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An alternative boom design and welding technique to minimize energy consumption during boom production

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Abstract. This paper presents an alternative boom design for mobile cranes and a method to produce it for minimizing the energy consumption during its production. The main change in the production of the crane booms is the shape of the booms. Normally, two symmetric boom parts are manufactured and, then, these parts are welded by two welding processes. In the proposed design, only one part is manufactured and bended at first. Therefore, one welding will be sufficient and a more energy-friendly process is achieved. With the proposed shape, the corner joints are eliminated when forming the boom shape, without any need to produce them beforehand. Single welding process is applied to minimize energy consumption during the manufacturing of the boom; thus, the welding quality becomes more important. In order to satisfy the welding quality, a welding manipulator is designed and manufactured. By using this welding manipulator, used in a closed area, and the applied filter devices, the harmful gases are not released to the operator and the environment. Finally, the energy and time required during the plasma-cutting process of boom parts are decreased by about 41% and the energy consumption during the welding process is decreased by about 53% compared to the traditional methods.

1. Introduction

Production of hazardous gases, mainly CO_2, SO_2, and NO_x, is one of the main reasons of global warming, which is one of the most important environmental problems of our time [1-5]. In addition to global warming, the gases released into the atmosphere cause a disruption in ecological balance, which is considered to be one of the most serious problems. Global warming is increasing due to the increased energy consumption day by day. On average, for each 1 kWh of energy produced by a coal power plant, approximately 1 kg of CO_2 is released to the atmosphere [6-8]. For this reason, it is essential to use energy in the most efficient way and to minimize the production of these gases. Nowadays, two very important research topics are minimization of energy consumption and production of such gases by creating alternative solutions [9,10].

Mobile cranes perform useful material-handling services around the world. They are commonly used for carrying, uploading, and downloading of industrial materials. One of the most important parts of the mobile cranes is booms, which are used for carrying the loads. Moreover, the flexible shape of mobile cranes provides them with efficiency and safety.

In this paper, an alternative boom design tech-

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nique to minimize the energy consumption and hazardous gas formation during the production of booms for mobile cranes is searched. Due to the complexity and high price of the large-volume metal production process, different metal pieces are jointed using a variety of welding methods [11-14]. Some welding methods applied in industrial purposes are corner joints, edge joints, lap joints, T-joints, and butt joints [15].

Laser welding method provides the best performance, but with low efficiency value; therefore, to reduce energy consumption and increase the efficiency, traditional welding methods such as arc welding are commonly preferred for joining metal pieces in the industry, especially in the manufacturing industry for joining the metal pieces thicker than 10 mm as it requires a vast amount of material and electricity [16].

Arc welding is the most widely used classical welding method and it has been used in the industry for a very long time [17]. The major advantages of the arc welding method are its non-complexity, low cost, flexibility for different purposes in jointing the metal pieces, and continuous integration due to technological improvements [18]. Because of these advantages, this welding method is still used in today's production processes; even it can be adapted to the automation technology [19-21]. The arc welding method can be applied as well with a welding oscillator instead of a manual operator due to continuous improvements in the automated processes. The experience and performance of the operator have a high impact on the quality of the manually performed welding processes. Using the welding oscillator has many advantages such as high quality welding performance, reduced production time and cost of labor, possibility of performing variant welding shapes that are not possible to fulfill by an operator, minimization of errors on the operator's side, and the lowest risk of work accidents [18].

Konya, located in Turkey, can be considered as the center for mobile crane manufacturing companies. These companies use the traditional boom manufacturing techniques such as jointing two steel pieces with two welding operations performed by an operator or using robotic manipulator. These traditional techniques necessitate four corner joint creation steps before welding the two metal pieces.

In the proposed alternative technique (patent pending), only one metal piece is bended to form the boom shape. The main advantage of this technique is decrease in the number of welding steps from two to one. However, in addition to this obvious advantage, the second advantage of this technique is the elimination of the corner joint steps as corner joints are formed naturally while bending the metal pieces.

One single welding step necessitates a high quality welding. In order to ensure the quality of the welding process, we have designed and manufactured a specific welding manipulator [18]. With the help of this manipulator, a high quality and automated welding process is achieved, which also helps to minimize the risks of the manual operation mistakes for the human safety and environmental protection [18,21,22].

The rest of the article is organized as follows: Section 2 explains the alternative boom design and Section 3 gives the details of the design of the welding manipulator. Results and discussions are given in Section 4, and Section 5 provides the conclusions.

