A Novel Method for the Real-time Force Losses Detection in Servo Welding Guns

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Abstract: Nowadays, real-time detection methods are increasingly necessary for predictive maintenance in production processes. Specifically, in the metal joining production processes that use the resistance welding process, the optimization of maintenance programs is sought to improve both the quality of the body and its manufacturing cost. In this novel paper a new method is presented for the sensorless detection of pressure losses in welding lines. The proposed system bases its operation on the measurement of the existing variables in the resistance welding process carried out using servo guns. This paper also shows the proposed system for the data acquisition, data sending and visualization in real-time of the health of the welding gun. This results in a system with a low installation cost but with great performance in reducing problems associated with force losses in welding guns.

1 INTRODUCTION

The resistance welding process is currently the most widely used metal joining process, especially in the automotive industry, where this process represents around 90% of the joints made in a car body. (Koskimäki et al., 2007; Yu et al., 2014; Hwang et al., 2013). Despite the great use of this process, the resistance welding process is highly complex, since this process involves different fields such as electromagnetism, thermodynamics, metallurgy and mechanics. (Li et al., 2007). Due to the importance of this process in the metallurgical industry, specifically in the automotive manufacturing industry, it is essential to guarantee the welding quality of each of the joints carried out during the production process.

The quality of the joint of each of the joints that are made through the resistance welding process is determined by the diameter of the weld nugget. This diameter is directly reflected in the joint design shear load requirement.

Depending on the specific characteristics of the joint, type and thickness of the metal, the type of welding transformer and electrode from the welding gun, several different parameters are required to form the desired weld nugget that meets the quality requirements.

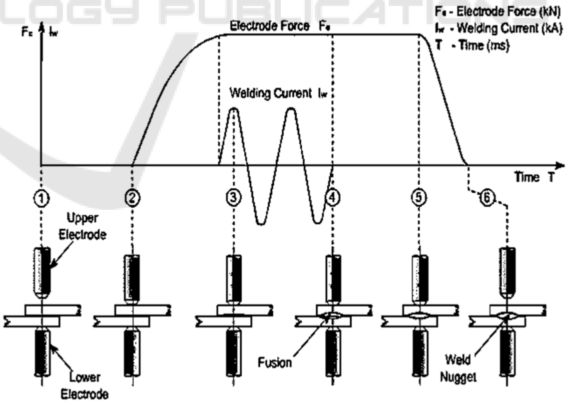

Figure 1: Spot welding process.

The three main parameters that can be controlled to obtain adequate quality in RSW are welding current, electrode force and welding time (Willian and Parket, 2004).

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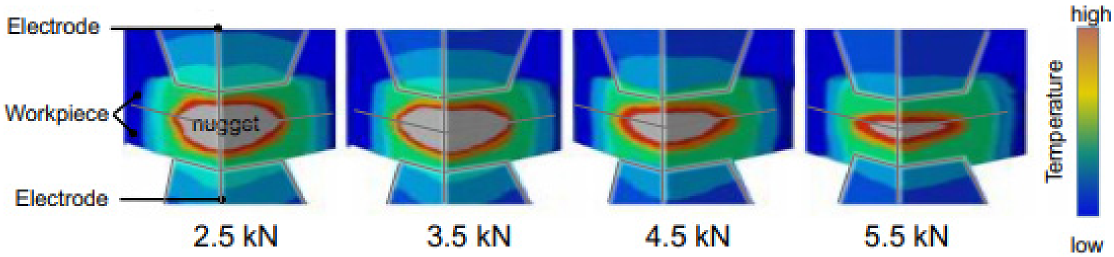


Figure 2: Influence of the electrode force on the temperature distribution (Kobayashi & Mihara, 2014).

Resistance welding is carried out according to the following process: the electrodes are closed at a determined force by squeezing the metal sheets to be welded. Once the programmed force is reached, it is maintained for a short period to eliminate any gaps that may exist between the sheets.

The welding current then flows through the electrodes supplying energy to contacting workpieces. Through the Joule effect, electrical energy is transformed into heat gradually spreading through the junction. Upon reaching the melting temperature, a liquid nugget is formed that grows as a function of welding time. Once the pre-set time has been reached, the welding current stops, and then the electrodes are released. Finally, the melting nugget solidifies, and the weld is formed. (Kang & Lilong, 2014).

