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A Review on Recent Trends in Robotic Welding

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Abstract— Robots have been extensively used in the industries in order to reduce the capital investment and increase the production. In the current scenario, robots are programmed to perform critical operations such as welding, powder coating, and material handling. This paper highlights the advancements of robotic operations and its applications with various metal joining processes. Various welding processes are discussed in detail in this paper. A brief description about the layout of the robotic cell has been introduced. Parameters to be considered for a robot selection for particular welding operation are discussed in brief.

Keywords: **Tandem welding, CMT, TIG Keyhole.**

I. INTRODUCTION

With the advancement in technology, efforts were made to minimize the involvement of humans in manufacturing, by replacing them with robots and automating the process. The results were excellent with context of quality, dimensional accuracy, surface finish etc. Welding was also no exception to this. So, human welders were replaced by robots. Robotic welding is by far the most popular application of industrial robots. Very good research works, achieving very interesting results, were done since the early 1980s, focusing issues like the welding process itself. Robot automation systems are rapidly taking the place of the human work force. One of the benefits is that this change provides the human work force with the time to spend on more creative tasks. The highest population of robots is in spot welding, spray painting, material handling, and arc welding. Spot welding and spray painting applications are mostly in the automotive industry. However, arc welding and material handling have applications in a broad range of industries, such as, automotive sub-suppliers, furniture manufacturers, and agricultural machine manufacturers.

The number of arc welding automation robot stations is growing very rapidly. The two most common stations are the GMAW (Gas Metal Arc Welding) station and the GTAW (Gas Tungsten Arc Welding) station. These two stations are the most common because they are so well suited to robot systems. Typically, a robot arc welding station is comprised of a robot, a robot controller, arc welding equipment, a work clamp and motion devices to hold work pieces accurately in position (considering heat deformation), robot motion devices to move around the robot for a larger working range and better weld positions, sensors, and safety devices

II. GAS METAL ARC WELDING

Gas metal arc welding (GMAW) also known as metal inert gas welding is a process in which arc is maintained between a consumable electrode and work piece in an inert gas atmosphere. The coiled electrode wire is fed by drive rolls as it melts away at the tip. Except for aluminium, a DC source is used with the consumable electrode as the positive terminal. For welding steel, a shielding is provided by CO2 for lowest cost. Normally, a high current density in the electrode (of the order of 10,000 amp/cm2) is used so that projected types of metal transfer results. The welding current is in the range 100-300 amp. The process is primarily meant for thick plates and fillet welds. [1]

MIG welding process is one of the most employed to weld aluminium alloys. There are three basics metal transfer in MIG welding process: Globular transfer, Spray transfer and Short-circuiting transfer. In the globular transfer, metal drops are larger than the diameter of the electrode, they travel through the plasma gas and are highly influenced by the gravity force. On the other hand, spray transfer occurs at higher current levels, the metal droplets travel through the arc under the influence of an electromagnetic force at a higher frequency than in the globular transfer mode. In short-circuiting transfer, the molten metal at the electrode tip is transferred from the electrode to the weld pool when it touches the pool surface, that is, when short-circuiting occurs. Figure 1.2, shows the typical range of current for some wire diameters. . [1]

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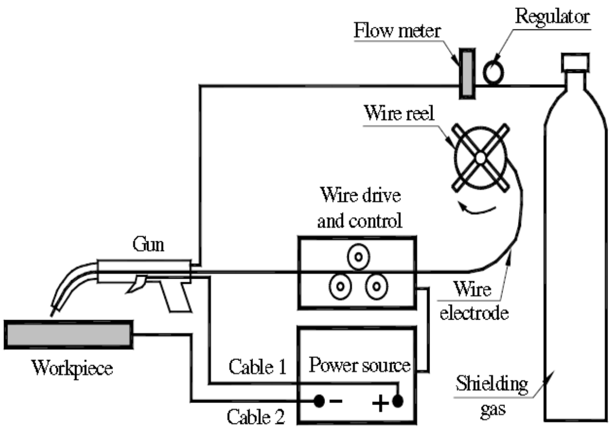

