BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXII No. 2/2010	215 – 220	Seria Tehnică

Methodologies for Increasing the Efficiency and Life Cycle of Industrial Robotic Welding Systems

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Abstract

The methodologies described and analyzed in the present article can be of interest for all the factors inside a company, who are responsible for the maintenance of robotic systems and also for decision factors that plan to acquire and implement a robotic welding system.

This paper presents the reliability analysis of overall robotic systems, based on the parameters of Mean Time Between Failures (MTBF) specific components of robotic systems for arc welding (robotic GMAW). It highlights the techniques to maximize and provides redundant solutions that allow an increase of the overall MTBF through applying certain measures in the design, implementation and operation phases. These theoretical considerations are further implemented in concrete robotic GMAW cases, suggestively pointing out both an increase of efficiency in the initial production phase as well as phenomena that occur nearing of prognosticated end of the expected lifecycles of the systems.

Introduction

Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join iron and steel by heating and hammering them. Arc welding and oxyfuel welding were among the first processes to be developed late in the century, and resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electroslag welding. Developments continued with the invention of electron beam welding and laser beam welding in the latter half of the century **1**]. Today, the welding science continues to advance. Robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties.

Lately robotic welding became very popular due to its advantages like:

- Production flexibility- robots can be easily and quickly reprogrammed for doing other industrial jobs;
- Productivity – they can operate almost 24/7,as the only time robots must be stopped is during maintenance work;
- Quality – Robots ensure always the same and higher quality as with manual welding. Because the robot is executing programmed movements on precise trajectories in each production cycle and respects the technological sequences, human error is removed;

- Repeatability – welds with the same welding parameters from one piece to another.

Because robotic welding systems became financially affordable and thanks to their great flexibility, many companies outfit these production lines with robotic welding systems. In particular companies that produce big batches of similar products greatly benefit from the advantages of robotic welding technology, but other companies witch apply welding in hazardous areas or have very difficult welding applications also rely on robotic welding. Another criteria for choosing a robotic welding system is personnel costs, where the basic rule is: manual welders cost more than a robotic welding system. There are advantages and disadvantages in robotic welding, for an example robotic welding can't adapt to arbitrary variations of the weld seam, (unless expensive sensors are applied) whereas manual welders can rapidly correct all flaws in the work pieces.

The need for upgrading to robotic welding systems is most of the times to reduction of production costs, therefore any decision for outfitting with robotic welding systems should be based only on economic factors. One should calculate exactly how much they gain and how much they need to invest. For an example one should analyze what needs to be changed before work piece standards could be upgraded to meet the higher precisions needed for robotic welding. Two matters must be cleared for the company management:

- Calculation of the involved costs;
- Analysis of the necessary changes in preparation and mounting of the components which have to be welded by robots.

Usually the management first decides to invest in robotic welding systems only after that they analyze what needs to be done to make it work.

These costs vary largely and their variation depends greatly on working conditions, work piece standard and the working environment. An example could provide an image for the robotization too: if one car is used in ideal conditions (such as roads without potholes, no dust, no injuries) and another identical car is used just as intensively in less ideal conditions (such as uneven roads introducing vibrations in the car's structure, busy / accelerated / careless traffic with accidents), then the degree of wear of this second car is much greater than that of the first car's. The cost of repairing the second car will also be much higher than for the first car. The industrial robot is in a similar situation. For the robot to be able to reproduce the same quality weld over and over, the degree of wear must be kept below a certain level. The cost of robot maintenance work necessary (C_r) to decrease wear varies depending on its severity. If we represent these variations in time (Δt), just as in equation (1), we can calculate the average operating cost for robotic welding systems (C_{emr}).

$$C_{emr} = \frac{\sum C_r}{\Delta t} \tag{1}$$

We can conclude that if we can extended the Mean Time Between Failures (MTBF) ($\Delta t_1 > \Delta t_0$), the average operating cost of robotic systems (C_{emr}) will significantly decrease.

