Estimation of Welding Costs During the Production of the Lower Pedestal Central Ring of the Hydraulic Excavator

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Abstract. The subject of this paper is the calculation of welding costs of the lower pedestal central ring of the hydraulic excavator. Purpose, applications and the main parts and functions of the hydraulic excavator are described in this paper. The effects of major welding methods on the overall standards of time and the main welding costs of the central ring of the lower base of a hydraulic excavator are analyzed and based on the cost calculations of welding, optimal welding procedures are selected for described welds to achieve minimum time needed with the lowest welding cost.

Keywords: Central ring · Hydraulic excavator · Welding · Maintenance

1 Introduction

Only with the use of construction machinery is it possible to carry out large construction projects in a very short time, to achieve the required quality and economic efficiency, and at the same time to humanize human labor. Construction machinery is therefore of great importance to the construction industry. Without them, the construction industry could not survive; they are its backbone. From levers, pulleys, wheels and ropes, construction has evolved to the point where its future lies in electronics, remote control, automata and robots. Therefore, the use of construction machinery requires a thorough knowledge of their capabilities and the areas in which the work is performed, which can be divided into 3 groups: [1].

1. Civil engineering works,
2. Construction works,
3. Other construction works.

Basic operating conditions of any construction machine are working temperature, stress and medium. According to the conditions of exploitation, the parts of the hydraulic excavator are subjected to bending as well as tensile, compressive, impact and dynamic

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stresses. In such conditions, excessive stresses are possible, resulting in unwanted defects. In order to prevent this from happening, it is necessary to carry out visual inspections of possible damages during exploitation and to remove them in a timely manner. In the case of a hydraulic excavator, a hydraulic drive is used. It is a drive based on the transmission of force by liquid, usually mineral oil containing zinc. Contact of the medium with water and impurities in storage should be avoided, and filtering during storage and immediately before use is recommended [2].

2 Hydraulic Excavator

Hydraulic excavators are construction machines used for excavation and demolition work. They have hydraulic drive, which is easier to handle and replaces cable excavators, which have mechanical elements such as winch drive and gearbox. Their range of application is wide, and they are mainly used for excavation. They are also used for demolition work, as even the smallest models are capable of demolishing buildings. Hydraulic excavators are also used to move large amounts of material from one place to another. They are completely dependent on the hydraulic drive [2]. The base consists of a track or wheel that allows the machine to move while supporting the undercarriage. The operator controls the hydraulic excavator with levers to raise and lower the two-piece arm and control the excavator arm. The drive section is located on the undercarriage and can be rotated 360 °. The two-piece arm and the excavator arm are connected to the drive section but are independent during control. Mining and big infrastructure projects are fields where hydraulic excavators are used extensively. These machines generally use tracked walking systems that have high ground adhesion in order to be reliable in the surroundings with harsh ground [3].

2.1 Basic Information About Welded Construction

Each hydraulic excavator consists of parts necessary for its operation. As a representative example, the RKE-2600 excavator model was selected, the main components of which are shown in Fig. 1.

The central ring of the hydraulic excavator was chosen as a representative example of welded construction. For the selected design, an analysis of the main welding costs was performed, and the most favorable welding procedures for each weld were selected. The central ring is the connecting part between the upper and lower parts of the hydraulic excavator and allows the upper part to rotate relative to the lower part of the excavator, which increases the range of motion of the excavator. Since the ring is subjected to extremely dynamic shock and pressure loads, high operational reliability is required, which is achieved through high-quality manufacturing and inspection. Figure 2 shows the central ring of the lower base of the Render RKE Hydraulic Excavator 2600.