Fig 1.The main process of MIG welding

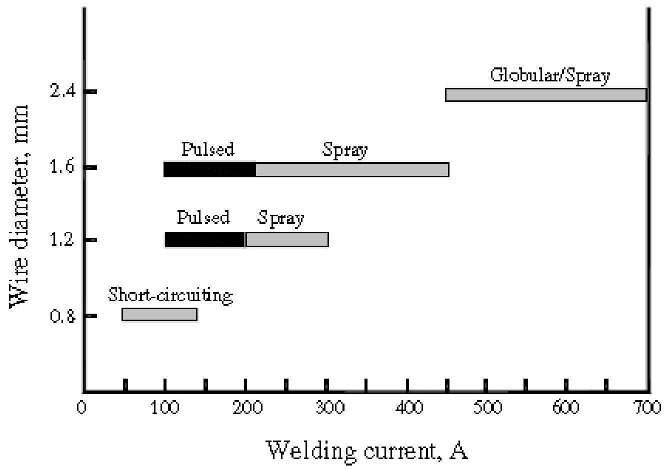

Fig 2. Welding current ranges for wire diameter and welding current. [1]

III. GAS TUNGSTEN ARC WELDING

Gas tungsten arc welding (GTAW) also known as tungsten inert gas welding is a process in which arc is maintained between a non consumable tungsten electrode and a work piece in a protective inert gas atmosphere. Figure.3 shows the TIG process. Filler material is used externally for the joining of the work pieces. Normally, a DC arc is used with tungsten as the negative pole. This is not possible for metals, such as aluminium and magnesium, where the oxide layer persists if the work piece is used as the anode. This layer prevents the formation of the weld pool. The mobile cathode spot can disperse the oxide layer but excessive heat is generated at the tungsten electrode if this is used as the anode.

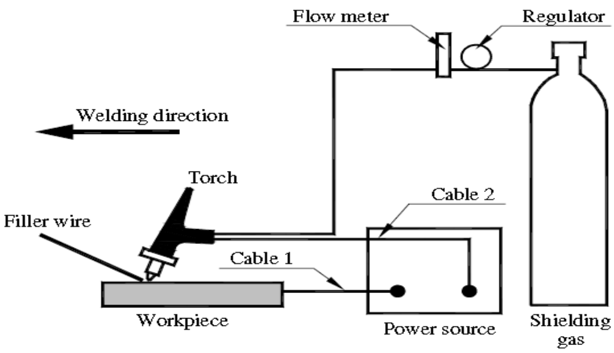

Fig 3. The TIG process. [1]

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Hence, AC arc is used for such materials. To avoid the melting of the electrode, thorium or zirconium is added to the tungsten (to increase the melting point). Argon is most commonly used to provide the inert atmosphere. Nitrogen is sometimes used for welding copper. To prevent the possible little contamination, an argon deoxidant is added to the filler.[1] Direct polarity is the most commonly employed in GTAW. This effect produces a high heat in the work piece and therefore gives a good penetration and a relatively narrow weld shape. When alternating current is used, is possible to obtain a good combination of oxides elimination (cleanliness) and penetration. This polarity is the most employed to weld aluminium alloys. The polarity system used in the TIG welding process is shown in Fig.4.

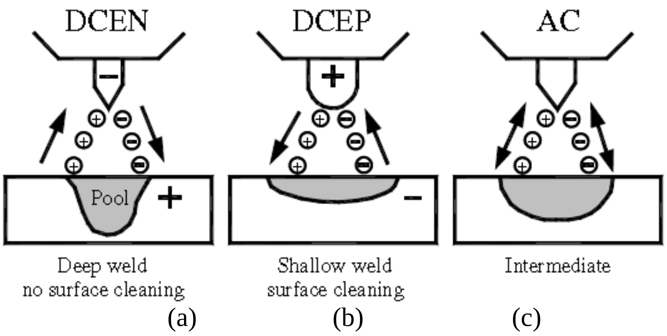

Fig 4. Polarity in TIG welding process. [1]

IV. INNOVATIONS IN MIG WELDING

The MIG/MAG welding is a process widely used both in the manual and mechanized modes. The search in this process is mainly focusing two objectives:

1. High productivity process for thicker plates and long welds.
2. Better penetration control for root passes and thin plates

A. High productivity variants: Tandem welding

Welding with the use of two electrode wires (Tandem) was applied for the first time for submerged arc welding. In the beginning of the nineties this solution was successfully transferred into gas shielded welding. The action of melted metal in two welding arcs, supplied from separate wire feeders, onto the common weld pool is applied in the Tandem method. Both welding current circuits are separated electrically, thus parameters can be set independently and individually for each welding wire.

