately.

Continuous monitoring of distortion was done through the six dial gauges. Welding runs were deposited alternately on each joint in the same set up. Root run for both joints were liquid penetrant tested and did not show any defect. Each run was allowed to be cooled to room temperature before dial gauge reading were taken and distortion pattern computed. Sequence of welding for the next run was determined after applying appropriate technology based on distortion noticed. After welding two runs, the tail stock centre was removed and shielding gas flow on the root side was stopped. After completion of welding both the joints were liquid penetrant tested and were found to be defect free.

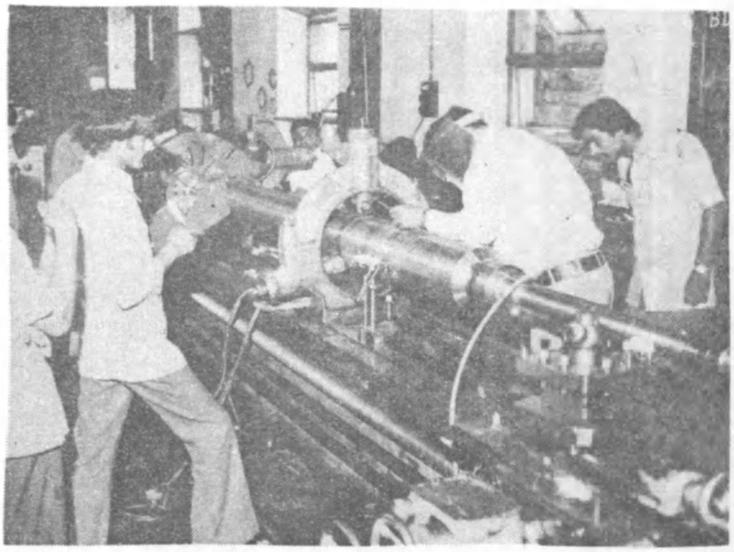


Plate-1 gives general arrangement of shaft on lathe for welding and Plate-2 shows the close up view of welding with details of gas connections and distortions monitoring devices.

Table 6 gives the readings of all dial gauges after completion of welding. It is clear from the figures that maximum distortion observed was only 0.5 mm which is at the end of top end piece. However for obtaining absolute concentricity, 0.9 mm machining should be done.

Welding shrinkage was also measured as decrease in length of the shaft after each run. Table-7 gives the readings. The cumulative shrinkage of all runs for both the joints put together was 7.7 mm against the allowance of 8 mm and hence well within limits.

Radiographic inspection was conducted in as welded condition and also after post weld heat treatment which indicated the excellent weld quality with zero defect level.

The post weld heat treatment is of special nature and the details of which are out of scope for the present paper. However it will suffice to say that it was conducted very successfully with little distortion added to the as welded condition.

Helium leak testing under vacuum was conducted on the job and the welds were found to have excellent leak tightness.

Every step in the progress of the job was conducted under the watchful eyes of the internal quality control department of the manufacturer, customer's project and inspection personnel and was also certified by third party quality surveillance of "Bureau Veritas".

VI. CONCLUSION

The results obtained on the job exceeded the expectations of all concerned. The experience of handling such jobs can induce more confidence in Indian equipment manufacturers which in turn will enable them to aim at still more complicated jobs.

The specifications involved may appear to be made with greater emphasis for safety, partly due to the cautious approach on part of makers of specifications. However, it should be received as the only hard way for development and should be taken in the right spirit as it contributes to the improvement of the technological ability of the country a whole.

VII. ACKNOWLEDGEMENT

The Author wishes to thank the Indian Institute of Welding for giving the opportunity to share his experience with all.

TABLE - 1

SPECIFICATION DETAILS OF STAINLESS & REFRACTORY FORGED STEEL FOR SHAFT

CHEMICAL COMPOSITION

Carbon	0.10% - 0.25%
Silicone	0.75% - 1.25%
Manganese	1.0% Max.
Nickel	10.0% - 13.0%
Chromium	20.0% - 24.0%
Tungsten	2.5% - 3.5%
Sulphur	0.02% Max.
Phosphorus	0.03% Max.

