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SN – Fusing

by
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SN-Fusing (also called Tin Fusing), is a method of joining copper electrical conductors, which results in an excellent electrical connection, without the need for any type of terminal or other mechanical holding device. Both bare and film insulated conductors (magnet or winding wire) can be joined. It is possible to join film insulated conductors, without prior removal of the insulation, which is automatically removed during the fusing process. It is also possible to use special very low cost terminals with the SN-Fusing process.

SN-Fusing requires that one of the conductors being joined be coated, or better, plated with Tin. The Tin acts as a cleaner or purifier of the metals that are to be fused. Without the Tin coating, a joint might be obtained, but it would not be strong enough to be effective. It is also possible to use Silver in the place of Tin, but normally silver is not practical, because of their cost.

For a valid joint to be obtained, all insulation and foreign matter must be removed by the fusing process. After this occurs, the Tin wets the un-tinned conductor and purifies the copper (or a copper rich alloy, such as brass) at the joint's interface. The fusing process continues to heat the joint, which results in the Tin being removed from the joint area. The joint area then consists of ultra-clean copper touching ultra-clean copper (or a rich copper alloy), under heat and pressure. Clean metals clamped tightly together and heated until just before they melt result in a diffusion weld or bond. The metal surfaces fuse and a bond is created.

Diffusion Bonding [also called Diffusion Welding] • "A solid state welding process that produces a weld by the application of pressure at an elevated temperature with no microplastic deformation or relative motion of the work pieces".

The definition above is from JEFFERSON'S WELDING ENCYCLOPEDIA, which was published by the American Welding Society of Miami, Florida - USA, in 1997, and is the industry standard definition, as defined by the American National Standards Institute (ANSI) standard A3.0-94, first published in 1940, and most recently revised in 1994.

Fusing - History

Fusing is a method of joining insulated or un-insulated low resistance wires, through the use of a very simple termination method, which uses a type of resistance fusing machine.

Fusing was originally developed in the early 1950's for use in the manufacture of small universal or D.C. electric motors. At the time, electric motor production for mass markets was quite small, armatures were machine wound, and the lead wires were inserted into slots in the commutator, by hand. The film insulation was manually removed from the wound lead wires, prior to insertion, and the wires were then joined to the commutator. The armature's commutator was then dipped into a molten solder bath. This worked well for low production, and is still being done by some small operations outside the United States.

As production increased and higher temperature insulation systems became available, a faster and more reliable joining method was needed. A fusing system was developed to connect the film insulated lead wires in the commutator's slot, without prior removal of the film insulation. The fusing process automatically removed the insulation. This process is still used today for high performance motors. The method of fusing wires into slots is also used for other limited non-motor applications.

As motor production increased, manufacturers wanted to eliminate the need to place the armature's lead wires into slots. Winding machines were developed to place the wire around pins or hooks (tangs) in the commutator, to which the wires were soldered.

Soldering was then eliminated by the introduction of tang commutator fusing. It is used today to manufacture at least 95% of all the universal or D.C. electric motor armatures produced in the United States, and at least 90% for the rest of the world. Fusing of slotted commutators increases the statistics to over 98% for the U.S. and 95% for the rest of the world. Fusing is the accepted method, that is used worldwide.

In 1962, a machine specifically designed for commutator fusing (for both tang and slotted armatures) was Patented (U.S. patent 3,045,103). The commutator fusing machine patented in 1962 is similar to the machinery used today. The new versions differ only in the fusing head's construction and the types of electronics used to control the fusing time, heat and current.

In the early 1950's fusing machines were developed for other than commutator fusing. Most were for terminating bobbin windings to tang terminals, set in bobbin spools. As time went on, tang termination systems were developed for attaching film insulated wire to just about any component. Today, tang termination can be used instead of most crimped terminals, as well as many applications where crimped terminals cannot handle the job. Normally, Tin is not a required component for tang fusing. This is because the process does not use high enough heat levels to remove the Tin from the tang's joint area. Therefore, a diffusion bond is not normally created during tang fusing.

SN-Fusing was first developed for joining a single strand of film insulated magnet wire to tinned stranded wire. The film insulation was automatically removed during the fusing process. Later, methods were developed for joining large numbers of magnet wires together using tinned tubes, and for joining magnet wire to tinned pins and terminals. Also, a process was developed for joining large tinned conductors to large commutators on starter and traction motors.

