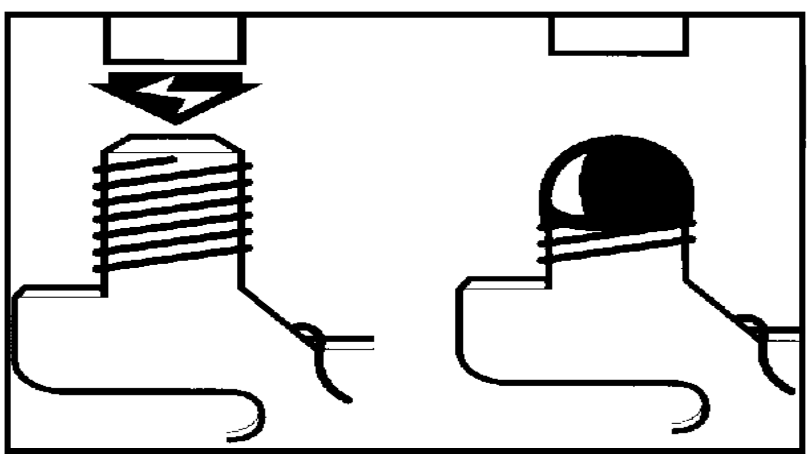
Pulsed Arc Welding for Coil Termination

The use of a Pulsed Arc TIG Welding System for the Joining of Enameled Copper Wire to Terminal Pins as used in Coil Manufacture

1.0 Introduction to Pulsed Arc Welding

MacGregor Welding Systems have developed a pulsed arc power supply for precision joining applications, where precise control and repeatability are of paramount importance. In the manufacturing industry today, many components use coils or relay switches in their applications and one of the main criteria in respects to such components is the joining or fusion of the terminal pins to the insulated copper wire. The process requires a number of turns of wire to be wound onto the pin at uniform height and density. The pin is then positioned beneath a welding electrode and an arc weld is used to remove the insulation and fuse the pin with the wire, as illustrated in Fig 1.

Fig 1: Illustration of the Principle of Pulsed Arc Welding - Coil post before and after pulsed arc weld



Process reliability in a manufacturing environment requires the balance of a number of factors. These principle factors are a combination of material, design, and process issues. Because of the number of influences and variables, MacGregor Welding Systems, Ltd. has approached the coil winding industry treating each application as a separate requirement. The result of this approach is a flexible line of equipment and a close partnership with a number of companies involved in the coil making industry.

The principle factors are as follows:

- Pin material
- Pin geometry and relation to wire diameter
- Grade of enamel on wire
- Single or skeined enameled wire
- Wire wrap - single or double, pitch, tightness and position on pin
- Shielding gas
- The equipment

2.0 Pin Material

The material chosen for terminal pins is one of the most important factors in relation to achieving satisfactory welding results. The selection of the material will have an impact on the temperatures generated during the process as well as the cosmetic finish of the weld upon completion.

While a wide variety of alloys and materials can be used successfully, the use of Brass as a pin material is not recommended. This is due to the low melting temperature and the characteristics of the Zinc content in the material. The low melting point of the material becomes an issue when the wire used either has a large diameter or a high temperature insulation (160℃ or higher). In these cases, the pin will melt down before the wire or insulation is heated sufficiently to allow for a weld to occur. This will leave the coil of wire in tact with the pin burned away.

The zinc content found in brass causes problems due to the instability of Zinc at low temperatures. The zinc becomes unstable and creates gas pockets in the molten material. These pockets can cause splatter and outgasing in the process as well as leave holes and imperfections in the pin weld. Due the considerable difficulties encountered with brass pin material, the acceptable process window, if one can be found, is very narrow and not well suited for production and manufacturing.

The two most favored pin materials for the pulsed arc welding process are copper or phosphor bronze. The higher melting point of these materials enables the insulation on the wire to be disrupted and fusion to occur between the wire and the pin. The materials are both stable and clean when heated to the required temperatures allowing for extended electrode life and improved cosmetic appearances.

Pins are generally pre-tinned for solder connections and many material specifications require this tit plating to be present. While tin is not required for the arc welding process, a light, uniformed amount of tinning can aid the process, as it melts uniformly down the pin and provides adequate adhesion for the coils wrapped further down the pin length. The wetting effect also aids by increasing the surface area of contact between the pin and the wire thus aiding in the transfer of heat required to burn or melt away the enamel.

While a light coating of tin can act as an advantage, heavy tin plating can be detrimental to the process. In large quantities, the tin will create a larger amount of contamination, and the flow of the material down the pin will effect the quality of the weld joint and ability of the weld to sufficiently remove the insulation.

