ADVANCES IN APPENDAGE JOINING TECHNIQUES FOR PHWR FUEL CLADDING

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ABSTRACT

This paper describes work carried out at the BARC on the development of a technique to join tiny appendages (spacers and bearing pads) to thin cladding (before loading of UO_2 pellets) by resistance welding for PHWR fuel assemblies. The work includes qualifying the process for production environment, designing prototype equipment for regular production and quality monitoring.

In the first phase of development, welding of appendages on UO_2 loaded elements was successfully developed, and is being used in production.

Welding of appendages on to empty clad tubes is a superior technique for several reasons. Many problems associated with development of welding on empty tubes were resolved. Work was initiated, in the second phase of the development task, to select a suitable technique to join appendages on empty clad tubes without any collapse of thin clad. Several alternatives were reviewed and assessed such as laser, full face welding, shim welding and shrink fitting ring spacers. Selection of a method using a mandrel and a modified electrode geometry was fully developed. Results were optimized and process development successfully completed.

Appropriate weld monitoring techniques were also reviewed for their adaptation. This technique is useful for 19, 22 as well as 37 element assemblies.

1.0 INTRODUCTION

The PHWR assembly depends on more than hundred tiny appendages for the vital function of spacing for coolant flow and bearing the load on the channels. At any time there are hundreds of thousands of appendages in the reactor, joined to clad by brazing or resistance welding. Their integrity is crucial during fabrication and subsequent performance of the fuel.

Beryllium coating and subsequent vacuum brazing is used by many fuel manufacturers. We also carried out development work in this area and optimized the parameters for the process. Fig.1 shows a metallograph of brazed joint. Simultaneously, development was carried out on resistance projection welding of appendages on loaded fuel elements as it is felt to be be superior to brazing. The brazing process has several drawbacks in fabrication and performance, viz. use of toxic beryllium, process intricacy and cost. Further brazing leads to change in cladding properties due to a large heat affected zone. Resistance welding route has hence been adopted in production of split spacer fuel assemblies of 19 and 22 elements type for 235 MWe reactors as well as for 37 element type assemblies for 500 MWe reactors.

It was felt desirable to load UO_2 pellets only after joining of appendages to clad for several reasons such reduced handling of UO_2, improved recovery, simplicity in fabrication, reduced damage to pellets etc. However, the development task was challenging due to low clad thickness (0.4 mm), narrow pellet clad gap, and the stringent quality control requirements.

Several alternative joining techniques were evaluated and development work was initiated.

2.0 WELDING ON EMPTY TUBE :

This task was taken up on a request from the Nuclear Power Corporation of India. The process is expected to improve in-pile performance of the fuel assemblies. The earlier developed technique of welding on loaded elements meets the requirements except that unlike brazing process, it is not carried out on empty tubes cladding.

The pellet-clad gap is so small that loading of pellets is always a critical operation. Though specified gap is 0.05 to 0.125 mm, any reduction in this will forbid entry of pellets. The clad thickness is so small that any application of heat and force will lead to distortion in ID. A process was therefore to be developed which would result in zero collapse.

Initially it was thought that unacceptable crevice corrosion may be caused at the gap between clad and appendage in the reactor. Combined with this a desire to increase the strength of joints led to development efforts on full face welding.

2.1 Selection of suitable joining technique:

The process has to meet the following criteria:

i. Metallurgically sound joint. ii. Adequate strength iii. Narrow heat affected zone. iv. Reliability and consistency of joint quality v. Adaptability to large scale production. vi. Adaptability to NDT vii. Simple and economical.

2.2 Shrink fitting of ring spacers:

Development work was carried out on a novel process of shrink fitting of ring spacers. It involves optimizing parameters for shrink fitting thin Zircaloy rings on cladding tubes which would act as spacers. Toolings were developed for this purpose and some shrink-fit joints were made by chilling process. Joint strength upto 300 Kg was obtained. The work was however, discontinued in favour of other developments.