During the welding process with the Tandem method both welding electrodes are placed one after another towards welding direction. First electrode, called leading electrode, ensures required penetration depth, while second one, called following electrode, provides required filling up of the pool, prolongs the time of its degasification and provides proper face shape, free from porosity and undercutting. Usually the leading electrode is of larger diameter, as it ensures approximately 65% of the whole deposition efficiency obtained in the welding process. Second electrode, which is placed in the backside part of the weld pool, is usually loaded with lower current intensity and controls melted metal of weld pool.

Pulsed current welding in the Tandem method is used very often. When the background current is applied onto the leading electrode, current pulse occurs on the following one (see Fig.5). This way of current pulse synchronisation enables heat input to be controlled and this method can be applied for welding of relatively thin-walled elements, welding in different positions and materials sensitive to a high amount of input heat (high-resistant steels, duplex steels, aluminium alloys). [2]

Application of Tandem welding instead of conventional MIG/MAG welding, especially on automated and robotised welding stations, allows travel speed to be increased even up to several meters per minute, depending on the thickness of welded elements and joint configuration. Such welding speed is impossible to reach during semiautomatic welding, therefore Tandem welding is usually applied in mechanised or robotic processes. Tandem method is one of the most effective methods of improving welding productivity.

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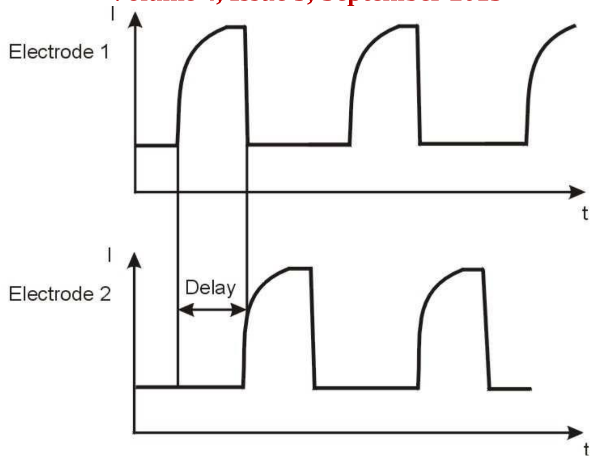

Fig 5. Current diagram for Tandem pulsed welding. [2]

Fig 6. Torch for tandem welding produced by Lincoln Electric. [2]

B. TIME Welding

Research on the improvement of welding productivity through application of higher density of welding current as well as compound gas shielding resulted in new variant of metal active gas welding, called T.I.M.E (Transferred Ionised Molten Energy). Factors which determine high process productivity are the high current density and four-component Ar-He-CO2-O2 shielding mixture of precisely chosen composition (depending on the welded material grade, e.g. for mild steels: 65% Ar + 26,6% He + 8% CO2 + 0,5% O2). The process conducted with high current density and welding speed is flexible and allows for three methods of metal transfer as a result of alteration of the wire feeding speed:

1. Short arc – wire feed speed up to approximately 8 m/min (arc voltage 16-23.5 V),
2. Direct spray arc – wire feed speed up to approximately 25 m/min (arc voltage 28-46 V),
3. Rotational spray arc – wire feed speed up to approximately 30-40 m/min (arc voltage 47-56V).

For each method of metal transfer spatter does not exceed 2%, the level of weld metal oxidation is also low. Rotational character of metal transfer ensures that fusion is wide and flat (Fig. 7), which provides uniform penetration into the joints walls, especially in fillet welds production. For wire feeding in the range of 20 to 25 m/min it is possible to acquire the deposition efficiency of 10-15 kg/h and for higher values even 26-27 kg/h.

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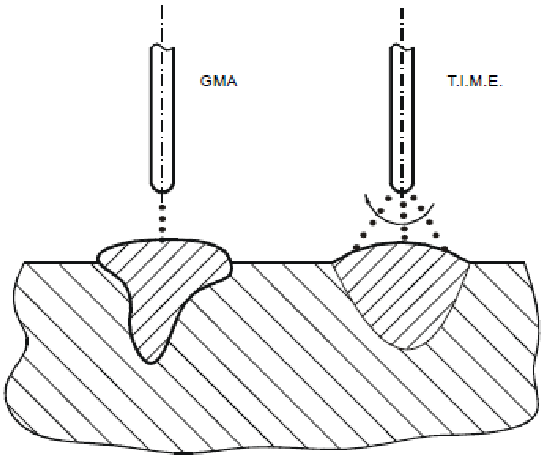

Fig 7.Shape of penetration for spraying transfer of metal in conventional MIG and rotational transfer in T.I.M.E process. [3]

The productivity of T.I.M.E. process has been shown in the form of deposition and surfacing rates for wide range of parameters with calculated losses for spatter. These losses are lower than in MIG/MAG, which helps to eliminate post-weld cleaning and improves significantly the welding productivity.