Fusing and Surface Adhesion

Fusing is a method of joining low resistance metals with a type of resistance welding machine, but without appreciable distortion of the parts being joined. Normally, when copper is resistance welded, it is drastically distorted. This does not occur with fusing. What actually happens in commutator fusing and tang fusing (which are not SN-Fusing processes), is that the parts are heated and pushed together until all the air between them is eliminated, and the high points of one part are pushed into the low points of the other, and vice versa. A surface adhesion contact will then hold the parts together. With SN-Fusing, a diffusion bond is developed. Commutator or tang fusing is not the same as SN-Fusing. With SN-Fusing there is a metallurgical bond. With commutator or tang fusing there is just a surface adhesion bond, which is physically held together by the fused tang terminal.

The surface adhesion contact is not a weld or diffusion bond. It is a thermo-compression joint, which affects only about 0.0002 of an inch (0.005 mm) of surface depth with no amalgamation or diffusion of metals. As the strength of the joint is not too great, it must be used only with parts specifically designed to be fused, such as a tang terminal, or wire slot. If the interface at the fused joint consisted of ultra-clean copper, which it does not, we might be able to obtain a diffusion bond instead of a surface adhesion or thermo-compression bond, and would not need the tang terminal or wire slot. However, the commutator or most tang terminals are not designed to handle the high temperatures required in SN-Fusing.

As stated above, the wire is heated during the fusing (not SN-Fusing) process. The heat at the surface of the wire can reach 1,000°F to 2,000°F (537°C to 1,093°C). This heat is usually not sustained for more than 450 milliseconds. Normally, for small wires, 64 to 160 milliseconds is the average time. During this time, insulated wire with any known film or plastic insulation, will be flash vaporized in a puff of smoke.

Welding or Fusing

The words fusing and welding are used interchangeably by most people. There is a great difference between the two processes and their machinery. Resistance welding (spot welding) is the process of joining metals by locally heating them to their plastic state, and then forging this plastic metal together. The metals being joined are heated internally by passing current through them. The resistance of the metal determines the amount of current and the time the current must be passed, to bring it to its plastic state. Because we want the metals being welded to heat internally, we must make sure that the devices (called electrodes) conducting the current have a lower resistance than those being welded.

Welding • "A joining process that produces coalescence [The growing together of growth into one body of materials …] of materials by heating them to the welding temperature …".

Resistance Welding * "A group of welding processing that producing coalescence of the faying [the mating surface of a member that is in contact with … another member to which it is to be joined] surfaces with the heat obtained from (electrical) resistance in a circuit of which the work pieces are a part, and by application of pressure".

The definition above is from JEFFERSON'S WELDING ENCYCLOPEDIA, which was published by the American Welding Society of Miami, Florida - USA, in 1997, and is the industry standard definition, as defined by the American National Standards Institute (ANSI) standard A3.0-94, first published in 1940, and most recently revised in 1994.

When fusing, we want just the opposite. The current carrying devices get hot because they have a higher resistance than the parts being fused. These hot current carrying devices (electrodes) dissipate their heat into the parts that are being fused.

Fusing heats the wire(s) and/or terminals. Any insulation around the wire is vaporized at this time. Theoretically, the wires should not be deformed, but usually they are, slightly. Wire flattened to no more than 200% of its original diameter is acceptable, in most cases. More than this will weaken the wires to a point where they might break from the slightest mechanical movement, such as when a surge of current is passed through them, or the connection vibrates.

In welding, we need a cooling system to protect the welding transformer, electrodes, and other current carrying devices from any heat transferred from the part being welded. As heat is developed in the parts being welded themselves, the cooling system will not have to absorb the majority of it, as the work will dissipate most of the heat throughout itself. In fusing, the heat is developed in the electrodes and dissipated between the work and the rest of the current carrying system. Therefore, the cooling system must be much larger when fusing versus welding. Heat is developed equally for their sizes, in either a fusing or welding transformer, but a fusing transformer must have a higher thermal rating, as more heat will travel to it from the electrodes.

