STATION-BASED DESIGN AND OPTIMIZATION SOLUTION FOR AUTOMATIC ROBOT WELDING SYSTEM OF TRUCK CHASSIS

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Abstract - Nowadays, applications of modern technologies for automatizing manufacturing processes take priority in industrial development strategies of Vietnam, particularly at Truong Hai Auto Joint Stock Company the manipulator welding robot is being chosen to increase the automation level and improve the product quality. This paper presents the result of a research on application of robotic welding for welding system of truck chassis in a car factory. This work takes part in a project in collaboration with Truong Hai Auto Joint Stock Company. This paper particularly focuses on presenting optimization problems to minimize the welding time of truck chassis.

Key words - welding techniques; CO_2 welding; chassis; linear optimization; welding robot.

1. Introduction

The car factory of Truong Hai Auto Joint Stock Company is one of the largest factories in Vietnam nowadays. However, cars assembly and production are still largely handmade in each workstation of each step. Among these steps, chassis welding step play a very important role. However, it is still performed manually at the factory of Truong Hai Auto Joint Stock Company. Manual welding obviously takes more times, manufacturers than robotic welding. Moreover, it usually produces worse weld quality. For this reason, the work presented in this project aims at automatizing the welding process of truck chassis by using manipulator robot.

Section 2 introduces the overview of the design of a semi-automatic welding system for truck chassis fabrication. The system design will be presented briefly before defining the main issues studied in this paper: optimization of welding system. Next, the optimization problem which aims at minimizing the synchronous operation time between the chassis carrier and welding robot, the main purpose of this paper, will be presented in section 3. The optimization problem will be solved thanks to GLPK software. The results will be evaluated based on data of a real chassis. Finally, section 4 concludes the obtained results.

2. Overview about design of a semi-automatic welding system of truck chassis

2.1. Operation of designed semi-automatic welding system of truck chassis

The welding process of a truck chassis may be divided into three main stages:

- Fixing and tack welding
- Main welding
- Delivering (finished product)

In the fixing stage, a fixture system is used to precisely and firmly jointtogether all the parts of a chassis (Figure 1) such as straight girder, cross beams, side beams, middlestraight beams, dump hinges... Then the chassis is tack welded before moving to the next station where it is definitely welded by robots.

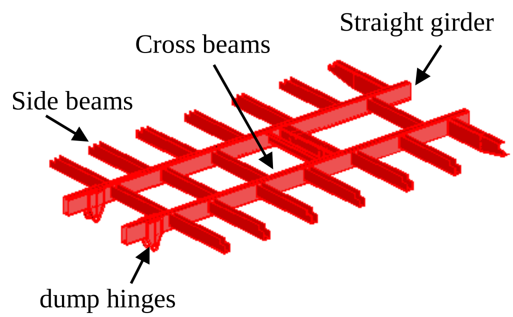

Figure 1. *Truck chassis structure*

At the main welding stage, welds (spot weld, seam weld) will be performed by manipulator robots [2], [3],[5]. The use of welding robot will helps to improve the weld quality and increase the productivity because robots can work in toxic environments conditions with high intensity.

2.2. Station-based design for control system

After considering different stages of a welding process, this section will describe the functioning of the semi-automatic welding system by dividing the system structure into stations. According to three different stages of welding process, three stations may be distinguished (Figure 2).

Station I: Fixing and tack welding;

Station II: Automatic welding by robots;

Station III: Delivering of finished product.