2.3 Full Face Welding :

Joining of full face of the appendage to clad will not only avoid crevice corrosion but will also improve the joint strength. Several methods were tried to achieve the objective. A 100 KVA synchronous timer power source was used and several experiments were conducted. While weld strength was achieved, weld zone showed shrinkage porosity and consistency in weld quality was poor. An alternative shim welding technique was also explored, but was not successful. These methods were not found suitable for this appendage geometry and thickness range, though found promising for higher thickness.

The satisfactory in-reactor performance of the earlier technique indicated that its welding specifications were adequate for requirements of strength, geometry and crevice corrosion . Therefore several other welding techniques were evaluated.

2.4 EB and Laser Welding :

Zircaloy has very good weldability for joining by EB and Laser welding. For equivalent weld penetration, EB requires lesser energy input and heat affected zone (HAZ) is very small. The welds are carried out in vacuum which protects the reactive metal though some loss of high vapour pressure alloying elements such as chromium, tin etc take place. Initially experiments were carried out with Nd-YAG laser to weld bearing pads. These pads had some modifications for heat balance which were found to be unacceptable. Subsequently, both types of appendages of actual sizes were welded successfully using 400 watt laser. The edges of the appendages were welded to clad using 56 joules in pulse mode. However, EB and laser welding were not found to be an economically viable techniques for production. A metallograph of laser weld is shown in Fig.2.

2.5 Ultrasonic Welding:

An assessment of ultrasonic welding was also carried out. The process was felt to be attractive because it offers several advantages such as full face and low temperature (cold) welding of appendages. Weldability of zircaloy using ultrasonic welding is reported to be very good. For bearing pads to thin clad tube geometry, a limited number of trials were conducted at power of 2.5 to 4.0 kw, and time 0.75 to 1.5 sec. Weld strength upto 350 Kg was achieved. The results were however not conclusive and the process was dropped. A metallograph of ultrasonic weld is shown in fig.3.

3.0 RESISTANCE PROJECTION WELDING :

Initially, it was felt that this process will not be appropriate for the objective since it involved joining of very thin components to thicker components and resistance welding requires application of force and heat together. However, to ensure minimum deviation from present production practice and facilitate ease in changeover from old practice, it was decided to work on this technique.

This technique gives a consistent and repeatable quality. It is fast and does not require highly skilled operators and results in a very small HAZ, heating and cooling rates are very high, in the range of 1000^{o}C/sec. Welding is carried out in local cover of inert gas, generally argon, but even in air, welds are satisfactory due to short time and fast cooling. Microstructure in weld zone and narrow HAZ consists of transformed beta structure.

3.1 **Development work :**

Characteristics of resistance welding, limitations of the geometry of components, problems in zircaloy welding, selection of power source etc., were thoroughly reviewed and evaluated. The work was planned and executed in a phased manner as follows for both spacers and bearing pads :

a. Selecting type of power source
b. Studying parameters and optimizing conditions of welding process.
c. Equipment development to suit production requirement
d. Quality control and weld monitoring.

3.1.1. **Power Source** :

The following power sources have been tried for the work :

i. Stored energy power source
ii. Direct energy power source:

a. A.C. type
b. D.C. type, with electrode positive
with electrode negative

A large number of experiments have been conducted with above alternatives. Welding conditions were set in each case. Good welds could be obtained in all cases. There were some variations in weld uniformity and depth of penetration. Best results were obtained with direct energy D.C. electrode positive power source. The results in different conditions are given in **Table 1.**

3.1.2 **Welding conditions**:

It was noticed that the clad collapse was sensitive to welding current and squeeze. The combination of both were carefully chosen and clad collapse was completely avoided. A large number of welds were made in different conditions and tested. Several modifications were made in the fix tures.Different types of locators were developed for spacers and bearing pads. Indexing of cladding for locating appendages at correct positions was carried out. A suitable mandrel was selected for internal support. For bearing pads, two types of projections were studied, namely button type and linear type. Strength was checked on a large number of welds.

4.0 RESULTS AND DISCUSSIONS

Resistance projection welding of spacers and bearing pads was carried out and various Q.C.tests were conducted on the welds. Projections helped in welding of appendages of different thicknesses. Direct energy, D.C. power source with electrode positive has given the least HAZ.