2.2 Sequence of Production and Control Activities

The sequence of production and control activities in the manufacture of the product, from the creation of the individual product positions to their assembly into the finished

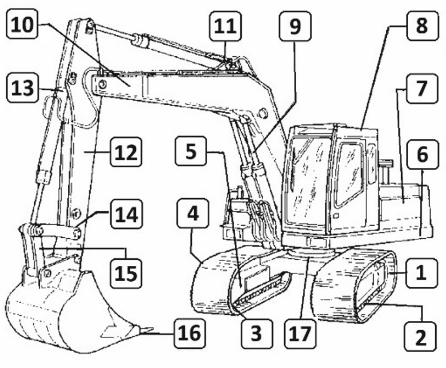

Fig. 1. Main parts of hydraulic excavator RKE-2600 [4] (1—track drive wheel, 2—track guide rollers, 3—track tension wheel, 4—tracks, 5—hydraulic motor, 6—superstructure, 7—covers with sound protection, 8—cabin with control devices, 9—lifting cylinder, 10—excavator boom (boom), 11—cylinder for penetration, 12—grab holder, 13—grab cylinder, 14—grab lever, 15—connecting rod, 16—gripper, 17—main bearing)

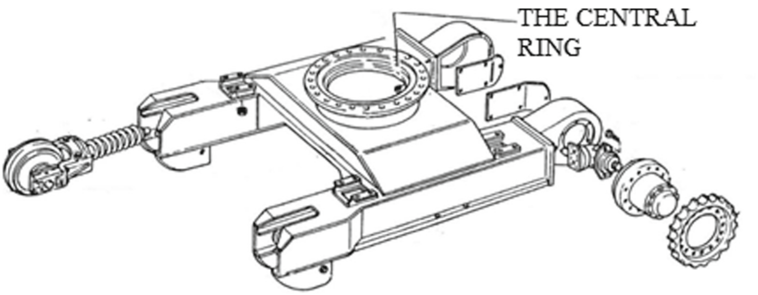

Fig. 2. The central ring of the hydraulic excavator [4]

product, is shown schematically in Fig. 3. The assembly consists of three positions. Each of the positions is made from a plate with certain dimensions (starting material). The starting material is formed into positions by cutting and bending processes, and the positions are assembled into an assembly by welding. Between the individual production steps, a position or an assembly passes through various controls (visual, dimensional, etc.). The control ensures the quality of production and the required reliability of the assembly. Positions of the central ring are shown in Fig. 4.

3 Analysis of the Main Costs of Welding Procedures

Procedure of joining several structural elements, known as welding, is becoming one of the most widely used procedure in the construction, railroad and automotive industries, as well as in shipbuilding and the offshore industry [6]. The definition of the ideal weld is very complex, but it can be said that the joined parts are in continuity. In practice, it is impossible to achieve an ideal weld, but there are several welding procedures that are

