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ERGONOMIC ASPECTS OF REAL AND VIRTUAL WELDING TOOLS

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Abstract: *In the past years, human factor (ergonomics) has assumed a point of crucial importance in engineering, design, development, service and maintenance sectors of industrial products and welding is a big part of this. In this paper, it will be presented the principals aspects and recommendations regarding ergonomics in welding sectors and also will be presented a case study of a welding tool (torch). The paper finally concludes with some recommendations related the used of welding tool (torch) and with a recommendation of a new study on ergonomics on Virtually Reality.*
Key words: *torch, welding process, Virtual Reality, ergonomics in welding, SOLDAMATIC simulator, Welding positions, worker safety.*

1. INTRODUCTION – PROBLEM DESCRIPTION, APPLICATION FIELD

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance [1; 2].

Welding is a versatile manufacturing process in metal fabrication industry and plays a vital role to produce almost all the Engineering products. Welding is estimated to contribute to almost 50% of the nation's gross national product. Welding often requires awkward body positions continued over a long period of time thereby causing high prevalence of musculoskeletal complaints and injuries including back injuries, shoulder pain, tendonitis, and reduced muscle strength. On this context, there is lot of scope for improvement in the operating (welding) postures which in turn will help to reduce discomfort and pain, thereby increasing productivity, worker safety and quality of work in welding-industry. Problems are in the mismatches between man and machine, improper layout design, unhealthy work environment and mainly ignorance among top to bottom [3].

The tools used during the welding process are very important and regarding the torches, a series of works [4; 5; 6; 7] dedicates topics on this theme highlighting the need to make ergonomic evaluations of them and to use the results in the search for new solutions for their improvement, thus contributing to reducing the harmful, negative effects that they have on the health of users.

There are many activities in which the skills and abilities that people have in carrying out tasks are required. The physical automation of the final works in an assembly system is achieved by 90% with people help [6].

Automation is dictated in most cases by a mass production volume, for products that have few product variant, mature products that do not require changes regarding the assembly process. For small and unique production series, and repair / reconditioning activities, the manually executed works are predominant. To remain competitive, companies must come up with automation solutions for small and medium series production.

Although these companies are oriented towards the use of collaborative robots and small and flexible units [8], manual welding still has a wide spread in the reconditioning and repair works where the work, the shape and the dimensions are different, there is a small number of parts and working tasks cannot be automated.

At the same time, the ergonomic analysis of the maintenance and repairs works, which are performed by the workers, leads to the improvement of the working conditions, of the operations themselves and of the general rules that can be taken into account in the product design process [9].

Effects that activities with potential for injury have lead both to an unsafe work place for the worker, his physical injury, the decrease of the number of parts/components he can complete in the working hours as well as the decrease of the quality of the executed works.

At the same time, the improvement of the quality of life, of the health status for the workers in the conditions of prolonging the retirement age are desired of the whole European community [10]. Their achievement can be solved by encouraging lifelong learning, ensuring a safe and healthy working environment, adapting the retirement age, rewarding retirement at an older age and discouraging early retirement.

Thus, integrated measures regarding the simultaneous exposure both to the environmental conditions - exposure to smoke, harmful substances, noise - as the conditions in which they work from the point of view of the physical strain and requirements are actual themes that lead to sustainability and the increase of the quality of life.

The paper presents some cases study of welding tool/ torch use in a manufacturing environment aiming to improve the quality and ergonomics of welding processes and also how the use the Virtual Reality techniques to increase the possibilities to communicate with employees, to achieve an effective training /work, higher flexibility and quick adaptability regarding to ergonomics principles.

2. ASPECTS AND RECOMMENDATIONS REGARDING THE OCCUPATIONAL HEALTH OF WELDERS

The welding process activities involve strong physical stress, which in many cases leads to back, muscle or wrist pain. Initial discomfort is usually an indicator of long-term, chronic illnesses, which will lead to giving up the profession, or retiring in case of illness. The active involvement of employees and employers in promoting the principles of improving working conditions has the effect of extending the operative capacity until the retirement age. From this point of view the design of welding torches is very important and related to the concept of ergonomics. In the same time ergonomics criteria relevant to hand-tool design are defined regarding the various clinical syndromes: size, shape, texture, purpose, ease of operation, shock absorption, and weight [11]. In addition, analyzing a “faulty–tool” indicators extract some ergonomic criteria for hand tools are extracted [12]:

(a) Static loading of arm and shoulder muscles;
(b) Awkward hand position, especially wrist deviation;
(c) Excessive or continuous pressure on the palm and fingers;
(d) Exposure to vibration and cold from power tools;
(e) Pinch points with double handle tools;
(f) Handles that require stretching of the hand to grip or high force to hold.

