Sensors are devices that monitor changes or variations in an object or process relative to a reference standard. Depending on their intended function, they can recognize changes in weight, vibration, motion, pressure, color, heat, light, magnetism or chemistry. They may be part of a system controlling a manufacturing process, activating a warning system, controlling vehicle motion or monitoring patient vital signs, to name just a few.

Sensor devices come in various forms and utilize different laws of physics. Fluctuations in sensible heat expand or contract a liquid column and form a thermometer when viewed against a calibrated reference scale. Differential thermal expansion of a bi-metallic strip provides mechanical motion to operate a switch or move a needle on a calibrated gauge. Volume or pressure changes resulting from thermal expansion (or contraction) of liquid in a sensing well create bellows or diaphragm movement useful for operating a switch or providing control of process gradients. Streetlights go on when the daylight dims the photocell output. Forces can be measured by detecting mechanical displacement, balance changes, elastic material movement or variations in electrical resistance. A sensor that supplies a signal by converting pressure to electrical voltage or digital output is called a transducer.

With today's fast moving technology, new sensors are constantly being developed with increased sensitivity. Often their components are miniaturized, utilize microelectronics and are precisely arranged in very small and compact assemblies. To protect them from the abuses of harsh environments, their packaging is designed for protection against contamination, vibration, moisture, impact, abrasion, heat or magnetic forces. In this way the sensor is assured consistent and reliable performance throughout the life of the product. Since mechanical assembly using screws or clamps can cause time related failures, welding is often the preferred joining process for both intermediate and final assemblies. And, since leak rates of less than 1x10-9 can be achieved, welding is almost mandatory when hermetic sealing is required.

Another important area of consideration in sensor design is fluid isolation. Many processes today use corrosive gases or demand very clean fluids (less than 0.1 micron particle count). These processes often require a 316L stainless steel or Hastelloy C isolation diaphragm as the only material in contact with the process media. It is easy to see the advantages that welding has in attaching such an isolation diaphragm to a connecting flange.

WELD CONCERNS

Sensor welding presents unique problems related to thermal effects. The steels used for housing and other components have melting temperatures in excess of 2500°F. Local surface temperatures at the weld may exceed 3000°F. Care must be taken in the location of sensitive components to avoid damage by heat transferred from the weld zone. Micro cracks in the heat affected zone can develop into leak paths, or worse, result in failure under load. Deposition of metallic vapors on electrical surfaces can destroy the sensor's ability to function.

Weld bead shapes should have smooth transitions with the base metal to avoid the development of stress concentration areas leading to early fatigue failures. Undercutting, concavity, and other visual defects are detrimental. Weld penetration conforming to the drawing or specification requirement is verified by macro or micro sectioning assemblies. This assures pressure integrity of the assembly at the required proof and burst pressures.

Sensors frequently include diaphragms as thin as .001" to provide the system response. Their thinness affords little resistance to bending or buckling, and they are easily distorted from the heat of welding unless special precautions are taken. If components are not kept in intimate contact, the heat from welding can cause burn through or melt back, most often ruining the assembly. To avoid this, some pressure monitoring assemblies incorporate a diaphragm that is sandwiched between two thicker sections.

Sometimes an actuator rod is coupled to a diaphragm, enabling the flexing motion to be transferred to perhaps a motion amplifying device, switch or a graduated control. This rod can be joined to the diaphragm by welding, however once again, the thin diaphragm, because of its minimal heat sink capability, is particularly sensitive to variations in the welding process.

Control of energy input is critical to avoid the conductance of excess heat into the sensor. This can damage sensitive electrical components, or result in distortion of the thin diaphragm. Residual stresses can have long term, insidious effects manifested as shortened fatigue life and calibration drifting. These concerns emphasize the importance of minimal heating and consistent control of weld penetration.

Occasionally, difficult to weld materials such as hastelloy, beryllium, brass and aluminum are used. Heat treatable alloys require special consideration in the development of weld parameters to preserve the special hardness, strength or corrosion resistance characteristics for which the material was selected.

For these reasons, the focusing and precise targeting characteristics of either the electron beam or laser welding processes are ideally suited for sensor manufacture. Their high energy density enables minimal heat to be used for critical, heat sensitive weld joints.