Spacers with two circular projection and bearing pads with three circular as well as linear projections were used and both gave satisfactory results. For the latter, projection height determines gap between pad and clad. Heat input and gap increases with projection height.

Weld strength was checked on individual welds. Final tests were carried out on a calibrated special weld strength tester. Strengths required were 60 Kg and 80 kg for spacer and bearing pads, respectively. Tests have met the following criteria:

a. Minimum strength of each value 60/80 kg
b. Mean strength less 2 sigma 60/80 kg

A large number of welds were tested for this purpose. Some of the results are shown in **Table 2**.

Internal collapse was tested in two ways; (a) by passing pellets of different diameters before and after welding and (b) by metallography. No collapse was noted after welding. A metallograph of the weld region is shown in fig 4.

Corrosion tests were carried out for bearing pads of both types. The results are shown in **Table 3**. The corrosion rate was found acceptable. Results did not indicate any difference between linear or circular projection.

5.0 EQUIPMENT DEVELOPMENT :

The program from the beginning envisaged adaptability to manufacturing work. Modified flow-sheet using this joining technique and the current flow-sheet are shown in Fig. 5. The technique is suitable for automation. After completion of development, a task to develop a design concept of a system for automated work was taken up. It included automated welding of appendages, a low inertia weld head, mandrel support etc. and a block diagram of the proposed design is shown in fig.6.

6.0 QUALITY CONTROL AND WELD MONITORING :

Standard non-destructive tests can not be applied readily to resistance welds. The quality control largely depends on destructive tests such as strength and metallography on sampling basis. In addition, statistical quality control is also followed by controlling mean minus 2 sigma values.

Several weld monitoring schemes were studied to assess the reliability of the welds. A weld monitor based on dynamic resistance (DR) was connected to the system and DR curves were studied for a large number of welds. Welds were destructively tested and results were compared with the curves. A very good correlation was established and a DR window was identified for acceptable welds. Fig.7 shows the details of the system. A study of weld upset was also made similarly. The work indicated that an effective quality control will require more than one monitoring system.

Some work on acoustic Emission (AE) testing was also carried out which indicated very encouraging results. The AE signals have been analyzed to distinguish deviation in heat parameters as well as projection geometry in different welds. Fig.8 shows schematic of AE monitoring set up response signals.

CONCLUSIONS :

A resistance projection welding process is developed to join appendages to cladding in PHWR fuel assemblies, and qualified for 19-element as well as 37-element type of assemblies. Weld strength, clad collapse, metallography and corrosion tests have been rigorously carried out and confirmed that they meet the specifications. An automatic welding system concept has been designed based on above technique which can achieve required production rate.

Appropriate Q.C. plans have been worked out to ensure the weld quality and consistency. Some of the weld monitoring system such as Dynamic Resistance, weld upset etc. have been successfully employed to assure the weld quality nondestructively.

ACKNOWLEDGEMENT

The authors would lke to express their sincere thanks to Shri MS Ramakumar, Director, Nuclear Fuels Group for his support and encouragement for this work. Authors thank Shri PG Kulkarni Head, T&I Section, AFD for supporting quality control work.

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TABLE-1

EFFECT OF TYPE OF POWER SOURCE

BEARING PAD WELD (STRENGTH IN Kg.)

MINIMUM SPECIFIED STRENGTH-80Kg.