In a welding system, pressure must be exerted on the parts to forge them together, when they reach their plastic state. The pressure must be regulated, so that there is just enough to forge the parts, as too much will cause the current to pass through them more easily, without heating them to their plastic state. If "just enough" pressure is used, there will be some surface resistance between the parts being welded, as well as the parts and the electrodes.

When fusing, we must have more pressure applied on the work, as we try to force the metals together, without them reaching their plastic state. This means that we are only softening the parts slightly, and relying on the pressure to force them together. Therefore, we must have constant heavy pressure exerted on the parts through the electrodes. Because of this, the fusing head is, of course, much heavier than a welding head, assuming the current carrying capacities are the same.

In fusing, we treat the wires as not being a part of the joint, until we remove the insulation, if any, oxides or foreign matter. This means that we must apply enough current to the electrodes to heat them to a point where they can dissipate enough heat to remove this insulation or foreign matter. As the wire itself can be damaged, this heating must be carried out in an extremely short time. The only way to do this is by flash vaporization. Normally, a resistance welding system would overheat, if we applied current densities per given time as great as used in fusing, even with the best of heat transfer systems (cooling systems). With fusing machinery, we must use heavier current carrying devices, more iron in our transformers, transformers with higher secondary voltages, and a completely different type of electrode system, in comparison to a resistance welding machine.

SN - Tin

Tin (SN-Stannum) is a natural element, that is a silver white metal with a bluish tinge. It is not oxidized on exposure to air at normal ambient temperatures. Tin is used mainly to coat metals, such as iron, steel and copper, to protect them from oxidation, as well as being an ingredient in soft solder. Pure Tin causes no harm to humans. It is, therefore, used as the main ingredient in pewter, which is made into eating utensils for humans. Tin has a low coefficient of friction, and therefore, is sometimes used in bearings.

Below is a listing of some of Tin's characteristics and specifications:

- Atomic Symbol - SN
- Atomic Number - 50
- Atomic Weight - 118.70
- Melting Point - 231.9°C (449.4°F)
- Boiling Point - 2.270°C (4,180°F)
- Tensile Strength - (20°C) 1.52 KG/MM^2 (2,161.94 PSI)
- Shear Strength - (20°C) 1.26 KG/MM^2 (1,792.14 PSI)
- Commercially Pure Tin - 99.85%

Tin acts as a solvent of copper. If Tin is heated until it is liquid, and a bar of copper is inserted into the molten liquid Tin, the copper bar would eventually dissolve. This solvent action or wetting is what allows Tin to coat copper by dissolving its surface molecules. Tin adheres or wets to copper's surface with a strength comparable to that which a piece of solid metal holds together, that is, by the attractions between adjacent atoms which are generally termed chemical forces. Tin being attached by such forces, cannot be mechanically pried off the copper's surface. Further, Tin cannot be completely drained off or wiped off when molten or liquid, for the copper's surface remains permanently wetted by a film of it.

A copper/Tin inter-metallic compound is formed whenever Tin wets copper. This compound itself is not strong or advantageous. Therefore, by using a minimum amount of Tin which is brought into contact with the base copper alloy, for as short a time as possible, we can "Tin" or coat the copper, while keeping the copper's basic strengths and properties. For tinning to occur, the copper must be relatively clean of any foreign matter. Without the wetting of the copper by the Tin, there is no tinning action, possibly only a mechanical anchorage at surface irregularities. Tin's interface with copper is chemical in character rather than purely physical, as it involves a non-mechanical or metal solvent action.

The copper/Tin inter-metallic compound that is formed when Tin wets copper is called bronze. However, the alloy produced when Tin wets copper is Tin rich. Bronze, traditionally, consisted of less than 8% Tin. The copper/Tin inter-metallic compound which results from the wetting action of the Tin, has less than 8% copper with the balance being Tin. This compound approximates the strength of Tin, and has none of the qualities of bronze.

Tin can also be applied to copper by electroplating or chemical plating in an alkaline sodium stannate solution or acidic stannous sulfate solution. This electro chemical tinning can be performed where dipping an article into molten Tin would damage it, or a pre-determined coating thickness is required. Electroplating of Tin on copper is covered by (U.S.) Military Specification MIL-T-10727A. Coating thickness is normally from 0.0001 to 0.0006 inch (0.00254 MM to 0.01524 MM).