2. Alternative boom design

Traditionally, booms for mobile cranes are manufactured by jointing two steel pieces with two welding operations performed by an operator. In this traditional technique, two steel pieces with appropriate dimensions are plasma-cut from the steel plate at first. Table 1 lists the details of this cutting step, taking a knuckle boom mobile crane as an example, which has 33 ton-meter

Table 1. Cutting data of the plate S690QL due to lower-upper pieces sizes of booms.

Welded booms	Thickness (mm)	Width (mm)	Length (mm)	Plasma speed (mm/min)	Plasma time* (s)	Consumed energy** (kWh)
Knuckle boom	10	840	2650	2600	162	1,3500
1. Extension	10	775	2750	2600	164	1,3667
2. Extension	10	715	2850	2600	165	1,3750
3. Extension	10	650	2950	2600	167	1,3917
4. Extension	8	600	3050	3300	135	1,1250
5. Extension	8	545	3150	3300	136	1,1334
6. Extension	8	500	3250	3300	138	1,1500
Total (The values are doubled because there are two pieces)					2134	17.7836

* When the plasma current is 130 A.

** The power of the plasma cutting machine is 30 kW (when the current is 130 A).

Table 2. The mechanical properties of the used quenched and tempered structural steel, S690QL (Steel Number: 1.8931)[23].

Designation	Mechanical properties (at 20°C)		
Nominal thickness (mm)	$\geq 3 \leq 50$	$\geq 50 \leq 100$	$\geq 100 \leq 150$
Yield strength Reh. (MPa, Min.)	690	650	630
Tensile strength Rm. (MPa)	770/940	760/930	710/900
Min.% elongation after fracture	14	14	14

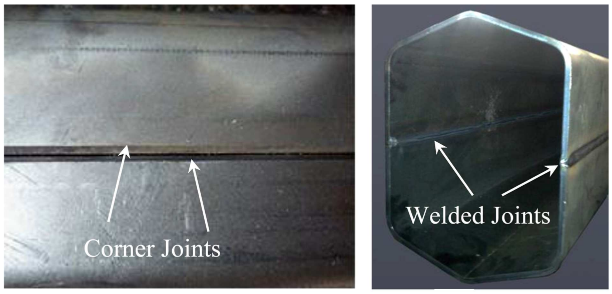
Table 3. The chemical composition of the used quenched and tempered structural steel, S690QL [23].

Element	Percentage	Element	Percentage	Element	Percentage
C	0.20	N	0.015	Nb*	0.06
Si	0.80	B	0.0050	Ni	2.0
Mn	1.70	Cr	1.50	Ti*	0.05
P	0.025	Cu	0.50	V*	0.12
S	0.015	Mo	0.70	Zr*	0.15

*At least 0.015% of grain-refining elements present.

(a) (b)

Figure 1. (a) Photos of the press brake used for boom bending step. (b) Control panel of the press brake.



(a) (b)

Figure 2. Traditional boom production: (a) Boom corner joints and (b) welded joints [25].

lifting capacity, maximum boom extension length of 15 m, and 6 boom extensions. For this example, quenched and tempered structural steel of S690QL plate is considered [23].

The properties of this material are summarized in Tables 2 and 3. As two steel pieces will be cut to form the boom, the values should be doubled to find the total energy consumption.

The required boom shape is achieved by pressing the plasma-cut pieces (Figure 1). In order to joint these two steel plates, two corner joints for each metal plate must be created at the boundaries. These corner joints are created using oxygen-acetylene cutting torch Figure 2(a). The shape and angle of the corner joints are the factors affecting the quality of the weld. The opening angle of the corner joints is chosen to be 45° in order to ensure the best welding quality [24].

After the creation of corner joints, two steel pieces are welded together by an operator using gas metal arc welding Figure 2(b). The welding process done in this way takes very long time and the desired shape and size of the booms are difficult to obtain because of using two steel pieces and the excessive deformation during manual welding. As the average length of the booms is a big number 3 m, eliminating excessive deformations of the weld is impossible.

In the alternative boom design proposed in this work (patent pending), several energy consuming steps of the traditional boom manufacturing are eliminated. The details of the alternative design and the way to perform it are as follows: A single steel piece is plasma-cut from the steel plate at first, which is large enough to form the boom shape after bending.

Table 4 lists the details of this cutting process, taking the same knuckle crane as that in the example. This single piece is again bent according to the size of the boom in the press brake Figure 3(a). However, after the bending process of the single metal sheet based on the boom shape, the corner joints are formed automatically as given in Figure 3(b). The corner joint creation steps are eliminated; the last step is to weld this single metal sheet to itself with a single welding process with the help of the welding manipulator designed and implemented in this study [25].

Table 4. The values of plate cutting for the booms obtained from a single piece.