	AC	D.C+	DC-
$\bar{X}$	111.38	101.82	107.5
σ	11.15	9.62	10.7
X min.	100	90	100
$\bar{X}-2\sigma$	89.08	82.58	86.1

TABLE-2

RESULTS OF CORROSION TEST

BEARING PAD WELDS

CONDITIONS:

PRESSURE	105 Kg/cm^2
TEMP.	400° C
PERIOD	14 Days

S. No.	WEIGHT GAIN (mg/dm^2)	TYPE OF PROJECTION
1	27.3	CIRCULAR
2	19.5	CIRCULAR
3	16..3	LINEAR
4	20.7	LINEAR
5	26.1	LINEAR

TABLE-3

QUALIFICATION OF APPENDAGE WELDING

SPECIFICATION (IN Kg.f)	BEARING PADS	SPACERS
MINIMUM STRENGTH	80	60
MEAN STRENGTH	80	60
$\bar{X} - 2\sigma$ (MIN.)	80	60
NUMBER OF WELDS	300	200
TEST CARRIED OUT		
COLLAPSE GO/NO GO GAUGE	O, K.	O.K.
SHEAR STRENGTH BY STRENGTH TSTER (IN Kgf)		
MINIMUM STRENGTH	94.3	60.7
MEAN STRENGTH	121.2	83.7
$\bar{X} - 2\sigma$	99.7	62.9
METALLOGRAPHY	O.K.	O.K.

