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# Development of a flexible robotic welding system for weld overlay cladding of thermoelectrical plants' boiler tube walls

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ABSTRACT

The walls of the boilers of power plants undergo corrosion and wear during operation. The reduction in thickness is measured periodically to prevent collapse of the tubes and consequent operation stoppages for long periods. The solution that is usually applied to increase the availability of power plants is gas metal arc welding (GMAW) cladding of the walls with metal alloys that are more resistant to wear. Application occurs in two distinct locations: the boiler and the workshop. Small worn areas are coated inside the boiler itself, while in the workshop, panels are coated so that they can either be used in the boiler's most affected regions or to produce new walls with higher wear resistance. Mechanized welding produces better results than manual welding; however, in current systems, the oscillating movement of the torch is generated by a single axis. This limitation renders the welding process unstable if the aim is to reduce bead reinforcement and the number of weld beads by increasing the amplitude of the torch oscillation. This instability produces high spattering and excess penetration due to the change in the contact tip to work distance (CTWD), since the power of the welding electric circuit is a function of this distance and since the constant changes in CTWD disturb the metal transfer dynamics. This paper shows that it is possible to overcome the technological difficulties for both application sites and to make automatic cladding operations more productive and of a better quality. For this, a dedicated Computer Numeric Control (CNC) robot with four degrees of freedom was developed, as well as the methodology for generation of its trajectory. The cladding obtained by pulsed GMAW with ER309L stainless steel is presented in order to validate the developments.



## 1. Introduction

During operation of the boiler, which is an essential part of a thermal power plant, it is exposed to extreme heat and chemical elements associated with the combustion reaction. This causes erosion and corrosion, which continuously degrade the tubes. This wear is also caused by the cleaning action (see Fig. 1b), which is performed periodically in order to maintain efficient heat transfer [1–3]. Thus, on certain occasions, a plant stoppage becomes necessary to inspect tubes [4]. For this purpose, scaffolding is installed (Fig. 1a), both for measuring the tube thickness and to determine the necessary recuperation procedure.

If the thickness measurements determine that tube wear is above a certain value (this will depend on the project characteristics), there must be intervention to recover the thickness. The recovery of the affected regions can occur in two ways: cladding via weld overlay, or by replacing the wall area (Fig. 2). In the case of replacement, the reintegration of the new wall portion is conducted via gas tungsten arc welding (GTAW) – see Fig. 2b and c.

Nowadays, new wall portions must have superior properties in relation to the original ones. This is achieved through cladding with special alloys such as stainless steel 309 and Inconel alloys via the GMAW process. Quality improves if the process is performed automatically on panels in the workshop and also at the worn regions of the boiler. Manual operations are unable to produce the appropriate cladding geometry, both in terms of a good relationship of deposited material/penetration and in relation to the surface finish. The first feature mentioned is related to the dilution of the added material with the base material, which should be as small as possible in order to obtain the best characteristics for

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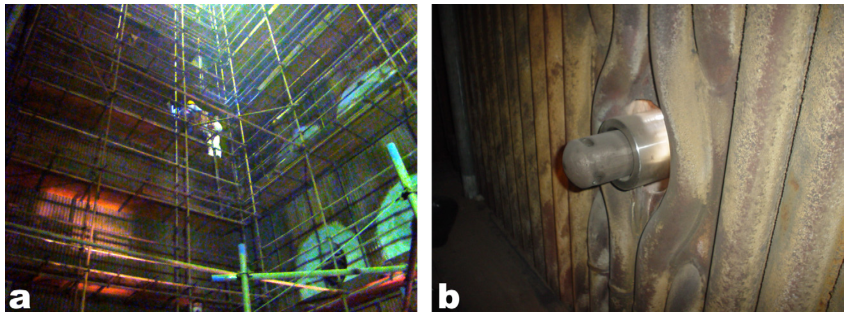


**Fig. 1.** (a) scaffolding for maintenance of the boiler; and (b) detail of the cleaning of the steam blower.

preventing erosion and corrosion. Obtaining a good finish prevents premature fouling of impurities which decreases the heat transmission. Furthermore, automatic welding enables smaller thermal deformation of the panel and savings in material added. However, all the aforementioned characteristics are dependent on the position of the cladding. The best position is vertical, as illustrated in Fig. 3. In this position, it is possible to match high GMAW arc power, at a region above the transition between short circuiting and spray metal transfer modes, with very high torch-displacement speeds, in order to obtain the good cladding characteristics that have already been mentioned.