Consequently, as long as it is not influenced by other external parameters, the welding current, the force applied by the electrodes and the welding time determine the heat given to the joint and therefore, they directly influence the final quality of the welds.

Different authors speak of the importance of force in the final quality of the weld, emphasizing the need to guarantee a certain force. (Lucas, 2003; Norrish, 2006; Brijesh, 2014).

As mentioned, resistance welding bases its operation on the Joule heat represented by equation 1.

$$H = \int_{T2}^{T1} I(t)^2 R(t)dt \quad (1)$$

where H is the amount of heat energy generated during the process, I(t) is the welding current, R(t) is the dynamic resistance of the sheet metals, T1 and T2 are the beginning and ending times of the operation, respectively (Henry,1910).

Resistivity for metals is usually considered to be independent of force. In contrast, in resistance welding, the contact resistance has a relationship with the force distribution, in addition to the variation of the contact surface conditions.

In general, due to irregularities in the electrode and the metal sheets to be welded, only a small part of the apparent contact area is in actual contact. During resistance spot welding the force created by the compression of the electrode breaks these irregularities and causes a decrease in contact resistance. this was demonstrated during the studies Dickinson's research and can be clearly seen in figure 1. Hence, not high enough electrode force cannot be able to create enough electrical contact at the interfaces and can cause concentrated heating and possibly local melting or even expulsions.

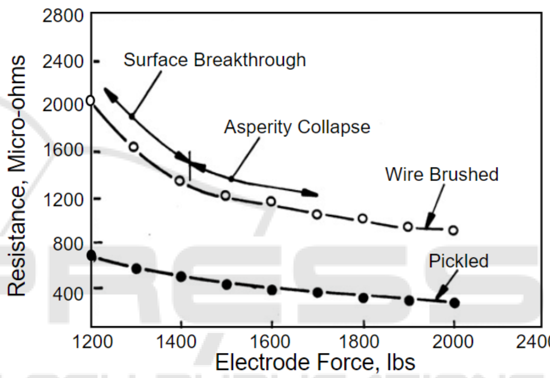


Figure 3: Relationship between dynamic resistance and electrode force (Dickinson, 1981).

Expulsion is a phenomenon that occurs when the expansion of the weld nugget exceeds the force of the supplied electrode, this causes an ejection of the molten metal from the weld zone during welding. due to force caused by the expansion of the weld nugget exceeds supplied electrode force. Furthermore, as the electrode force decreases, the diameter of the welding nugget increases and the resistance of the weld until ejection occurs (Zhang et Al.2009).

The contact resistance is also influenced by the surface condition of the metal sheets. The presence of Oil, dirt or any other foreign content causes a change in the resistance. The effects on contact resistance of these foreign contents decrease rapidly after the force of an electrode is applied. The contact surfaces have peaks and valleys. When subjected to low force, metal-to-metal contact will be only the peaks. The resulting contact area is less than that produced by an appropriate force. Therefore, the contact resistance will be greater, causing a greater amount of heat to be generated.

In short, it could be summarized as the lower the force, the greater the interfacial resistance, which results in a greater generation of heat at the tip-to-sheet and sheet-to-sheet interfaces.

Then, it can be stated that the welding force plays a crucial role in the quality of the final joint. (Zhang & Senkara,2005) (Wang & Wei,2001).

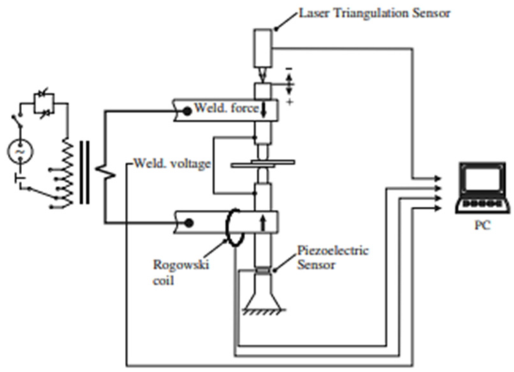


Figure 4: Schema piezoelectric sensor.

Currently, the measurement of force loss in real welding lines presents a series of drawbacks depending on the method used for this detection.