Ergonomic construction of equipment or organization of work according to ergonomic principles is not sufficient in all situations, adopted techniques and a right posture contributes decisively to avoid long-term diseases. Physical stress is often taken seriously only when it turns into pain, and for those who need to pay close attention to handling and welding positions. Welders work requires the entire body, especially the muscles and joints.

Particularly for welders is soliciting frequent muscles in static positions that are maintained for a long time the situation can be observed in the Figure 1. The most affected areas, in order of decreasing incidence are:

- Back disorders of the spine;
- Tendon disorders, calcification of tendons, joints;
- Shoulder injuries;
- Chronic inflammation of the knee;
- Chronic inflammation of the hip joint.

Fig. 1. Welding positions from factory [author's photos].

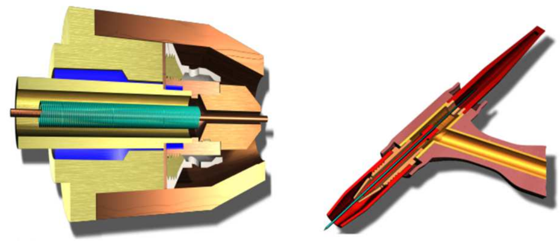


Fig. 2. Cross section from the MIG-MAG and TIG/WIG torches

It has been demonstrated that the torch itself plays an important role in muscular welder strain and the welding position. The most used welding processes are MIG-MAG and TIG/WIG and both processes use torches.

3. TOOL DESIGN IN CASE OF MIG-MAG AND TIG/WIG

Both tools, TIG/WIG or MIG-MAG, are developed on the same principle. The MIG-MAG torch has inside wire and WIG torch has the Wolfram electrode inside. Both torches require protective gas, which passes through the cables attached to the torches and protects the welding bath. In the figure 2 it can be observed a section from a TIG/WIG and MIG-MAG torch. The welder can weld in all the welding positions according to EN ISO 6947 with both torches (Figure 3).

The papers will present a comparison of two TIG/WIG torches from different years (1980 and 2019) and with SOLDAMATIC TIG/WIG torch (2010). The old torch TIG/WIG is for 315 A, is water-cooled and its weight is 2495 grams with cables. The ESAB torch TIG/WIG is for 250 A, is cooled with water and weights 1690 grams. Both have cables 4 m long, the ESAB torch is much more flexible.

In case of SOLDAMATIC TIG/WIG torch the weight is 1500 grams because it has lighter cables and is more ergonomic regarding the weight and correspondent strain in welder arm muscles.

For the chart in the Figure 4 it can be observed that the weight of the torch from 2019 is much smaller, is approximately 67% from the old torch and the SOLDAMATIC TIG/WIG torch has the slightest weight.

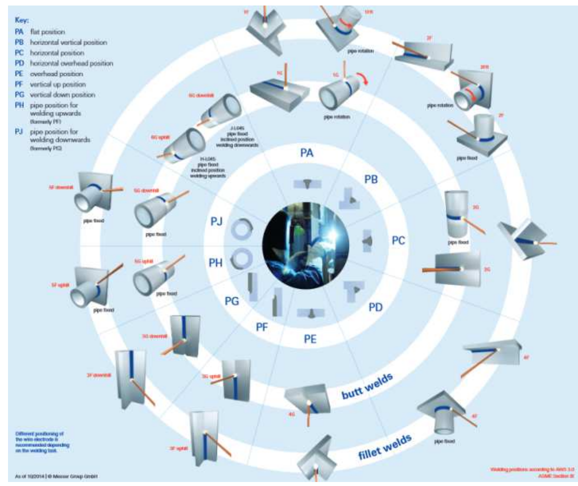


Fig. 3. Welding positions (MESSER) according to ISO 6947:2019 Welding and allied processes — welding positions.

