PERFORMANCE OF INDIGENOUS RESISTANCE WELDING EQUIPMENT FOR PHWR FUEL FABRICATION IN NFC

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ABSTRACT

Indigenisation of critical equipment for manufacturing of PHWR fuel and automation in the production line have been the main thrust in NFC in recent years. As part of this endeavour, resistance welding equipment for end plug welding of Zircaloy-4 clad Uranium Oxide fuel pin and end plates of 19-element fuel bundles have been developed .The paper discusses the equipment design features, critical operating parameters and performance of these indigenous welding machines.

1.0 INTRODUCTION:

After successfully completing the fabrication of fuel bundles for the half charge of the initial core of Rajastan Atomic Power Station -1 (RAPS-1) in Bhabha Atomic Research Centre, Trombay, the industrial scale production activity of PHWR fuel was shifted to Nuclear Fuel Complex in the early 1970 's. The initial production campaign of natural UO_2 fuel was initiated with equipment imported mostly from the West, in general, and Canada in particular. Thereafter, the equipment were progressively replaced with indigenous ones[1] , particularly in the new production lines that were set up for meeting the ever increasing fuel demand of Nuclear Power Corporation of India Limited (NPCIL). Indigenously designed and manufactured critical equipment for fuel pin and fuel bundle welding were qualified and put into production, meeting stringent quality standards. These machines differ from earlier imported machines with respect to: a) design features like mechanical system, power & welding control and monitorings systems, b) critical operating parameters and c) performance. The present paper summarises some of the features of these equipment and their performance in recent years.

2.0 DESIGN FEATURES OF EQUIPMENT:

2.1 Mechanical System

The end plug welding machine is a special purpose unit consisting of two weld heads which are positioned in a staggered manner on both sides of a conveyor. The Zircaloy-4 cladding tube loaded with high density UO_2 fuel pellets is clamped in a four-jaw collet. The high accelerating weld head which holds the end plug moves on linear guide rods[2]. The end plugs are loaded into the weld head automatically from an end plug storage magazine. The initial movement of weld head is done by a pneumatic cylinder and squeeze force is applied by a diaphragm cylinder. After completion of welding at one end, the loaded tube is transferred to second weld head for carrying out welding on second end. Photographs of new machine and earlier machine are given in Fig-1.

The construction of end plate welding machine is based on a press type design. The machine consists of radial and rotary indexing tables , weld head and specially designed fixture for holding fuel elements and end plates. The novel feature of this equipment is the gripping and tilting mechanism which facilitates reversing of the fuel bundle for carrying out welding of the fuel elements to the end plate on the other end of the fuel bundle. The same mechansim will be exploited for fabricating the end plate welding machine of 37-element fuel bundles for PHWR 500. The machine is also provided with loading and unloading slide table for transferring the fixture loaded with elements from loading side to welding station and welding station to unloading side. Photographs of new machine and earlier machine are given in Fig-2.

The complete operation of these welding machines is carried out through programmable logic controller with fault code display and annunciation, unlike earlier machines having hardware logic. The machines can be operated in manual, semi-automatic and automatic modes. Provision is made to bring the machines into initial condition mode by pressing a single button to work on auto-mode.

2.2 Power &Welding Control :

Synchronous welding controls are used in both the machines to initiate welding cycle and for controlling heat input. Thyristors are used in place of ignitrons. The controllers are semi-conductor/IC based compared to earlier valve version, which used to give rise to variations in percentage heat settings and number of cycles. An independent 11 kV/433 V, 1600 kVA transformer is employed with automatic voltage regulator for obtaining voltage within specified limits. Constant current feed back with up-slope is employed in place of multiple heat-cool cycles for pre-heat. Bus bars in one end plug welding machine are designed to get additional electro-magnetic force proportional to welding current for getting forge force during welding[3]. In the second machine, this technique is not employed. For end plate welding, percentage heat setting mode is used with constant voltage feed back.