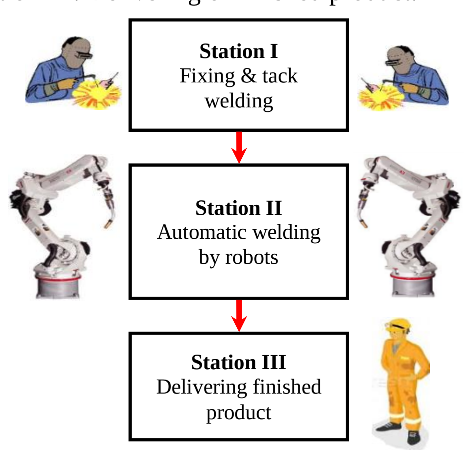

Figure 2. *Station-based design for control system*

Station I consist of a Fixed frame and a Shuttle car. The frame is fixed to the floor. The Shuttle car can move translationally on Fixed frame from Station I to Station II and then in reverse direction. Chassis parts are firmly jointed at Station I. Then they are tack welded before moving to the station II for the main welding stepperformed by robot. After transferring the chassis from station I to Station II, Shuttle car will return to its original position at the station I so that workers can continue to perform a new assembly and tack weld for a new chassis. Therefore, Shuttle car plays an important role in coordinating the functioning of the station I and that of the station II.

Station II consists of a Fixed frame and an Operation car. The Operation car can move translationally on Fixed frame. It receives the tack welded chassis frame from the Shuttle car and carries it to different pre-indicated stop position so that manipulator robot can perform easily all the welds. Robot's stand is fixed on the floor. The Operation car of station II starts when the Shuttle car already returns to its original position at the station I. When robots performed all the welds and finished the main welding step, Operation car continues to bring the welded chassis to the station III. After delivering the welded chassis at the station III, Operation car returns to its original position at station II, where it wait for receiving tack welded chassis from Shuttle car. The process continues.

2.3. Station II: Synchronous operations between Operation car and welding robot

Station II is the place where main welding step is performed automatically to joint cross beams, side beams, middle straight beams, dump hinges...to straight girder.

The Operation car is designed and fabricated with high precision. The ability to achieve repeatable accuracy is ± 0.1 mm.

Operation carfunctioning: The moving speed of the Operation car will be controlled at two levels of speed. When the Operation car approaches the indicated stop position, it is slowed down and stopped at right position with high accuracy level.

Stop positions of Operation car: Stop positions of Operation car are determined thanks to the side beams of chassis. In other words, the maximum number of stop positions is equal to the number of side beams. It means that the real number of stop positions may be smaller than that of side beams so that it satisfies: all the welds may be performed by robots.

Positioning system consists of position detectors and clamping system. Whenever an approaching side beam is detected thanks to detectors, clamping system is activated if this side beam corresponds to a desired stop position. The clamping system will firmly clamp the side beam to fix the chassis. Then two manipulator welding robots which are placed symmetrically on the both sides of the chassis will start to perform welds. At each stop, robot on each side can perform many different welds to joint one beam or more than one beam (or other part) to straight girder. After finishing all necessary well at each stop the welding torch will return to its original position. The clamping system will relax the side beam. Then the Operation car will start to move to the next stop position. The process continues until all welds are done.

2.4. Chassis structure

This section broaches welds need to be performed by welding robot on a real truck chassis. Examples of required welds on the real chassis number FLD600 is shown in the Figures 3 and 4, including:

- Vertical seam weld;
- Horizontal seam weld.

There are totally 45 seam welds need to be performed on a FLD600 chassis as shown in the Table 1. In comparison with results obtained from [4], weld features have been considered. Seam welds are taken into account instead of considering all seam welds as spot welds for simplicity.

