GAS TUNGSTEN ARC WELDING IN A MICROGRAVITY ENVIRONMENT

WORK DONE ON GAS PAYLOAD G-169

BY

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ABSTRACT

In this paper the work done on GAS payload G-169 is discussed. G-169 contains a computer-controlled Gas Tungsten Arc Welder. The equipment design, problem analysis, and problem solutions are presented. Analysis of data gathered from other microgravity arc welding and terrestrial Gas Tungsten Arc Welding (GTAW) experiments are discussed in relation to the predicted results for the GTAW to be performed in microgravity with payload G-169.

OBJECTIVE

The objective of GAS payload G-169 is to provide information on the feasibility of Gas Tungsten Arc Welding (GTAW) in a microgravity environment. A thorough analysis of the weld produced by the payload in space will be done and compared to terrestrial welds produced with the same apparatus. To date GTAW has not been performed in space. The data received from G-169 should have particular significance for the assembly of the space station power system tubing.

The material to be welded is stainless steel 316 L (low carbon). The specimen is a tube 2.00 in. in diameter with a wall thickness of 0.0625 in. A bead on plate weld will be performed.

EXPERIMENTAL DESCRIPTION

As many of the experimental components as possible are off the shelf, commercially produced products. Using off the shelf products shortens the payload design time and ensures reliability.

Payload G-169, shown in Fig. 1, consists of: an experimental mounting rack, a GTAW power supply, a GTAW orbital weld head, a dc to ac power inverter, a pressure vessel of inert gas, a sealed battery box, a battery pack and a payload controller.

EXPERIMENTAL MOUNTING RACK

The experimental mounting rack consists of four shelves, 19.75 in. in diameter. Two of the shelves are 0.250 in. thick and two are 0.125 in. thick. Six, 0.375 inch diameter rods are used for support. Tubing, 0.500 in. diameter, is compression fit between the shelves for spacing and support. All parts of the rack are made of 6061-T6 Aluminum.

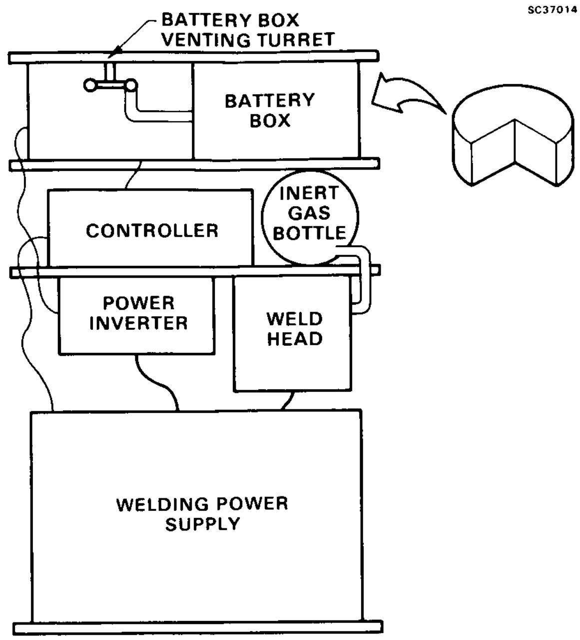

Fig. 1 Cross section of payload G-169.

GTAW POWER SUPPLY

The GTAW power supply is a modified System Technika International Nika Power 100. The Nika 100 is microprocessor based, allowing the storage and control of welding schedules. The power supply operates on 115 Vac @ 60 Hz. The power supply receives ac current and converts it to dc current for welding. The output characteristics of the power supply are dependent on the weld schedule to be used, that, in turn, being dependent on the material to be welded.

GTAW ORBITAL TUBE WELD HEAD

The orbital weld head is a modified System Technika International model 6003 Orbital Tube Weld Head. The model 6003 will accommodate up to a two in. outside diameter tube. The weld head includes a "U" style clamp, that prevents the tube from rotating. A tungsten electrode is mounted in a gear-driven track that rotates around the tube. The electrode consists of a rod of tungsten with 2% thorium, 0.0625 in. in diameter. A schematic diagram of the weld head is shown in Fig. 2. The weld head houses a chamber that is purged with an inert gas to prevent oxidation of the weld. A gas line inside the tube gives gas coverage to the underside of the weld, preventing oxidation of the specimen.