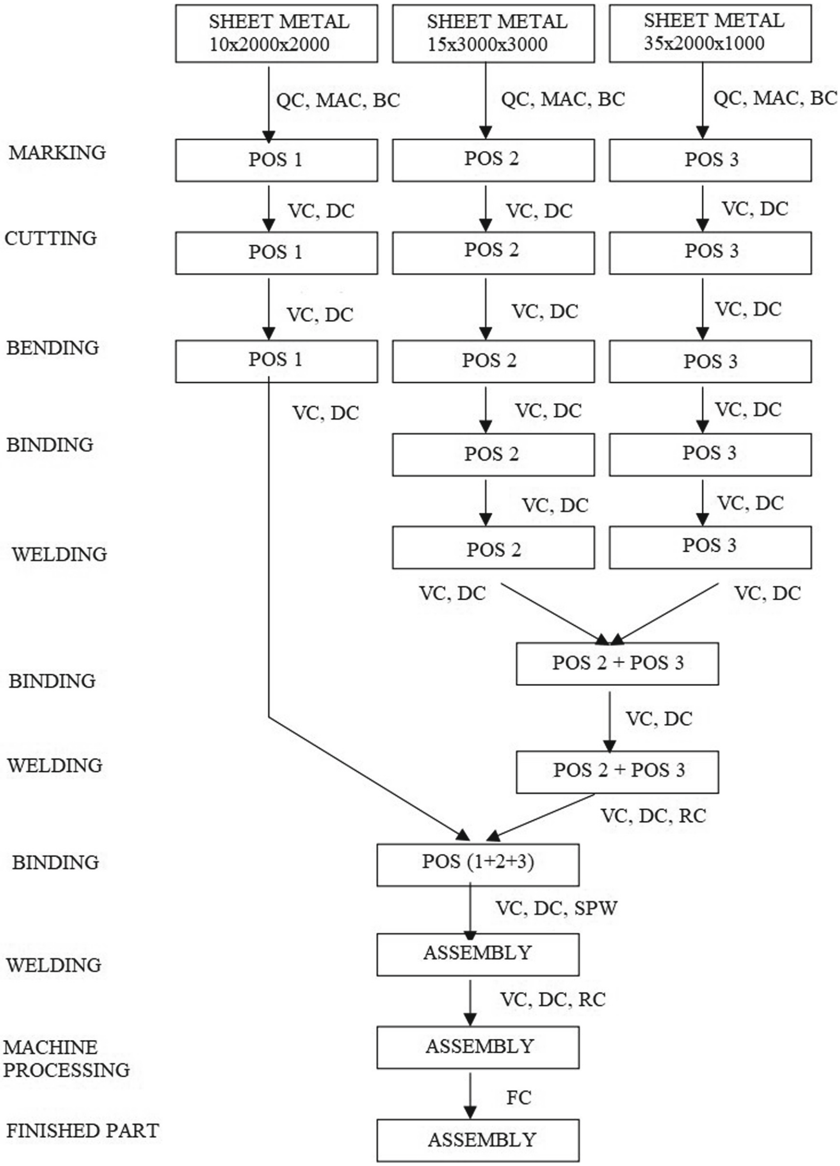

Fig. 3. Sequence of production and control activities [5] (VC—visual control, DC—dimensional control, RC—radiographic control, QC—control quality, MAC—material attestation control, BC—batch control, SPW—stoppage point works controls, FC—final control)

designed to produce acceptable welds. Since there are different types of metals, joints, and applications, the welding engineer must identify the requirements needed for each weld and select the appropriate welding procedure [7].

