Welding Processes Adopted for the Manufacture of Diesel Electric Locomotives at Varanasi

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1. Introduction

1.1 This paper describes some important aspects of the manufacture of diesel locomotives which would be of particular interest to a Weld Fabrication Engineer. Keeping in tune with the theme of the seminar, a major portion of the paper is devoted to a few specialised welding processes adopted in the fabrication of the locomotive sub-assemblies. It is also proposed to briefly touch upon the current manufacturing activities undertaken at DLW as also the salient features of the locomotive design.

2. Manufacturing Activities

2.1 The Diesel Locomotive Works are primarily engaged in the manufacture of BG (WDM-2) and MG (YDM-4) diesel electric locomotives to meet the mixed operation requirements of the Indian Railways. In the recent years, however, the production activities have been considerably diversified to include the manufacture of such items as :

(i) heavy duty diesel shunting locomotives (WDS6) for use in steel plants.

(ii) locos for export—DLW has recently completed an order for supply of 15 locos to Tanzania,

(iii) 1.75 MW diesel generating sets for the public sector undertakings, private bodies and also for the Railways,

(iv) mobile diesel generating sets,

(v) power packs, new engine blocks and repair of the old engine blocks received from the Railways.

(vi) spare parts for meeting the maintenance and emergency requirements of the Railways, Steel Plants and for export purposes and

(vii) developmental items, such as, the manufacture of fabricated design of high speed bogies suitable for running upto 200 KMPH.

3. Salient Features of the Locomotive

3.1 The BG locomotive is powered by Alco Model 251-B, 16-cylinder Vee diesel engine rated 2600 HP at 1000 RPM and the MG and WD56 locomotives by Alco Model 251-D, 6-cylinder In-line diesel engine rated 1350 HP at 1100 RPM. Both models of diesel engines follow a four stroke cycle, are turbosupercharged and aftercooled and have a bore of 9" and stroke of 10.1/2".

3.2 The chassis consists of the underframe, superstructure, trucks and auxiliary equipment. The underframes are of welded construction, the BG design being

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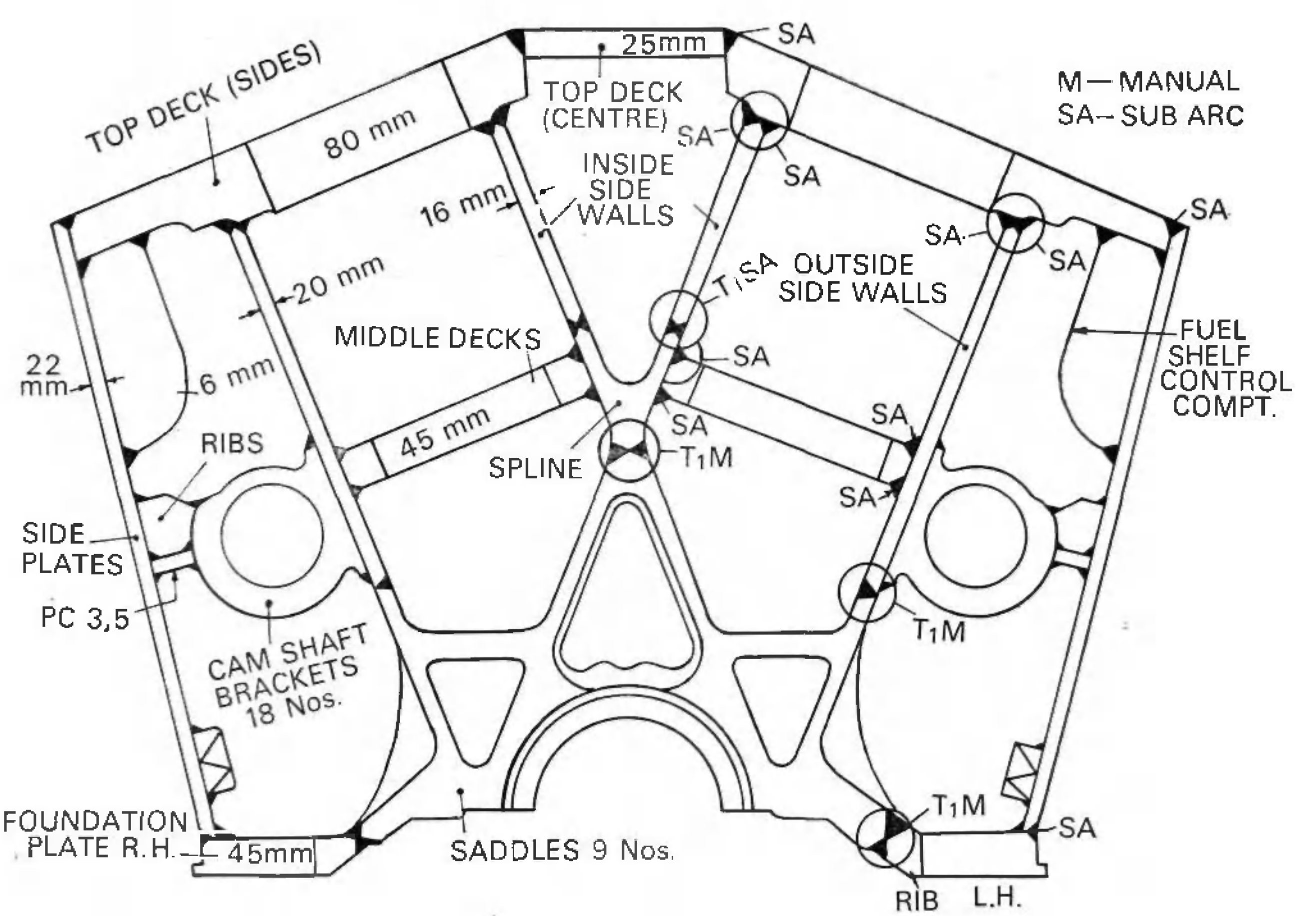
ANNEXURE—1