3.0 Pin Geometry

Pin geometry can have a definitive effect on the final joint achieved. A round section pin will give the most uniform melted ball on the end. However, the pins generally used in coil manufacture are square. The square in is used because it simplifies the winding process by allowing for the wire to be easily wrapped around the pin at the start and finish winding. In pulsed arc TIG welding, the use of a square pin does not present problems in related to the pin, but rather related to the wire wrap. The third pin geometry found is rectangular section. If rectangular pins are used, then problems of achieving a uniform melt can be experienced. These problems are typically seen in applications using pins whose width is four times or more the thickness of the pin.

Because the manufacturing of coils is a combination of various processes, the use of square pins is most common due to the added reliability and simplicity in the winding portion of the process. When using square or rectangular pin geometries, it is best to use radiused corners. The presence of sharp corners has two potential negative effects on the process. The first is a reduction in the surface area of the pin that is in contact with the wire. The surface area of this interface is directly related to the amount of heat that can be introduced into the insulation and wire as well as the rate at which it can be introduced. The second consideration is the presence of sharp corners in contact with the wire. In certain cases these corners can cut into the wire when the wire is heated, causing weakened strength and possible failure. These variables are described in section 6 in greater detail.

Other pin geometry considerations are generally governed by the coil shape and the access required to complete the process. The welding electrode must have clear access to the top of the pin. This means that the pin can not be covered when the welding process occurs. The proximity to the coil body should also be taken into consideration, as the weld will produce heat in the pin that could damage or discolor the coil body. This is particularly important when plastic coil bodies are employed.

The pin must also extend to a position that allows for access by a return contact. This contact enables the welding current to return to the power supply. This is typically accomplished by extending the pin through the moulding and then clamping it with a conductive clamp.

The diameter of the pin is generally determined by a combination of the wire size and the requirements on the pin in its final application. While there is no set relationship or curve of wire to pin diameter relationships, a larger wire will require the use of a larger diameter pin to allow for sufficient thermal mass to be present in the pin to dissolve the wire and create the weld.

As a general guideline, the following observations have proved to be successful in numerous production applications. With wire diameters up to 0.3mm a pin diameter of 1.2mm has been found to be acceptable. With wires above 0.3mm, a pin diameter of 1.6mm or greater has been found to be more effective.

Fig 2: Photo of Pin and Wire Weld Area

4.0 Grade of Enamel on Wire

Various grades of enamel are used as insulating media on wires in coil manufacture. The higher the temperature grade of the enamel, the more difficult it becomes to achieve good fusion between the wire and pin. As previously discussed, this is particularly difficult if brass is used as the pin material. As a general rule of thumb, the stability of the pulsed arc TIG welding process begins to deteriorate significantly when insulation temperature ratings are greater than 180°C. At this point careful consideration should be made of the application and process prior to introducing a process into a production environment.

In cases where high temperature enamel is required, there are several methods that can be employed to help ensure a reliable process. The first of these is the selection of the pin material to be used. Both copper and phosphor bronze pins have higher melting temperatures so the molten pin material will have a greater thermal energy available to break down the wire insulation. The use of dual pulse weld can also be employed to allow for both a heating / insulation removal pulse and a welding pulse to be programmed. Determination of the most suitable process settings and features is typically accomplished through testing of the actual product to be welded.

The lower the temperature of the enamel, the more flexible and tolerant the process will be. A general rule of thumb states that and insulation below 180°C is suitable for a pulsed arc TIG welding process.

5.0 Single or Skeined Wire

Ideally, a single wire presents the most stable and consistent configuration for achieving a successful and consistent welding joint. While the use of single stranded wire is preferred, the welding of skeined wires can be accomplished if proper consideration is given. As with any variation in the process, the use of skeined wires has its own set of difficulties and process rules.

With single strand wires, the relationship between wire diameter and pin size has to be considered. A fine wire on a large diameter pin can result in the breaking of the wire due to the amount of heat needed to melt the post. The current and time required to form a molten ball on the end of the pin can be excessive for the wire, resulting in burn back of the wire below the molten tip of the pin. Conversely, a larger diameter wire on a small diameter pin will result in the pin melting back inside the wire winding with no fusion.

When skeined wires are used the number of wires in the skein and the diameter of those wires has to be considered in relation to the pin diameter chosen. With very fine wires in the skein, a smaller pin diameter is preferred. Although there is an increase in the total amount of heat energy required to accomplish the successful fusion of the pin and the wires, the individual failure characteristics of the strands in the skein remain the same as they would be if the wire was wound as an individual strand. This means that applications where skeins of fine wire are welded require careful consideration and testing in the initial stages of the project to identify and control the variables that would lead to strand damage during the weld.

Inversely, If the skein is from larger diameter wires this presents a greater heat sink factor around the pin. In this case, it is common practice to place the winding lower on the pin to allow for more material to be melted prior to contact with the wire. The increased molten mass allows for a proper fusion with each of the strands and increases the heat energy, thus compensating for the increased heat sinking. Wire wrap in relation to the pins is discussed in Section 6. Figure 3.1 shows the effect of mismatch between wire and pin diameters.