WELD JOINT DESIGN

In some instances the weld joint is a combination of thin and thick materials producing unbalanced heating during welding. It is evident that with GTAW techniques, a thinner detail would melt back before a thicker member reached it's melting point. Solutions to this problem include the use of fixtures designed to chill or cool the thin component in order to decrease the heat imbalance. Heating imbalances can also occur when materials having dissimilar thermal conductivity or melting points are welded, such as joining copper to stainless steel. The use of either electron beam or laser should always be considered in these situations. Their precisely focused and targeted beams can be positioned to favor the thicker detail, thus delivering different energy levels to each of the components.

Joint design is critical to consistent weld quality, and the vast number of possible weld configurations makes the subject too large for the scope of this article. Suffice it to say that multiple iterations may be necessary before a final configuration is achieved.

PROCESS SELECTION

Product designers and manufacturing engineers should have an overall basic understanding of the commonly used welding processes. Too often the welding requirements are ignored, making the final assembly operation the most difficult, troublesome and costly phase of the manufacturing process. Each metal joining process has its unique characteristics. In selecting a process for a specific joining operation, the particular requirements and conditions involved must be examined. Questions such as depth of penetration, joint preparation, cleaning, inert gas or vacuum shielding and weld joint accessibility need to be addressed. Other factors such as proximity of the weld area to heat sensitive materials must be considered. And of course, the cost of the operation, whether performed in-house or sub-contracted, must be economically feasible.

Electron beam, laser beam, plasma arc and gas tungsten arc are the dominant choices for sensor welding processes. Technically, electron beam and laser are the ideal candidates of choice. The precise narrow welds and low total energy input prevent distortion and minimize heat-affected zones. Both processes produce welds of high metallurgical quality. In view of these significant advantages one would question why any welding process other than electron beam or laser would be considered. Perhaps the most comprehensive answer is cost. The capital investment starts at $150,000.00. Depending on energy output levels, automation, number and range of axis of motion control and other levels of sophistication, the cost can quite easily exceed several hundred thousand dollars.

LASER WELDING

The laser welding process uses a focused energy beam diameter in the order of .030" or less. The weld joint fit-up must be machined to close tolerances, with a joint gap of less than 0.004" desirable and zero gap as the goal. Gaps exceeding 0.005" quickly become unweldable as there is simply insufficient fusion material available. Occasionally filler wire or shims can be tacked or otherwise secured along the joint, but this operation adds greatly to the cost of the process. Automatic filler wire feed is very difficult since it must be precisely fed into a very small weld pool with exact and unforgiving timing.

When the workpiece can be designed and fabricated in anticipation of using either the electron beam or laser process, the results are unrivaled. The lack of distortion, minimal defects, high metallurgical quality and (in the instance of laser) the exceptional potential for high volume automation can make these processes very cost effective. The basic reason for the laser's automation capability is perhaps best summarized in the statement, "lasers have freedom of movement." Laser focusing and beam delivery optics are readily incorporated in computer programmed multi-axis motion systems. High volume production assemblies can be manipulated under programmed optic motion for welding. Special environments (other than cleanliness) are not needed for the laser to function. If inert gas shielding is required to protect the workpiece from oxidation, it is easily controlled in the programmed weld parameters. The freedom from the physical limits of vacuum chambers enables large workpieces to be welded. The laser emits a beam of concentrated light free of restraining cables, electrical connections and limiting arc length requirements. In addition the raw, collimated laser beam can be projected great distances to time-sharing workstations.

The laser's most significant limitation is weld penetration. Generally the process is limited to a penetration depth of less than 0.100" (and most commonly to 0.030" or less). Although very high power lasers are available, with greater penetration ability through "keyholing" techniques, they are more cost effective for processes such as drilling, trepanning, and cutting. Fortunately, weld penetration capability of less than .100" encompasses nearly all sensor requirements.

ELECTRON BEAM WELDING

The electron beam process, on the other hand, has the ability to penetrate as little as a few thousandths of an inch, to depths exceeding 10". The stream of focused electrons can penetrate materials with low thermal conductivity to even greater extents. In this regard, electron beam welding has no rival. The process is performed in a high vacuum environment, and the result is that there is virtually no chance of oxidation of the workpiece.

The EB process is readily adapted for small production lots or prototypes. Computer stored or documented parameters are quickly set up for repeated large or small production runs as well. Modern vacuum chambers with state or the art seals and high performance pumping systems enable rapid evacuation of chambers, making the process economical. With a microscope viewer, the electron beam (as with the laser process) becomes an extremely accurate tool with resolutions of beam placement in the order of 0.001", making thin, critical welds commonplace.