SECTIONAL VIEW OF THE ENGINE BLOCK

of box type and the MG and WDS6 being of conventional I-Beam centre-sill type. The locomotive is mounted on two, six-wheel, three-motor, trimount type, cast steel trucks having primary coil spring suspension on four sets of double equalisers.

3.3 The electrical transmission equipment has three main groups, namely; rotating machines, control equipment and dynamic brake unit. The rotating equipment consists of traction generator and motors, auxiliary generator and exciter. The basic excitation system employed is Type 'E' control using semi-conductor devices. Both BG and MG locomotives are provided with dynamic braking units, in addition to the air-brake system employed on the locomotives.

4. The Application of Welding Techniques in the Building of a Diesel Locomotive

4.1 The manufactuing operations at DLW, employ the very best in professional skills and process technology and rigid quality control throughout the manufacturing cycle of the diesel locomotive. The anatomy of a diesel locomotive would show a large number of weld fabricated structures which are separately manufactured as sub-assemblies and then assembled together to form a diesel locomotive. The plant and the equipment installed at DLW is the latest in the field of welding technology and sophisticated welding techniques are adopted to ensure quality product alongwith an optimum rate of production.

4.2 To give an idea of the application of the welding techniques adopted at DLW, it is proposed to discuss the manufacture and/or reclamation of the following important sub-assemblies :—

(*i*) Engine block
(ii) Underframe
(iii) Superstructure
(iv) Aluminium pistons

5. Fabrication of Engine Block of WDM-2 Locomotive

5.1 The engine block is the principal structural member of the diesel engine. It is a composite weldment with heavy steel forgings, which serve as the crank shaft housings and hence, become the backbone of the structure. The decks and the foundation plates are built round the steel forgings to form the box section which provides the maximum rigidity. The successful manufacture of the engine block requires :—

(i) right quality of steel suitable for welding,
(ii) proper electrodes,
(iii) proper welding techniques and
(iv) proper test procedures.

5.2 The steel has not only to meet the requirements of weldability and physical properties, but it should also be free from defects such as laminations. The plates and billets are, therefore, subjected to ultrasonic test before use. The plates used have thicknesses varying from 6 mm. to 80 mm. and conform to IS-2062. The principal structural members of the engine block are profile cut out of plates on the automatic flame cutting machines. Spline is machined out of billet 5″×7″ conforming to IS 1875. The spline being the most highly stressed item, it is made out of one piece instead of being fabricated. Considering the large size of the engine block (162—1/16″ length × 50-7/8″ width and 36-3/4″ height), the welded joints have to necessarily have a proper fit particularly at the fillet joints. As such, the plates are subjected to a straightening operation on a 200 ton hydraulic press before use.

5.3 The engine block weldment employs both manual and automatic welding processes. The long continuous welds which run through the entire length are mostly done by the "Automatic Submerged Arc" welding process and the short runs are made by the manual metal arc process. For each engine block, the manual arc welding process requires 1800 pieces of electrodes and the submerged arc welding process requires 110 Kg of wire and 150 Kg of flux for deposition of 34 beads (consisting of 28 single pass and 6 double pass) each 164″ long. Total approximate length of welding in engine block is 926 ft. The total time for fabrication of engine block is 1070 man hours, out of which 428 are manual arc welding hours, 125 submerged arc hours and the rest are fitting, grinding, shot blasting and machining hours.