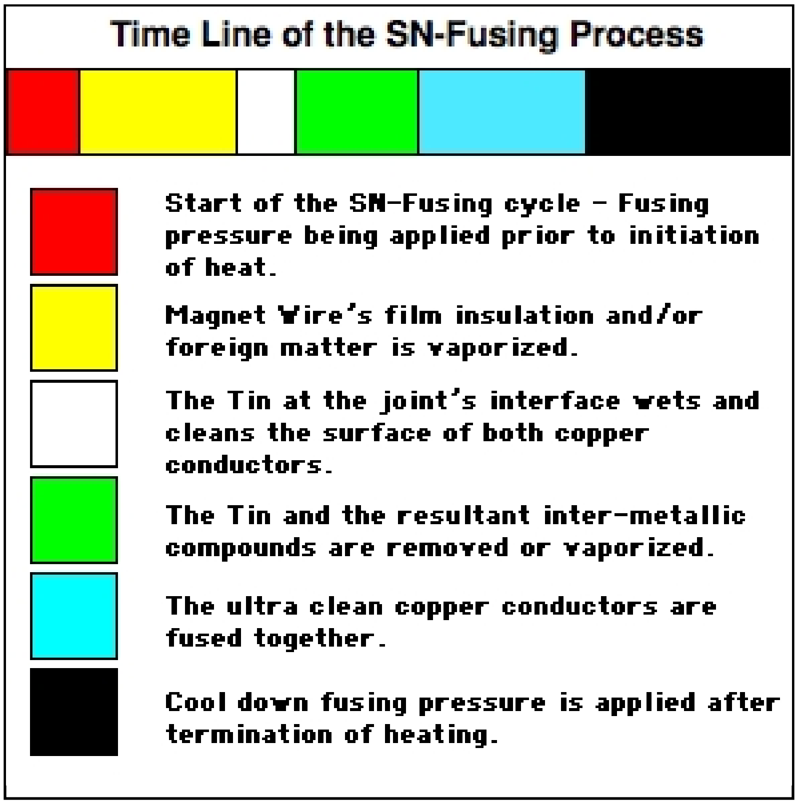
SN - Fusing

SN-Fusing consists of six basic steps that are detailed below. These steps are carried out automatically, usually in less than one second, by the fusing machine.

Fusing pressure is applied to the conductors that are being joined, until a preset level of pressure is reached. At this point, heating is initiated.

As explained in the section on fusing, heat is applied to the fusing electrode(s), and then dissipated into the parts being fused. As heat in the parts being fused increases, first the magnet wire's film insulation, if any, is vaporized. Then the Tin, which is at its molten point, acts as a solvent to clean the surface of the copper conductors. As the dissipated heat increases, the Tin and inter-metallic compounds are vaporized or driven from the joint's interface. The resultant ultra-pure copper at the interface of the conductors is then fused, resulting in a diffusion bond. However, the fusing pressure must be continually applied, until the joint cools to a reasonable temperature, or the plastic metals will break apart, because of the contractual forces that are being applied to them during cooling.

Without the use of Tin as a metal cleaner, fusing can occur if there is a mechanical device to hold the joint together, such as a tang or wire slot. Electrically, the joint which does not use Tin as a cleaner is valid. Mechanically, it is not always valid. The tang or wire slot is used to



mechanically hold fused conductors in place. For commutator fusing or tang terminal fusing, no advantages have resulted with the addition of Tin. Most likely, the mechanically held joint is stronger than that joint produced using Tin. However, when holding the conductors together, with no mechanical securing devices, such as a terminal, SN-Fusing is the only way to achieve the connection.

The Tin allows the conductors at the joint's interface to be ultra-clean. Because there is no foreign matter or gases at the interface, there is a mingling of molecules. In actuality, this is a diffusion of vacancies where voids are filled with matter that is in their plastic state. If the conductors at the joint's interface are not ultra-clean, a fused connection will occur, but there will not be a true diffusion bond. Instead, there will be a surface adhesion effect, which is described in the above section on Fusing and Surface Adhesion. When using Tin in a joint, enough heat must be applied to vaporize or remove the Tin and any inter-metallic compounds, otherwise, the joint will be adulterated and a diffusion bond will not take place.

