APPLICATION OF MEDIUM FREQUENCY WELD CONTROLLER FOR RESISTANCE WELDING PROCESS IN PHWR FUEL MANUFACTURING

D.S.SETTY, A.RAMESHWAR RAO, K.Y. NARAYANA AND R.N.JAYARAJ

Nuclear Fuel Complex, Hyderabad
Department of Atomic Energy
Government of India

ABSTRACT

Nuclear Fuel Complex (NFC) has been continuously engaged, for the past three decades, in the manufacture and supply of 19-element natural uranium dioxide fuel bundles to all the Pressurized Heavy Water Reactors (PHWRs) in India. Starting with classical wire-wrap-design fuel bundles in early seventies, changeover to production of split-wart design fuel bundles was made in mid eighties. Several innovative production processes and quality control systems were developed and employed successfully in the production of more than 230,000 number of fuel bundles of split-wart type. The unique feature of these bundles is the attachment of spacers and bearing pads to the fuel elements by employing simple, cost-effective and environment-friendly resistance welding techniques in place of conventional Beryllium brazing process.

Direct-energy and stored-energy power sources are employed for accomplishing bearing pad and spacer pad welds. The process has been well standardized with respect to selection of electrode material, weld current, weld time, pulse width etc. to obtain good quality welds consistently. In order to further improve the quality of appendage welds, especially to minimize metal expulsion defect and spread of weld strength values, experiments were carried out by employing medium frequency weld controllers. Remarkable improvements in reducing the heat-affected zone, scatter in weld strength values and spark tendency were observed in the experiments carried out with medium frequency controllers.

The paper highlights the comparative behavior of appendage welds carried out with direct-energy, stored-energy and medium frequency power sources. The factors governing the superior quality appendage welds that can be obtained with medium frequency weld controllers are also discussed in the paper.

1.0 INTRODUCTION:

During early 1970's, the production of PHWR fuel on industrial scale started with wire-wrap design and later during mid 1980's was switched over to split-wart design. Split-wart design was aimed at reducing zircaloy weight, number of welds per bundle and fretting-related fuel failures in the reactor. Several developmental efforts in the areas of component manufacturing, standardization of welding and quality control procedures, equipment manufacturing etc., have resulted in achieving the desired confidence level for mass scale production. So far some 230,000 numbers of fuel bundles with split-wart design were manufactured and irradiated successfully in the reactors.

Power source selection and weld parameter optimizations are two important stages in the appendage welding process. Direct and stored energy power sources are employed for these critical operations. In regular production, defects like weak welds and reverse welding are sometimes encountered, which are detected by incorporating suitable gadgets on the machine. Occasional metal expulsion defect in the weld joint may lead to fuel tube puncture, there by causing rejection of fuel element at the helium leak testing station. To avoid metal expulsion defect and also to minimize the spread of weld strength values, latest feedback type medium frequency weld controller was tried to study its suitability for this critical operation. The following sections of the paper high lights the comparative study of various types of power sources and their suitability for employing them for appendage welding.

2.0 DIRECT ENERGY POWER SOURCE:

A.C. power source consists of timer for controlling the phase angle and duration of the weld current and a power transformer to convert high-voltage, low-current to a high current, low voltage energy [1]. This high weld current is passed through the weld joint by simultaneously applying squeeze force to accomplish the weld. The actual current depends on output voltage setting, electrical resistance of the material and the percentage of weld current allowed by the controller. However, in actual practice, it is known that the variations in input voltage greatly influences the welding current and consequently the weld quality. Though presently, feed back controllers for a.c. welding systems are available to precisely achieve the set level of current, they are efficient only for multiple weld cycle applications. For the appendage welding process, the required weld time is found to be a maximum of one cycle and hence these feed back a.c. controllers can not function efficiently.

By incorporating suitable voltage and frequency cut-off systems on the machine, the direct energy power sources could be used for bearing pad-welding process.