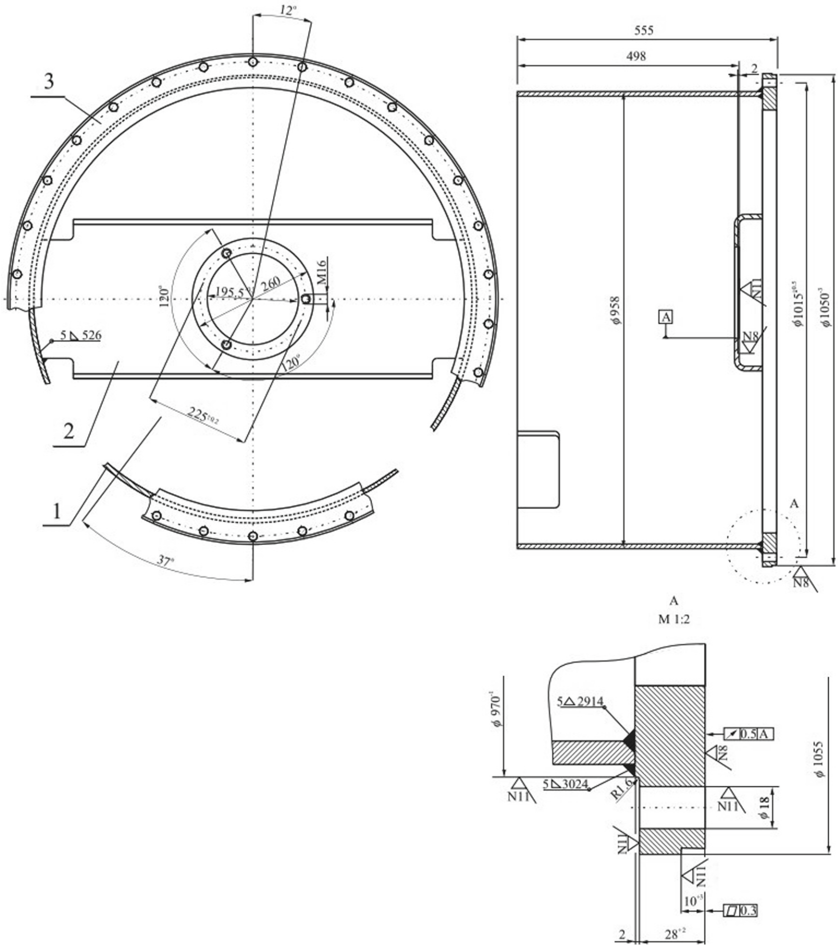

Fig. 4. Positions of the assembly

The purpose of technological analysis and cost optimization is to achieve maximum profit. How to ensure maximum profit, it is necessary to choose the optimal solution for the welding process, optimal groove shape and appropriate groove tolerances. Profit can be expressed as the difference between the price that the product can achieve in the market and procurement and manufacturing costs. As the price of the welded product is defined by the market, it is desirable to reduce production costs to the smallest possible measure to maximize profit. The correct choice of welding method and of other factors that affect the cost of the welded product can be achieved the smallest costs, and thus the highest profit. The control and measurement of all variables of the process are the most important steps in the optimization of all welding parameters involved [8]. The most common electric arc welding procedures are:

MMA Welding—Manual Metal Arc Welding,

MIG/MAG Welding—Metal Inert/Active Gas Welding,

SAW Welding—Submerged Arc Welding,

TIG Welding—Tungsten Inert Gas Welding.

MAG, MIG and TIG welding belong to semi-automated, while SAW welding belongs fully automated welding procedures. Each of these procedures is performed differently and their main welding costs are also different. Increased attention must be paid to the strength calculation, the composition of the material used and welding to avoid any failures [9]. It is very important to accurately determine the residual stresses, since their occurrence is one of the consequences of the process of welding. Nowadays it is indispensable to perform numerical simulations of the process of welding with FEM [10–12]. In the following chapters, the main costs of individual welding procedures are briefly described.

3.1 Manual Metal Arc Welding (MMA Welding)

The main costs of MMA welding are:

1. Electrode cost,
2. Power cost,
3. Personal income cost (workers' wages),
4. Costs of power source (machine) for welding.

The cost can be expressed in HRK/kg deposit or HRK/m weld length. It is argued that it is more appropriate to express the cost in HRK/kg deposit. This is because a different amount of deposit can be used for 1 m of weld, and the cost is proportional to the mass of the deposit.

Electrode cost can be estimated from the following expression: [13]

$$T_{\text{electrode}} = C^{1}_{\text{electrode}} \times k'_{t} \tag{1}$$

where $C^{1}_{electrode}$ is the unit price of electrodes and k'_t is the electrode melting coefficient, which expresses the amount of electrode mass together with coating required to deposit 1 kg of deposit. This coefficient depends on the thickness of the electrode coating, the amount of iron powder added to the coating to increase its effectiveness and the amount of waste ("stick") from the electrode that the welder leaves unused. This waste should be as small as possible and can be 30–50 mm if care is taken. A larger waste due to carelessness causes higher costs.

The expression for power cost is equal for every welding process: [13]

$$T_{\text{electricity}} = \left[\frac{U \times I}{1000 \times \eta_{\text{s}}} \times \varepsilon + N_0(1-\varepsilon)\right] \times \frac{1}{k_{\text{t}} \times \varepsilon} \times C^{1}_{\text{electricity}} \tag{2}$$

where U is the arc voltage, I is the welding current, η_s is the degree of useful operation of the machine and ε is intermittency, the time of switching on the electric arc. N_0 is the power consumed by the machine at idle when the arc is not burning. Power is then used for the working fan, friction, magnetic field dissipation, and heating of the conductors in the machine. Also k_t is the electrode melting coefficient and $C^1_{electricity}$ is the unit price for current.

Personal income cost is also equal for every welding process and it can be calculated from the following expression: [13]

$$T_{PIE} = \frac{PIE}{k_t \times \varepsilon} \tag{3}$$

where PIE is the gross amount of PI (personal income) that results when the net PI is added to the compulsory contributions to the social community (pension and health insurance and other funds).

The last main cost is the cost of the welding machine for which the following expression applies: [13]

$$T_{machine} = \frac{C_N}{\text{number of working hours per year}} \times \frac{1}{k_t \times \varepsilon} \tag{4}$$

where C_N is the purchase price of the machine. This includes the annual depreciation rate, the annual amount for maintenance, and the interest or tax on the operating fund. The number of working hours per year of the machine in one or more shifts depends on the actual use of the machine. The total main cost is equal to the sum of all individual welding costs.