At least, commercially pure Tin must be applied to one of the conductors. The minimum thickness of the Tin on the conductors should be approximately 0.0002” inch (0.00508 MM) for copper and 0.0005” inch (0.012 MM) for brass. No more than a 0.004” (0.1016 MM) coating should be added. If too thick a coating of Tin is applied, too much copper will be converted to inter-metallic compounds and too much heat will be required to vaporize the Tin and these compounds. The heat being applied to the joint is used to remove any insulation, foreign matter, Tin and inter-metallic compounds, not to melt or vaporize the copper conductors. If we could fuse two conductors that had an ultra-clean interface, without any pre-cleaning, we would use a relatively low level of heat to accomplish this. The high levels of heat are required, when cleaning is performed during the fusing process. We cannot control the level of heat required to remove the magnet wire's film insulation, or other foreign matter on the conductor; however, we can control the amount of Tin present at the joint, which effects the level of heat required to produce an acceptable connection.

We have been talking about Tin (SN - Stannum) - pure Tin. SN-Fusing must use pure Tin, at least at the 99.84% level of commercially pure Tin, not solder or any other Tin alloys. Any lead metal added to the Tin will retard the cleaning effect, and introduce an environmental problem. As we vaporize the Tin and inter-metallic compounds, particles can be suspended in the air. Commercially pure Tin and Tin/copper inter-metallic compounds are not hazardous. However, lead (metal), and its fumes or particles would have to be controlled, as they are dangerous.

Silver and Gold Fusing

There are other metals, Silver (Ag), and Gold (Au) which have properties that are similar to Tin with regard to its solvent action against copper, and is sometimes used to plate or coat copper for fusing.

Silver which has a higher melting point, is not as aggressive a solvent as Tin, but will practically serve the same purpose. Silver costs about as much per Troy ounce as Tin costs per pound. Silver would be used instead of Tin only when the wire must be used in a high temperature environment.

Gold (Au), also is a solvent of copper, but is not normally used as a coating for copper that will be fused, because of its very high cost.

SN-FUSING APPLICATIONS

The SN-Fusing process replaces many known conductor joining methods used today. It always produces a valid joint at a lower cost, when compared with the process it replaces. As an example, SN-Fusing can be used as a valid substitute for some commutator brazing applications. It can be used for producing copper magnet wire connections in place of soldering, terminal crimping or terminal displacement. Below is a brief explanation of some presently used SN-Fusing technologies.

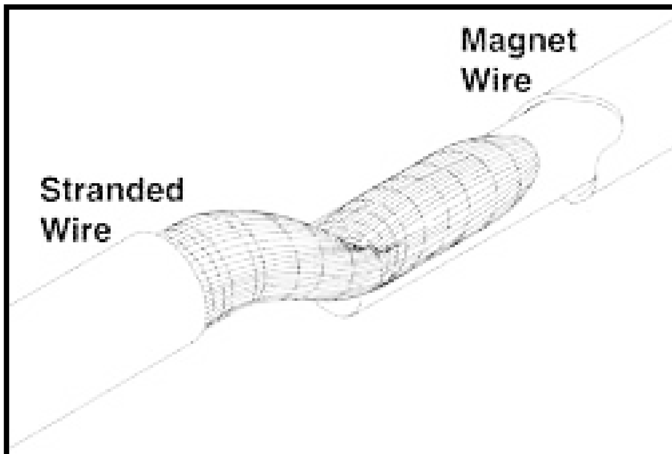
Fuse-A-Wire System

Prior to the development of fusing, magnet wire insulation had to be mechanically, chemically or thermally removed prior to soldering, or terminal application. Solderable magnet wire insulation is removed by the heat of the molten solder, during the soldering operation. Magnet wire insulation is mechanically removed or displaced during the terminal's application, by the physical construction of the terminal.

Solderable or self-fluxing magnet wire insulation will not adulterate the soldered joint. It either melts away from the source of heat, or melts into the surface of the solder and acts as a type of flux. Non-solderable insulation has either too high a destructive temperature, or will contaminate the soldered joint. Therefore, non-solderable insulation must be mechanically or chemically removed prior to soldering.