Welded booms	Thickness (mm)	Width (mm)	Length (mm)	Plasma speed (mm/min)	Plasma time* (s)	Consumption energy** (kWh)
Knuckle boom	10	1680	2650	2600	201	1,6750
1. Extension	10	1550	2750	2600	199	1,6593
2. Extension	10	1430	2850	2600	198	1,6510
3. Extension	10	1300	2950	2600	196	1,6334
4. Extension	8	1200	3050	3300	156	1,3010
5. Extension	8	1090	3150	3300	155	1,2917
6. Extension	8	1000	3250	3300	156	1,3010
Total (The values are doubled because there are two pieces)					1261	10,5124

* When the plasma current is 130 A;

** The power of the plasma cutting machine is 30 kW (when the current is 130 A).

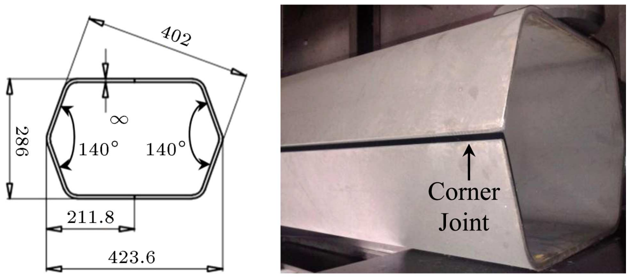


Figure 3. (a) Bending dimensions of the sample boom [25]. (b) Corner joint after bending.

As can be seen from Tables 1 and 4, the alternative design has two main advantages over the traditional method. First, the welding time and the consumed energy for the welding processes are reduced. Moreover, cutting the steel pieces from the steel plate will consume less energy and time. Second, the corner joint creation steps are completely eliminated; thus, the total energy consumption to manufacture the booms is reduced significantly.

3. Design of the welding manipulator

Due to two important reasons, a manipulator is designed during this study. First, as the booms will have a single welded line (the boom shape will not be 100% symmetric due to this welded side), this single welded line should be as high quality as possible. The quality of the welding performed by an operator will not be as good as that of the welding done by an automatic machine. Second, operators will not be exposed to the harmful gases generated during the welding operation. Furthermore, these gases can be filtered using related apparatus so that the environment protection is achieved. The block diagram of the system explained above is shown in Figure 4.

The MIG method chosen for the boom welding of this study is one of the most suitable arc welding methods as it is easy and cheap and does not leave any residues. The specifications of the MIG welding machine chosen for the welding process are given in Table 5. Similarly, Table 6 lists the technical specifications of the welding oscillator [18].

The flow diagram of the system operation is given in Figure 5. The operation of the system can be summarized simply as follows: Initially, the boom to be welded is fixed. The torch is brought to the starting point of welding. Two-axis movement control automation operates the torch. To achieve a high quality welding, it is best to use a constant speed. Welding current, welding wire, and wire feed speed are chosen according to the needs of the required welding

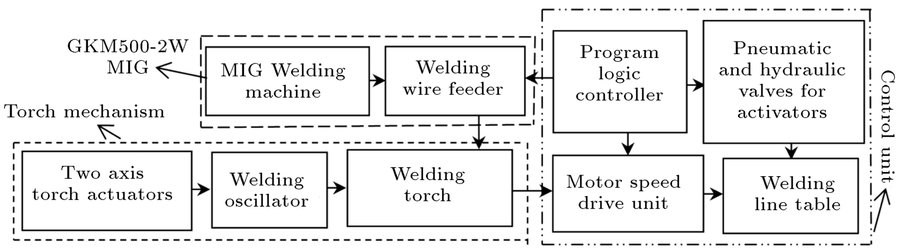


Figure 4. System configuration of welding manipulator.

Table 5. Technical specifications of the GKM500-2W MIG arc welding machine [26].

Item	Specifications
Input voltage	3 phase, 380 V, 50-60 Hz
Power	27.5 kVA
Open circuit voltage	16-57 V
Current range	40 A–500 A
Duty cycle	60%, 500 A; 100%, 400 A
Protection class	IP 23
Wire feeder	0.8, 1, 1.2, 1.6
Wire type	Fe–Flux cored

Table 6. Technical specifications of the GKM500-2W MIG arc welding machine [26].

Item	Specifications
Right width	Maximum 30 mm (step 0.1 mm)
Left width	Maximum 30 mm (step 0.1 mm)
Sweeping angle	$\pm$ 30°
Left speed	0 $\sim$ 4 m/min (step 0.1 m/min)
Right speed	0 $\sim$ 4 m/min (step 0.1 m/min)
Stop time on the left	0 $\sim$ 6.0 s (step 0.1 s)
Stop time on the right	0 $\sim$ 6.0 s (step 0.1 s)
Stop time on the center	0 $\sim$ 6.0 s (step 0.1 s)

Table 7. Boom welding parameters depending on the thickness of the work-piece.