Fig 8. TIME 540 from FRONIUS. . [4]

C. Low-energy MIG/MAG Welding Processes: Cold Metal Transfer

The CMT (Cold Metal Transfer) process (Fronius, 2004) is a revolution in welding technology, with respect to both, welding equipment and welding applications. The CMT process is not only a completely new process, which is unknown until now, but it also opens a new field of application since it widens the limits of Gas Metal Arc Welding (GMAW), allowing the arc joining of steel to aluminium in a reproducible manner for the first time.

There are materials and applications that cannot withstand the constant heat of a welding process. In order to avoid weld-pool drop-through, to be spatter-free, and to be amenable to metallurgical joining, they need lower temperatures. With CMT, this is now possible. The term “cold” has to be understood in terms of a welding process, but when set against the conventional MIG/MAG process, CMT is indeed a cold process.[4]

CMT can be described as a GMAW process where heat input is low as compared to the conventional dip arc process. The CMT-process is a dip arc process with a completely new method of the droplet detachment from the wire. In the conventional dip arc process the wire is moved forward until a short circuit occurs. At that moment, the welding current rises. Causing the short circuit to reopen and allowing the arc to ignite again. There are two main features of the MIG/MAG process: on the one hand the high short circuit current corresponds to a high heat input. On the other hand the short circuit opens in a rather uncontrolled manner, resulting in lots of spatters in the conventional dip arc process. In the CMT process the wire is not only pushed towards but also drawn back from the

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Volume 4, Issue 5, September 2015
work piece – an oscillating wire feeding with an average oscillation frequency up to 70 Hz is used. There are three features of the CMT process, which distinguish this process from a conventional GMAW process. [4]

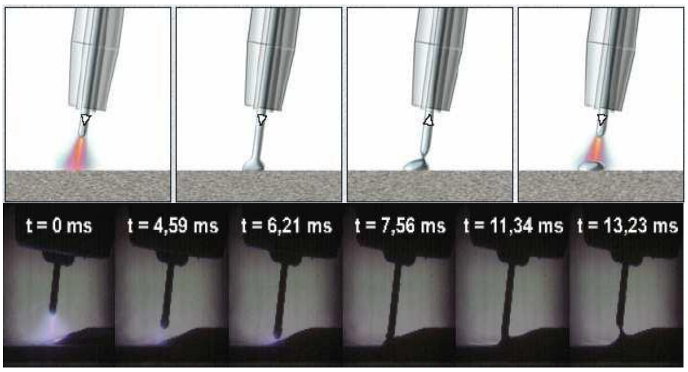

Fig 9. Principle of CMT process and view of its one cycle. [4]

First of all, the wire movement is directly included into the welding process control. Until now the wire feed speed during welding was either fixed or had a predetermined time schedule (e.g. synchropulse). In the CMT process the wire is moved towards the work piece until a short circuit occurs. At that moment the wire speed is reversed and the wire is pulled back. When the short circuit opens again, the wire speed is again reversed, the wire moves towards the work piece again and the process begins again. There is no predetermined time schedule for the wire movement, but the occurrence and the opening of a short circuit determine the wire speed and direction. It can be said that there is an interaction between the processes in the welding pool and the wire movement. This is the reason why one can only speak of an average oscillation frequency of the wire. The second feature which characterizes the CMT-process is the fact that the metal transfer is almost current-free, while the conventional dip arc process corresponds to a high short circuit current. In the CMT process the current is no longer responsible for the opening of the short circuit. When the wire is drawn back, the movement supports the metal transfer due to the surface tension of the molten material. Therefore the current during the short circuit can be kept very low and the heat input is also very small. Finally the CMT-process is characterized by the fact that the wire movement supports the metal transfer as mentioned above. Figure 10 presents a CMT unit for robotized welding, though the process is often used in the manual mode.