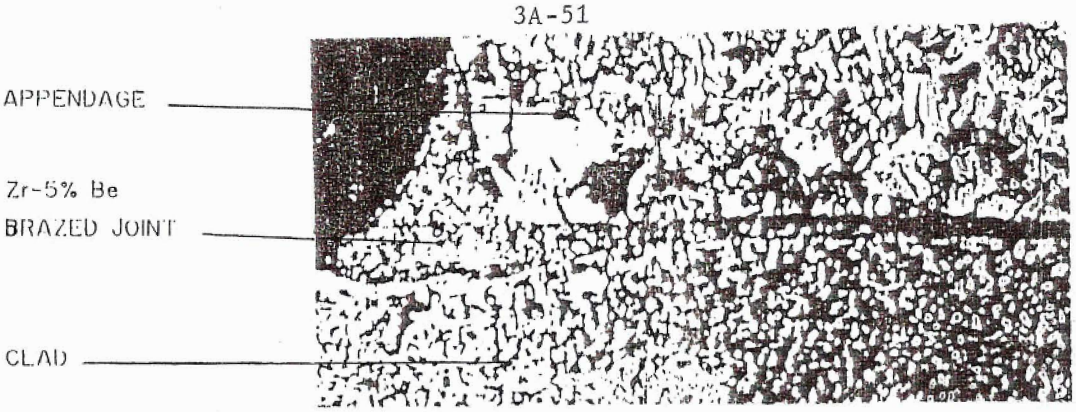


FIG. I ZIRCALOY CLAD TO APPENDAGE BRAZED JOINT

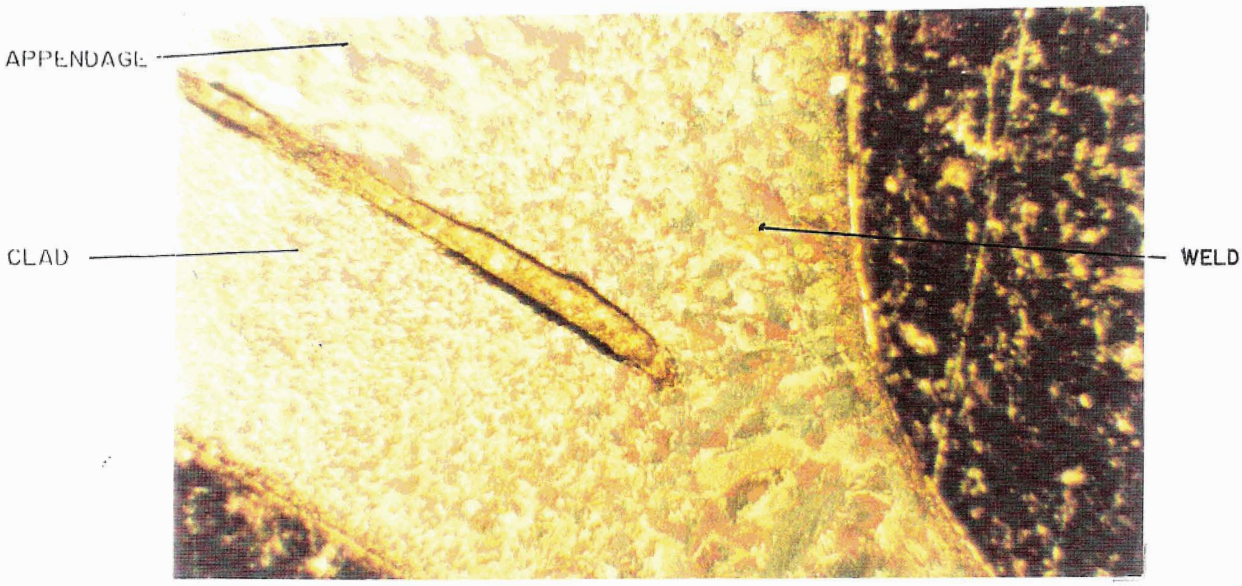