DC TO AC POWER INVERTER

The Nika 100 requires 115 Vac @ 60 Hz for operation. Since the power source for the payload is dc batteries, the production of ac current from the dc source is accomplished by means of a power inverter. The inverter chosen is the SPS 1607A Static Power Inverter manufactured by K.G.S. Electronics. The inverter receives 28 Vdc and inverts it to 115 Vac @ 60 Hz at a 1.2 to 1.6 KW output.

SEALED BATTERY BOX

The battery box is a 6061-T6 aluminum core internally coated with a nonconductive, electrolyte resistant material. The bottom plate is recessed out to

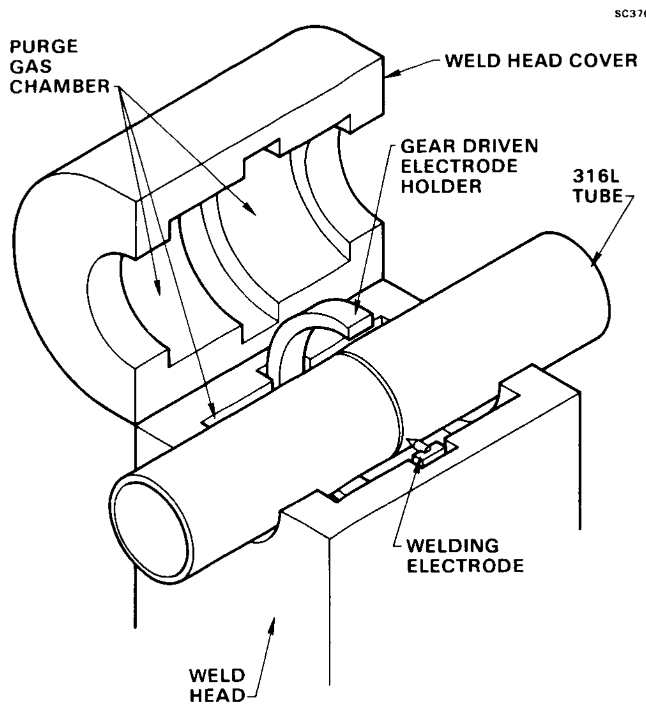

Fig. 2 Schematic diagram of in-place tube weld head.

secure the batteries. A mid-shelf made of plexiglass supports the top of the batteries. The top plate contains a vent that is plumbed up to the venting turret. Along the box sides are contact points for charging, power output, and thermistor leads. Before space flight the top and bottom plates will be sealed to the box via an "O" ring, compression fit to prevent gas leakage.

BATTERY PACK

The battery pack consists of 37 Gates Cyclon "J" cells. The "J" cell is a 2 V, 12.5 Ah battery. The battery pack consists of 3 separate subpacks of batteries all housed in the sealed box. The welding power supply requires 28 cells, the payload heaters need 6, and the controller needs 3 cells.

INERT GAS PRESSURE VESSEL

Argon is an inert gas commonly used to protect the weld pool from oxidization during solidification. In order to reduce the environmental parameters affecting the weld, an inert gas flow over the molten zone is used. During the welding process, an argon pressure bottle supplies a constant flow of gas purging the welding area of any other gases. The bottle is a spun aluminum core wrapped with fiberglass, manufactured by Structural Composite, Inc. A valve and regulator are used to reduce the bottle pressure to a safe line operating pressure.

PAYLOAD CONTROLLER

The payload controller consists of a Program Logic Sensor (PLS), a timer, and an analog to digital comparator (see Fig. 3). The PLS has two functions: one is to activate the welder upon indication of appropriate operating temperature, and