MECHANICAL PROPERTIES AT AMBIENT TEMPERATURE

Ultimate Tensile Strength	55 kg/mm^2 min
Elastic Limit (0.2%)	24 kg/mm^2 min
Elongation (on 5d)	30% min
Impact Strength (U Notch)	4 kg/cm^2 (Ave)
Hardness	190 - 250 H_B

TABLE - 2

DETAILS OF WELDING CONDITIONS FOR WELDING PROCEDURE QUALIFICATION

Welding Process: Gas Tungsten Arc Welding

Base Material) As per Table - 1
Filler Material)

Current : Direct : Polarity : Electrode Positive :
Position . : Down Hand : Pre-Heat Temperature: Nil ;
Inter-run Temperature : 125°C max.

Run No.	Filler Dia (mm)	Welding Parameters: Current (amps)	Voltage (Volts)	Speed (mm/min.)	Shielding Gas Flow Rata: Face Side (lit/min.)	Root Side (lit/min.)
1.	3.2	120	14	85	6.1	3.8 - 4.7
2.	3.2	95	13	93	5.6	4.7
3.	3.2	100 - 110	14-15	51	5.6	-
4.	3.2	110 - 115	15-16	90	5.6	-
5.	3.2	110 - 115	15-16	84	5.6	-
6.	4.0	130 - 135	18-19	88	5.6	-
7.	4.0	130 - 135	18-19	58	5.6	-

TABLE - 3

TEST RESULTS OF WELDING PROCEDURE QUALIFICATION

(a) Non-Destructive Tests :

1. Visual Inspection (100%) : Satisfactory
2. Liquid Penetrant Inspection (100%) : Satisfactory as per specification.
3. Radiographic Inspection with double walled technique (100%) :

(3.1) With centering ring before post-weld heat treatment : Satisfactory as per specification

(3.2) With centering after post-weld heat treatment : Satisfactory as per specification

(3.3) Without centering ring after post-weld heat treatment : Satisfactory as per specification

b) Destructive Tests :

1. Transverse Tensile Test : Satisfactory

Specimen No.	Ultimate Tensile Strength (kg/mm^2)	Elongation (on 5d) (%)
1.	68.3	33.3
2.	68.1	33.3

2. Guided Bend Test : Satisfactory

Specimen No.	Face Bend	Root Bend
1.	Satisfactory	Satisfactory
2.	Satisfactory	Satisfactory

3. Microscopic Examination : Satisfactory

Observation : Ferite distribution is fairly uniform, No microcracks, lack of fusion, lack of penetration and porosity is observed.

4. Texture Test : Satisfactory

Observation : One small defect observed.

Less than 1% : Found acceptable.

Table - 4

Details of Welding Conditions for Top End Piece to Central tube Joint

Run No.	Filler Dia.(mm)	WELDING PARAMETERS Current (Amps)	Voltage (Volts)	Speed (mm/min)	SHIELDED GAS FLOW RATE Face Side (lit/min)	Root Side (lit/min)
1.	3.2	120-125	13-14	62.86	5.6-7.1	2.8-3.8
2.	3.2	120-125	13-14	79.45	5.6-7.1	2.8-3.8
3.	3.2	130	15	53.45	9.4	-
4.	3.2	120	13	64.50	9.4	-
5.	3.2	120	13	65.51	9.4	-
6.	4.0	150	18	36.11	9.4	-
7.	4.0	ł50	18	48.93	9.4	-