Item	Specifications
Thickness of the piece (mm)	10-8
The consumption rate of the wire feeder (mm/s)	19-17
Welding speed (mm/s)	4.5-7.5
Diameter of the wire (mm)	1.2-1.2
Used current (A)	280-230
Protective gas CO_2-Ar (L/min)	16-15

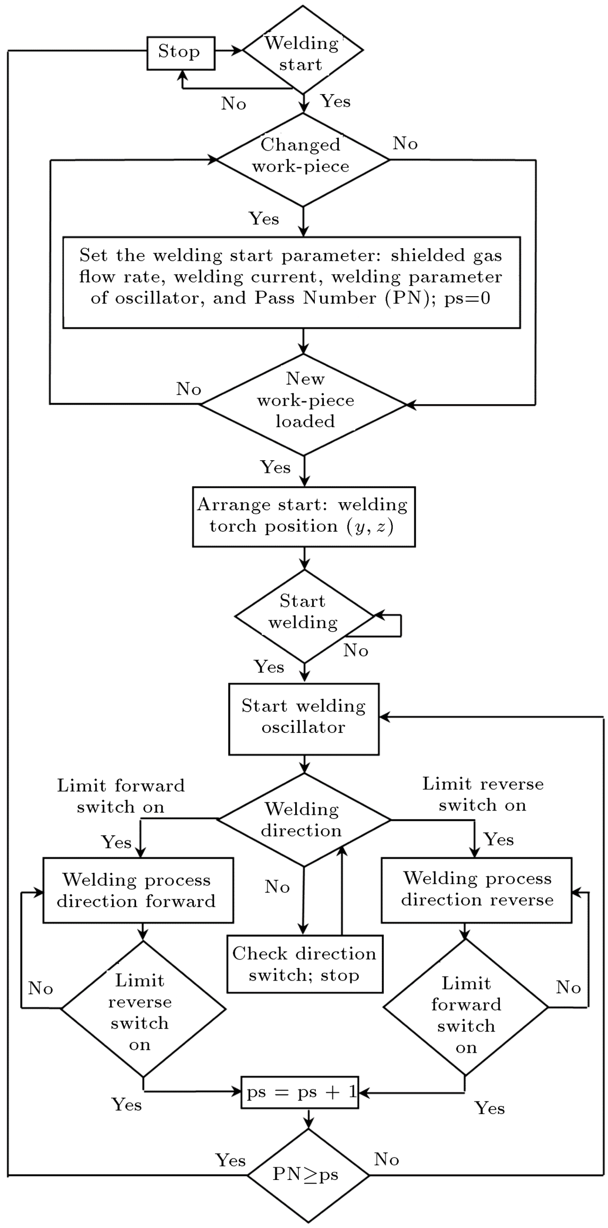


Figure 5. Flow diagram of welding manipulator.

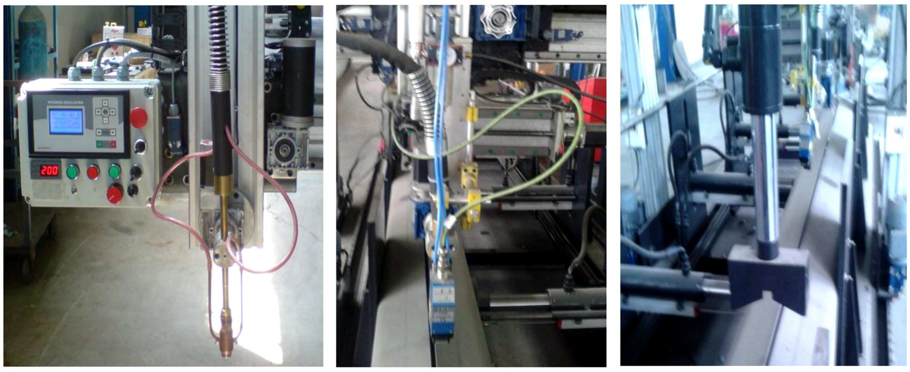
process. Using a protective gas during the welding process is of great importance for the welding quality. During the welding process, the flow of the protective gas is controlled. The parameter of wire feeder speed is adjusted on the speed control unit. The selected welding parameters depending on the thickness of the boom are shown in Table 7.

Figure 6 shows the designed welding manipulator and includes the initial prototype Figure 6(a), the final prototype Figure 6(b), and the extra precautions taken to minimize the bending of the boom shape due to temperature variations after the welding Figure 6(c).