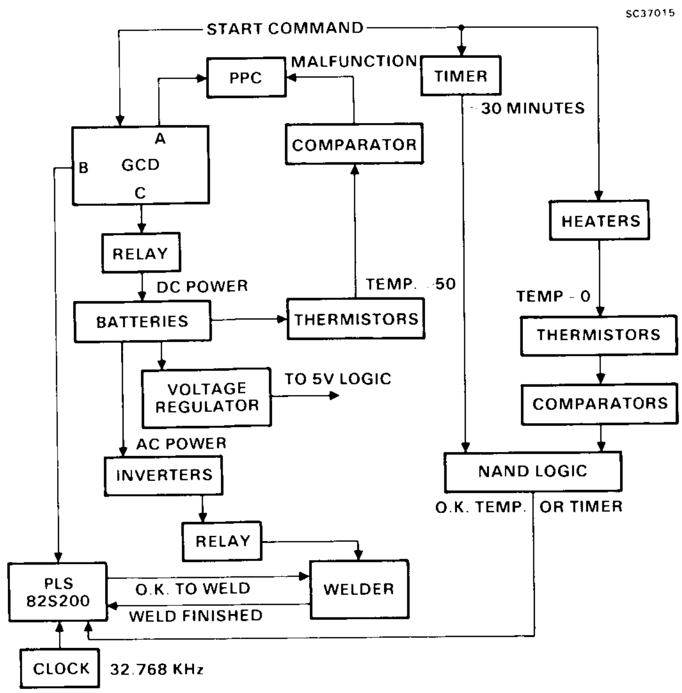

Fig. 3 Payload G-169 electronics block diagram.

the other is to send a signal to the GCD (gas control decoder) to interrupt power to the payload in the event of a thermal runaway (battery over-temperature). Upon payload activation the timer is started. The only function of the timer is to signal the PLS to attempt a weld start even if proper temperatures are not reached by a preset time, so at least some sort of data may be obtained. The analog to digital converter reads the analog signals coming in from the temperature thermistors and converts them to digital signals for use by the PLS.

PROBLEM ANALYSIS

During the development of G-169 the following problem areas were identified and addressed: (1) battery selection; (2) sealed battery box design and venting; (3) temperature control; and (4) electromagnetic interference (EMI) production.

BATTERY SELECTION

The Nika 100 requires 115 Vac at 60 Hz and converts it to dc power for welding. The initial battery pack configuration used dc battery power interfaced directly to the welder dc power input. Unfortunately, the dc to dc interface requires seven different voltages for welder operation, and thus seven different battery packs. If any one of the seven failed to produce its required power, the payload could be inoperative. Thus, an alternate power supply approach was required.

The second option, which was adopted in the final design, is to take the dc battery power and run it through an inverter to produce the ac current necessary to operate the standard Nika 100. The Nika 100, a very reliable power supply, is allowed to distribute the power as needed. This second method is obviously simpler and more reliable.

The testing of a battery to show that it is safe for space flight is an arduous task. Because of this a decision was made to use a battery that had already met the requirements for space flight. A logical battery choice is one of the Gates cells which have been used frequently in space payloads. Because of the payload's large power requirements, the first choice was the Gates Cyclon "BC" cell. After some research it was discovered that the "BC" cell had not yet met the requirements for space flight. The next choice was the Gates Cyclon "J" cell. The "J" cell is a 2 V, 12.5 Ah lead acid battery that has been proven safe for space flight.

SEALED BATTERY BOX DESIGN AND VENTING

The payload requires 37 Gates Cyclon "J" cells for operation. Because of the large number of cells, the potential exists for the production of explosive gases. Thus, as a part of a safety review NASA required that the battery package be vented out of the canister. A safe venting system requires a sealed metallic, nonconductive electrolyte resistant battery box, battery supports, and the necessary plumbing to the canister lid.

The battery box has an aluminum core with a nonconductive, electrolyte resistant internal coating. The batteries have top and bottom restraint plates to ensure stability against vibrational loading. A clearance of 0.50 in. exists between the top of the batteries and the battery box lid.

The plumbing from the battery box lid to the canister lid consists of VCR fittings manufactured by Kilsby Roberts Co. The VCR fittings are high pressure, close tolerance fittings used to connect tubing. All plumbing parts are stainless steel and are butt welded together.

TEMPERATURE CONTROL

Two temperature control problems have been identified. One problem is the effect of below 0°C temperatures on the microcircuitry. The majority of the electronic components used on G-169 meet military specification (subzero operation), but there are a few that do not. Operation of nonmil spec chips in subzero temperatures can cause failure. To prevent failure from occurring, heaters are located around the temperature critical circuitry. Upon activation of the payload the heaters are turned on if subzero temperatures are encountered. Once above zero temperatures are indicated by the thermistors, a signal will be sent from the PLS to the welder for activation.

The second problem is concerned with battery over-temperature. Because of the large amount of current required, excessive battery temperatures could occur. To prevent the batteries from overheating, temperature thermistors are used to sense temperature extremes. If a thermistor indicates excessive temperature a signal is sent to the GCD to shut down the system.