2.3 Monitoring Systems:

P.C. based weld monitors are employed for monitoring voltage, current, displacement (only for end plug welding), and force. The sampling is done at a time interval of 0.1 ms. All the values during the welding are acquired and stored. The data can be presented in a tabular form or graphically. Minimum and maximum values can be assigned for each parameter and an audio-visual alarm is generated if the values fall beyond the set parameters. Provision is made to enter the corresponding quality control results of each for further analysis.

3.0 OPERATING PARAMETERS:

During commissioning of equipment, intensive trials are conducted for checking the performance of individual components and are evaluated with respect to consistency, repeatability and accuracy of each operation. Before the units are qualified for production, engineering experiments are conducted to optimise the parameters. Then the machines are qualified as per the stipulations laid down by quality assurance department.

Secondary voltage, squeeze force, pre-heat, weld heat cycle/current and different timings between each operation are the main parameters controlling the weld integrity in addition to weld joint configuration. The operating parameters for different machines differ slightly in view of the presence/absence of magnetic forge force during welding, and up-slope mode during pre-heat. Typical operating parameters are given below:

	SECONDARY VOLTAGE Volts	SQUEEZE FORCE Newtons	PRE-HEAT		WELD-HEAT	
			NO. OF CYCLES	CURRENT kA	NO.OF CYCLES	CURRENT kA
Machine – I	15.0	1250	9	5.5	2	13.5
Machine-II	6.6	3200	5 4 UPSLOPE	1.5 – 3.0	2	13.0

Similarly electrode force, number of pre-heat/weld cycles and percentage heat setting are themain parameters for end plate welding machine. To reduce the waviness on end plate during welding, a pre-heat cycle is introduced and different percentage heat settings are employed for central/inner and outer elements. A typical set of operating parameters is given below:

SECONDARY VOLTAGE Volts	SQUEEZE FORCE Newtons	PRE-HEAT		WELD-HEAT	
		NO. OF CYCLES	PERCENTAGE HEAT	NO.OF CYCLES	PERCENTAGE HEAT
4.4	1200	1	10	2	45 FOR C&I 50 FOR OUTER

4.0 PERFORMANCE OF EQUIPMENT:

During the first qualification campaign of end plug welding machine, 300 welds are evaluated for weld fusion, weld rating, eccentricity, helium leak and percentage of helium in cover gas. Statistical parameters like average, standard deviation and process capability index are calculated. Some of the welds are ultrasonically evaluated followed by detailed microstructural investigation for ensuring weld integrity. During the production campaign set up and process welds (after every 40 welds) are carried out and evaluated by ultrasonic testing [4] and metallography methods. Performance of these machines are controlled by control charts, frequency of occurrence of weld failures due to fusion and rating, helium leak and percentage of helium content in the fuel pin. The performance of end plug welding machines is given in Table-1and Fig-3.

During initial qualification of end plate welding machine, two assemblies are welded. The assemblies are tested for dimensional requirements. Few welds are checked for weld metallography and the rest for torque strength [5]. During production, set up welds are daily evaluated for torque strength. All the assemblies are subjected to dimensional checks and helium leak test after back filling with helium. The performance of the machine is given in Table-2 and Fig-4.

5.0 CONCLUSIONS:

Indigenous design, manufacturing, erection and commissioning of the resistance welding machines has given tremendous confidence in obtaining best operating parameters during engineering experiments and qualifying the machines for production. These efforts have paved the way for fabricating similar machines indigenously for the production of 37-element fuel bundles in NFC.