3.0 STORED ENERGY POWER SOURCE:

This technology stores the energy in capacitor banks before discharging it into a special pulse transformer, which in turn reduces the weld voltage and then sends the weld energy through the parts to be welded. Weld energy is controlled in terms of power and time (watt-sec). Stored energy weld control system is open- loop type, meaning that the actual weld energy flowing through the parts to be welded will change from weld to weld because of variations in secondary circuit resistance and component dimensions. More over, in the stored energy power sources available in the market, weld time selection is very limited. The basic current profile is used to turn on a specific amount of weld current for a fixed pulse time [1]. The basic current profile some times can cause weld expulsion and electrode sticking when welding the thermally resistive materials. This source discharges the current in exponential form with a high peak current. When this high peak current pulse is passed through the material under certain process deviated conditions, metal expulsion may take place at the weld interface, which is not acceptable for the appendage welding process in the PHWR fuel manufacturing.

Though this power source is not influenced by the input voltage variations, it is having tendency of weld expulsion occurrence at the weld joint.

4.0 MEDIUM FREQUENCY WELD CONTROLLER:

A three-phase or single-phase 50Hz current is passed into a rectifier for producing direct current. The d.c. produced is passed into an inverter, where it is converted back to high frequency a.c. in the range of 3 to 50 kHz. This high frequency a.c. is passed into a transformer for bringing down the voltage and increasing the current. It is again rectified to d.c. and passed through the filter for smoothening the d.c. supply across the welding terminals. This is represented in the form of block diagram in the fig.1.0 [1][4]. The output d.c. current can be controlled by varying the pulse width, which is called pulse width modulation method (PWM). Electrical output parameters like current and voltage basically depends on the variations in the secondary circuit resistance during welding process. Precise control over the current and time are possible with the latest feed back type closed medium frequency weld controllers.

To achieve six-sigma level weld quality power sources with a high degree of consistency are required. High frequency inverter and linear DC technologies having, closed-loop control over weld current, weld voltage or weld powers can be employed for such critical applications like appendage welding. Weld currents for this appendage welding ranges from 500 to 4000 amperes. Weld time is typically programmed in fine resolution, 1 ms time increment as opposed to the older one-cycle i.e. 20 ms time increments found in a.c. weld controllers. This also takes care of line frequency variations [1].

Resistance welding process can be broadly divided into three stages like (a). removal of surface oxide layers. (b). metallurgical joining of nascent metal surfaces. (c). weld nugget formation under the controlled weld parameters[2]. Initial joint resistance along with physical properties of the material decides the power source capacity. Higher currents are required in the beginning for breaking the oxide layers after which the joint resistance drops drastically making the power source to respond in a very short time for controlling the current. In the resistance welding applications severe current variations affects the weld quality that at times can lead to weld expulsion defect at the interface. Medium frequency weld controllers can better achieve this type of fast response to load requirement in controlling the current to the weld joint, which in turn reduces the weld expulsion defect.

Following advantages can be obtained from medium frequency weld controllers,

1. Direct current flows in the secondary welding circuit of the transformer, as a result inductive resistance of the secondary window looses its influence on the welding current even with variable throat depths.
2. The weight of the welding transformer is reduced.
3. Incidence of weld expulsions is drastically reduced.

4. Steadier current allows smooth weld nugget formation.
5. Longer electrode life as sparking between electrode and job is reduced.
6. Suitable for thin sheet and moderately conductive materials.

5.0 EXPERIMENTS AND RESULTS:

With an aim to eliminate the weld expulsion defect and reduce the process variations in the appendage welding, medium frequency weld controller was tried. The results are encouraging as consistent welds were achieved. The new weld controller is having special features like ramp, weld, cool and multiple pulses. Weld trials with various weld patterns at different current and time settings were conducted and studied for the quality evaluation. A single pulse of around 10 ms duration has given better results as compared to long duration and multiple pulses for both spacer pad and bearing pad weldings. After optimizing the weld parameters, different sets of welding trials were taken for comparing the power sources. With a weld sentry unit, parameters like peak current, r.m.s current, voltage etc., have been logged for evaluating the power source performance. Typical waveforms captured for all the three power sources are shown in the Fig.2.0.