5.4 *Electrodes for Manual Metal Arc Welding*

While developing the electrodes to meet the requirement of this vital weldment, extensive tests had to be conducted, not only to determine the physical properties and other qualities, but also to determine the suitability for welds which have to comply with stringent radiographic standards. The electrodes used for the manual metal arc welding are :—

1. Rutile Iron-oxide AWS/ASTM E6020 (IS E442412) for down hand, horizontal fillet, butt welds and suitable for X-ray quality joints.

2. High cellulose Potassium type all position AC/DC AWS/ASTM E6011 (IS E104411) electrodes capable of giving X-ray quality joints.

5.5 *Submerged Arc Welding*

5.5.1 An imported AC welding head of 1250 amps. capacity is used for submerged arc welding. This machine has a carriage as well as a hopper arrangement and depending upon the welding requirement, each one is used in turn. The welding current ranges from 550 to 950 amps. depending upon the thickness of the joints.

5.5.**2** Wire used for submerged arc welding is coiled, copper coated, size 5 mm. with low carbon content conforming to IS 2879-1964. The chemical composition of the wire is C-0.08%, Mn-0.46%, P-0.018%, S-0.022, Si 0.01%.

5.5.**3** The flux used is an agglomerated type coarse grain flux having the property of transfer of manganese and other elements for giving crack resistant quality of weld deposit. The flux is a mixture of powders of pre-determined particle size and each particle is chemically basic in character. These particles are not fused and are, therefore, highly reactive. This property facilitates transfer of manganese and other alloying elements to the weld deposit in large amounts. Silicon transfer is much lower with these fluxes compared to the fused fluxes, and this is a desirable feature because high Mn-Si ratio makes the weld deposit more ductile and crack resistant. These fluxes should be heated in an oven at 250°C for 2 hours as moist flux generates hydrogen in the arc and causes cold cracks in the weld deposit and in the heat-affected zone.

5.6 *Sequence of manufacture of engine block*

5.6.1 Some of the important stages of the manufacture of engine block are described below :—

5.6.2 The foundation plates, forged saddles and the spline are clamped together on a cast iron fixture mounted on roll over rings. The saddles and foundation plates are given a pre off-set with 1/8″ shim in the centre tapering down to 0 at the ends. This off-set is needed to neutralise the distortion effects of welding. These are then tack welded with 4 or 5 mm. E6011 electrodes and manually welded with E6020 electrodes in the down hand position. These welded joints are subjected to 100% radiographic examination. Any defects detected during this examination are gouged out and are welded to give a 100% radiographic quality joint. This is necessary as these three important components namely, the foundation plates, saddles and spline form the backbone of an engine block and the nucleus around which the entire block is fabricated.

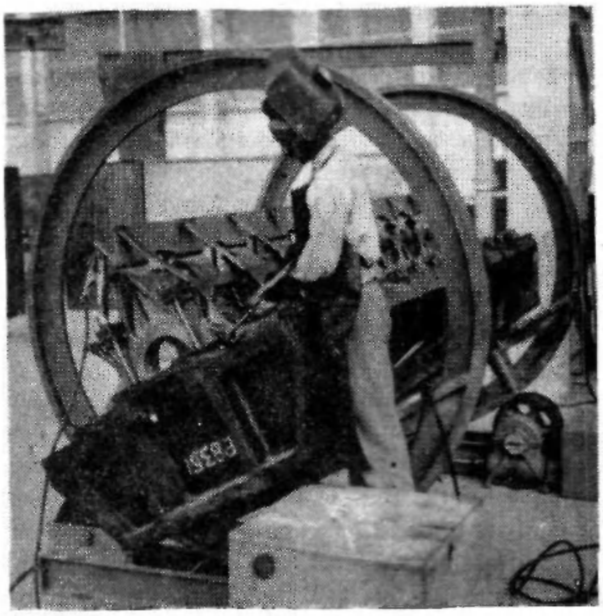
5.6.3 The inside walls, outside walls, middle decks, top decks, side plates, fuel shelf compartments, cam bearing supports and end plates are welded in sequence around the above nucleus by manual as well as submerged arc electric welding processes. In between the above sequence of fabrication, the critical joints are subjected to radiographic examination. The weldment is also taken to the planning machines to maintain the overall dimensions and for proper edge preparation to ensure a good quality welded joint.