ELECTROMAGNETIC INTERFERENCE (EMI)

Electromagnetic Interference (EMI) is a high frequency electromagnetic wave. When an electrical current is passed through a wire a magnetic field is set up. The greater the current the greater the magnetic field. A high frequency alternating magnetic field produces an electromagnetic wave.

EMI can travel through air, up electrical cables, or along any other conductive path. Any type of device capable of receiving high frequency waves can receive EMI output. Upon receipt of EMI a current is produced. If the current produced is high enough, damage to the system can occur. EMI can activate or deactivate an idle or running system. EMI can seriously affect computers and radio communications. The Nika 100 utilizes a high frequency starter to initiate the arc. This starter is a major producer of EMI.

The standard GAS canister will attenuate up to 70 dB of EMI. It is strongly suspected that the combination of the power supply and the power inverter, both EMI producers, will exceed the 70 dB limit. EMI can be measured by the use of a spectrum analyzer with a calibrated antenna. EMI is effectively shielded by the use of copper screen, metal foils and metallized elastomer gaskets. It is desirable to entrap EMI as close to the source as possible.

EXPERIMENTAL HYPOTHESIS

To date no data exist on Gas Tungsten Arc Welding in space. The United States, the USSR and West Germany have done considerable research in other areas of microgravity welding.

The exact influence that gravity has on weld effectiveness is not known. A majority of space welding experiments show areas of commonality, but there are areas of discrepancy. The effects of gravity can be seen in buoyancy driven convection, surface tension, bead geometry, hydrostatic pressure, and removal of trapped gases. In a microgravity environment some of these conditions have negligible effects.

In welding, the effects of gravity are most important in determining the properties of the solidified material. Although gravity has no direct effect on grain structure or other microstructural properties (these are determined by crystallization kinetics, which in turn is controlled by short-range intermolecular forces), it can, however, indirectly affect solidification through its effects on fluid motion [1]. The motion of the liquid metal is a major factor in the stability of the pool and also, through convection, affects heat transfer within the pool thereby controlling the penetration and cross-sectional profile of the weld fusion zone [2]. The elimination of the buoyancy driven convection may have the effect of substantially reducing or eliminating macro- and micro-segregation from the solidified weld [3].

Previous experiments show a correlation between a microgravity environment and a more uniform grain size throughout the heat effected zone. This could possibly be accounted for by the lack of buoyancy driven convection, thus creating a slower solidification rate. The solidification rate is shown to also be a function of the thermal conductivity of the specimen.

The lack of buoyancy driven convection could prevent the removal of entrapped gas bubbles in the fluid metal. The entrapped gases could cause potential voids and an increase in the porosity in the space-welded specimen. The entrapped gases could chemically alter the corrosion-resistant properties of the stainless steel.

The shape of the fluid weld pool in a microgravity environment is a subject of controversy. One theory suggests that the absence of gravitational and hydrostatic forces will cause the liquid pool to take on a shape that minimizes surface energy. A minimum surface energy configuration would be spherical in shape. This analysis suggests that the bead shape will be determined solely by surface tension.

An alternate theory suggests that in a microgravity environment a liquid medium has a greater affinity for its parent material then it would in a one "g" environment. This affinity could cause the fluid metal pool to be drawn back to the parent material, and thus result in a thinning of the weld pool. A horizontal cross-sectional view of the weld pool would show an hourglass shape. This theory states that surface tension is the driving force in weld pool shape but that the bead geometry is affected by the affinity for the parent material.

The specimen to be welded is stainless steel 316 L, a material with low thermal conductivity. From the data analyzed and the fact that the specimen has a low thermal conductivity, one is lead to believe that the space-welded specimen will exhibit a heat-effected zone almost entirely comprised of small grains. At the interface of the heat-affected zone with the parent material, macro- and micro-segregation should exist producing a grain size gradient.

This analysis suggests that the bead geometry of the space-welded specimen should be about the same as its earth-based counterpart, a shape somewhere between what the two above stated theories suggest. G-169 utilizes an argon purge to protect the weld from oxidation. This purge, being a gas flow, could possibly create convective cooling, thus allowing convective heat transfer. The temperature gradient produced by the convective cooling could cause a migration of any entrapped gases to the weld surface. Overall, the weld produced on G-169 should be a better weld in terms of strength and penetration. The physical appearance should show a bead that is similar to its earth-based counterpart but with a smaller, more uniform granular structure.

ACKNOWLEDGMENT

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