FIG. 2 ZIRCALOY-2 CLAD TO APPENDAGE LASER WELD

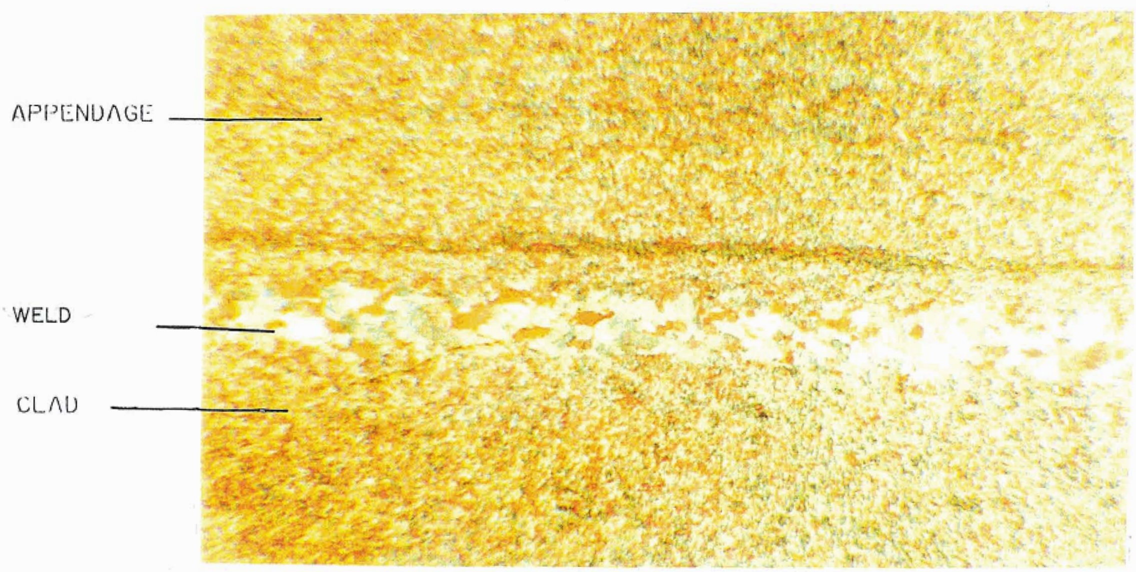
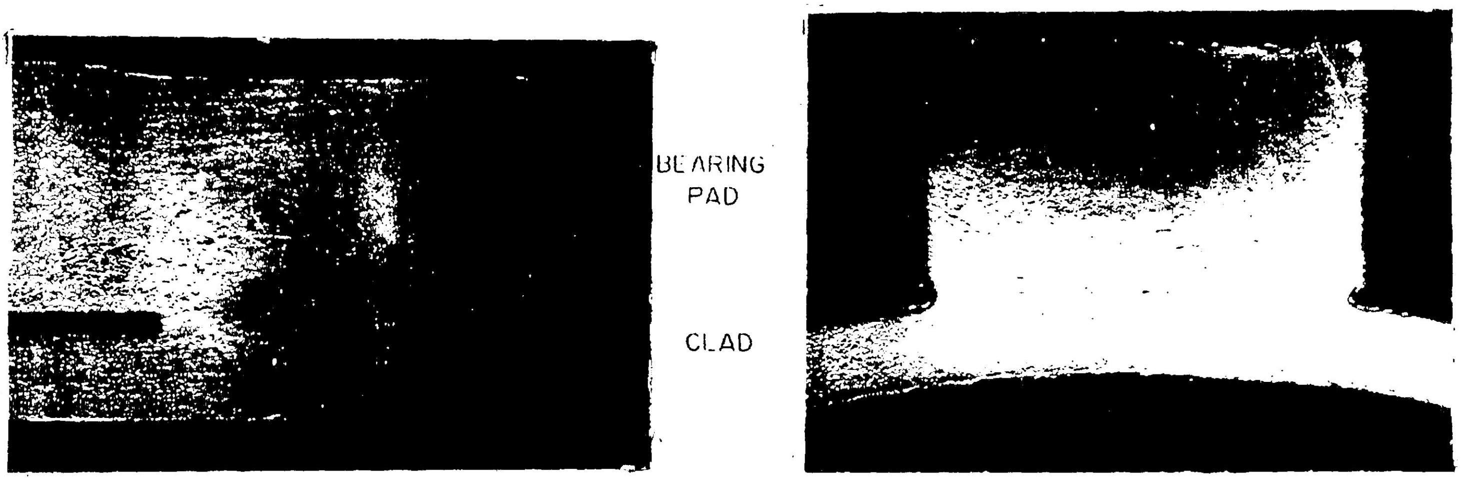