For evaluating the power sources, welds were analysed by all types of tests like visual, dimensional, mechanical and metallurgical. Standard deviation of the shear strength values is plotted against Set No. for bearing and spacer pad welding operations with direct energy, stored energy and medium frequency power sources as shown in the Fig.3.0 and Fig.4.0. From this it can be observed that standard deviation is more for the welds taken with direct energy power source, and is less for the welds carried out with stored energy and medium frequency power sources.

Microstructure for both bearing and spacer pad welds taken are shown in the Fig.5.0 and Fig. 6.0. The Heat Affected Zone is narrow for the stored energy and medium frequency power sources. Sheath depression is also less and is found to be within the specification. Table 1.0 gives the detailed evaluation results.

However, under slightly varied process conditions like fluctuations in input voltage, deviations in component conditions etc., which can be expected in mass production, medium frequency weld controllers offer the best quality of welds.

6.0 ACKNOWLEDGEMENTS:

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7.0 CONCLUSIONS

1.1 In direct and stored energy power sources the secondary current is influenced by the secondary circuit resistance variations, which in turn affect the weld quality in mass production.

1.2 Stored energy power source is found suitable for appendage welds and reduced scatter in the weld strength values. However occasional metal expulsion tendency is observed in mass production. Weld expulsion is most unacceptable defect in thin wall appendage welding process as this may result in sheath puncture.

1.3 Medium frequency power source is found suitable with short duration current pulses for producing consistent quality welds with smooth nugget formation.

1.4 From the waveforms, it can be seen that using medium frequency power source, desired current pattern to the weld can be achieved.

8.0 REFERENCES

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Table-1.0

Quality control test	**Evaluating Parameters**	**Direct energy power source**	**Stored energy power source**	**Power source with MFWC**
Mechanical	(a)Shear strength variation (Std. deviation) (b)Helium leak testing.	5 to 7 O.K.	3 to 6 O.K.	3 to 6 O.K.
Visual	(a) Electrode impression (b) Sparking/ Expulsion	Predominant Cannot be controlled	Predominant Cannot be controlled	Less Can be controlled

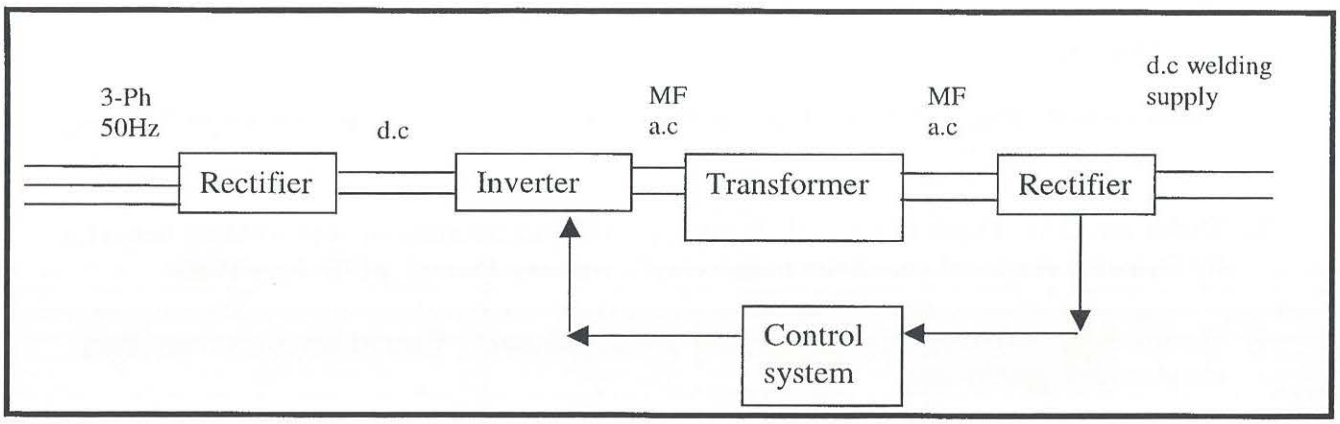


Fig. 1.0: Block Diagram Of Power Source With Medium Frequency Weld Controller (MFWC)