Table - 5

Details of Welding Conditions for Bottom End Piece to Central Tube Joint

Run No.	Filler Dia (mm)	WELDING PARAMETERS Current (Amps)	Voltage (Volts)	Speed (mm/min)	SHIELDED GAS FLOW RATE Face Side (lit/min)	Root Side (lit/min)
1.	3.2	120-125	13-14	66.73	5.6-7.1	2.8-3.8
2.	3.2	120-125	13-14	79.75	5.6-7.1	2.8-3.8
3.	3.2	130	15	51.36	9.4	-
4.	3.2	120	13	65.77	9.4	-
5.	3.2	120	13	50.75	9.4	-
6.	4.0	150	18	38.29	9.4	-
7.	4.0	150	18	52.26	9.4	-

Table - 6

Dial Gauge Reading on the Shaft After Welding

Loaction of Reading	Dial Gouge D1	Dial Gauge D2	Dial Gauge D3	Dial Gauge D4	Dial Gauge D5
0°	+0.01	0.00	-0.01	+0.03	+0.02
90°	-0.16	-0.01	0.00	-0.13	+0.27
180°	-0.38	-0.04	0.00	-0.04	+0.52
270°	-0.22	-0.07	-0.015	-0.24	+0.22
0°	+0.01	0.00	-0.01	+0.03	+0.02

Remarks : Maximum distortion observed is 0.5 mm. machining needed to get both ends concentric is 0.9 mm.

Table - 7

Shrinkage Data on Welding

Layer No.	Run No.	Shrinkage Reading (mm)
1.	1	2.5
2.	2	1.2
3.	3	0.8
4.	4 & 5	2.5
5.	6	0.5
6.	7	0.2
Total Shrinkage observed		7.7

Quotes on Quality

November 1986 was observed as the Quality Month all over India, to emphasise that a change in attitude needs to be brought about so that quality of the work improves - step by step.

On our part, we take this opportunity to publish a collection of quotations and comments on quality, in the perspective of industrial products.

Editor

* Straight jacket definition of Quality : Conformance to specification and achieving Zero defect.

* Definition for long range planning : Quality is what the customers want, where they want it, when they want it, at the agreed upon price.

* Quality is a continuing search for excellence, striving for the best and refusing to accept even the second best.

* Quality is a dynamic concept. One has to keep running in order to keep in the same position. Unless there is an effort to improve quality, it is difficult to remain at the top.

* To end with Quality, start with House-keeping

Housekeeping means orderliness; Orderliness leads to cleanliness; Cleanliness brings in QUALITY.

To end with Happiness, start with Quality.

QUALITY leads to productivity; Productivity promotes prosperity; Prosperity bestows HAPPINESS.

* Quality is not a mirage. It is attainable, step by step.

* The 40-30-30 Rule on Quality Problems based on the Japanese Theory states that as a general rule 40% of all quality problems as the customers perceive them, are the result of poor design and engineering; another 30% are the result of errors made during manufacturing; while the remaining 30% relate to the non-conformance of supplies purchased from the outside vendors.

* Where care stops, Quality drops.

* Funny thing about quality is - if you refuse to accept anything but the best, you very often get it.

* Inspection of finished products by an outside agency is no guarantee of the quality of a product for quality cannot be inspected into a product. It has to be built into.

* Quality - a way of life

- a need of the hour.

* Quality is never an accident. It is always the result of intelligent effort and there must be a will to produce a superior thing.

- John Ruskin

* It is only through insisting on attention to details, on check and double check, and on each person doing his part that we can hope to get the job done right the first time.

- Bernard Osle

* Doing things right the first time sounds like nothing more than commonsense. But it is much more than that - it is the key to business survival and growth in an increasingly competitive environment.