3.2 Metal Inert/Active Gas Welding (MIG/MAG Welding)

The approach to calculate the main cost of MAG/MIG welding is similar to the approach to calculate the main cost of MMA welding. The difference with the main cost of MMA welding is that the cost of the wire used instead of the electrode is added to the cost of the welding gas. The parameters of MAG /MIG welding also differ significantly from the parameters of the MMA process. Gas cost can be calculated from the following equation: [13]

$$T_{CO2} = C_N \times K_{CO2} \tag{5}$$

where T_{CO2} is CO_2 gas cost and K_{CO2} is CO_2 consumption coefficient.

3.3 Submerged Arc Welding (SAW)

The calculation of the main cost of SAW welding is similar to the calculation of the same with the MMA and MAG/MIG process. The difference with the MAG/MIG process is that powder is used instead of a shielding gas, while the SAW process uses wire instead of the electrode used in the MMA process. Approximately 1,2 kg of powder is required for 1 kg of deposition. The exact expression for the cost of powder is following: [13]

$$T_p = 1,2 \times C_p \tag{6}$$

where T_p is powder costs and C_p is powder price.

3.4 Tungsten Inert Gas Welding (TIG Welding)

The calculation of the main costs of TIG welding is analogous to the calculation of the main costs of previous welding processes.

4 Welding Costs of the Selected Representative

In the production of any product, the goal is to obtain the highest possible profit. It will depend primarily on the choice of the welding process, the choice of the groove and the appropriate tolerances of the groove. It can be expressed as the difference between the price of the product on the market and the total cost. Since the price of the product is determined by the market, the cost of production must be reduced in order to maximize the profit. When welding the central ring of the lower part of the base of the hydraulic excavator, due to the thickness, shape of the groove and inaccessibility, not all welds can be welded using the same procedures. The most important thing is to choose a technological welding process so that the cost is minimal. Therefore, the welding of weld 1 connecting Position 1 is performed using the SAW process, and the other three welds are welded using the MAG/MIG process. The total main costs of each weld and the whole series are shown in Fig. 5.

WELDING PROCEDURE	WELD 1		WELD 2		WELD 3		WELD 4	
	Total main costs T_z HRK	Total main costs for the entire series T_{ser} HRK	Total main costs T_z HRK	Total main costs for the entire series T_{ser} HRK	Total main costs T_z HRK	Total main costs for the entire series T_{ser} HRK	Total main costs T_z HRK	Total main costs for the entire series T_{ser} HRK
REL	27,71	1385,5	6,80	340	20,39	1020	50,81	2541
MAG/MIG	12,49	614,5	3,06	151	9,19	452,5	22,90	1127
SAW	8,09	404,5	-	-	-	-	-	-

Fig. 5. Total main costs for individual welds and the entire series

By choosing a technological welding process for each weld, the lowest welding cost for the entire assembly is achieved. Based on the values already calculated, the main welding cost for the entire series of 50 pieces is T_{ser} = HRK 2134.7. If all welds were welded using the MMA process, the cost for the series would be T_{ser} = 5286.5 HRK, while welding all welds using the MAG/MIG process would reduce the cost for the series to T_{ser} = 2345 HRK. MAG/MIG welding results in a lower amount of main costs compared to REL welding, but still a higher amount than the already chosen technological solution (a combination of SAW and MAG/MIG welding).

5 Conclusions

This paper describes importance and use of construction machinery including hydraulic excavators which are commonly used as construction machinery to carry out larger construction projects to reduce construction time.

As a representative example for analysis of welding cost in construction machinery production, a central ring of one hydraulic excavator was chosen. In order to select optimal welding procedure regarding production cost, a cost of MMA Welding, MIG/MAG Welding, SAW Welding and TIG Welding are calculated and analyzed for four welds of the central ring of excavator. Analysis was performed for one central ring as well as for production series of 50 pieces.

Analyzing the main costs of welding the central ring of the hydraulic excavator, it was found that the combination of the SAW and MAG/MIG processes is a cost effective solution in this case. With the proposed welding methods, a full penetration of the weld root also have to be achieved in order to avoid the possibility of crack formations and weld failure.

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