It is not practical to burn away non-solderable magnet wire insulation, as carbon will remain and adulterate the soldered joint. This insulation can be removed mechanically or with a fused salt bath. The fused salt chemically dissolves the insulation, but a conductor so treated, must be thoroughly cleaned, to remove all of the corrosive fused salt.

As a practical matter, most magnet wire that is connected to bare stranded or solid wire is mechanically crimped together with a crimp type terminal. The terminal, of course, must be manufactured, which adds cost to the connection. This type of terminal is only used to physically hold the magnet wires and stranded and/or solid bare wires together. If a method could be developed to attach the wires together without the use of a terminal, the terminal's cost would be eliminated, which would then lower the cost of the end product.



An illustration of a magnet wire being joined to a tinned stranded wire.

Ninety percent of the copper stranded wire used in the United States for electrical applications is tinned. It is almost impossible to obtain un-tinned stranded wire from stock. Therefore, there is usually no premium or additional cost when using tinned stranded wire. Tin coated stranded wire is not as prevalent outside the U.S.

A method called the Fuse-A-Wire System was developed to connect film insulated magnet wire to tinned stranded and/or tinned solid bare copper wire, without prior removal of the magnet wire's film insulation. No additional materials or filler metals are required to achieve a valid joint. The magnet wire and stranded and/or bare wire combination are placed in the machine's tooling – a pair of fusing electrodes, and the machine is activated. In less than one second the magnet wire's film insulation is removed and the connection is made. The Fuse-A-Wire machinery can produce either a pigtail connection or a splice connection. When producing the pigtail connection, the machine can cut any excess wire, if desired.

When connecting fine wire, fusing current is turned on once, and then off. When connecting wire combinations larger than 200 CMA (Circular mil area) (0.1 Square MM), a pulsation fusing system should be used. This method turns the fusing current on and off repeatedly in a pre-programmed cycle for a predetermined number of cycles. If the pulsation method is not used, too high a level of heat would be required to remove the Tin from the joint area.

The non-Tinned conductors (normally the insulated wires) should be smaller in cross sectional area than the tinned conductors. This means that a single magnet wire conductor or many magnet wires can be joined to a tinned conductor, as long as the magnet wires never are larger in cross section than the tinned wire.

By incorporating the Fuse-A-Wire System, which uses the SN-Fusing method, into the production process, a valid electrical connection can be achieved without adding any material or cost, other than the cost of the machinery, and the utilities required to operate it. As crimp or displacement terminals do not have to be used, their cost savings will normally pay for the machinery in a few months.

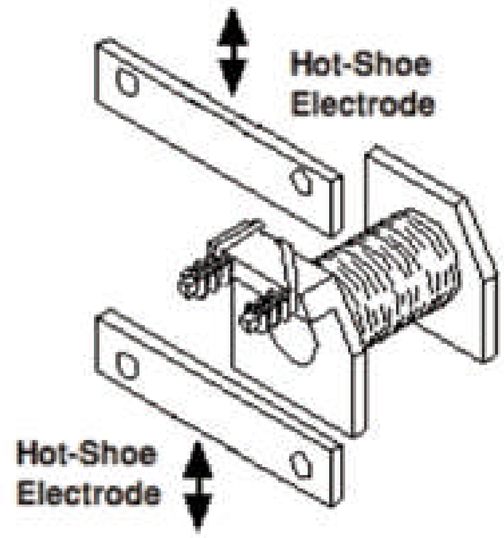
Hot-Shoe Fusing

The Hot-Shoe fusing method uses a type of fusing machine (which is quite different from the Fuse-A-Wire machine) where a single electrode is itself individually heated. This means that only one fusing electrode is required. No other fusing electrode or ground electrode is used. It is possible, however, to have two electrodes touch the conductors being fused, but they are each independently heated. When two electrodes are used, its like having two separate fusing machines, fusing a single joint.

The Hot-Shoe system is normally used to fuse items where only one electrode can touch the conductor. The conductor that the hot electrode touches can be insulated or non-insulated. However, one of the conductors must be Tinned. If two electrodes can physically touch the conductors, both can be used. Better results are normally obtained with two Hot Shoe electrodes.