As with all major capitol equipment procurements, manufacturing facilities must give serious consideration to utilization percentages if they were to acquire this process for in-house use. Utilizing job shops specializing in the use of this high-tech welding equipment easily solves this problem.

PLASMA ARC WELDING

Plasma arc and gas tungsten arc welding equipment are relatively inexpensive. Although they cannot duplicate the energy density, precision and limited peripheral effects of the laser and electron beam welding process, they are well suited for sensor assemblies designed and fabricated in anticipation of their use. Of these two "production workhorses," plasma arc welding more closely satisfies the need for the precision welding usually required for sensors.

The plasma arc is achieved by first establishing the arc (and generating the plasma) inside the torch head. The plasma, at temperatures as high as 30,000°F near the tungsten electrode, exits from the torch through a small diameter, aerodynamically designed constricting orifice. The orifice collimates the plasma and dramatically concentrates its energy into a beam-like, high velocity stream. The small diameter constrained plasma column provides directional control and produces narrower welds than the gas tungsten arc process. The plasma process produces deeper penetration than GTAW at the same energy levels.

More importantly, the higher energy density of the concentrated plasma results in more rapid heating of the weld joint and significantly reduces the heat-affected zone adjacent to the weld. Plasma arc equipment and power supplies incorporate all of the electronic control circuitry and components necessary for repeatable weld processes. These features include control of pulse rates, pulse profiles, current sloping and arc polarity. Though arc length is less critical with PAW than with GTAW, automatic arc length control is also integrated to accommodate variations in weld joint run out.

GAS TUNGSTEN ARC WELDING

Though developed over 50 years ago, the use of the gas tungsten arc process did not reach prominence until the 1940's when the aircraft industry recognized its advantages over gas welding. Helium was first used as the inert gas for electrode and weld joint shielding. The process was called Heliarc. Later, argon was substituted for the helium and the process was labeled "TIG" for Tungsten Inert Gas, recognizing the use of both the helium and argon inert gasses. The name has been further refined to Gas Tungsten Arc Welding (GTAW) since other gasses, such as hydrogen, are sometimes combined.

The GTAW process continues to be a production workhorse in most industries where metal joining is required. Although most often performed manually, it sometimes is integrated into fully automated systems.

In the hands of a skilled welder, the process is extremely flexible. The welder's ability enables him to readily adapt to joint configurations and compensate for fit up tolerances and other variables. The skilled welder easily accommodates for joint gaps, mismatch, and other irregularities that would be unacceptable for precision automated machine welding. Unlike the machine dependent laser and electron beam welding processes, the need for precise and consistent joint preparation, though preferable, is not necessary. Machine welding requires defined parameter development, as manipulation and correction during the course of the weld is very limited if not impossible. The skilled welder, on the other hand, becomes and assumes the role of machine, computer, axis of motion, scanner and inspector. The intrinsic value of manual welding, whether GTAW or PAW, is the ability to produce high quality welds, with maximum flexibility and minimal capital investment. The availability, minimal development and low capital equipment cost are offset by the labor-intensive nature of the process, with the level of quality dependent on the skill and consistency of the welder. Transfer of an operation from one welder to another, or between shifts or facilities, can become difficult.

The broad arc configuration of the gas tungsten arc process and its much lower rate of energy input to the workpiece result in a wide, high volume melt, and a more extensive heat affected zone. As discussed previously, these conditions can easily become the source for distortion, cracking, porosity and stresses.

SUMMARY

It is impossible to summarize or state without reservation which fusion welding process should be used for maximum efficiency in a given production application. There can be many specific variables and subtleties. There are, however, some generalities to help define a given process for sensor welding:

- For penetration beyond 0.250" without preparation of the weld joint for filler metal, electron beam is the indisputable candidate.

- For critical, heat sensitive weld joints and widely dissimilar materials laser and electron beam would be favored.

- When distortion to any degree is unacceptable laser, electron beam, and plasma arc are suitable choices.

- For high volume, long production run welding of sensor assemblies, laser offers the best approach.

- For maximum flexibility, immediate use, minimal development, less critical joint tolerances, and low capital investment plasma arc and gas tungsten arc are the dominant choices.

ABOUT THE AUTHORS

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