First, the use of piezoelectric sensors or strain gauges gives good results in welding lines but represents too high a cost, which, in most cases, makes their installation unfeasible (Podržaj et al, 2011) as seen in the figure 4.

Secondly, this measurement can be carried out with manual dynamometers, in the same way, this method provides a reliable result and more versatility since the same dynamometer can be used for all welding guns because this function is done through an operator. The main problem of this method is that the data is not available in real-time, so it is necessary to carry out preventive maintenance, generating personnel costs.

In short, there is currently no truly implantable method for detecting force losses in welding guns for high production factories.

For this reason, this research proposes the use of stiffness measurement to create a real-time measurement system integrated into the welding lines for the detection of force losses.

2 EXPULSION AND FORCE IN REAL WELDING LINES

For a first evaluation of the relationship between force and the presence of projections in a real welding line.

For this, a welding gun that due to force problems has begun to present a high number of expulsions is evaluated. Specifically, this welding gun performs 13 welding points on a specific part of the body, the tests are carried out on an electric welding gun, ServoGun.

The phase difference between the real force of the gun and the nominal force programmed is measured with a dynamometer. This makes it possible to assess the state of the welding gun and the influence on expulsions.

Table 1: Nominal and Real Forde before calibration.

Nominal Force [DaN]	Real Force [DaN]	Difference [DaN]
150	77	73
200	93	107
250	111	139
300	131	169
350	157	193
400	192	258

Once the state of the welding gun has been determined, the data of average projections during production are taken, obtaining the data measured in figure 6.

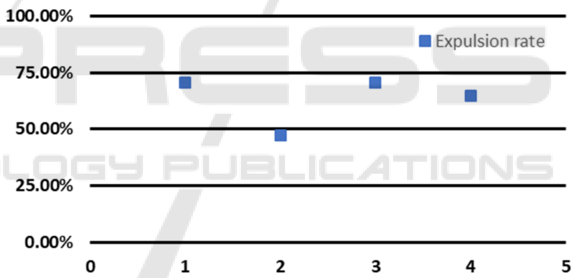


Figure 5: Expulsion rate before force calibration.

As can be seen, the expulsion data is above the usual and adequate values for optimum quality. Thus, a force calibration is performed to reduce the difference between the nominal force and the actual force.

It is assumed that initially the weld was programmed with an adequate force and that, therefore, when the force returned to its original value, a notable reduction in expulsions will be observed.

After performing the calibration, the real and nominal force data and the difference between them are taken again, in order to observe the improvement in force and the relationship with the improvement in the expulsion rate. These data are shown in table 2.

It can be seen that when carrying out the calibration, the difference between the nominal force and the real force is significantly reduced so that the

Table 2: Nominal and Real Forde after calibration.

Nominal Force [DaN]	Real Force [DaN]	Difference [DaN]
150	152	2
200	202	2
250	262	12
300	310	10
350	355	5
400	417	17

force applied to the weld joint will be more similar to the programmed force.

In the same way, as in the previous case, the data on the expulsion rate is taken during the manufacture of four parts of the body by the same welding gun, obtaining the results shown in figure 7.

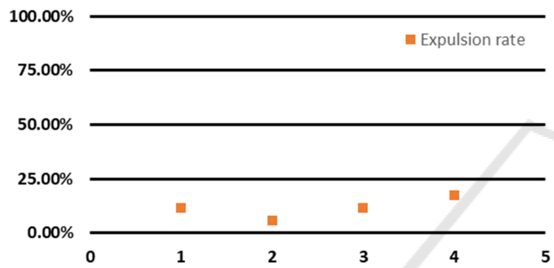


Figure 6: Expulsion rate after force calibration.

As can be seen from the comparison between figures 6 and 7. The problems due to lack of force cause an increase in expulsions in the production lines, causing an increase in the expense for the repair and cleaning of the welded parts. For this reason, the interest in finding a system for the real-time detection of force losses increases.

3 FORCE AND BENDING IN REAL WELDING LINES

In order to obtain a viable method for the detection of lack of force, the measurement of the bending of the arms of the welding guns is considered.

Different authors have studied the measurement of the encoder of the servomotors and the influence of the bending on the real value of the electrode position.

