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Comparison of conventional and robotic workplace based on economic and production indicators

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Semi-automatic GMAW process can ensure high quality of welded seams. However, the problem of finding enough qualified welders hit a large number of companies in our industry. A large number of certified welders in recent years were retired or is very close to retirement. On the other hand, a very demanding training for acquiring certificates and the general climate in the country related to mechanical engineering and mechanical engineering industries, have made that fewer and fewer young people opt for this job. The development of robotics in recent years made the welding robots with highly improved performance at significantly lower prices. The same welding process – GMAW process applies at robotic workplace. Advanced software features, ease of programming and improved reliability have made the robotic welding cells represent a solution that is imposed by itself.

Keywords: welding, GMAW process, the robot, costs, productivity

1. INTRODUCTION

Welding is dominant technology that is the used in the production of boilers for central heating of one domestic manufacturer. Preparing of parts is performed on the equipment that provides high-accuracy of measures and shapes, trained welders are engaged, modern semiautomatic GMAW equipment and gas mixtures are used and welding technology is designed by certified engineers.

The interest of the company is to ensure consistency of its product quality, higher productivity and efficiency, higher profits and sales of products to the European market. It is expected that these goals will be achieved in case that finalization of the production would be done by robot.

The structure of costs in the process of welding according to the Lincoln Electric Company, Fig. 1, shows that 80% belong to labor costs and material costs account for 20%. Reducing of these costs, even to a small extent, leading to significant savings and increased profits. Participation of component in the total cost implicitly suggests two possible conclusions:

- materials have very low rates (and additional supplies), or
- very high cost of labor.

The aim of this study is to determine this relationship in our environment and whether it is justified to apply robots, i.e. to assess conditions in which their use is justified.

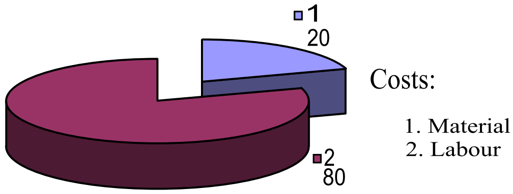

Fig. 1. Structure of welding costs [1]

2. COST ANALYSIS

Operating expenses are monitored by constant reviewing of the costs level in the following segments:

- training of welders,
- overtime work,
- shielding gases,
- filler material (NJ / kg),
- workspace (NJ/m^2)
- safety equipment,
- ventilation,
- control of welded joints,
- scrap and finishing of parts,
- other costs.

It is desirable to constantly monitor level and transormation of costs and to bilance it for each business year (calendar), because it creates the basis for determining the strategy for the future. Of course, the current changes are used for prompt actions. Still, important decisions need knowledge of the state of costs for longer period of time. Decision to install a robot can not be made based on consideration of the current level

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of costs. The shortest period is one year, but it is not reliable if the management does not follow the trends over a longer period of time and if not realize the prediction of changes in the near or distant future.

Table 1 shows the reduced cost structure in terms of application of welding equipment for semi-automatic GMAW. Shown structure does not explicitly take into account all the cost elements listed in the previous chapter, because it starts from the fact that they do not change significantly.

Table 1. Costs structure for GMAW welding.

No.	Label	Equation		Value	Note/Description
1.	ℓ			34 m	Length of all boiler's weld seams
2.	m			250 kg	Mass of one boiler
3.	m_{dm}	$0.05 \cdot m$	$0.05 \cdot 250$	8 kg	Mass of filler material for one boiler
4.	m_{dm1}	m_{dm}/ℓ	8/34	0.235 kg/m	Mass of filler material per 1m of weld seam
5.	C_{dm}			75 NJ/kg	Price of filler material
6.	T_{dm1}	$m_{dm1} \cdot C_{dm}$	$0.235 \cdot 75$	17.63 NJ/m	Costs of filler material per 1m of weld seam
7.	V_{gm}	$k \cdot V_b$	$1.8 \cdot 40$	72 ℓ	Consumption of gas mixture, V_b=40 ℓ volume of gas tank
8.	C_b			2650 NJ	Price of full tank of gas mixture
9.	C_{b1}	C_b/V_b	2650/40	66.25 NJ/ℓ	Price of 1 ℓ of gas mixture
10.	T_{gm}	$V_{gm}/\ell \cdot C_{b1}$	$72/34 \cdot 66.25$	140.29 NJ/m	Costs of gas mixture per 1m of weld seam
11.	NS			190.25 NJ/h	Costs of welder per one hour of work
12.	Pr			20 m/smena	Productivity of welder per shift
13.	Pr_1	Pr/8	20/8	2.5 m/h	Productivity of welder
14.	T_{r1}	NS/P_{r1}	190.25/2.5	76.1 NJ/m	Costs of welder per 1m of weld seam
15.	T_1	$T_{dm1}+T_{gm}+T_{r1}$	17.63+140.29+76.1	234.02 NJ/m	Unit costs of weld seams per 1m
16.	T_{pa}	$T_1 \cdot \ell$	$234.02 \cdot 34$	7956.68 NJ	Production costs for all seams

The typical cost elements are:

- T_{dm1} = 17.63NJ/m - Cost of filler material per 1 m of weld seam (7.53%),
- T_{gm} = 140.29 NJ/m - Cost of gas mixture per 1 m of weld seam (59.95%)
- T_{r1} = 76.1 NJ/m - Labour costs per employee per 1 m of weld seam (32.52%)
- T_1 = 234.02 NJ/m - unit costs for a weld seam made by semi-automatic process (100%).