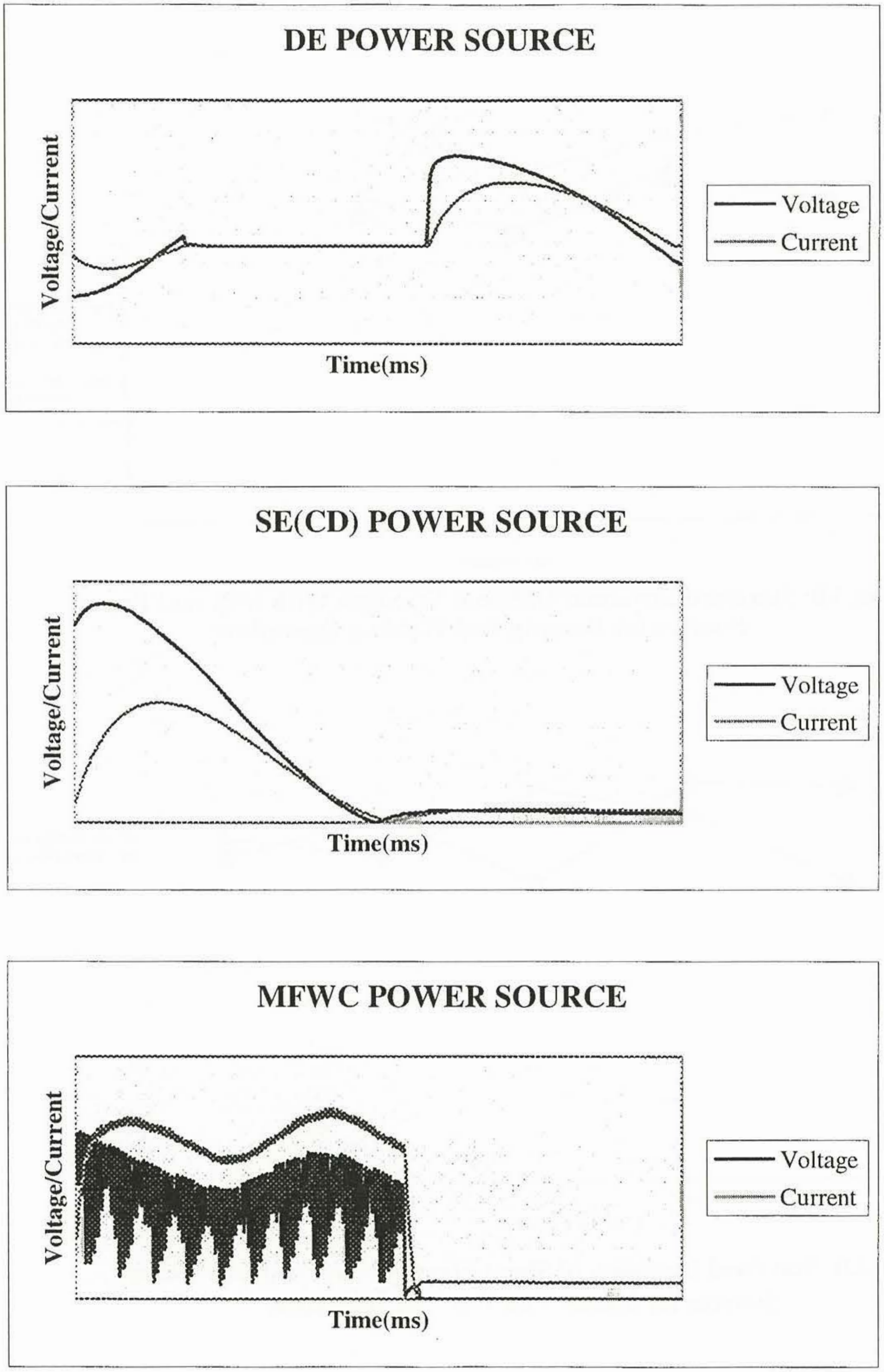


Fig. 2.0: Wave Forms For Current And Voltage With Different Power Sources