From general economics practices we know that the profit of a company (I) is defined by the quantity of products sold (V), total fixed costs (F), total variable cost per product (C) and the end price of the product (P) [3]:

$$I = V * (P - C) - F \tag{2}$$

As it can be seen in equation (2), the profit (I) may be increased if we reduce the variable costs (C) or expand the amount of products sold (V) (through higher quality). At the same time we know that normally fixed costs (F) can't be changed, neither should we change the end price (P), even if quality gets better.

In this paper we try to describe the main factors influencing the value of the average operating cost of robotic welding system (C_{emr}), typically these costs take approximately 20% of the total variable production costs (C). Because debugging a problem of a robotic welding system takes time and time is money, especially when dealing with a high productivity robotic system, it is preferred to minimize stop times or with other words maximize MTBF.

Main Factors that Act on the MTBF

The main factors that act on the MTBF can be grouped into three main categories: factors caused by the environment, factors caused by human mistakes and factors caused by worn parts.

In the heavy metallurgic industry the environment of the robotic welding system may contain the following negative factors:

- Extensive dust, metallic particles, moisture or greasy in the air

It is produced by several causes, but the most common is from the wear of the concrete floor and insufficient cleaning of the interior of workspaces. Concrete wear and dust creation is increased by heavy traffic, (different industrial lifting cranes, forklifts used very frequently in the plants). Robotic welding system filters can only do so much (they apply only to electronics cabinets, not mechanical components).

This phenomenon occurs due to grinding metal surfaces, example grinding of tack welds or grinding of weld grooves. The size of the metallic particle is roughly a tenth of a millimeter. These particles together with the grinding stone particles fall to the ground from where due to traffic, they are transported all across the site, they even mix with air and deposit inside sensible equipment. Not only are these particles extremely dangerous and could cause overheating and electric shocks but they also represent serious health problems

The main cause is the deterioration of waterproofing of the roof or of the foundation. This issue occurs especially when working in maximum 2 shifts, at the beginning of the first shift and only when the area is not sufficiently heated to temperatures at least above 15 C°. Another problem arising from damage to waterproofing is rain water slipping through the roof and falling on equipment inside a robotic welding system, causing short circuits, major failures of the entire system.

This phenomenon occurs when pneumatic actuators are being used. The pneumatic actuators need lubricated air to prevent wear. Sealing gaskets and other connecting components along the air supply line lose tightness over time allowing greasy air to escape into the environment.

- High temperatures, lack of ventilation, lack of thermal insulation

In periods when the temperature exceeds 36 C° there is a danger of equipment overheating. High heat significantly decreases the lifetime of electronic components (like electrolytic capacitors). They often cause unpredictable defects, which can be very difficult to identify, these often surface when the original negative factor is not present.**2**]

- Low temperatures, lack of heating, no thermal insulation

In periods when the temperature reaches below 20 C° the danger of condensation depositing becomes highly possible. At temperatures below 5 C° defects may occur due to frost or incorrect operation, as in case of Liquid Crystal Displays (LCD), which are often used in robotic welding systems.**2**]

Regressive factors that are the result of human mistakes planning and in the operation of a robotic welding system can be the following:

- Unqualified robot servicing staff

If the robot's operating stuff hasn't been trained (or trained sufficiently), it can lead to dangerous situations or lead to rejection of welded pieces because of weld defects. Because of the additional repair operations, higher production costs result. The robot programmer must be a person with a higher degree of qualification than the operators. The robot programmer is responsible for every movement the robot makes during a welding program. If the programmer was not properly trained, he may be faced with unknown situations, which can lead to mistakes.

- Variations of joints parameters

These variations occur mainly because companies are usually working with large tolerances. That allows them to use consumables more, or to use old machinery for work piece processing. It is difficult for a robotic welding system to weld parts with joint variations. Frequently found problems consist of variation in root gaps and weld seem volume, which require from the robot to adapt welding parameters like speed, wire feed, oscillation.