6.0 Wire Wrap

The pattern of the wire wrap on the pins, and the position of the wire in relation to the end of the pin is important if successful welded joints are to be achieved. The wire wrap on the start and finish pins is different due to the winding patterns allowed by automatic equipment. On the start pin, winding normally commences at the bottom of the pin, up to the top, then back down the pin and into the coil. For the finish pin, the wire comes directly from the coil and is wound round the pin terminating at the top.

On the start pin, the dual wrapping of the wire can impact the weld quality. The start pin will sometimes require a greater amount of current or time to be used to compensate for this. The increased heat sinking capability of the wire causes the increase in required heat.

Too heavy a wrap at the top of the pin can create a high heat sink value, making it difficult to achieve disruption of the enamel and fusion between the pin and wire. Higher welding currents to overcome this factor can result in the wire burning back where it crosses over the start wrap at the top of the pin. This is a particular problem when high temperature enamel is employed on the wire. Ideally, the wire should be open wrapped up the pin with two or three turns close wrapped at the top.

The wire should then be brought away down the pin with an open wrap technique **(Figures 3.1 & 3.2).** The position of the wrap relative to the top of the pin is important. A sufficient and consistent length of pin must extend above the wire in order to achieve a controlled amount of melt and allow the weld to encompasses the top wind on the pin.

The length of pin that extends above the coil wrap can vary relative to the wire/pin diameter ratio. Generally the larger the wire diameter the longer the extension of the pin should be for a single diameter of pin.

The wire wrap on the finish pin should be open wound up the pin terminating in two or three close winds at the top. The pin length above the wire again needs to be controlled, as it is preferable to use the same welding parameters on both pins **(Figures 3.1 and 3.2).** Because there is less wire on the finish pin, the finish wrap can be wound closer to the top of the pin to allow the same programmed weld pulse to be used. This might not be possible in all applications but does simplify the process and the equipment.

In addition to the winding location and pitch, the tension of the wire as it is wound needs to be controlled. This is particularly critical on square or rectangular section pins. If the corners of the pins are not radiused, necking of the wire can occur on the corners with a high wire wrap tension. With thermal cycling and vibration, breakage of the wire can occur at these weakened points, leading to failure of the component in operation.

It is important that the wire is wrapped closely to the pin. A loose wrap will result in burn through the wire with no fusion to the pin. If the wire is loose in space it will not receive sufficient heatsink from the pin to withstand the heat introduced during the process.

Fig 3.1 Wire Wrap Configuration of the Relay Coil

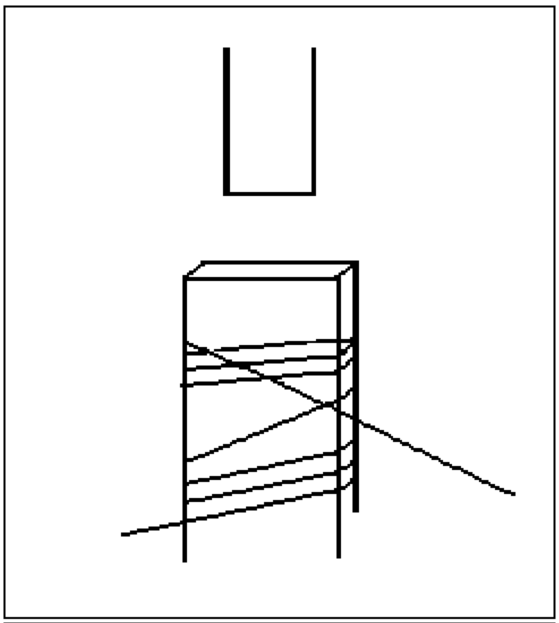
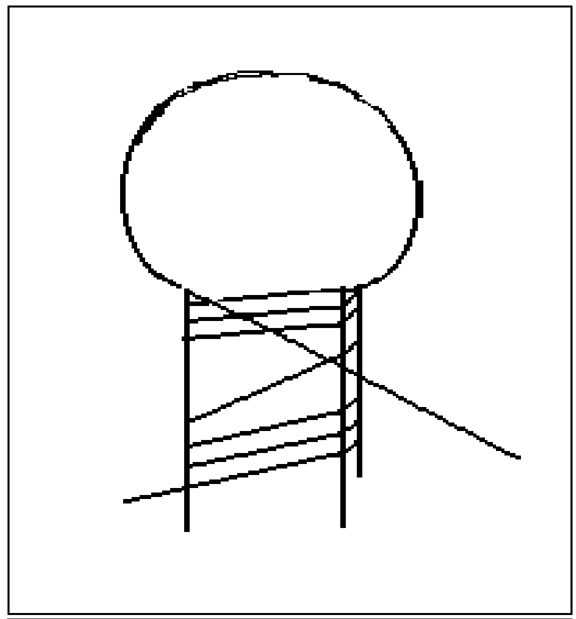