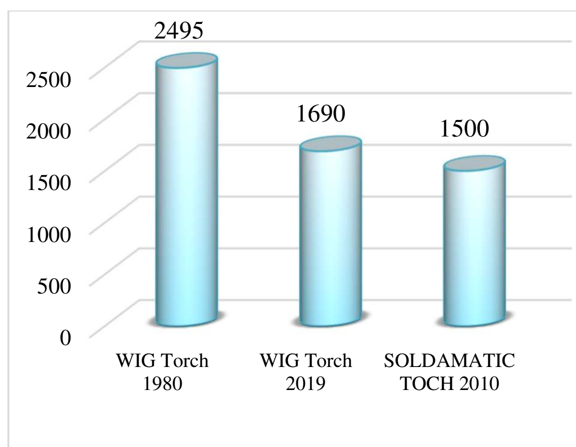


Fig. 4. The weight of the TIG/WIG torches

The welder's process of holding a welding torch for welding operations is essential, it is like that of a person lifting heavy objects.

The lower back pressure mainly indicates the force of the L5/L4 lumbar vertebrae [13]. The lower back pressure values were collected during the execution of the three welding action modules and compared with the database of The

National Institute for Occupational Safety and Health (NIOSH) to determine whether each value was within the controllable range. According to the NIOSH database, a lower back disorder might occur when the lower back pressure exceeds 3400 N [14]. The higher the value, the greater the possibility and severity of lower back injury [15].

Another comparison is between two torches for MIG/MAG process that are quite similar and SOLDAMATIC MIG - MAG torch. The torches are one water-cooled and one air-cooled. MB 40 is air-cooled and weighs 3420 grams and is for 400 A (MIG - MAG Torch 2000). WS 50 is water cooled and weighs 3100 grams and is for 500 A (MIG - MAG Torch 2019). The differences are not significant in terms of weight.

Fig. 5a. The TIG/WIG torches

Fig. 5b. The SOLDAMATIC TIG/WIG torch.

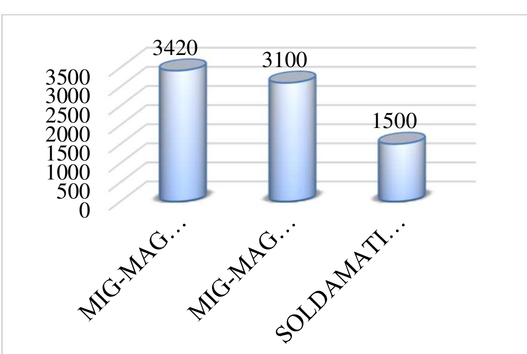


Fig. 6. The weight of the MIG-MAG torches.

In case of SOLDAMATIC MIG-MAG torch the weight is 1500 grams because have lighter cables and are more ergonomics.

In case of MIG –MAG torches it can be observed that the weight are quite similar the difference was that the torch from 2019 has a weight less than 10% but the SOLDAMATIC MIG - MAG torch is proximally at the half of the MIG- MAG torches.

With a smaller weight, the torches from the SOLDAMATIC simulator, the torches are basically an improvement of the tools used by welders and at the same time they are part of the new technology of Virtual Reality. With a lower weight the pressure that will be directed into the welder's body will be much lower.

Only protection against harmful radiation, nuisance and high temperatures is not enough. It must be completed with the adoption of good posture and a choice in case of the torch, high degree of economy and efficient organization of the workplace. Adopt a balanced lifestyle to avoid overweight and recuperation breaks for the execution of movements, stress relief are additional measures that must be considered

Fig. 7a. The both MIG - MAG torches.

Fig. 7b. The SOLDAMATIC MIG - MAG torch.

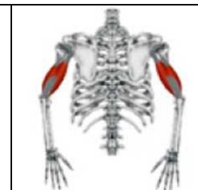
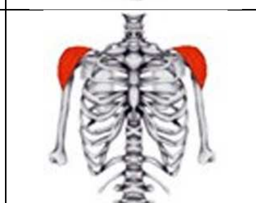
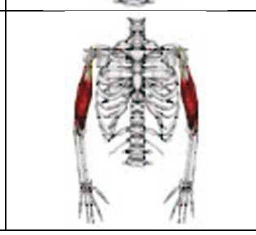
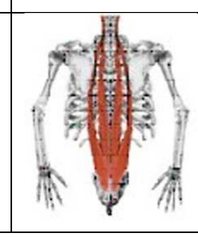
4. CASE STUDY

4.1. Analyzing the behavior of the students during the training with the normal torches (MIG-MAG or TIG/WIG) and with the SOLDAMATIC simulator torch

ABICOR BINZEL and the Department of Sports Medicine of Justus Liebing University, Giessen, Germany had shown through a study that the torch itself plays a special role in the muscular demand of the welder. The use of light torches has the effect of reducing the load to 5 out of 8 evaluated muscles. The study was conducted in the direction of the reduction of muscle tension in the shoulders and arms. In the next chart it can be observed that activity of the muscle in case of two tips of torches from ABICOR BINZEL [16] as seen in Figure 8 and Table 1.