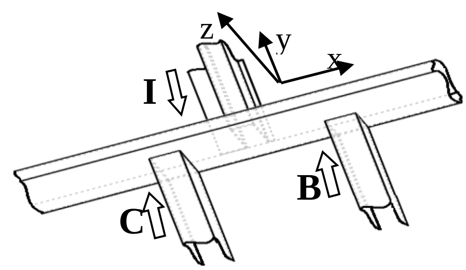

Figure 3. *The part of chassis number FLD600*

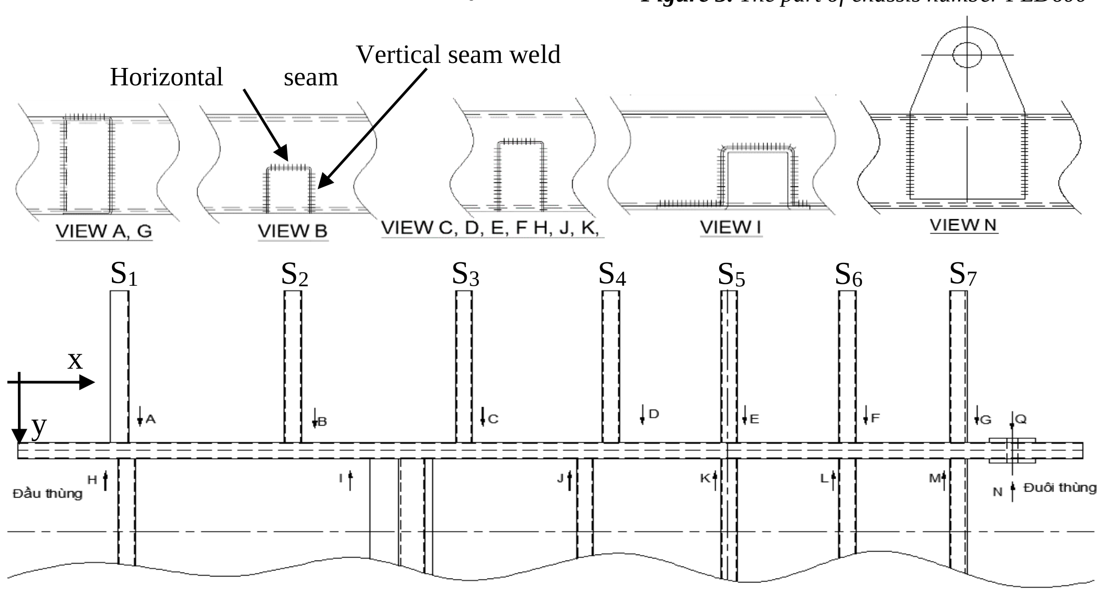

Figure 4. *The structure of chassis number FLD600*

3. Optimizing the number of stop positions of Operation car in the synchronous operation between robot and Operation car

In this section, linear programming approach is considered [1], [6]. Since the operating time at the station I and III depend on operaters, this article focus only on optimizing the operating time in the syschronous operation between robot and Operation car at station II [7].

With the assumptions that the spending time for detecting and clamping a side beam for each stop position of Operation car is constant and that the mean value of torch speed to move from a weld to another is constant, therefore the total time to perform all expected welds on a chassis depends on the number of stop positions of Operation car. In this paper, an optimal algorithmis introduced to:

- Determine the minimum number of stop positions and corresponding stops so that robot can perform all the welds.

- Determine welds need to be performed respectively at each stop.

3.1. Linear programing-based problem formulation

a. Variables and parameters

$\mathbb{S} = \{S_1,...S_i,...S_n\}$: is the set of possible stop positions of Operation car. The maximun number of possible stop positions is equal to the number of side beams. In fact, Operation car will not stop at each possible stop positions but only at some of them. It will be computed and preset thanks to optimization algorithm.

δ_i: is a binary variable which indicates whetherthe Operation carwill stop ornot at the position S_i, $\delta_i \in \{0;1\}$.

If $\delta_i = 1$, the Operation car will stop at the position S_i. Clamping system will be activated to clamp theside beamcorresponding to the desired stop position S_i.

If $\delta_i = 0$, the Operation car will not stop at the position S_i.

A vector may be defined as the result of aptimization approach:

S_1	…	S_i	…	S_n
δ_1	…	δ_i	…	δ_n

$\wp = \{P_1,...P_j,...P_m\}$ is a set of welds need to be performed (See rubric 3.3).

$\beta_{s_i p_j}$: is a binary variable which indicates whetherthe weld P_j will be performed or not when the Operation car stop at the position S_i, .