- Incorrect assembly of parts, incorrect assembly devices

This factor is also a very common problem. This happens because the devices for assembling parts allow assembly of less than perfect components, while maintaining important assembly attributes. In case of robotic welding this method has the disadvantage to allow too much variation of joint gaps. This is not the case while using manual welding, manual welders can quickly adopt and correct when necessary.

- Tolerance of the fixture

It can happen that a badly designed workpiece fixture may allow work piece displacement. Although there are several simple sensors that can detect a displacement, it is preferable not to use these because they need additional time (increasing overall production costs).

- Lack of safety devices

The lack of certain safety devices may allow collisions of the robot with foreign objects, for example: scaffolds, ladders, doors, a piece that is conveyed/carried and other possible objects found inside a production plant.

- Unnecessary robot movements

In many cases this factor is ignored / neglected. The robot's movements produce wear. This creates a backlash in the robots joints, which will cause loss of accuracy of the robot. This problem is created during programming, and it remains ignored during testing, afterwards shortening the MTBF when production starts. Another problem is created by friction of materials such as the bundle of cables and tubing brushing on the robots body or the work piece, these causes wear of the protective sleeve of cables and cable bundles. After protective sleeve damage short circuits or liquid and gas leakage can occur.

- Neglecting the periodic maintenance operations

To extend the MTBF of a robotic system, moving parts must be protected, greased and cleaned from dust. Almost all heavily wearing parts are outfitted with motion loss reduction possibilities. Robotic welding system are composed off robots with 6 joints and up to 12 possible external axes for positioning the robot or work piece, the total system accuracy depends on each axis working at 100% efficiency. If these are not cleaned and greased when necessary MTBF will decrease significantly, leading to frequent stops and problems.

The third category of factors that are caused by parts with extensive wear can be the following:

- Consumables with inferior qualities

Consumable wear contributes in the decrease of system performance. Even in the absence of environmental disturbances (such as dust), all parts of the system that fit under the criteria of consumables can cause problems. Excessive spatter, defects in the weld, false weld root detection, variation weld welding wire speed (weld parameters), overheating of weld gun, are only a couple of the possible results. The consumables are the variable parts of a robotic welding system, meaning robot behavior changes when consumables degrade. Problems derived from consumable wear. Are the most common and they are often mistaken for equipment failure. Usually by personal of companies that just started applying robotic welding systems.

Preventive Measures and Methods for Mitigation of the Circumstances

There are two types of joints in a robotic welding system, rotational joints and the linear joints. In cases of the rotational joints, dust protection systems can be very simple and most of the systems are sealed, lubricated for life. There is very little maintenance work involved with rotational joints.

In the case of linear joints, the solution is not that simple, most of the translation systems are several meters long, dust protection is possible in these cases as well but it’s problematic. This type of joint needs frequent cleaning and greasing.

The rotational joints have special greasing nozzles through which fresh grease can be introduced in to the ball bearings or closed gearboxes, the used old grease will be pushed out on the edges of the axis joints. Linear joints on the other hand need more intensive work, they need to be cleaned, then the special linear bearings need to be refilled with fresh grease, the rack needs to be cleaned and greased by hand using a medium sized brush. In normal conditions these operations need to be executed on a weekly or monthly base.