6.0 ACKNOWLEDGEMENTS:

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7.0 REFERENCES:

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TABLE 1 - PERFORMANCE OF END PLUG WELDING MACHINES

DURING QUALIFICATION

	EARLIER MACHINE	**NEW MACHINE**
	Minimum/Maximum	**Minimum/Maximum**
Weld fusion	180/200	190/225
Weld rating	0/1	0/1
Eccentricity	Within limits	Within limits
He. Leak	Nil	Nil
% of He. in cover gas	92% / 98%	96% / 99%
No. of welds	60	300
Average Fusion	192.33	220.29
Standard Deviation	5.30	5.80
Average – 6 SD	160.53	185.49
CPK	1.96	2.59

DURING PRODUCTION

	NEW MACHINE
No. of lots welded (Lot = 20 elements)	615
No. of Welds tested (Process)	615
No. of lots rejected due to Metallography failure	0
No. of elements He. Leak Tested	22566
No. of elements rejected due to He. Leak	1
% of elements rejected due to He. Leak	0.004

TABLE 2– PERFORMANCE OF END PLATE WELDING MACHINES

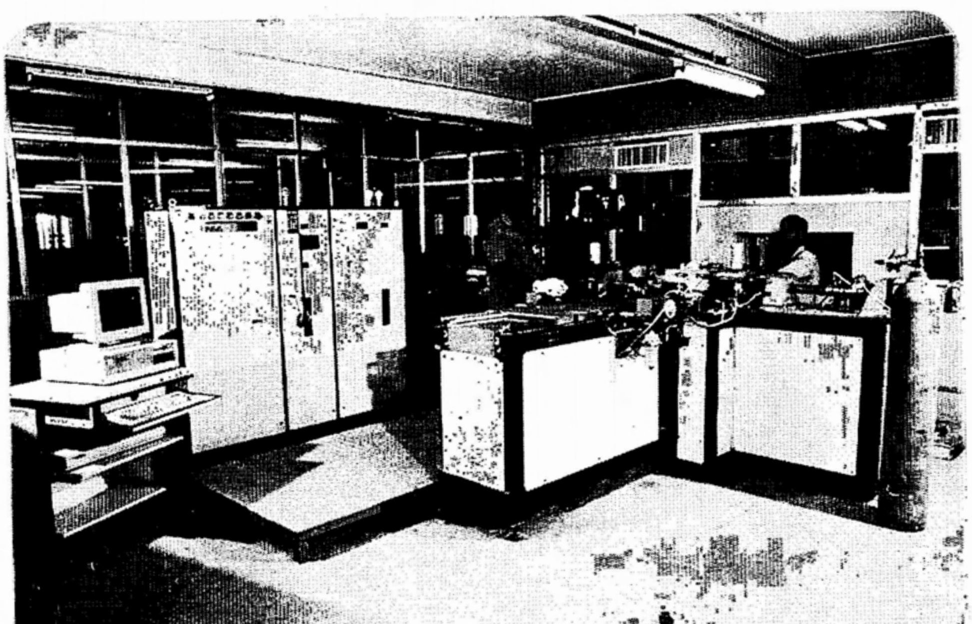
DURING QUALIFICATION

* Visual Inspection	Free from any defects	
* Dimensional inspection	Acceptable dimensionally	
* Metallography	No weld defects observed	
* Strength Evaluation(No. of welds 66)	**NEW MACHINE**	**EARLIER MACHINE**
- Maximum value	9.73 Nm	8.79 Nm
- Minimum value	7.68 Nm	6.90 Nm
- Average	8.22 Nm	8.19 Nm
- Standard Deviation	0.398 Nm	0.449 Nm
- Average – 2 * S.D	7.42 Nm	7.29 Nm
- CPK	1.83 Nm	1.59 Nm