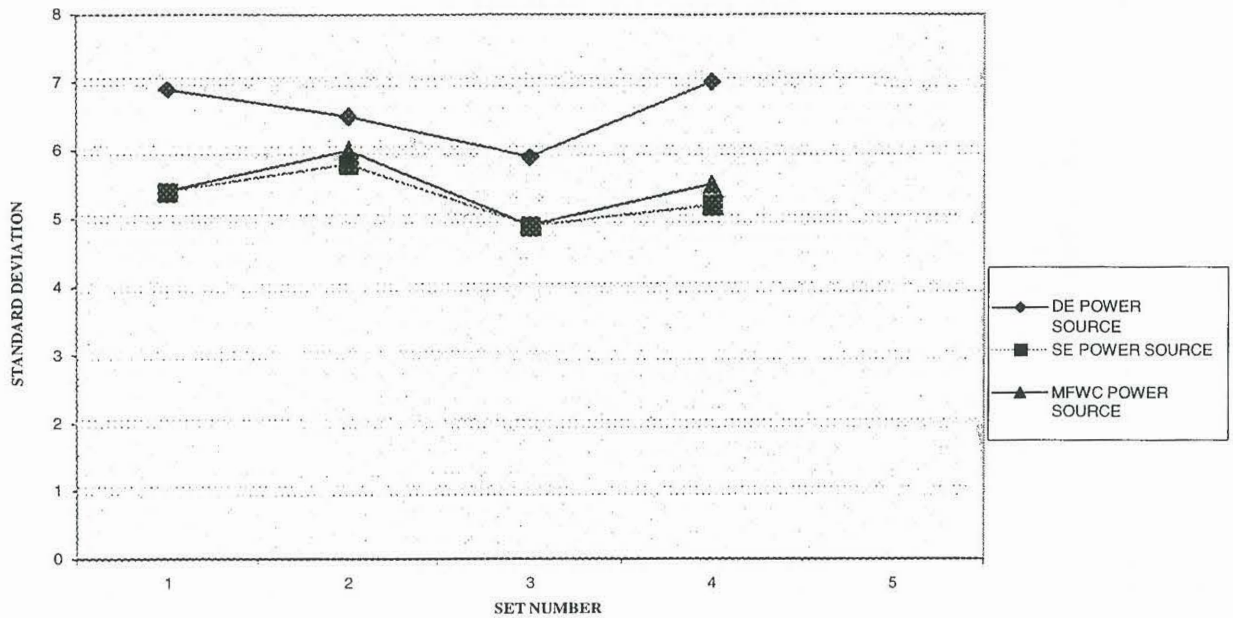


Fig.3.0: Standard Deviation Of Shear Strength With Different Power Sources for Bearing Pad Welding Operation