5.6.4 After the welding operations have been completed, the weldment acquires its final shape of an engine block. The engine block is then stress relieved at temperature ranging from 1150 to 1200°F in a stress relieving furnace capable of accommodating two blocks at a time. The final engine block is machined to very close tolerances and as such, it is necessary that all stresses developed during the fabrication stages are completely relieved before final machining is undertaken on this block.This would ensure a longer life in service without any distortion which would normally result on account of very high alternating stresses that the engine block is subjected to, during its service. The engine block is then shot blasted, hydrostatically tested to a pressure of 75 psi and then handed over for lay out and subsequent machining operations.

5.6.5 The details given above, would give an idea of the complex operations involved in the fabrication of this heavy weldment weighing 6.25 tons. There are 55 different stages through which an engine block has to pass during the course of its manufacture and it takes 60 days for it to get completed.

6. Fabrication of underframe

6.1 The BG underframe is designed to withstand a maximum static squeeze test load of 400 tons without signs of any permanent distortion. The underframe load transfer members are so designed as to transfer the vertical load on to each trimount bogie in the ratio of 60% through the centre pivot and 20% through either of the two loading pads. The under frame is welded, utilising plates ranging from 1/4" to 1" thick. The main structure of the underframe is made out of ASTM-A-441 high tensile steel, having 1.5% vanadium, 1.5% manganese and 0.22% carbon. The underframe is about 52' long and is made in three sections—the two end sections and the centre section. The centre section also forms the fuel tank of the locomotive having a capacity of 5000 litres and the fabrication has to be leak-proof. The manufacture involves special welding skills and use of fixtures and positioners.



Set up of a 16 Cylinder Engine Block.

6.2 In the fabrication of the end sections and the centre section, apart from manual metal arc welding, semi-automatic welding process with flux cored wire (without gas shield) as detailed at para 10.1, is adopted. After the above three sections are fabricated separately these are welded together employing butt joints, the welds of which must comply with radiographic standards. The sequence of preparation of these joints plays an important part in inducing the required camber of the underframe. While undertaking the welding of the joints the vertical joints are completed first. The ends are clamped firmly on to the surface plate and the down hand bottom plate joints are then welded. Two welders simultaneously attend both the down hand joints. The camber is obtained by inducing a calculated distortion in the structure by means of welding heat. This is accomplished in two stages i.e. on the surface plate and in the up right position and is then checked at the final check stand. The final camber is 1/2" to 3/4".

6.3 Starting from the initial operation of flame cutting of components upto the final assembly, the complete cycle for the fabrication of a WDM-2 underframe is 96 days.

7. Fabrication of Superstructure

7.1 The superstructure comprises of 5 major assemblies —short hood, driver's cab, contactor compartment, hood over engine and radiator compartment. All these are thin sheet fabricated structures manufactured out of 1/16" and 1/8" steel sheets. Apart from the manual metal arc welding, spot welding technique is also used for welding of smaller components.

8. Salvaging of Engine Block

8.1 Apart from undertaking the manufacture of new engine blocks for locomotive production as well as for supply as spares to the Railways, DLW has also undertaken to salvage the old engine blocks removed from the locomotives after 15-20 years of service. As against the common use of cast blocks in the diesel engines on European Railroads, the DLW built locos have a fully fabricated engine block which lends itself to repairs at all locations.

8.2 On receipt of old blocks from the Railways, these are cleaned, inspected and a detailed inspection report is prepared indicating the nature and extent of repairs required to be done on various components. The areas which usually require building up by welding are crank bores, upper liner bores, lower liner bores and serrations. For this building up, E6013 electrodes (IS E317412) are used which are basically light coated medium penetration electrodes, having a very smooth arc. Necessary precautions are taken to prevent distortion by peening and cooling the adjoining areas with the use of compressed air. Presently, DLW is undertaking the repair of 7 engine blocks a month and this is expected to be gradually raised to 10 blocks a month.