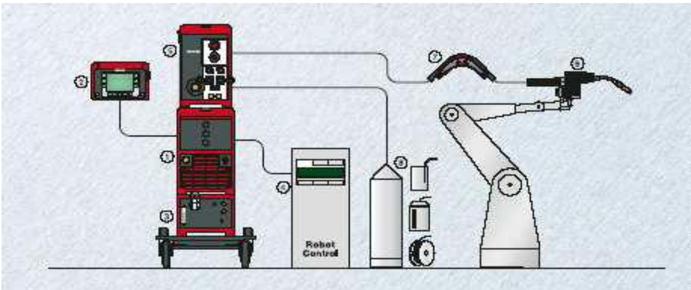

Fig 10. Configuration of robotic welding station with CMT unit. .[4]

D. Surface Tension Transfer

Surface Tension Transfer – STT (Deruntz, 2003) welding is a GMAW, controlled short circuit transfer process. Unlike standard CV GMAW machines, the STT machine has no voltage control knob. STT uses current controls to adjust the heat independent of wire feed speed, so changes in electrode extension do not affect heat. The STT process makes welds that require low heat input much easier without overheating or burning through, and distortion is minimized. Spatter and fumes are reduced because the electrode is not overheated – even with larger diameter wires and 100% CO2 shielding gas. This gas and wire combination lowers consumable costs.[3]In this process, the melting electrode material contacts the weld pool on the work piece before detaching, creating a periodic short. Typical waveform cycle periods are 1/120 s and is presented in Fig. 11.

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Volume 4, Issue 5, September 2015

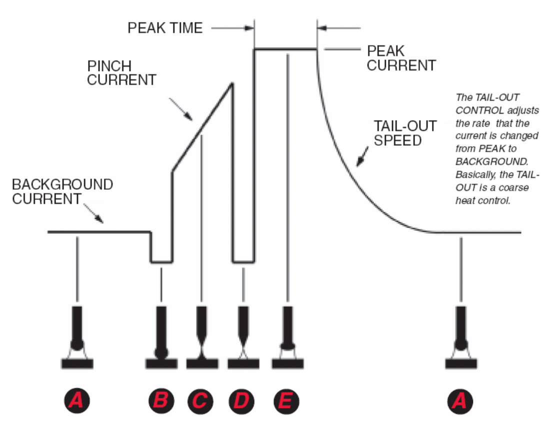

Fig 11. Typical waveform in STT process. [3]

Explanation of each process phase is given below:

A. STT produces a uniform molten ball and maintains it until the "ball' shorts to the puddle.

B. When the "ball" shorts to the puddle, the current is reduced to a low level allowing the molten ball to wet into the puddle.

C. Automatically, a precision pinch current wave form is applied to the short. During this time, special circuitry determines that the short is about to break and reduces the current to avoid the spatter producing "explosion".

D. STT circuitry re-establishes the welding arc at a low current level.

E. STT circuitry senses that the arc is re-established, and automatically applies peak current, which sets the proper arc length. Following peak current, internal circuitry automatically switches to the background current, which serves as a fine heat control

V. INNOVATIONS IN TIG WELDING

A. TIG Keyhole

TIG keyhole (K-TIG) mode (Jarvis, 2000; CSIRO) variant was first developed by the Australian industry in late 1997, regarding weld bead stability, depth welding profiles and significant production increase. The welding process has been jointly developed by CSIRO (Commonwealth Scientific and Industrial Research Organisation) and CRC-WS (Cooperative Research Centre for Welded Structures), which has introduced an unique and remarkable high productivity potential solution to joint ferrous, nickel and titanium alloys (plates and tubular products) from 3 – 12 mm thick. K-TIG welding is an automated welding process which operates at higher currents than conventional TIG in order to puncture a small opening through the root face of the work piece without need of backing bar. The electromagnetic force (Lorents forces), which is dependent on the square of current, will induce a depression or cavity on weld bead surface.[5]This weld pool displacement must be formed as part of the welding process, allowing the generated welding energy to be delivered in depth from the surface through the liquid weld pool, as a result of combined action of highly localized energy and pressure . The surface tension will be responsible to drive the opening cavity to a very stable keyhole geometry being the ruptured root surface an important root to allow the pressure within the cavity to be released. Finally, as part to dynamic mechanism it is important to keep the opening root surface small avoiding any loss of material in the training regions of the weld pool. One of the most important advantages of K-TIG technology is the particularly simple square edge preparation needed. Filler metal can be used to compensate poor fit up, reduce undercuts, provide additional reinforcement, or modify the microstructure of the weld metal. In figure 1.12 it is possible to compare features and respective depth welding profiles between conventional TIG and K-TIG for 10.5mm AISI 304 Stainless Steel. K-TIG has proved to be a high potential technology for production increase at lower cost guaranteeing however incomparable welding quality standards when compared with traditional welding processes. [5]

