Laparoscopic welding

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Abstract. The paper presents a new way of repairing defects that can occur in areas with low access for the operator. A modified TIG welding torch with a 300 mm neck length is used. The picture of the metal bath is taken over by a videoendoscopic camera and displayed on a screen. The welder makes the necessary corrections by handling the TIG gun remotely. Images are shown during welding. Also shown are some welding samples. After analyzing the evidence, it can be concluded that the defects found at relatively large distances can be repaired thru welding, without the need to dismantle the facility requiring reconditioning. Taking this into consideration, the new technology it greatly reduces repair costs and runtime. The necessity of making such a pistol came in response to various industrial repair requests. Most applications were in the field of spiral heat exchangers where interventions are difficult due to reduced access space below 25 mm. Such equipment is useful in various engineering fields such as: aviation, structure, landing gear train- here are periodically inspected areas using endoscopes but cannot intervene because there is no possibility of access for the operator; thermodynamics - heat exchangers, indifferent of the type of construction, with pipes, plates or spirals; Industrial plants - pipeline; metal structures of any kind - bridges, boats, halls, buildings; automotive industry - construction or repair.

1. Introduction
This paper presents a new technology of welding of parts in conditions where the physical access is limited, meaning the clearances less than 15 mm corroborated with the large distance between the operator and the welded area of 0.3 - 1 m. The maximum length of a welding cord without interruption of the electric arc is about 30 - 50 mm.

The experiments are part of the UPB-GEX research contract no. 35/2016, project code 397. During the experiments, the TIG process was used, modifying a TIG flexible-necked TIG pistol powered with wire electrode. The difference from the standard procedure is that the metal bath image is taken over by a camera and the welding operator does not look through a welding mask but on a monitor, just like a laparoscopic surgery. The handling of the pistol can be done in two ways, one standard, by the pistol handle, the second being using some servomotors. In this paper, the first version is presented and the welding samples were pipes in which artificial defects were made. Artificial defects such as pores, longitudinal or transverse cracks inside the pipes are presented. After the welding, the pipes were inspected by various defectoscopic methods, finding the frames made with the new equipment and the TIG laparoscopic welding technology within the quality level for imperfections B and C according to SR EN ISO 5817:2015.

From a scientific point of view, the design of this equipment and related technology is a worldwide novelty. Such equipment is useful in various engineering fields, such as:

a) aviation - structure / drive train - are areas inspected periodically with endoscopes but it is impossible to intervene thereupon, because there is no access;
b) thermotechnics - heat exchangers, regardless of their construction type, with pipes, plates or coils, where the structural elements cannot be repaired locally and must be replaced;

c) industrial installations - pipe routes;

d) metal structures of any type - halls, buildings, bridges, boats, etc.;

e) automotive industry - construction or repair;

f) thermal or hydro power plants where defects can occur on piping and other facilities.

When designing this TIG miniature welding equipment, an analogy with the operating/investigation mechanisms in the medical field was made, especially with laparoscopic surgery, of course, with the adaptations specific to the melting welding technology, namely: positioning and handling of the welding pistol, real-time visualization, working temperature, protection gases specific to welding, heat and technical gas evacuation, modification of welding parameters, etc.

There are currently TIG welding equipment/machines/accessories that can perform manual/mechanized/robotic welding but their sizes are relatively large, having at least two of their dimensions over 25 mm [2, 3]. For manual welding, the neck of the pistol can be rigid or flexible and its positioning and handling during welding is done directly by the operator, usually from a small distance, approximately 50 - 70 mm. There are also pistols with longer fixed or flexible necks, up to 250 mm, but their handling is also done manually and therefore the quality of the joint decreases considerably. For mechanized welding, the pistol neck is fixed to a rigid support, being handled by means of an electrically actuated mechanism [4].

In the robotic welding, the pistol is fixed to the arm of a robot that can describe complex movements, but the sizes of the pistol are large, at least 40 mm in one direction and the access is limited by the complexity of the construction. Moreover, being a robotic welding, for the performance of a welding cord, new software has to be designed first, then checked on the piece and only afterwards the welding can proceed. If during the welding, from various reasons, the subassemblies have moved away from the pistol, welding has to be remade.

The necessity of making such a pistol came in response to various industrial repair requests. Most of the applications were in the field of spiral heat exchangers and pipes [1]. In these cases, the clearance is relatively small, below 20 mm, and the defects are on the inside at a distance of at least 150-200 mm (figure 1).