9. Reclamation of Alumunium Pistons

9.1 Amongst the various types of main pistons used in the power packs of diesel locomotives, there is one type in which the body is made of forged aluminium alloy with a ring carrier of forged aluminium with Ni-resist rings shrunk fit on it. A facility has been set up at DLW for undertaking the reclamation of the old pistons of this type in use on the Indian Railways by rebanding of pistons. On receipt of the old pistons, the ring carriers are removed and after a thorough cleaning and treatment, a new ring carrier is shrunk fit on the crown of the piston and then welded. The automatic Metal Inert Gas (MIG) welding technique is adopted for this purpose. The inert gas used for providing the necessary shielding is pure argon having 99.99% purity. The 1/16" dia. aluminium wire, Almigweld 4043, is used for welding the ring carrier. In the initial stage, there used to be heavy rejections due to excessive porosity in the welds. These problems have been overcome by ensuring intensive cleaning and temperature control.

10. Special Facilities to Promote Weld Efficiency

Some of the special facilities and weld aids provided at DLW to promote weld efficiency, are described below:

10.1 Semi-automatic Fluxcored (Nongas shielded) arc Welding Process

10.1.1 This process generates its own arc shield from the flux ingredients contained within the tubular electrode, thereby eliminating the need for external shielding gases, such as argon or carbon dioxide. This modern welding technique is made use of in the fabrication of the underframe centre section and end sections.

10.1.2 The equipments used for this process consist of :—

1. Semiautomatic Welder
   (a) Wire Feed Mechanism
   (b) Wire Reel
   (c) Input and Output Cables
   (d) Controls
2. Welding Gun with 15 ft. Cable Assembly.
3. Motor Generator Power Source rated 525 amps. at 100% duty cycle.

The electrode used is imported tubular electrode designed for multi pass welding (.120" dia.).

10.1.3 The main advantage of this process is that it is an extremely rapid welding process. The weld metal deposition rate by this process is of the order of 35 lbs. per hour as compared to 8 lbs. per hour achieved with a 1/4" electrode by manual metal arc welding. It does not require the use of any external shielding gas such as CO_2 or argon, since the flux core generates its own protective atmosphere in the same manner as the coating on the stick electrode does. The slag is easily removed and the voltage and current are independently controlled at the wire feed unit.

10.2 Carbon Arc—Air Gouging Process

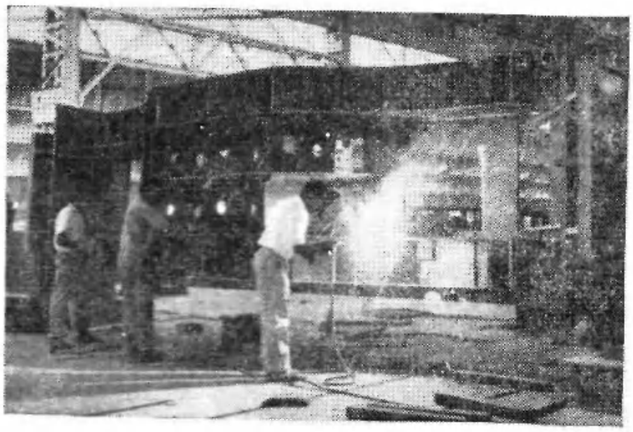
This process is adopted at DLW for gouging out any defective weld metal deposit. In this process the arc is struck between a consumable copper coated carbon rod and the job. The metal portion to be gouged gets molten and is removed with a jet of compressed air leaving a clean gouged surface. With the use of this equipment, the gouging of the defective weld metal can be controlled to a high degree of precision. This sophisticated process was adopted in DLW for the first time on the Indian Railways and has been found to be very useful as compared to the coventional methods involving the use of pneumatic tools or gas flame.

10.3 Automatic Flame Cutting Machines

To enable profile cutting of structural members out of steel plates to intricate contours for the fabrication of engine blocks, underframes and other sub-assemblies of the diesel locomotive, automatic flame cutting machines have been provided at DLW. These are special purpose machines with tremendous potential for a rapid production rate commensurate with the requirement of the assembly sections. The oxy-cutting operation is performed by a battery of 8 torches, the movement of which is controlled by an electronic tracing head, using paper templates instead of the conventional and costly metal templates. Plates upto 15″ thickness can be cut on these machines. There are 6 such machines provided at DLW.

10.4 Electrode Storage and Use of Drying Ovens

Normally, all welding electrodes must be used in a dry state. This requirement is particularly a must in the case of low hydrogen electrodes. Electrodes have a tendency to pick up moisture from the air when the atmosphere is humid. Damp electrodes cause weld porosity, fuse slowly, produce weak arc and result in considerable spatter. For radiographic quality welds, electrodes must be dried in an oven irrespective of the fact whether these are conventional electrodes or low hydrogen electrodes. Keeping this special requirement in view, adequate care has been taken at DLW to keep the electrodes free of moisture during their storage in the stocking wards as well as at the time of usage on the shop floor.