Fig 3.2 Post Welding Relay Pin Head



The principle behind this style of wire wrap is that when the arc strikes the pin, the pin melts over the wire and creates a molten ball, which fuses the pin material and the coil wire together. For this reason, the wire is not taken from the highest point on the winding, but tracked back down the pin for a distance. The wire is routed away from the weld area to prevent excessive heat from building up in the wire as it returns to the coil. This heat buildup can cause the wire to break. The time, current level, and distance from the top of the pin to the wire wrap all contribute to the amount of molten pin material and fused wire.

7.0 Shielding Gas

The tungsten arc process normally employs an inert gas as a shielding media over the electrode and weld pool. The shielding gas provides arc stability and joint integrity in normal welding practice. The use of shield gas in coil termination is not necessary in over 90% of applications. This is beneficial from a cost perspective as well as a heat vs. current flow perspective. Because of the shape of the coil pin, the unit does not tend to have difficulty striking an arc either with or without shielding gas.

Oxide contamination has not been found to present a problem in production because the materials used typically emit low levels of residue. The deposits left from the burned enamel do require evacuation or removal. Failure to do this will yield a black or Grey colored soot on the nearby components. This contamination can also build up on the electrodes if not effectively removed from the weld area.

The use of a transverse airflow across the pins can eradicate most of this problem. This system can also be augmented by the use of a vacuum system to draw and gather the particle contamination and remove it from the weld area. The best configuration for such a system is to push the contaminated material from the coil and then use the vacuum to draw the material away from the electrode. This will reduce the amount of material deposed on the electrode and lengthen the cleaning intervals.

The arc voltage will be higher when welding in air than with a shielding gas. This can be an advantage in this application as it provides higher arc energy for a given welding current. This enables lower welding currents to be used.

Electrode life will be affected by welding in air as opposed to a shielding gas. The results and impacts of this are application and material dependent. The effectiveness of the contamination removal is also a primary factor in electrode life. Because of the cost of machine down time, a quick-change type electrode head system is employed in several applications to allow for rapid changing of the electrodes for off site dressing at a later time.

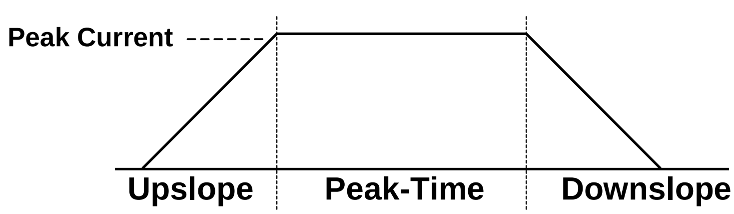
8.0 The Equipment

MacGregor Welding Systems, Ltd. offers a wide range of pulsed arc welding power supplies. These range from lab models with multiple options, to production models that incorporate only the features of value to a customer. The systems are available in 1, 2, 3 and 4 output models to allow for a single power supply to be used in automation of high-speed production. Single output standard models include the PA-60 and PA-100. Multiple output models are available in ranges from 10-60 amps. These units are built to customer or application specification.

Each unit is capable of producing a pulse of accurately controlled current and duration. A specially developed arc start system is used incorporating a high voltage DC impulse, operating in conjunction with a stabilizing power supply. This ensures that the arc ignition occurs consistently and reliably with minimal radiated interference. The options for arc failure detection arc voltage monitoring, and gas flow control are available on all models. The single output units (PA-60 and PA-100) have the ability to run in continuous mode as well as provide a current modulated output.

Closed loop techniques are used to ensure a stable output, which is independent of mains supply variations, temperature and cable lengths. This is accomplished through transistorized output control and an analogue feedback and drive circuit. This control system offers rapid response to process changes and provides stability in the weld output.

8.1 The Welding Parameters



The diagram is a representation of the duration of the welding pulse.

- **(US)** - Upslope Time (optional in multiple output systems)
- **(PT)** - Peak Time (standard on all units)
- **(DS)** – Downslope Time (optional in multiple output systems)

9.0 Summary

The various considerations in the successful use of pulsed arc TIG welding for coil termination require that the equipment supplier, coil body supplier, and the equipment user work in conjunction with one another. MacGregor Welding Systems, Ltd. has fostered this type of relationship with various equipment and material suppliers in the coil winding industry.

The availability of pre-production trials and full feasibility studies offers the customer the ability to review the process in several stages before investing in capital equipment. Initial consultancy is free of charge and available to both new and existing customers. Full feasibility and capability studies are available as a charged service and can include the development and refinement of product and handling tooling.

If you have any additional questions on this or any other welding process, please feel free to contact us at:

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