Specifically, some authors established a relationship between the measurement of the position of the electrodes and the indentation of the weld. (Yu-Jun et al.,2020).

In welding guns, the fixed electrode arm of a servo gun can be considered as a cantilever beam with limited stiffness, this means that a non-negligible deviation can occur in the arm of the fixed electrode (Tang et al., 2003).

As Yun et al. show in their research, the fixed arm can be simplified and reduced into three parts and P3, as shown in figure 7 each considered as a beam of uniform cross-section. This means that the bending moment M_z is distributed evenly along the direction length of the part P3, this happens in the same way with the axial force F_x. Therefore, the longitudinal surface deformation of the piece P3 can be considered constant Fig 8.

If the theory of elasticity is followed, the longitudinal surface deformation ε_{3x} and deflection D_f of the electrodes can be calculated following equation (2)(3). where F is the force of the electrode, E refers to the elastic modulus of the beam, A1 and A3 are the cross-sectional areas of part G1 and G3, l2 is the length of the piece G2, w3 is the width or diameter of the cross-section of the part G3, I2 and I3 are the moments of inertia of part G2 and part G3, respectively. γ and λ are the proportionality coefficients between ε3x and F, Df and F, respectively.

$$\begin{cases} \varepsilon_{3x} = \frac{F}{EA_3} - \frac{Fl_2w_3}{2EI_{G3}} = \gamma F \\ \gamma = \left(\frac{1}{EA_3} - \frac{l_2w_3}{2EI_{G3}}\right) \end{cases} \quad (2)$$

$$\begin{cases} D_f = \frac{F}{EA_1} + \frac{Fl_2^3}{2EI_2} + \frac{F}{EA_3} = \lambda F \\ \lambda = \frac{1}{EA_1} + \frac{l_2^3}{3EI_2} + \frac{1}{EA_3} \end{cases} \quad (3)$$

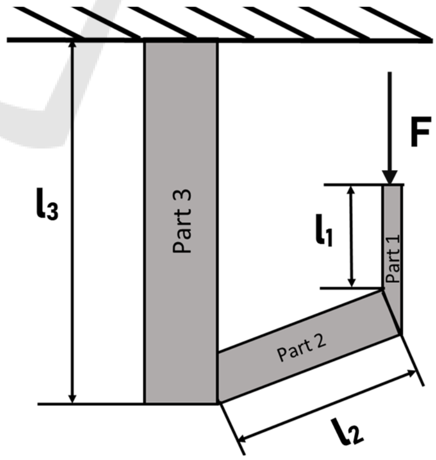


Figure 7: Schema Force in fixed arm.

From the previous equations (2)(3) a relevant conclusion can be drawn for this study, and this conclusion is that there is a proportional relationship between the force and the deflection marked by the proportionality variable λ. Therefore, if the relationship between deflection and force is established, the pressure variations can be determined based on the variations in deflection. To see the real behaviour in a welding line, the electrode displacement data is taken in a welding gun installed in a production line.

For this, the electrodes are closed without any metal sheet between them, in such a way that if it is considered that there is no influence of the force, this position should remain stable despite the changes in force. However, as it has been explained if this relationship exists, it is expected to observe how as the force of the electrodes increases, therefore, their closing position increases.

This test is carried out on a ServoGun, in such a way that the position value can be obtained directly from the encoder rotation value, shown in degrees Fig9. The behaviour of two different welding guns located on different production lines is analysed. In the first one (Gun 1) it can be seen how as the force increases, the position of the encoder increases, behaving almost proportionally (R^2=0.988).

Similarly, if the encoder position curve generated by the change in force for gun 2 is analysed, it can be stated that it also presents a linear behaviour, but, in this case, there is a greater slope of the curve, that is, this welding gun features a greater displacement for the same force range.

In both cases, the behaviour between the displacement of the electrode and the force is affine. Since, as it was deduced from equations 2 and 3, the displacement is proportional to the force, but also the encoder adjustment component must be taken into account, since the position of 0 degrees should be equal to a force of 0 kN, but sometimes due to a bad configuration, the zero of the encoder does not coincide with the real zero of the welding gun, when the electrodes are in contact without applying pressure.