Automation could be achieved through the use of anthropomorphic robots, but the cladding would be limited to small-sized tubes. Furthermore, the installation of such robots over panels in the factory or boiler walls would be too cumbersome. Therefore, in certain power plants, portable automatic Cartesian axis systems are used in order to cover a considerable area of tubes; these often have a pendular kind of motion. However, there are no dedicated solutions so far, only adaptations of welding manipulators for generic use. Fig. 3 shows a typical example of this type of adjustment. It is a GMAW system with a Prismatic-Prismatic-Rotational (PPR) series kinematic chain and three degrees of freedom, fixed to the boiler wall by two horizontal rails. The first prismatic joint determines the welding speed (vertical). The second prismatic joint positions the torch in the transverse direction of the weld (horizontal). The rotational joint performs pendular oscillation of the torch.

The limitation of these devices is the absence of an adequate trajectory. There is no dedicated software with which it is possible to program the cladding of a series of pipes of a certain length. The completion of each weld bead must be done with a manual repositioning of the manipulator. Moreover, the oscillation of the torch is limited to only one axis of the manipulator: Y linear or angular A.

In the linear oscillation (Fig. 4a), the contact tip to work distance (CTWD) varies dramatically from a minimum extreme position (Q1) to a maximum extreme position (Q2). A better solution with smaller CTWD variation is achieved by employing angular oscillation (Fig. 4b), where the shape of the motion is pendular and there is a minimum CTWD in the central position of oscillation and two maxima at the extreme positions Q1 and Q2. Thus, if the amplitude of the oscillation exceeds a certain value, there will be problems with consistency of the weld deposit, since the process becomes unstable due to the large variation in the CTWD. This instability produces discontinuity of the geometry of the weld bead and penetration, as well as excessive spatter, which is characterized by the waste of welding wire [6]. In both cases, the possible amplitude of the oscillation is highly limited in imposing a greater amount of adjacent weld seam claddings. Therefore, to reduce the number of weld seams, a constant CTWD is necessary during the weaving movement of the torch (Fig. 4c). For this, the *A*, *Y*, and *Z* axes must move simultaneously and in a synchronized manner.

## 2. Weld overlay cladding strategy

The boiler walls can be characterized by a set of geometrical parameters: *a*, *b*, *c*, and *d*; as shown in Fig. 5. The weld beads

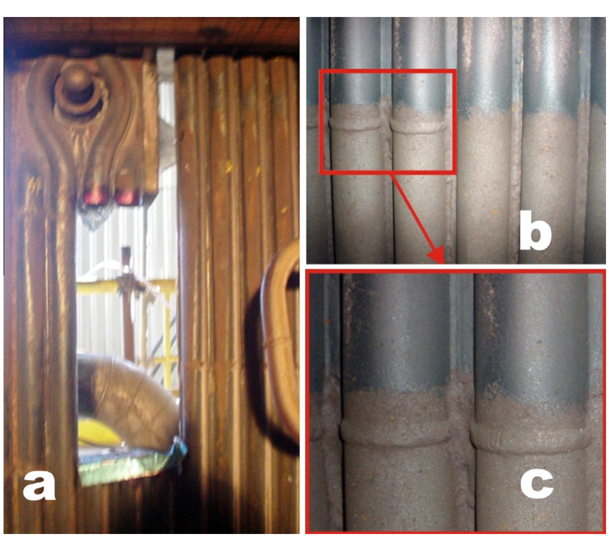


**Fig. 2.** (a) removing the worn tube; and (b) and (c): new tubes joined by manual GTAW.

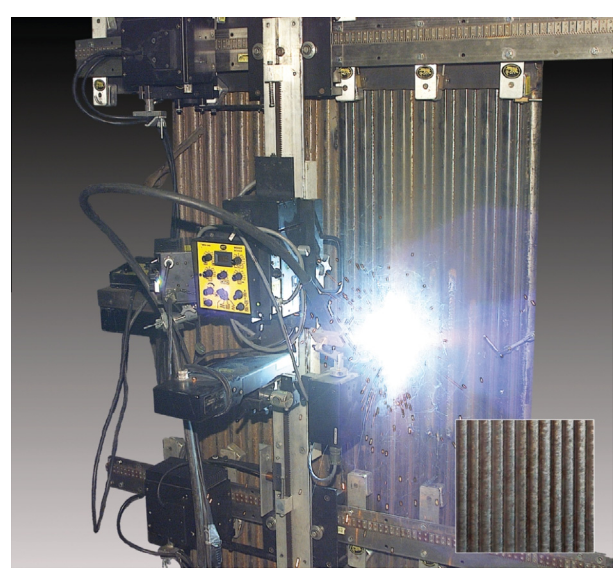

**Fig. 3.** Robotic system adapted for cladding boilers [5].