- Philips Bi Crosby

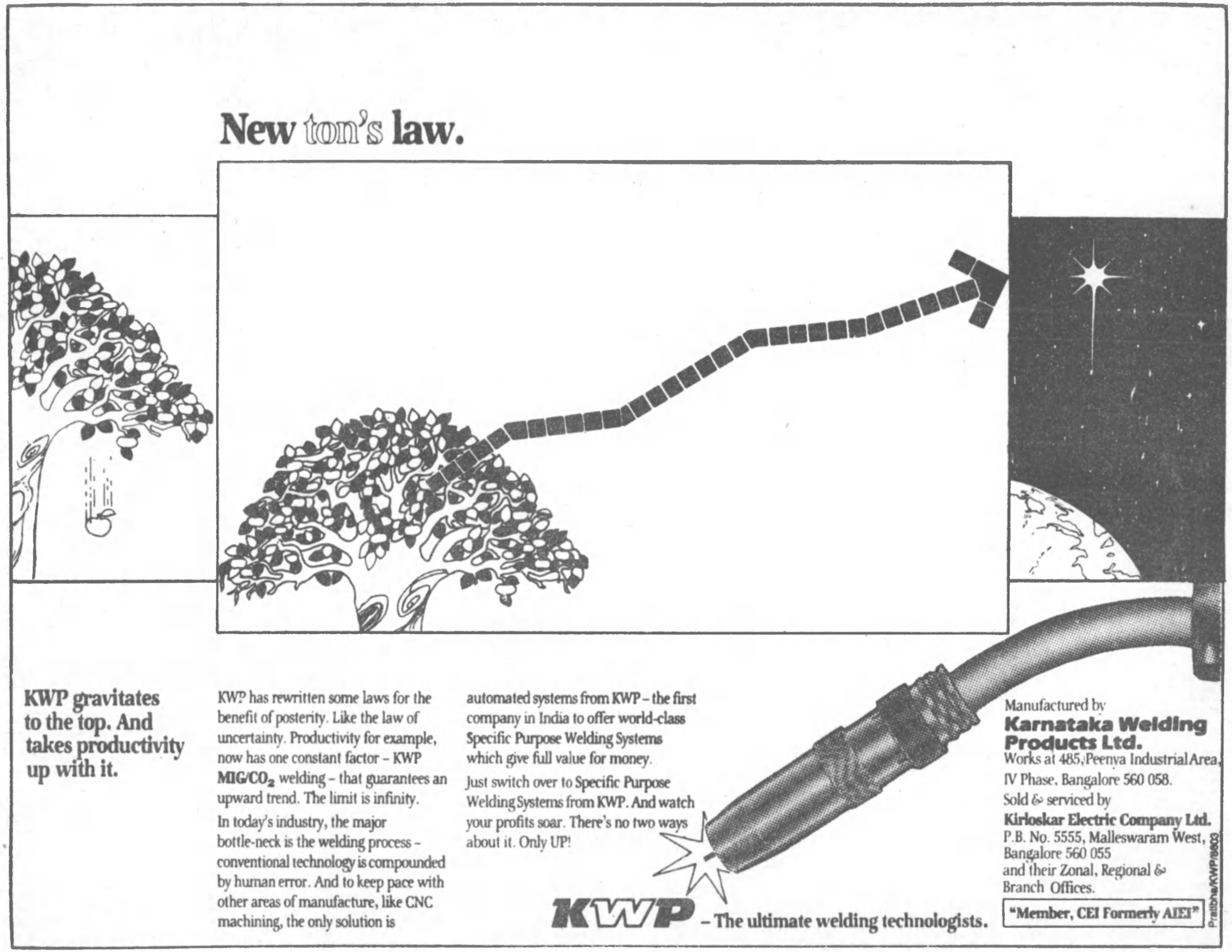
* It is not our internal definition of quality that must shape what we build and sell; instead, it is the customer's definition because competition is now fierce in our business. Customer definitions of quality create a constantly moving target, with good quality continually driving out bad, and better quality driving out the merely good.

- James E Olson

* It must be realised that quality can be achieved only through a sustained systematic effort at all levels. This would call for developing and establishing a commitment to quality at the national level. And a beginning can be made in this direction by educating managerial and technical cadres as well as workers for equipping them to meet the emerging challenge of quality.

- G.W. Datey

The collections presented are from ISI Bulletin, Vol. 38, October 1986.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