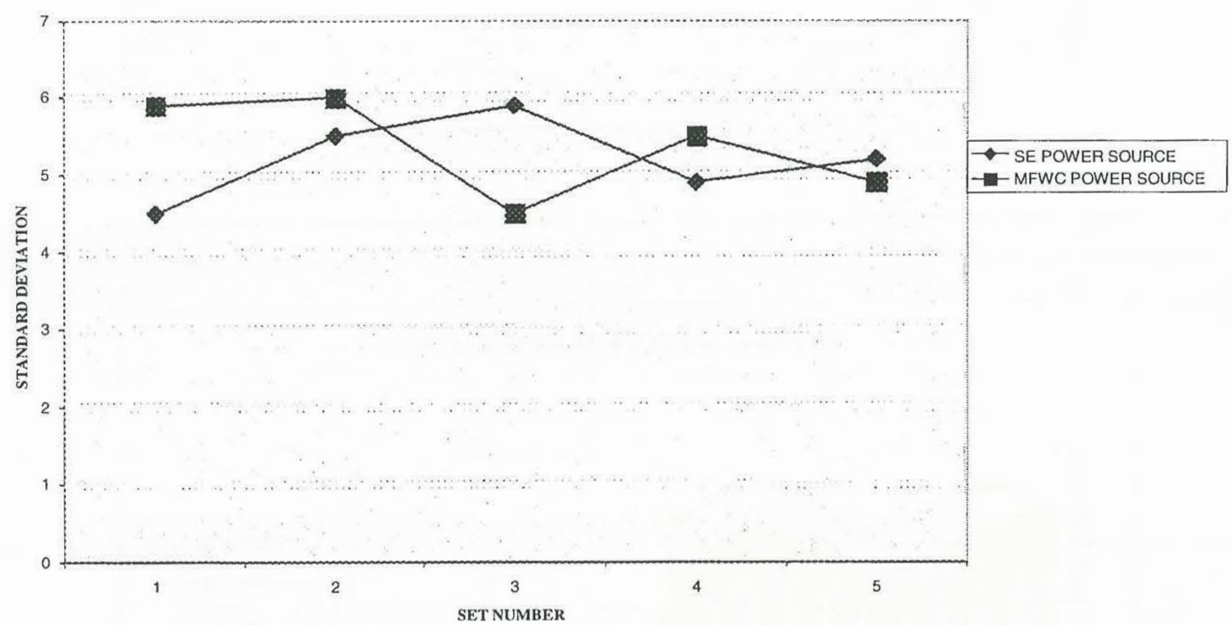
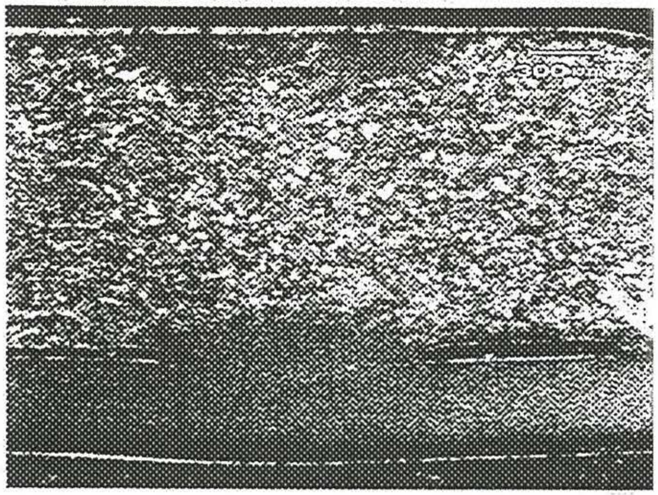
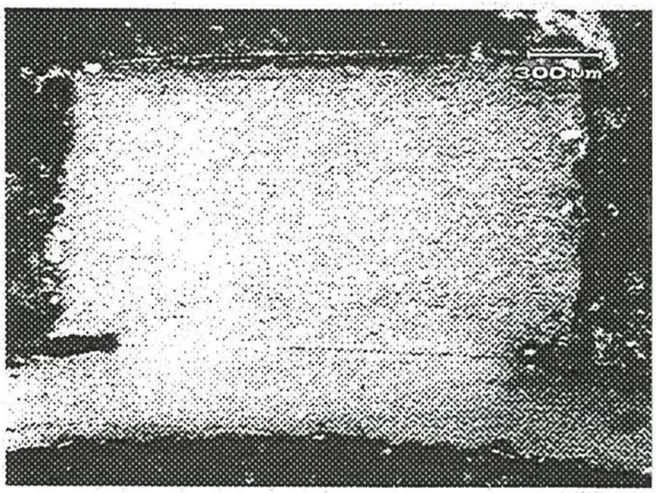