Welding of fuel tank section of a Broad Gauge Locomotive.

For the storage of electrodes, a special electrode ward has been set up, provided with central heating arrangement. On the shop floor, wherever low hydrogen electrodes are in use, adequate number of electrode drying ovens have been provided so as to enable preheating of electrodes to a temperature of 150°C for an hour to drive away any moisture prior to their use.

11. Current Problems

11.1 In the foregoing paragraphs, various manufacturing operations involving weld fabrication of some of the important sub-assemblies of diesel locomotive have been discussed. There are a few problems currently being faced at DLW as mentioned below. This opportunity is being taken to seek guidance from the welding experts from the Industry and the Institutes assembled here, to help DLW in resolving these problems.

11.2 Non-availability of some of the consumables and welding accessories indigenously.

11.2.1 Tubular wire used as the electrode for the semi-automatic fluxcored arc welding process, is not available in the country. We have to find a substitute in lieu of this tubular electrode. Its consumption is approximately 100 lbs. per loco. The typical chemical analysis of the all weld metal deposited by this tubular electrode is as under :

C	—	0.16%	Si	—	0.25%
Mn	—	0.8%	Al	—	1.5%

The important physical properties are :

Tensile strength—82,000 to 96,000 lbs. per sq. inch
Yield—60,000 to 70,000 lbs. per sq. inch.
Elongation—17 to 27%.

11.2.2 For automatic submerged arc welding, suitable flux and wire are at present being supplied only by one source in India. Not only is it necessary to have some other sources developed for the manufacture of these items, it would also be beneficial if instead of this basic character flux used now, a fused flux is developed which would eliminate the problems connected with absorption of moisture from the atmosphere. The consumption of the flux is 150 Kg. and the wire is 110 Kg. per loco.

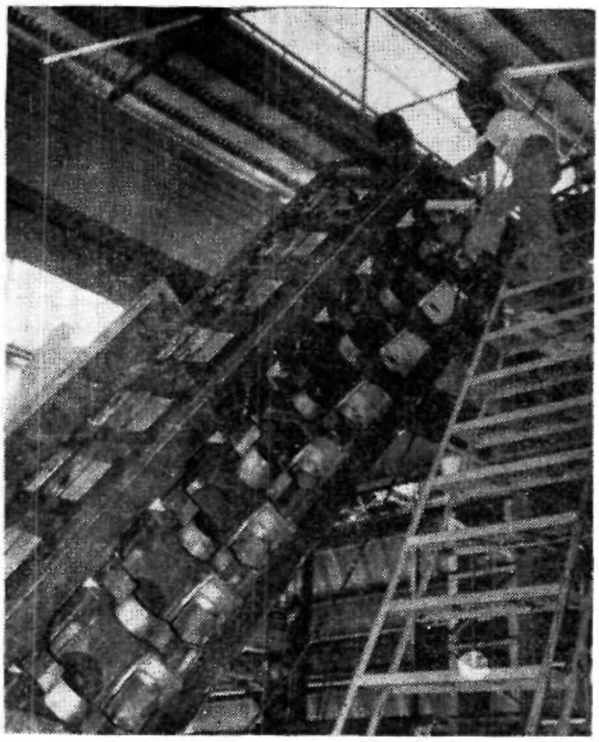
11.2.3 Electrode Holder

Some of the critical welding work undertaken at DLW necessitates the use of fully insulated heavy duty electrode holders, suitable for currents upto 600 amps. Electrode holders of this range are not easily available in the country. In the past, DLW had been using imported fully insulated electode holders for this type of application. Indigenous development to match this type of service requirement would be welcome.

11.3 Reclamation of Cam Shafts

Cam shafts are manufactured out of steel to specification AISI E1050+0.2% Chromium. After machining, these are subjected to induction hardening process to induce a surface hardness of the order of RC 58 to 62. During the course of service, the cam shafts get worn out at the cam lobes resulting in the cam shafts getting rejected and requiring replacement.

The worn out cam shafts could be reclaimed provided a suitable electrode for undertaking this work is developed. Of late, there have been some attempts in this direction. However, a concerted co-ordinated drive is required to solve this problem. With a continuous increase in the fleet of diesel locomotives on Indian Railways, there is a tremendous scope for undertaking this reclamation work which would result in a substantial saving, apart from assisting the Railways in keeping the locomotives in running condition. Any effort in the direction of development of a suitable electrode for this purpose would be welcome.



Down-hand welding of a cylinder block mounted on a manipulator.