As result, two main conclusions can be drawn from this real experiment: First, in a real welding gun the elasticity law is fulfilled and there is a relationship between the bending and the displacement of the electrodes. Second, the ratio between electrode displacement and force is not necessarily the same for all welding guns, depending on the mechanical and physical characteristics of each one.

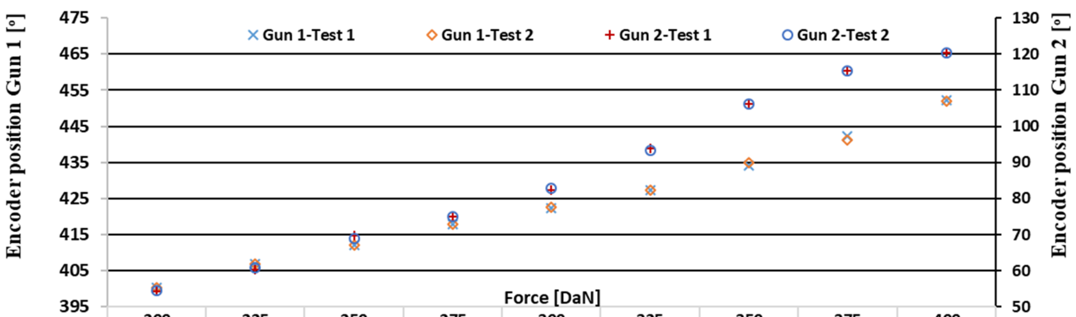
4 METHOD FOR DETECTING LOSS OF FORCE

The method investigated in this paper bases its operation on the measurement of the displacement of the electrode for the detection of force losses. As explained in the previous section, there is a linear relationship between the bending of the arms of the welding electrodes and the force applied to them. This method is specially designed for the detection of power losses in servo welding guns.

Since there is a real relationship between the position of the electrode and the force applied on them, a system for measuring the position of the electrodes at different forces is designed. In such a way that possible variations in position could be monitored in real-time.

The measurement system is carried out as follows: First, the PLC sends the order to change the electrodes to the robot. After carrying out this change of electrodes, the gun is sent to carry out the first milling to avoid shear problems when making the measurements.

Once the milling is finished, the wear of the electrodes stored in the robot is reset. When all this



	200	225	250	275	300	325	350	375	400
Gun 1-Test 1	400.2	407	412	417.9	422.38	427.43	434.25	442.14	452.21
Gun 1-Test 2	400.2	407	412	417.9	422.49	427.43	434.88	441.18	451.93
Gun 2-Test 1	54.36	60.36	69.62	75.09	82.27	93.8	106.3	115.27	120.25
Gun 2-Test 2	54.42	60.83	69.03	74.9	82.77	93.4	106.1	115.28	120.4

Figure 8: Real relationship between force and encoder position.

process has been carried out, the electrodes are in the optimal state to begin with the measurement of the force loss following the newly proposed method.

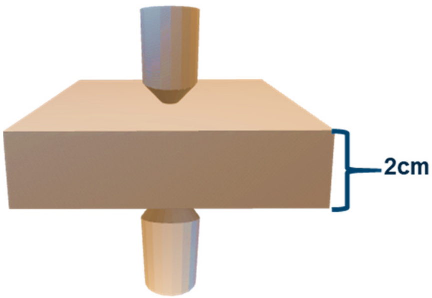


Figure 9: Schema measure operation.

To measure force wear, the electrodes are closed by pressing a 20mm thick metal piece Fig 10. In such a way that if the real position reached by the electrodes is measured, it will represent how much they have bent.

Specifically, two measures are carried out, the first of them executing a low force and the second of them executing a force at the maximum capacity of the welding gun. This is due to the fact that, on occasions, the welding guns lose force in a certain range, that is, the wear of the force does not occur equally in all the command forces.