Table 1

Types of muscles [16]

Muscles	Type of muscles		Muscles	Type of muscles	
1	Neck muscles/ M. trapezius		5	Arm muscles/ M. triceps brachii caput lateralis	
2	Neck muscles/ M. infraspinatus		6	Arm muscles/ Mm. flexor	
3	Shoulder muscles/ M. deltoideus medialis		7	Arm muscles/ Mm. extensor	
4	Arm muscles/ M. biceps brachii caput breve		8	Back muscles/ M. erector spinae	

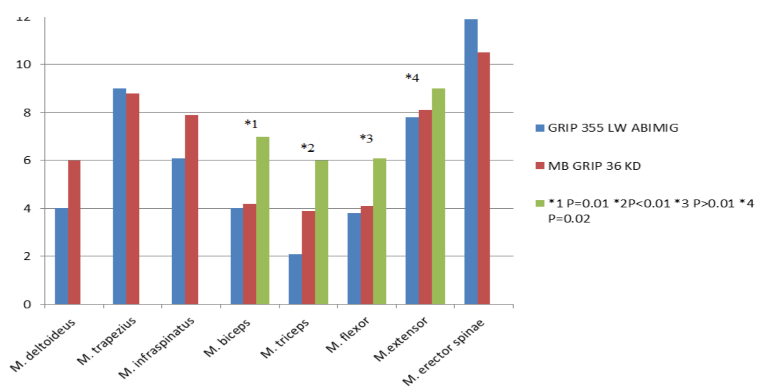


Fig. 8. Muscle activity (% max. for a) in case of two torches [16].

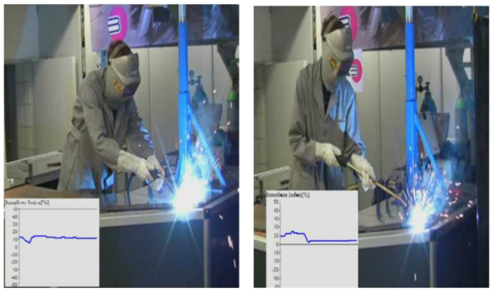


Fig. 9. The welder in the same welding position but with two different torches (one standard and one with long neck) [16]

Fig. 10. The welder with sensors for monitoring the muscles [16]

Regarding welders the reduction of muscle tension/ pressure can be made by using of rotary and interchangeable necks on torches.

In the study had been observed that [16]:

- In the use of the standard torch in the position shown in Figure 9 above when the welder made movements back and forth the lumbar (pelvic) area is the most affected (48.35%);
- In the use of the long neck torch only 3.07% is affected the lumbar area.

To summarize, it may be stated that it is primarily the shoulder and arm muscles that are strained during welding work in the PF (vertical up position, Figure 3) and PD (horizontal overhead position, Figure 3) positions and that a lighter welding torch proved to be advantageous and less of a strain.

The reduced-weight welding torches have been in use on an industrial scale for over a few years and have received a very positive reception among professional welders. The excellent balance and slightly curved handle sit comfortably in the hand and the weight reduction means that welders feel less strain in their daily work. The weight reduction has been possible largely due to the use of light metal components for the live cables in the hose package where the otherwise conventional copper has been substituted by light metal components. Despite the reduced weight, the welding torches are completely suited to industrial use and compliant with the current standards and regulations, particularly EN 60974-7 [17].

To increase the safety and the ergonomics concepts in case of the welder's trainings it can be used the Virtual Reality or the Augmented Reality.

Augmented reality is a new form of human-machine interface, which inserts information via head mounted displays in the users' field of view. The insertion is context dependent, i.e. compatible to and derived from the observed object, e.g. the real field of view of a mechanic is extended by the insertion of instruction sheets. By methods of virtual and augmented reality, additional information can be inserted depending on the application. This information can be derived from the welding power supply (e.g. electrical welding parameters, wire feed), directly extracted from the images (dimensions of the arc) or transferred by another computer (constructional details, like work piece geometry).