$\beta_{s_i p_j} = 1$ if the Operation car stops at the positionS_i and robot perform the weld P_j.

$\beta_{s_i p_j} = 0$ if Operation car does not stop at the position S_i / or it stops at the position S_i but robot does not perform the weld P_j.

A matrix may be defined as the result of aptimization approach:

	S_1	…	S_i	…	S_n
P_1	$\beta_{s_1 p_1}$	…	$\beta_{s_i p_1}$	…	$\beta_{s_n p_1}$
…	…	…		…	…
P_j	$\beta_{s_1 p_j}$	…	$\beta_{s_i p_j}$	…	$\beta_{s_n p_j}$
…	…	…		…	…
P_m	$\beta_{s_1 p_m}$	…	$\beta_{s_i p_m}$	…	$\beta_{s_n p_m}$

$d_{s_i p_j}$: is the distance from the robot stand center to the weld P_j when the Operation car stops at the position S_i. $d_{s_i p_j}$ is constant.

A matrix of distance from robot to welds $P = \{P_1,...P_j,...P_m\}$ at different stop positions $S = \{S_1,...S_i,...S_n\}$ of Operation car may be defined.

	S_1	…	S_i	…	S_n
P_1	$d_{s_1 p_1}$	…	$d_{s_i p_1}$	…	$d_{s_n p_1}$
…	…	…	…	…	…
P_j	$d_{s_1 p_j}$	…	$d_{s_i p_j}$	…	$d_{s_i p_n}$
…	…	…	…	…	…
P_m	$d_{s_1 p_m}$	…	$d_{s_i p_m}$	…	$d_{s_n p_m}$

b. Constraints

Constraints on welds:

For verticalwelds and horizontal welds which are located at lower position: each weld P is performed only once even though Operation car stops at different positions, thus:

$$\sum_{i=1}^{n}\beta_{s_i p_j} = 1 \qquad (1)$$

For horizontal welds located at high position: each weld P is performed only once either from the right side or from the left side. It depends on the actual position of the robot to welds, therefore:

$$\sum_{i=1}^{n}\beta_{s_i p_j/left} + \sum_{i=1}^{n}\beta_{s_i p_j/right} = 1 \qquad (2)$$

Constraints on the working envelope of robot:

Let R_{max} be the maximum radius of the working envelope of robot. At each stop position S_i of Operation car, the performed weld P_j must locate within the working envelope of robot arm, therefore:

$$\beta_{s_i p_j}.d_{s_i p_j} \le R_{max} \qquad (3)$$

Constraints on stop positions of Operation car:

When Operation car does not stop at position S_i,$\delta_i = 0$, all variables $\beta_{s_i p_j}$ musts equal to 0. Otherwise it may be 0 or 1 because $\delta_i = 1$, therefore:

$$\beta_{s_i p_j} \le \delta_i \qquad (4)$$

c. Objective function

As introduced previously, the optimization problem of welding time is considered as a problem of minimizing the stop position of Operation car, and it ensures that all welds will be performed. Optimization problems are considered may be solved in two steps:

Step 1: Solving the linear programming problems with objective function which allow to minimum the number of stops position of Operation car. Objective functionis given by:

$$Min\left(\sum_{i=1}^{n}\delta_i\right) \qquad (5)$$

Step 2: Let's note that with the number of stop position founded in the step 1, suppose it is n_{min}, some combinations of n_{min} stop positions of Operation car may allow satisfying that all welds will be performed. Therefore, in this step 2, the number n_{min} founded in Step 1will be assigned as a constraint. A new objective function allows minimizingthe total distance from robot tothe performed welds (corresponding to each stop). It is given by:

$$\sum_{i=1}^{n} \delta_i = n \tag{6}$$

$$Min\left(\sum_{i=1}^{n} \beta_{s_i p_j} . d_{s_i p_j}\right) \tag{7}$$

3.2. Problem solving

In this paper, solver GLPK is chosen to solve the linear programing problem.

a. Input data

Input data of the problem include:

The radius of robot working envelope: robot arm used in this project is the Panasonic TA-1400 with accuracy of ± 0.1 mm. The maximum radius of working envelopeis R_{max} = 1374 mm.