![Figure 1. Spiral heat exchangers.](image)

2. Defects produced by corrosion and cavitation

During the use of heat exchangers, various phenomena arise due to fluid flow velocity, viscosity, and hardness of the micro particles in the fluid. The defects observed over time have been analysed and the main causes of their production are erosive corrosion and cavitation.

Erosion corrosion occurs due to the movement of the fluid along the surface of the material. Erosion corrosion is generally accelerated when the fluid entering the exchanger comprises air or solid particles[10]. The main factors influencing erosive corrosion are the "turbulence" as well as the parameters specific to fluids circulating through the exchanger, such as the flow rate, the level of particles in suspension, the level of present air bubbles, the partial local pressure, and the geometric shape of the piece, in this case spiral.
The erosion corrosion model is represented by directional grooves, waves, valleys, holes or depressions in the form of a horseshoe, star or half-moon [12]. The turbulences applied on the inside of a tube can lead to rapid increase in erosion rates and ultimately to material breakage. These defects occurring inside a spiral heat exchanger can be seen in figure 2. The effects of corrosion and cavitation inside the exchanger can easily be observed. With the help of the newly designed welding pistol, some of these specific defects can be solved by welding without decommissioning the exchanger.

Cavitation, sometimes referred to as cavitation corrosion or cavitation erosion, is the dynamic process of forming, developing and imploding of bubbles or cavities filled with vapours and gases from a liquid [11]. This process is caused by the decrease of local pressure under certain critical values; depending on the cavitation pressure, these can be:

- vaporous - characterized by a decrease in pressure below the liquid saturated vapour pressure corresponding to its temperature;
- gaseous - characterized by the diffusion of the gas from the liquid into the cavitation bubble and the progressive increase thereof. In this case, the local pressure is not required to drop to the value of the liquid vapour pressure.

Among the factors favouring the emergence and development of cavitation bubbles, we first mention the decrease of pressure but also the existence of impurities, microfiches, grooves and solid bodies.

These factors determine the retention of microscopic volumes of undissolved gas in the liquid thus creating cavitation nuclei or germs. When the pressure reaches critical values such as vapour pressure, the cavitation nuclei or germs kindle the vaporization phenomenon, and with the evolution of the gas from the liquid and the evaporation of the surrounding liquid the cavitation nuclei develop, forming bubbles or cavities filled with a mixture of dissolved gases and/or liquid vapours [15].

![Figure 2. Defects produced by erosion and cavitation.](image)

3. Design and realization of welding torch

In order to repair such defects, we started from the analysis of several constructive variants of liquid-cooled pistols. We have chosen a SR 24W FX flexible neck pistol. The chosen pistol was redesigned in the sense that it was added the welding wire feeding part - the roll. The welding wire is brought past the tungsten electrode by means of a metal guide tube [5]. The guide tube was attached to the pistol body and its neck so as to form a common body (figure 3).

The existence of the feed material - the wire electrode - from the guide tube is made by means of a contact nozzle. The control of the two subassemblies, pistol and un winder, is done separately. The pistol has kept the On/Off control from the button, and at the un winder both the On/Off control and the adjustment of the feed rate of the wire electrode is made by means of a pedal actuated by the operators foot [7].
Figure 3. Laparoscopic welding pistol: a - detail of attachment of the nozzle to the wire electrode; b - design view; c - pistol section: 1 - tungsten electrode; 2 - electrode brush; 3 - nozzle port tweezers; 4 - gas nozzle; 5 - tubular felixic conductor; 6 - electrical insulator

Several types of video endoscopes have been tested to view the piece, possible defects and molten metal bath during welding. The main criteria for choosing were: manoeuvrability, gauge dimensions, possibility of clamping, optical image transmission mode, self-cleaning, working temperature, operator-to-laparoscope end-tube distance.

Following the tests, the 6 mm Meterland Wireless Video Inspection Camera (ML BHR-105) was selected. The camera was mechanically mounted in an experimental test stand, and the images were sent to a monitor, and saved and stored as computer files. One of the advantages of recording is the possibility to review and analyse the phases during welding. The designed welding equipment is provided with lenses to magnify the surface image of the piece up to 4 times, a powerful light to ensure adequate illumination of the welding area and miniature video camera. The camera sends the images inside the sample to a computer monitor in the reconditioning workshop.
4. Experimental part. Laparoscopic welding process

The experimental test stand consists of: 1 - panel, 2 - inlet pipe, 3 - guide bushing, 4 - sample, 5 - supporting feet, 6 - monitor stand (figure 4). All components are welded, except component no. 4 which is inserted into the guide bushing for the repair and testing of the welding technology.