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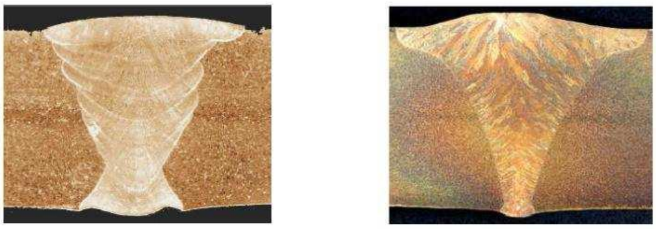

Fig 12. Penetration profile comparison between conventional TIG and K-TIG for 10.5 mm Stainless Steel. [5]

VI. ROBOTIC WELDING

There is a huge number of products that require welding operations in their assembly processes. The car industry is probably the most important example, with the spot and MIG/MAG welding operations in the car body workshops of the assembly lines. Nevertheless, there are an increasing number of smaller businesses, client oriented, manufacturing small series or unique products designed for each client. These users require a good and highly automated welding process in a way to respond to client needs in time and with high quality. A robotic system consists of following points:

A. The Robot and the Controller

A robot is programmed to move the welding torch along the weld path in a given orientation. The robot is typically comprised of a large number of links and linkages, which are interconnected by gears, chains, belts, and/or screws. The majority of industrial robots are actuated by linear, pneumatic, or hydraulic actuators, and/or electric motors. Most of the high-end robots currently use AC servo motors which have replaced the use of hydraulic actuators and, more recently, DC servo motors. AC servo motors are essentially maintenance free which is very important in industrial applications. The controller is the brain of the robot arc welding system. This is because the controller stores the robot programming and arc welding data, and performs the necessary computations for robot control, typically by a high-speed microprocessor. The controller provides a signal to the actuators and the motors by programmed data and position, speed, and other information obtained from various sensors. The controller is now integrated to govern not only the robot but also any peripheral devices, such as manipulators. When the system is required to weld a work piece that has a complicated geometry, the simultaneous coordinated control of the integrated controller is inevitable. [6]

B. The Welding Equipment

One of the most important characteristics is stability of power. It is recommended that the welding equipment generates a short arc with fewer spatters for a good welding quality even at high speeds. The Wire feeder has wheel rollers to advance the wire. Some feeders have four rollers speed sensors for more accurate wire feeding by push-pull action. Also, a wire feeder with shorter length to the torch is better in terms of a response time. Therefore, a good location for the wire feeder for a robot system is at the end of the upper arm of the robot .A slender welding gun is better for maneuverability but, in case of a collision, sufficient strength must be guaranteed. It is also necessary to ensure that the torch is equipped with shock absorption devices such as springs. It is also important to have a cooling system (a circulating water, in general) to protect the torch against heat deformation. Fronius has developed a new technique called as CMT which can be used as an alternative to the cooling system. [4]

C. Manipulators / Fixture

A robot has a limited working range and accessibility, therefore, in many cases a manipulator has to be considered. A manipulator is a device holding the work piece and is moved around (typically with linkages) for better access and welding positions. The advantages of a manipulator include:
A) A manipulator can easily be moved around the work piece for the best welding positions.
B) A manipulator can reduce the variation in the lead and the lag angles of the tip.
C) Welding can be performed in a stable flat welding position by a synchronized and simultaneous control of a robot and a manipulator.
D) Any hard-to-reach positions can be accessed more easily.
E) A manipulator increases the working range of a fixed floor mounted robot or an inverted robot. [6]

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 5, September 2015

D. Power sources

Power sources for GTAW are generally of the constant current type with drooping volt-ampere static curves. Light weight transistorized direct current power sources are currently used, being more stable and versatile than the old thyristor-controlled units. In rectifier-inverter power sources the incoming AC current is rectified and then converted into AC current at a higher frequency than that of the mains supply, in the inverter. Afterwards high voltage AC current is transformed into low voltage AC current suitable for welding, in the transformer, and then rectified. The aim to increase the current frequency is to reduce the weight of the transformer and other components of the source such as inductors and capacitors. Most common GMAW power sources are of the inverter type with architecture similar to that represented in Figure 2.3, but providing a constant-voltage output. A constant-voltage power source used in conjunction with a constant speed wire feeder can provide self-adjustment and stabilization of the arc length, in order to compensate for the variations in the torch to work-piece distance. [6]