For the reasons of safety and collision avoidance, robot stand is located at a distance of 884 mm from the symmetry axis of the chassis.

A real chassis frame prototype is selected to calculate in this work, it is FLD600, is presented in Figure 4 (designed and provided by Truong Hai Auto Joint Stock Company). Seven possible stop positions corresponding to 7 side beams of the chassis: S_1... S_7.

Matrix of $d_{s_i p_j}$ value.

b. Output data

The computed outcome given by solver GLPK includes:

Determine the minimum number of stops and corresponding stop positions through variables δ_i so that robot can perform all welds.

Determine the welds need to be performed at each stop position through variables $\beta_{s_i p_j}$.

3.3. Result and discussion

After solving the formulated problem by GLPK, some results are obtained:

• The minimum number of stops is 4; they are P1, P3, P5, and P7.

• Welds should be performed at each stop position are shown in table Table 1.

• Total distance from robot to welds calculated by expression (7) is 43 757 [mm].

Table 1. *Welds need to be performed at each stop position*

Stop positions	Performed welds
S_1	P_{AV1} P_{AH2R} P_{AV3} P_{BV1} P_{BH2L} P_{HV1} P_{HH2L} P_{HV3}
S_3	P_{BV3} P_{CV1} P_{CV3} P_{DV1} P_{DH2L} P_{IH1} P_{IV2} P_{IH3R} P_{IV4} P_{IH5} P_{JV1} P_{JH2L}
S_5	P_{CH2R} P_{DV3} P_{EV1} P_{EV3} P_{FV1} P_{FH2L} P_{GH2L} P_{JV3} P_{KV1} P_{KH2R} P_{KV3} P_{LV1}
S_7	P_{EH2R} P_{FV3} P_{GV1} P_{GV3} P_{QV1} P_{QV2} P_{LH2R} P_{LV3} P_{MV1} P_{MH2R} P_{MV3} P_{NV1} P_{NV2}
Do not stop at S_2, S_4, S_6	

From solving step 1, we have the minimum number of stops is 4. There are 3 cases where the number of stops is 4, which also satisfy the conditions thatall welds may be performed: {$S_1S_2S_4S_7$}, {$S_1S_3S_4S_7$} *and* {$S_1S_3S_5S_7$}.

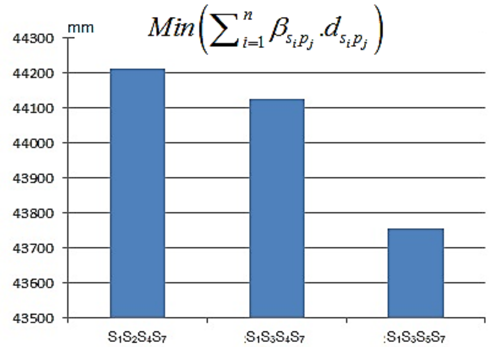

Figure 5. *Total distance from the robot to welds in different cases of fore stop positions of Operation car*

Comparison results, as shown in the Figure 5, show that, among these cases, the total distance from the robot to welds is smallest in the case of 4 stop {$S_1S_3S_5S_7$}.

4. Conclusion

This paper introduces a design and a solutionfor optimizing the functioning of a automatic welding system using robot. First, a station-based design is proposed. Based on this design, the paper focuseson optimizing the operating time in the syschronous operation between robot and Operation car at station II. Thus, it allows increasing the productivity. In detail, anoptimal algorithmhas been introduced to determine the minimum number of stop positions and the correspondingstops so that robot can perform all the welds. The proposed algorithm also allows determiningall thewelds need to be performed respectively at each stop.

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