DURING PRODUCION

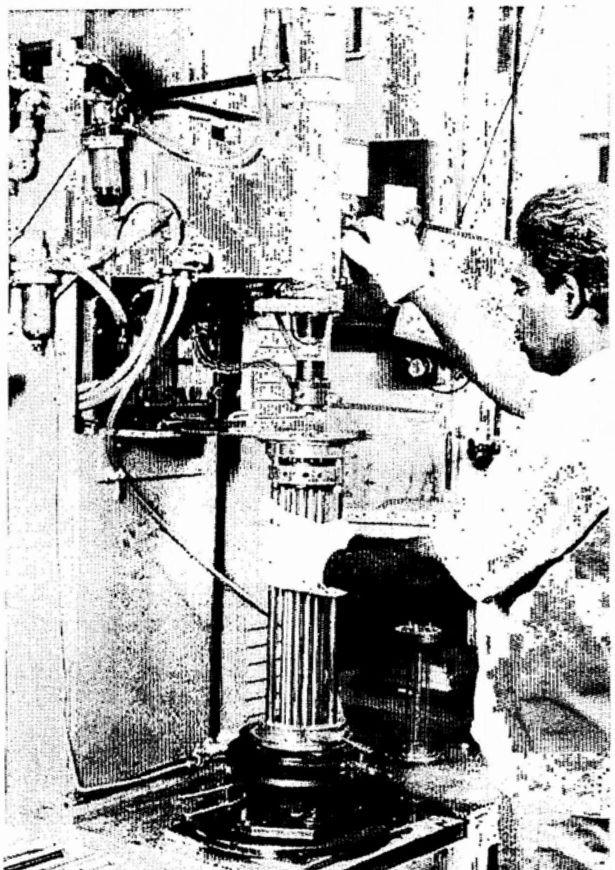
	NEW MACHINE
* No. of Assemblies Welded	1226
* Strength Evaluation (Process Control)	
- No. of welds	200
- Maximum value	10.6 Nm
- Minimum value	8.7 Nm
- Average	9.6 Nm
- Standard Deviation	0.44 Nm
- Average – 2 * S.D	8.7 Nm

EARLIER MACHINE

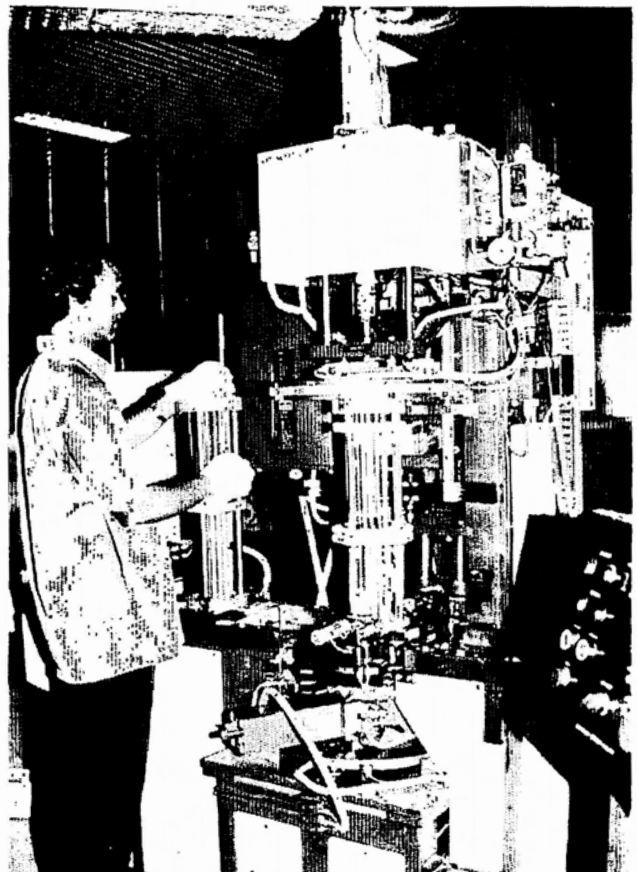


NEW MACHINE

FIGURE-1 : END PLUG WELDING MACHINES



EARLIER MACHINE



NEW MACHINE

FIGURE-2: END PLATE WELDING MACHINES.