FIG. 3 ZIRCALOY CLAD TO APPENDAGE ULTRASONIC WELD



(a) LONGITUDINAL SECTION

(b) TRANSVERSE SECTION

FIG. 4 RESISTANCE WELD

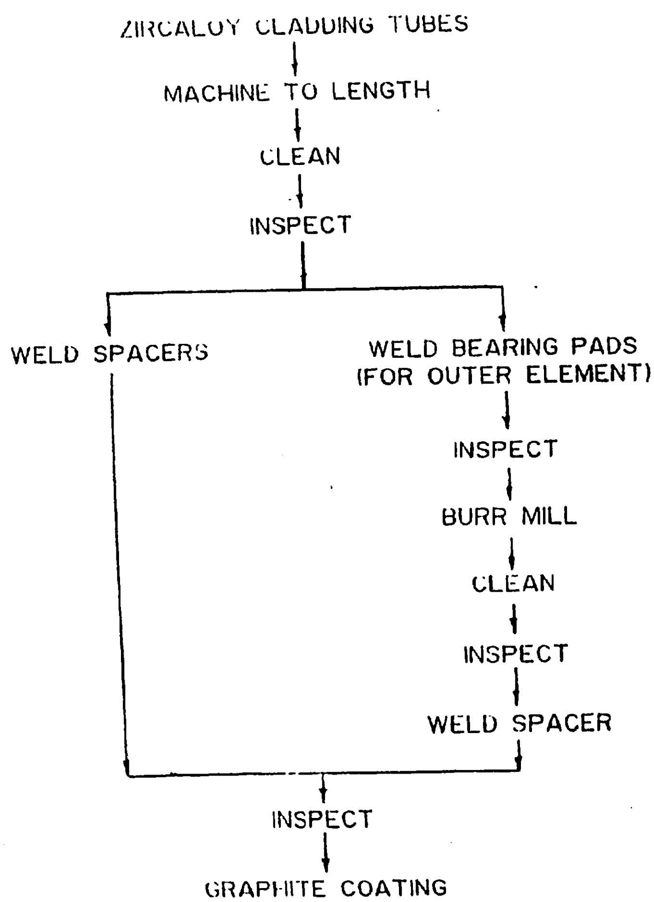


FIG. 5 FLOW SHEET FOR EMPTY TUBE WELDING

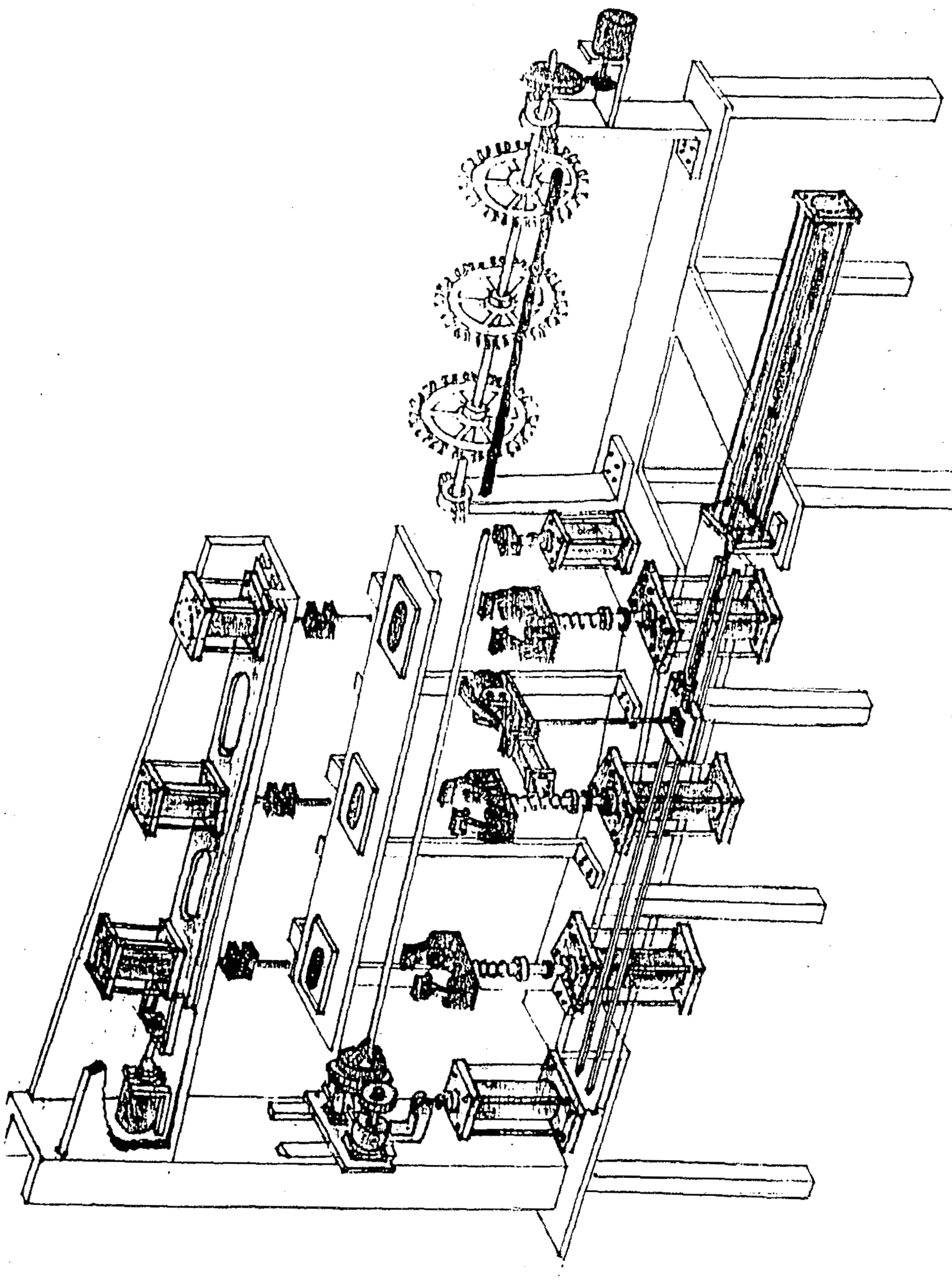


FIG. 6 APPENDAGE WELDING SYSTEM (SCHEMATIC)