Figure 4. Experimental stand: (a) - the scheme of the principle; (b) - overview with monitor; 1 - panel; 2 - inlet pipe; 3 - guide bushing; 4 - sample; 5 - supporting feet; 6 - monitor console.

In the inlet pipe of the panel, the endoscopic video camera is inserted and fixed using a metal tube (figure 5). The received signal will be transferred to an LCD monitor and recorded throughout the repair. The camera may have different sizes, from 2.5 to 9 mm. A wired camera with a diameter of 6 mm was used in this work. It is possible to use cameras that can rotate on the two axes so that the defect can be viewed in optimal conditions.

Figure 5. Clamping of the endoscopic video camera.
In the guide bushing 3, the sample is inserted and fixed. In order to test the new welding technology, several material deposits were initially executed on a support plate. Thereafter, samples were made from a steel pipe, in which artificially created defects such as pores, grooves, holes have been prepared, which were then repaired by welding, see figures 6 and 7.

![Figure 6. Before welding, circular defects.](image)

![Figure 7. Before welding, elongated defects.](image)

The elongated defects attempted to simulate possible cracks in the pipe in the longitudinal or transverse direction.

The welding process was TIG. The parameters of the welding regime were:
1) Welding current Is = 80 – 100 A
2) Welding voltage Us = 21 V
3) Wire electrode feed rate Vs = 1.5 m / min.
4) Protective gas Ar 100%
5) Diameter of the wire electrode d=1mm
6) Diameter of the tungsten electrode used 1.6mm

The welding process ran intermittently, meaning that at the beginning only the welding arc was started for heating the parts and melting the defect edges. Then, depending on the molten metal bath, electrodes were added at different speeds. Aspects during welding can be seen in figure 8.

![Figure 8. Stages of the laparoscopic welding process.](image)

Another advantage of this new welding technology is that the welder operator did not have to use the welding mask but he looked directly into the monitor, improving his working conditions.
After welding, the samples were inspected by radiography testing (RT) using the acceptance criteria for defects of welded joints, indicated by SR EN ISO 5817-2015 [16]. After the RT examination of various samples laparoscopic welded, it could be concluded that the quality of welded joints is as follows from the point of view of the imperfections found: 70% in B (high) and 30% in C (average). The samples after the non-destructive testing were declared fully usable and functional.

![Image](a) ![Image](b)

**Figure 9.** Reconditioning of defects by laparoscopic welding.

5. Conclusions
The design of this pistol and related welding technology will open a new era in the welding industry. The possibility of making large-scale welding works and in hard-to-reach places will open up new research directions in all industrial fields. An analogy with the medical field can be made, where the discovery of the possibility of laparoscopic investigation or surgery has led to new, less invasive, less costly surgery methods and very good results compared to classical ones.

The TIG welding process was chosen because TIG welds are characterized by excellent quality, due largely to the protection afforded by inert gas, the passage of the feed material through the electric arc is practically splash-free. The feed material is not connected to the electric welding circuit, so it is not transferred through the space of the arc but it is only melted there from. Thus, there is the possibility of independent control of the thermal source and the introduction of feed material. The weld is not covered with slag and as such it is not necessary to clean the welded joint. The process allows excellent control over how the welding roots are formed.

A particular advantage of this new welding technology is that it has improved the working conditions of the welder operator, who does not have to use the welding mask, but he directly watches the entire welding process on the monitor. Ensuring a safe and healthy work environment is currently a key priority for all employers. This new laparoscopic welding technology supports all companies that have a legal duty to oversee employees on the line of occupation protection to enable them to carry out their work safely.

In the field of engineering, laparoscopic welding, being a completely new concept, will develop at a very accelerated pace in several directions. Multiple types of repair/reconditioning operations can be done with this new equipment and related technology. These include applications for reconditioning pipes made of thin-walled metal sheet, aluminium, alloy, copper and reactive materials; to the execution of the pipe end-to-end joints and, in general, to the one-sided access situation, under severe quality conditions.

Laparoscopic welding can be a good choice for the following industrial areas: periodic inspection of aircraft; industrial heating plants, heat exchangers; metal constructions; the energy industry (components of thermo- or hydro- power plants) and many others, solving problems that were difficult or even impossible to solve in the past.
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