Figure 2. which is made based on these data, shows that the cost of materials (filler and consumables) constitute 40.05% of the total cost, which is twice the value of one wich is shown in bilance on Figure 1. The reasons for these differences are in a lower cost of human labor in our conditions. On the other hand, costs of filler materila are four times lower than the cost of protective atmosphere.

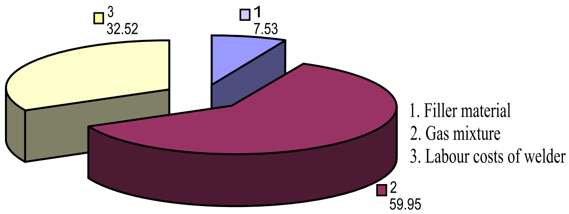

Fig. 2. Structure and participation of costs for production of all weld seams made by GMAW

Half of length of the boiler seams can be made by robot. The costs of such variants of the boiler production are shown in Table 2. Since the length of seams that are made in this way, it is normal that the same would happen with the cost of semiautomatic GMAW(implemented by welders). Unit costs of filler materials and gas mixtures are not significantly changed since the implementation of the robot does not change amount of deposit and gas mixture which are consumed per unit of seam length. Although the robot can achieve greater welding speed, practically it is not feasible considering the technological capabilities (speed of dissolution of materials, metallurgical reasons).

Integrated cost T_{IT} = 9513.37 NJ, column 17 in Table 2, are calculated by superposition of costs that belong to the conditions of manual and robotic technology implementation, when one half of seam lengtheach is carried out by each of them. There is an obvious increase in the absolute amount of costs compared to those that are typical for a human workplace (T_{PA} = 7956.68 NJ, column 16, Table 1). This increase is not negligible (16.36%) and it is particularly pronounced when it is determined for the entire one-year series.

Table 2. Welding costs for classic and robotic GMAW

No.	Label	Equation		Value	Note/Description
1.	T_1				Costs of GMAW per 1m of weld seam
2.	ℓ			17 m	Length of seams made by semiautomatic GMAW
3.	T_{pa}	$T_1 \cdot \ell$	234.02·17	3978.34 NJ	Costs of seams made by semiautomatic GMAW
4.	ℓ_R			17 m	Length of seams made by robot
5.	m_{dm}			4 kg	Mass of filler material for robor
6.	m_{dm1}		4/17	0.235 kg/m	Mass of filler material per 1m of weld seam
7.	T_{dm1}	$m_{dm1} \cdot C_{dm}$	0.235·75	17.63 NJ/m	Costs of filler material per 1m of weld seam
8.	V_{gm}	$k \cdot V_b$	0.9·40	36 ℓ	Consumption of gas mixture, V_b=40 ℓ volume of gas tank
9.	C_b			2650 NJ	Price of full tank of gas mixture
0.	C_{b1}	C_b/V_b	2650/40	66.25 NJ/ℓ	Price of 1 ℓgas mixture
1.	T_{gm}	$V_{gm}/\ell_R \cdot C_{b1}$	36/17·66.25	140.29 NJ/m	Costs of gas mixture per 1m of weld seam
2.	NS_R			6400 NJ/h	Costs of robot per one hour of work
3.	v_R	0.5m/min		30 m/h	Robot welding speed
4.	T_{R1}	NS_R/v_R	6400/30	213.33 NJ/m	Costs of robot per 1m of weld seam
5.	$T_{\{1}$	$T_{dm1}+T_{gm}+T_{R1}$	17.63+140.29+213.33	371.25 NJ/m	Unit costs of weld seam made by robot
6.	T_R	$T_{R1} \cdot \ell_R$	371.25·17	6311.25 NJ	Costs of weld seams made by robot
7.	T_{IT}	$T_R + T_{pa}$	6311.25+3978.34	10289.59 NJ	Costs of weld seams production using integrated technologies (semiautomatic+robot) per boiler

Typical elements of cost for robotic workplace:

T_{dm1} = 17.63 NJ / m – Costs of filler materials per 1m of seam length (4.75%, a), or 2.9%, b))

T_{gm} = 140.29 NJ / m - Costs of gas mixture per 1m of seam length (37.79%, a), or 23.18%, b))

T_{R1} = 213.33NJ / m - Costs of robot per 1m of seam length (57.46%, a), or 35.24%, b))

T_{S1} = 371.25 NJ / m - Unit costs achieved by applying robots per 1m of seam length (100%, a))