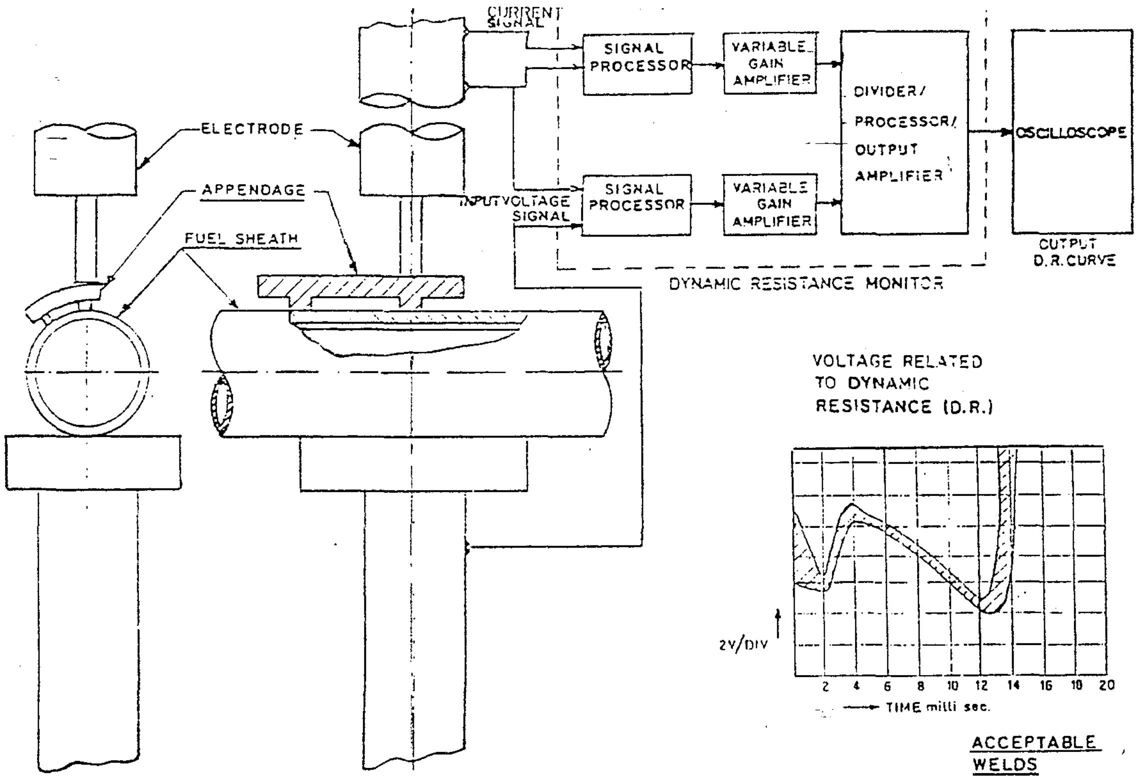
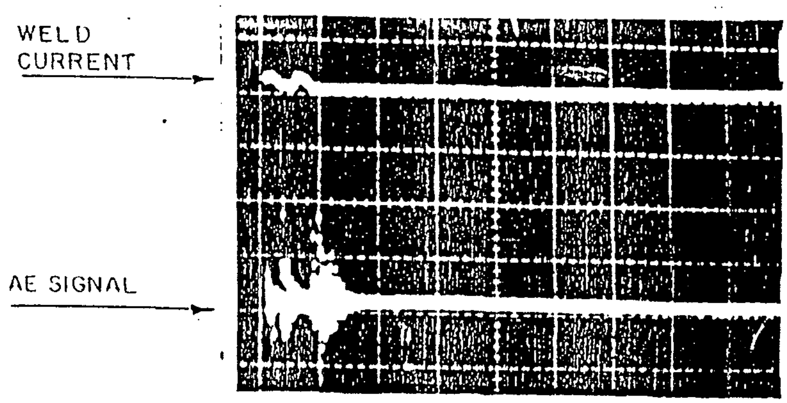


FIG.-7 DYNAMIC RESISTANCE WELD MONITOR



SWEEP : 20 ms / div
VERTICAL AXIS : 5 V / div

DATA RECORDED AT 45 dB OF THRESHOLD SETTING

FIG. 8 AE SIGNAL OF APPENDAGE WELD