Figure 7 shows the sample welded booms using the designed welding manipulator; the first with very fast welding speed Figure 7(a); then, with fast welding speed Figure 7(b); and, finally, with the required welding speed Figure 7(c). These booms are welded under approximately 20 psi Ar and CO_2 gases, which prevent oxidation problems. 8 mm thick pieces are welded using 390 A of current and 10 mm thick pieces are welded using 410 A of current with 3 passes. The welding operation is carried out in a closed and air filtered chamber to minimize the effects of the hazardous gases generated during the operation on the operators and the environment.

4. Results and discussions

Welding tests of boom samples designed and manufactured with the alternative method and the boom



(a) (b) (c)

Figure 6. The implemented welding manipulator: a) Initial prototype, b) final prototype, and c) pressing corner joint of boom with hydraulic activator after welding process [25].

(a) (b) (c)

Figure 7. Three samples of welded booms using the designed welding manipulator: a) Very-high-speed welding, b) high-speed welding, and c) required-speed welding.

Table 8. Welding test tensile experiment.

Welding Type	Traditional	Traditional	Alternative	Alternative
Max. load (Fm, kN)	135.6	129.7	159.9	160.9
Pulling tension (Rm, N/mm^2)	682	652	795	800
Yield strength (Rt, N/mm^2)	497	513	602	605
Elongation at break (A 5.65)	8.75%	6.125%	14.37%	13.89%
Result	Break has been observed at the welding zone.		Break has been observed out of the welding zone.	

samples with the traditional design and manufacturing method are made in the laboratory of KOSGEB in our region, and test results are given in Table 8. Tests were done in accordance with TS EN ISO 6892-1 [27]. Sizes of the sample booms were also in accordance with the test protocol as follows: thickness (a) 7.95 mm, width (b) 25.0 mm, cross-section (So) 198.8 mm^2, body length (Lc) 80.0 mm, first measuring length (Lo) 80.0 mm, and last measuring length (Lu) 87.0 mm. Tests were done with DARTEC brand M9000 Model 600 kN universal testing machine according to TS EN ISO 6892-1 [27]. As seen from the test results in Table 8, the performance of the alternative boom design and manufacturing method proposed in this study is better than that of the traditional boom design and manufacturing method. Hence, in addition to the energy saving advantages and minimizing the risks of the hazardous gases on operators and the environment, the proposed alternative design and manufacturing method provide booms with better performance for mobile cranes.

Table 9 summarizes the energy consumption aspects of the traditional method and the proposed alternative method. As a result of the interpretation of the calculated data in Table 9, cutting the boom plates in plasma as a single piece instead of two pieces leads to an average of 41% less energy and time; moreover, welding the piece consumes approximately 53% less energy, time, and material. Hence, an optimized boom manufacturing process is achieved, which minimizes the use of manpower, energy, and material.

5. Conclusion

An optimized high quality boom manufacturing process is achieved, which minimizes the use of manpower,

Table 9. Comparison of the conventional and the new boom manufacturing methods [25].

Welded Booms	Conventional boom production method			New boom production method		
	Welding time (s)	Welding energy consumption (Kwh)	Used welding wire (m)	Welding time (s)	Welding energy consumption (Kwh)	Used welding wire (m)
Knuckle	1930	9.65	185	900	4.500	92
1.extension	2010	10.0503	196	940	4.700	95
2.extension	2080	10.4004	206	975	4.875	98
3.extension	2150	10.7502	209	1005	5.025	102
4.extension	1526	7.2061	135	713	3.3669	65
5.extension	1576	7.4422	147	735	3.4708	67
6.extension	1630	7.6972	145	762	3.5983	70
Total	12902	63.1964	1223	6030	29.5361	589

energy, and material. It is shown that the energy and time required during the plasma-cutting process of boom parts are decreased by about 41%, and the energy consumption during the welding process is decreased by about 53% compared to the traditional methods. Thus, 41% savings can be achieved with the proposed method.

For further studies, this paper will provide a guide to the related industry to consider their production line, as significant amounts of energy, manpower, and material usage can be saved with alternative design and manufacturing methods. In Konya, which is one of the most important centers regarding mobile crane manufacturing in Turkey, approximately, 49 MWh energy can be saved and 49 ton CO_2 gas release to the environment can be prevented in the welding and cutting processes annually. Material and manpower savings as well as minimizing hazardous gas production will increase the importance of this study. This study is an example which shows that industry can create such alternative production methods to minimize the production of hazardous gases and the consumed energy in order to control and minimize the global warming issue.

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