The most sensible parts of a robotic welding system are the welding machine and the robots control cabinet. These two main parts of the system are very sensible when subjected to external factors like dust deposits which block cooling systems, metallic dust which in addition can cause electronic malfunctions. The electronic parts of a welding system can overheat due to high ambient temperature, or can malfunction or even break because of very low temperatures. These components should be protected against frost temperatures under 5 C° and too high temperatures above 40 C°. Greasy air or moisture in the air can penetrate these devices and in certain situations cause great damage. Greasy air together with dust deposits on ventilation parts eventually stopping them. It is very sticky and thermally isolates components preventing adequate cooling. Measures for preventing damage to these crucial components of an industrial welding robot include weakly routine cleaning operations, and ways to increase shielding. When planning a new robotic system one should take into consideration all of the above described factors and plan ahead to counter their effects. There are optional cooling systems for control elements. Protection against low temperatures can be easily done using a local heating source. It makes sense to plan a complete shielding of the robotic welding system from the surrounding industrial environment, by building a closed enclosure for each system. Another option is to build a shielding enclosure only for control cabinet and the welding power supply. These enclosures represent additional costs, but they will be quickly recovered due to reduction of maintenance costs. Other advantages in shielding the entire system is protecting other personnel of the exposure to constant welding arc and noise, and preventing unauthorized access (thus lowering the chance of accidents). If it is not possible to isolate the robot from harmful external factors, then try isolating these external factors by moving them farther for an example.

In case of factors, resulting from improper operation or maintenance, all the parts of the robotic welding systems are affected in the same manner. The only preventive measure is appropriate and regular robot personnel training. Personnel should be motivated to pay more attention, and there should be fixed maintenance works scheduled. The personnel that assembles welding parts for robotic welding systems should also be trained regularly, so they can provide correctly assembled workpieces for the robot.

If the assembly devices permit variations then engineers and those responsible for part production, should work together in order to identify methods to correct the flaws. Often it is much easier to correct workpiece preparation then to try and weld the less than perfect work pieces on a robotic welding system. Various sensors were developed to counter these variations, but as the variations diversify the cost of the sensors increases exponentially. Companies that plan to implement robotic welding system should work in strong collaboration with system integrators. Explain each problem that the production currently faces, study the cause of these problems, let robotic system specialists analyze the current situation. Every problem is solvable. Not every weld must be robotized, some very difficult ones could be welded manually, and this measure will lower initial installation costs.

While programming the robot for the welding tasks one should keep in mind that each movement of the robot means wear of the moving joints. One should avoid unnecessary movement. Over time some of the joints that move in a restricted area, for example generating oscillation moves while welding, will have more wear. To increase MTBF the programmer should find an alternative position for that weld. Alternating the programs from time to time will reduce overall wear.

Periodic maintenance work is very important, it prevents extensive wear and it evaluates the current state of the robot.

The third category of factors mostly affects the welding equipment of the. For an example wear of the wire nozzle can cause misinterpretation of the sensor data when using arc sensors to track the welding groove. If quality of the welds is an important issue then studies must be made to estimate lifecycle of consumables and change them in time. There are some methods of increasing life cycle of these consumables, the most important ones:

- Cleaning using compressed air of the wire guides,
- Best practice is to preventively change consumables before they cause problems. Determine MTBF for consumables and change before that.
- Keep weld roots free of greasy substances.
- Inspect work piece condition before mounting on robotic welding system, check for variations of the weld groove.

References

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Metode de creştere a eficienţei şi duratei de viaţă a sistemelor industriale de sudură robotizată

Rezumat

Metodele prezentate şi analizate în prezentul articol se adresează atât factorilor care în cadrul unei societăţi răspund de buna stare de funcţionare a unui sistem robotizat (compartimentele de mentenanţă), cât şi persoanelor care intenţionează să investească în dotările specifice tehnologiei robotizate.

Lucrarea prezintă analiza fiabilităţii globale a unui sistem robotizat pornind de la parametrii de bună funcţionare medii (MTBF) specifici componentelor sistemelor robotizate pentru sudarea cu arcul electric (SR/SAE). Se evidenţiază tehnici de maximizare a MTBF globale prin măsuri în fază de concepţie – proiectare – execuţie – exploatare precum şi soluţii redundante care permit o creştere a disponibilităţii echipamentelor. Consideraţiile teoretice sunt apoi transpuse în cazul unor SR/SAE concrete, exemplificându-se sugestiv atât creşterea eficienţei în fază iniţială, cât şi fenomenele care apar în jurul apropierii de limita duratei de viaţă prognozată a sistemelor.