E. Welding torch

The TIG welding torch holds the non-consumable electrode, assures the transfer of current to the electrode and the flow of shielding gas to the weld pool. Torches with welding regimes up to 200 A are generally gas-cooled and those with continuous operation between 200 and 500 A are water-cooled. Non-consumable electrodes are composed of pure tungsten or of tungsten alloys. Pure tungsten electrodes can be used with DC but are more sensitive to contamination, have lower service life-cycle and exhibit higher tip deterioration than alloyed electrodes. These electrodes can be used in welding of aluminium and magnesium alloys on AC. Thoriated tungsten (2% ThO2) electrodes are widely used in industrial applications due to its excellent resistance to contamination, easy arc starting and stable electric arc. In MIG welding the electrode feed unit and the welding control mechanism are generally furnished in one integrated package. The electrode feed unit pulls the electrode from the reel and pushes it through a conduit to the welding torch (gun). This unit is composed of a direct-current motor, that varies the motor speed over a large range, a gear box and two pairs of rolls with a pressure adjusting screw and wire guides, that transmit mechanical energy , straighten and guide the electrode. [6]

F. Arc striking technique

Arc initiation by touch striking was used formerly in manual GTAW, but this technique is very sensitive to tungsten contamination, adversely affecting the service life of the electrode. Programmed touch striking is an alternative technique developed for automatic systems. In this technique current and voltage are limited when electrode touches in the work-piece, in order to prevent electrode contamination. [6]

G. Welding speed

On TIG welding the effect of increasing the welding speed for the same current and voltage is to reduce the heat input. The welding speed does not influence the electromagnetic force and the arc pressure because they are dependent on the current. The weld speed increase produces a decrease in the weld cross section area, and consequently penetration depth (*D*) and weld width (*W*) also decrease, but the *D/W* ratio has a weak dependence on travel speed. In case of MIG welding increase in the welding speed gives a decrease in the linear heat input to the work-piece and the filler metal deposition rate per unit of length. The initial increase in welding speed can cause some increase in penetration depth, because the arc acts more directly in the parent material, but further increase in speed decreases penetration and can cause undercut, due to insufficient material to fill the cavity produced by the arc. [6]

H. Shielding gas

Shielding gases are used in order to prevent atmospheric contamination of the weld metal. This contamination can produce porosity, weld cracking, scaling and even change in the chemical composition of melted material. Besides shielding gas also has a large influence on the stability of the electric arc. Argon is the most used GTAW shielding gas. It has low ionization potential and is heavier than air, providing an excellent shielding of the molten weld pool. Argon is used in welding of carbon and stainless steels and low thickness aluminium alloys components. For welding thick aluminium work-pieces and other high-conductive materials, such as copper alloys, helium is recommended because it has higher ionization potential than argon, needing higher voltage for arc initiation and maintenance, but producing higher heat-input. Helium or helium/argon (30-80% He) mixtures[6] allow increased welding speed and improved process tolerance. [2,6]

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ISO 9001:2008 Certified
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Volume 4, Issue 5, September 2015

Gases used in GMAW can be pure gases, binary, ternary and exceptionally quaternary mixtures. Carbon dioxide is an active gas and is used in welding of carbon steels. It produces high levels of spatter but provides high penetration depth. Binary mixtures are commonly argon/carbon dioxide (up to 20% CO_2), argon/oxygen (up to 5% O_2) and argon/helium (up to 75% He). The most common ternary mixtures are argon/oxygen/carbon dioxide, used in welding of carbon steels, argon/helium/carbon dioxide and argon/carbon dioxide/hydrogen, used in welding stainless steels. [2,6]

VII. CONCLUSION

In this paper, the innovations in welding are presented, with the objective of demonstrating how the various components of a robotic welding system can be executed. Following conclusion can be drawn:

- The innovation processes presented above are capable of performing welding on numerous types of materials irrespective of their geometry.
- New and different type of innovations in welding can be easily adopted by the use of robotics and automation.

VIII. FUTURE SCOPE

The automated welding techniques can be used for various numbers of applications. Further, it can be applied to do brazing and soldering applications. A robot can be designed for soldering and brazing applications, which will minimize the human efforts and will increase the accuracy of the product to be soldered and brazed.

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