The vocational schools - high schools with technical specific activities will have the possibility to see a welding line or a welding process if they do not have access to a real one. Also, it can be used in students' trainings in welding techniques [17]. Virtual Reality allows conducting several analyses related to designed prototypes, such as: dimensions of devices and possibilities of adjustment to height of the human operator, and arrangement of control and signaling devices according to the rules of ergonomic design [18].

A further possible application is the use in training of welders the welding laboratory with AR or VR. By using of a second head-mounted display, teacher and trainee can observe the same welding process. The influence of changing welding parameters on the weld quality can be directly examined [19].

The organization of a welding school can be achieved by the placement of several welding simulators.

It can be observed that the two laboratories coexist: the training with the help of AR does not include the practice with real learning environment, working on complex systems the transition between real and virtual, the need for communication and cooperation between real people where the process takes place and those who are at a distance - experts, student etc. is an important way of collaboration. It is possible to design and test virtual prototypes of workplaces without necessity to build physical prototypes.

In the following there will be presented the augmented reality from SOLDAMATIC.

Augmented reality systems support a variety of services, such as selecting parts from a warehouse and sending repair instructions to mobile devices. These systems are currently in the beginning, but in the future, companies will make much greater use of augmented reality to provide operators with real-time information to improve work decision-making procedures. For example, operators may be instructed on how to replace a part in time to their own system that needs remediation. This information can be displayed directly in their field of view using devices such as augmented reality mask.

The virtual training with the SOLDAMATIC simulator is used in the practical part of the International / European Welding Engineer courses. With the help of augmented reality, the student can simulate almost any welding process (SE, MIG-MAG, and WIG) and finally, together with the practice instructor, can analyse the obtained joint (Figure 13).

SOLDAMATIC simulator is the world's first training solution in augmented reality (AR) welding training. It applies the principle of computer games to motivate learners, can adapt to the needs of learners and possess ecological technology reducing pollution risks because everything is virtual.

The pictures below show the welding positions using the SOLDAMATIC welding simulator. Real welding mask, with an Augmented Reality vision module is used at the training with the Soldamatic Simulator. The new head mount (Figure 13) provides a more comfortable and ergonomic welding experience.

Fig. 11. Welding laboratory with AR or VR.

Fig. 12a. Welding position using SOLDAMATIC simulator.

Fig. 12b. Welding process using SOLDAMATIC simulator (WIG/TIG process).

Fig. 13. Mask/Head mount SOLDAMATIC.

The training with SOLDAMATIC simulator provides the necessary knowledge and abilities in three main types of welding: MMA/SE, MIG/MAG and TIG/WIG. Trainees will gain skills in work with ferrous and non-ferrous metals and different types of seams. During the training, special attention is paid to body ergonomics as [20]:

- Lifting heavy loads (cylinders, cables, etc.). Awkward body postures (outreached arms, awkward position of neck and head, kneeling/squatting);
- Static body positioning (long duration of tasks, manual precision);
- Continuous force (grip strength).

During 2014 – 2020 period in Romania at the IWE (International Welding Engineer) course to the Romania Welding Society a half of practical part (30 hours) are made with SOLDAMATIC welding simulator and over 200 International Welding Engineers were trained with SOLDAMATIC simulator.

Analyzing the behavior of the students during the training with the normal torches (MIG-MAG or TIG/WIG) and during the training with the SOLDAMATIC simulator torch could be observed that the students were more relaxed, the weight of the torches being much smaller the student managed to do more exercises in the same welding position.

Below is presented a case study on SOLDAMATIC Simulator to prove that this smart tool can improve the laws of work – ergonomics.

4.2. Case study: Butt welding - TIG/WIG process performed with the simulator SOLDAMATIC

The Figure 14 shows the WIG welding process for a corner joint. The SOLDAMATIC simulator presents the possibility to store welding parameters:

- The angle of inclination of the pistol: it was 48 representing a 90% percentage, this percentage meaning that it was almost perfect;
- The angle during welding: it was 16, registering a percentage of 93%;
- Advance speed: 3.1 mm/s with a 97% percentage, resulting in a good working speed.

Welding defects:

- Porosity: it was 0, a very good result;
- Splashes: 5% was recorded, which is a favorable percentage for this weld.

Equipment settings:

- Intensity of the welding current: during the welding process, an intensity of 20 V was chosen;
- Welding wire speed was 4.7 m/min;
- Gas: had a flow rate of 13.5 l/min.