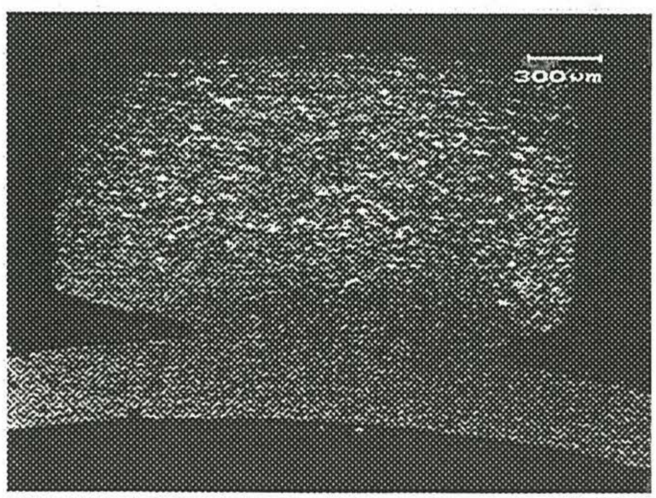
Fig. 4.0: Standard Deviation of Shear Strength with Different Power Sources for Spacer Pad Welding Operation



Direct Energy
Power Source
(Axial cross section)

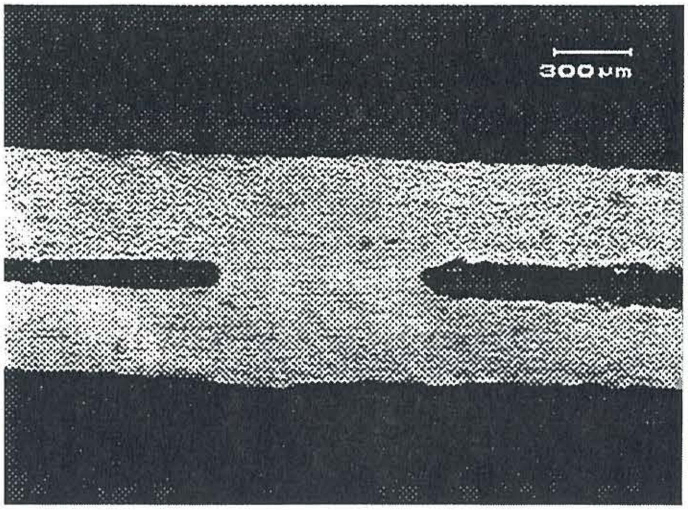


Stored Energy Power
Source
(Radial cross section)

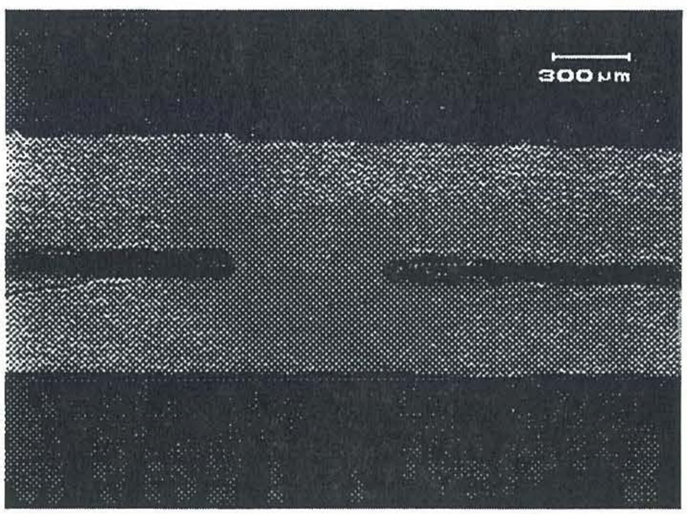


Medium Frequency Weld
Controller Power Source
(Radial cross section)

Fig. 5.0: Weld Microstructure of Bearing Pad Welding with different Power Sources



Medium Frequency Weld
Controller
Power Source



Stored Energy (CD)
Power Source

Fig. 6.0: Weld Microstructure of Spacer Pad Welding With Different Power Sources