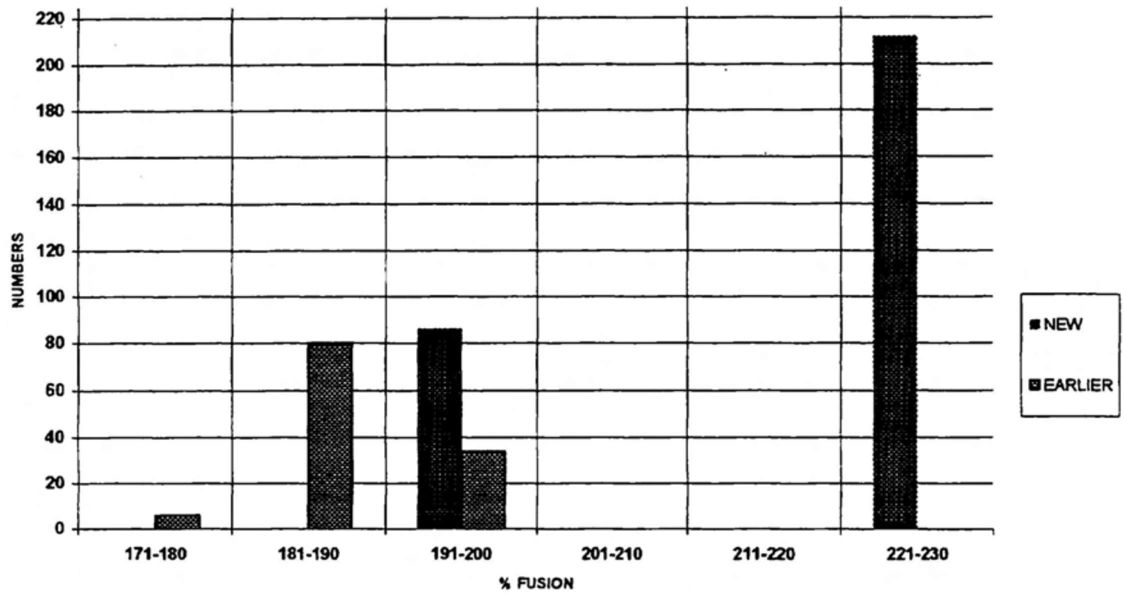


FIGURE-3: PERFORMANCE OF END PLUG WELDING MACHINES-COMMPARISION

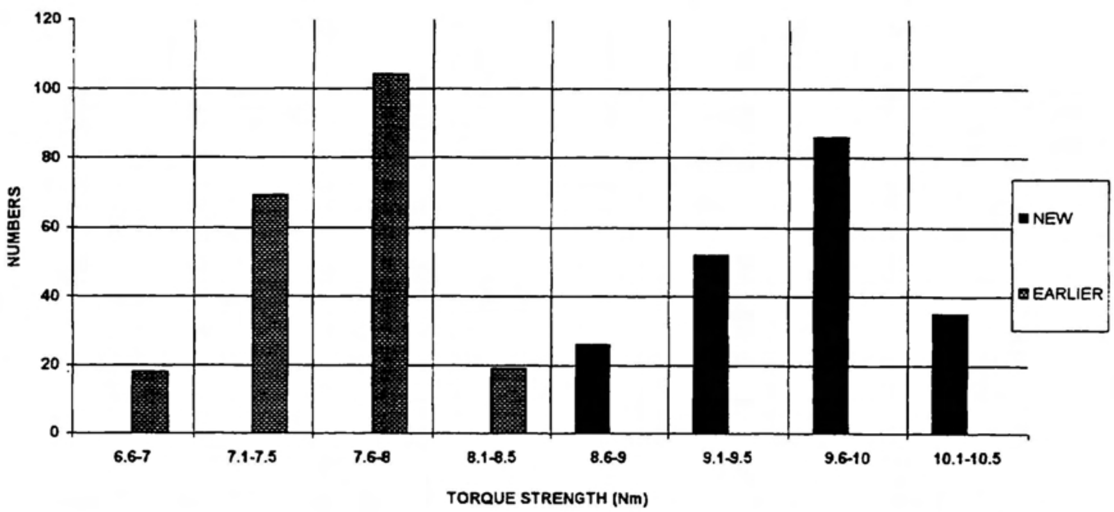


FIGURE-4: PERFORMANCE OF END PLATE WELDING MACHINES-COMPARISION