T_{r1} = 234.02 NJ / m - Labour costs per employee per 1m of seam length (38.66%, b))

T_{IT} = 10289.59/17 605.27 = NJ / m - Cost of integrated technology of boiler production (100%, b))

Fig 3a. clearly shows increase of the material costs share in total costs compared to those shown at Fig 1 (filler and consumables material). Robot costs in relative comparation (57.46%) are less than the cost of human labor (59.95, Figure 2). However, the absolute amounts of human labor unit costs are lower for almost three times (76.1 NJ / m, Table 1) compared to the absolute amount of unit work costs of robot (213.33 NJ / m, Table 2). Production of all seams in terms of combinations of human and robotic work, Figure 3b shows that the share of materials is still larger than those which is shown in Figure 1 (26.8% vs. 20%), and that, for the same amount of work, labor costs of welder (35.24%) lower than the work costs of robots (38.66%).

Fig 3. Structure and participation of costs at boiler seams production at robotic workplace (a) and at both workplaces (b)

3. ANALYSIS OF PRODUCTIVITY

In essence, productivity is defined as the number of processed workpieces per unit time, [1]. Following analysis is conducted in accordance with this definition. Table 3 shows systematized indicators of productivity in case when all seams are made by GMAW procedure implemented on conventional workplace (welder). Table 4 contains data on productivity in two cases. When the robot is applied for production of half the length of boiler seams (A) and when applied for production of all seams (B), i.e. in case when welders are completely excluded from the production.

If, however, unchanged number of welders would be involved in the production of half the total length of seams on the boiler, then in one year they could twice as much boilers or N_{z2} = 13,920 units / year. In this case, the second half of seams would be made at robotic workplace, table 4A. For one year it could weld total amaounts of boilers N_R = 13,875. It is obvious that in analyzed company similar studies has led to employed number of welders. They can work in one shift or multiple shifts, but can not produce more units than what is calculated. Working in over shifts provides less investment costs in the company.

Table 3. Elements of productivity for classic workplace

No.	Label		Equation		Value	Note/Description
1.		n			40	Number of engaged welders
2.		L_z			20 m/smena	Length of weld seams made by welder per shift
3.		ℓ_R			34 m	Length of weld seams made by robot per boiler
4.		ν_z	L_z/t	20/8	2.55 m/h	Welding speed (welder)

No.	Label	Equation		Value	Note/Description
5.	n_{kz}	$\nu_z \cdot n/\ell$	2.55·40/34	3 kom/h	Number of boilers which cam be made by 40 welders for an hour
6.	N_{kz1}	$n_{kz} \cdot 8$	3·8	24 kom/dan	Number of boilers per day
7.	t_z			290 dana	Number of working days for welder
8.	N_z	$N_{kz1} \cdot t_z$	24·290	6 960 kom/god	Annual production of boilers

Table 4. Elements of productivity for robotic workplace

No.	Label	Equation			Value		Note/Description
			A	B	A	B	
1.	n_R				1	1	Number of robots
2.	ℓ_R				17 m	34 m	Length of weld seams made by robot per boiler
3.	ν_R	0.5 m/min			30 m/h	30 m/h	Welding speed
4.	η_R				90%	90%	Robot efficiency (annual)
5.	t_R	$\eta_R \cdot 24$	0.9·24	0.9·24	21.6 h	21.6 h	Effective working time of robot per day
6.	n_{kR}	ν_R/ℓ_R	30/17	30/34	1.76 kom/h	0.88 kom/h	Number of boilers made by robot per hour
7.	N_{kR1}	$n_{kR} \cdot t_R$	1.76·21.6	0.88·21.6	38.016 kom/dan	19.0588 kom/dan	Number of boilers made by robot per day
8.	t_{Rg}				365 dana	365 dana	Number of working days per year
9.	N_R	$N_{kR1} \cdot t_{Rg}$	38.016·365	19.0588·365	13 875 kom/god	6956 kom/god	Number of boilers made by robot per year

4. EPILOGUE

These data suggest the following conclusions.

1. At the total bilance of the welding cost, European / American relations of work and material, there is not significant differences than at us. - pictures 1 and 2

2. Use of robots is not profitable, i.e. substitution of human labor in conditions of relatively low salaries of workers (comparison of absolute amounts of the costs in Tables 1 and 2).

3. Even less profitable is complete substitution of human labor by two robots that are based on data obtained from column 16, Table 2 (TR = 2 · 6311.25 = 12622.5 NJ). The cost of one boiler would be 36.96% higher than the price of the boiler-made by semi-automatic GMAW.

4. The integrated operation of robots, which produces NR = 13,875 pcs / year boilers, and semi-automatic GMAW (40 welders working and producing N = 2 · 2 · Nz = 6960 = 13,920 pcs / year) achieved twice as much productivity compared to those when only welders works.

5. Substitution of all welders with two robots (production without people), would gain to productivity of $N = 2 \cdot 2 \cdot N_R = 13{,}875 =$ 27,750 units / year, which is almost four times higher than if all seams are produced only by welders.

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