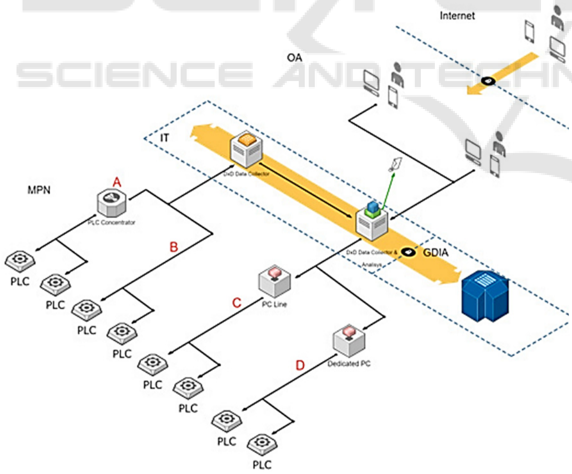


Figure 10: Real-Time data collection Schema (Garcia & Montes, 2019).

Once these measurements are obtained, they are sent to the PLC. The PLC, upon receiving the position measurements, sends them labelled to the Rslinx and through the MQTT protocol they are stored in a database to be analysed.

To send and display these data, the same system used by Garcia & Montes (2019) for data acquisition from PLCs in real-time in factories is used.

5 REAL CASE IMPLEMENTATION

This method is being tested in a real welding line on which real-time data of force wear is being collected.

In this specific case, the programming was done on a Kuka KRC4 robot with an ARO ServoGun 3G pistol. For this, the check-up was programmed as described in the previous section and began with the acquisition and sending of data for its analysis.

In the first place, it can be observed in figure 11 how when working at a higher pressure (3.5kN), the virtual thickness detected by the method is less than in the case of low pressure (1kN) since the deflection of the arms is directly proportional to force.

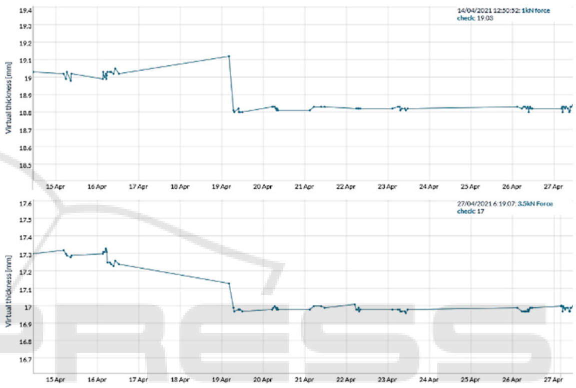


Figure 11: Historical data of the force check position measurements.

After a period of time of correct operation of the method, the pressure was checked according to traditional methods, using a dynamometer. This check showed that there was a lag of -300DaN between the nominal pressure and the real pressure so the calibration was carried out. As can be seen in figure 11, as of April 19, once the calibration was carried out, it was verified that when adjusting the pressure by increasing the pressure, a change was experienced in the virtual thickness measured. That is to say, in short, the method is capable of detecting pressure changes in real welding guns.

This leads to the expectation that when the high force begins to wear out, the value of the position will begin to approach the value of the low force position. Approaching the minimum position value established, which in this case is 20 mm due to the thickness of the part on which the electrodes are closed.

In short, data monitoring has begun, hoping that as wear occurs in the welding gun, the system will be able to detect them.

With all that is exposed throughout this section, it can be affirmed that the method is capable of detecting power loss problems in welding guns without the need for an external sensor, only using the existing variables in robotized servo guns.

6 CONCLUSION

Throughout the paper, the importance of the force parameter in the resistance welding process has been shown, emphasizing the influence of force losses and the appearance of expulsions.

The need to measure force losses and the difficulty in applying current methods to carry out force detection in large production factories has also been discussed throughout the paper.

For all this, a novel method has been presented for the real-time detection of force losses based on the relationship between bending and the applied force. This method provides the following advantages over the previous methods:

- Reduced implementation costs: It is only necessary to program the robot and the data collection system. As it is a method based on the analysis of variables of the servo gun welding gun, it is not necessary to acquire any type of additional sensor.
- Real-time measurement system: The system proposed for the implementation of the method makes it possible to view the data at any time, being possible to generate alarms as soon as the loss of force occurs.
- Maintenance cost reduction: since the force value is acquired directly from the welding line, it is not necessary to carry out any other type of maintenance to determine force losses, so preventive maintenance plans carried out can be reduced.

In short, throughout this paper, a response has been given to a problem that exists in factories that produce metal joints that use servo guns for resistance welding. It is expected that future research will present optimizations to the method and success cases for the final validation of the method.

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