The welding parameters settings for this welding were correctly chosen respectively the technical parameters registering a score of 95/80. The advantages of using the SOLDAMATIC welding simulator are:

- Reduction of environmental pollution by approximately 97.3%;
- Cost reduction on the market by 81.08%;
- Attractive and innovative technology for students who want to learn welding processes by registering a percentage of 75.68%;
- Safety is the most important, registering a percentage of 72.97% it is safer to use the simulator than the welding itself because there is the appearance of burns, impaired vision etc.;
- To improve the welding process for training, the augmented reality mentioned above is used as the appropriate technology, recording a percentage of 81.10%, respectively the virtual reality registering a percentage of 18.90%;
- Greater security in the phase of training, not exposing to the fumes generated in the process, to the high temperature developed in electric arc region;
- A short time to conduct the study because risk factors are greatly reduced, the weight of used tools is substantially reduced so that the discomfort of the welders has decreased.

5. CONCLUSIONS

The use of proven ergonomic principles can dramatically improve the way a welding operator performs a task, thereby reducing the exposure to risk factors and simultaneously increasing productivity. The use of different tools can make a big difference on an operator’s long-term health and well-being, as well as on the company’s bottom line. For example, operators who weld with pistol grip tools, such as a welding torch, and use their finger to apply pressure for an extended length of time can develop “trigger finger”.

This problem can be resolved easily by using a welding torch with a locking trigger or if the weight of the torch is too high the operator can have a big discomfort in arm and shoulder muscles.

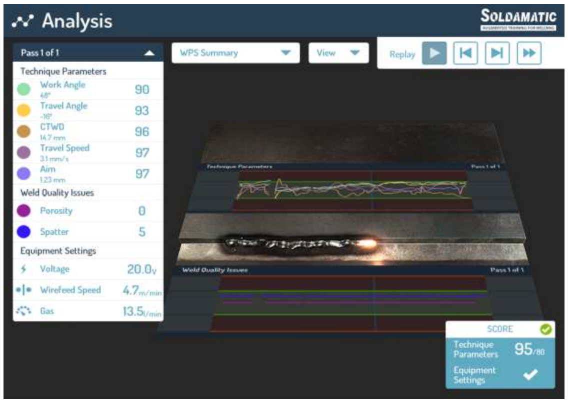


Fig. 14. Case study butt welding using SOLDAMATIC simulator (WIG/TIG process).

Welding operators should position their work between the waist and shoulders, whenever possible, to ensure they are working in a close to a neutral posture. Achieving this posture may mean using work stools or height-adjustable chairs, as well as lifting tables and rotational clamps or other material-positioning equipment. All these solutions can reduce awkward postures and allow employees to work in more neutral positions.

Welding torch with rear swivels on the power cable can help reduce the stress of repetitive motions. Different combinations of handle angles, neck angles, and neck lengths also can keep an operator's wrists in a neutral position. In some cases, a welding torch with a rotatable neck can help the welding operator more easily reach a joint, with less strain on the body. Manipulators, lighter-weight welding torch, lighter power cables with low stiffness and cable supporting balancers also can be invaluable. The working height of a welding operator's hands should typically be at elbow height or slightly below.

In the field of Virtual Reality in welding training in the future regarding ergonomic concept the research can be continued with the impact of the mask/Head mount SOLDAMATIC in the comfort condition of the trainees / welders. The mask/Head mount SOLDAMATIC is very important because without the mask the welder cannot see all the process and for the welder that are familiar with normal welding processes they are placed in a very strange situation because at the beginning they cannot follow the virtual arc of the process.

Future research will be developed in a collaborative manner, by supporting innovation in a proactive way as mention in [21; 22].

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Aspecte ergonomice ale instrumentelor de sudare în mediu real și virtual

Rezumat: În ultimii ani, factorii ergonomici au început să aibe o importanță din ce în ce mai mare în toate sectoarele industriale de la concepția de produs, dezvoltarea de servicii, activități de întreținere. În acest din urmă caz, procedeele de sudare și tehnologiile asociate acestora au o mare pondere. În acest articol, vor fi prezentate principalele aspecte și recomandări privind ergonomia în sectoarele de sudare și, de asemenea, va fi prezentat un studiu de caz privind pistoletele de sudare. Lucrarea se încheie cu câteva recomandări legate de folosirea uneltelor/pistoletelor de sudare și cu o recomandare a unui nou studiu privind aspecte ergonomice ale utilizării realității virtuale.

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