The Hot-Shoe system incorporates a Thermal Monitor/Controller (TM/C). This device monitors and regulates the temperature of the Hot-Shoe electrode, not the joint being fused. Without the TM/C, the electrode would overheat and possibly damage the conductors being fused. Overheating could also damage or melt the plastic support in which a terminal that is being fused, is mounted. The TM/C uses a fiber optic to collect thermal data in real time. It monitors the temperature of the Hot Shoe's fusing electrode and terminates heating after the electrode reaches a predetermined temperature.

Hot-Shoe equipment is used to fuse magnet wire to round tinned pin terminals, square tinned pin terminals or flat tinned terminals. Normally, round/square pin



A diagram of Hot-Shoe fusing electrodes fusing a bobbin

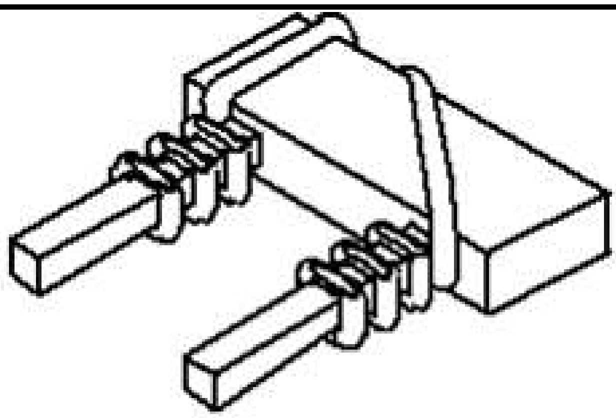
terminals use dual electrodes. Flat terminals can use either single or dual electrodes. However, any terminal that is used must be tinned.

The patented Hot-Shoe machinery can also automatically terminate magnet wire to tinned pin terminals that are inserted into bobbins. Automatic coil winding machinery wraps or spirals the start and finish leads around appropriate tinned pins that are set into the bobbin. During winding, taps can also be pulled and automatically wrapped around other pins. After winding, the bobbin is placed into the Hot Shoe machine where the magnet wire's insulation is automatically removed and the connections are made between the wire and pins, all at the same time.

Another application for the Hot-Shoe system is to fuse tang type commutators using only one electrode. This is ideal for fusing carbon commutators as well as other commutators on which it is not possible to place a ground electrode.

Hot-Shoe Commutator Fusing

With the introduction of carbon commutators, for some universal and D.C. electric motors, a single electrode commutator fusing process is required. The Hot-Shoe system using tang commutators was found to meet this requirement. A single electrode Hot-Shoe fusing machine is used to fuse the lead wires to the tang. This electrode



A diagram showing magnet wire wraped around a pin which has been fused to the pin with a Hot-Shoe fusing machine.

will mechanically close the tang and then apply heat to fuse it.

It is possible to use the normal commutator fusing process, as well as the SN-Fusing process with the Hot-shoe fusing machine. Which process is used, is determined by the construction of the commutator. SN-Fusing can be used for connecting lead wires to commutators, but a lot more heat, than is normally needed for commutator fusing, would be required. This extra heat could destroy the commutator, unless it was originally designed to accept the higher heat levels. Commutator Fusing (not using the SN-Fusing process) produces a compression bond, which is not as strong as the diffusion bond produced when using the SN-Fusing process (Refer to the previously described description of SN-Fusing). However, over the years, it has been found that the normal commutator fused joint is more than sufficient for joining lead wires to electric motor commutators. Therefore, most applications of fusing commutators with Hot-Shoe machines, uses the commutator fusing process (Compression Bonding), not the SN-Fusing process (Diffusion Bonding).

Three Electrode Strip'N-Fuse Fusing

The Strip'N-Fuse process is similar to the Hot Shoe process, but has one dual hot electrode and one un-heated electrode. It can be used to join film insulated magnet wire to tinned pins and terminals, but the Hot Shoe machine is faster and more efficient.

The Strip'N-Fuse process can also be used to resistance weld insulated materials, if those materials can be welded. This is because the dual heated electrode acts as a single electrode in a standard resistance welding and/or fusing circuit, while the non-heated electrode completes the welding and/or fusing circuit.

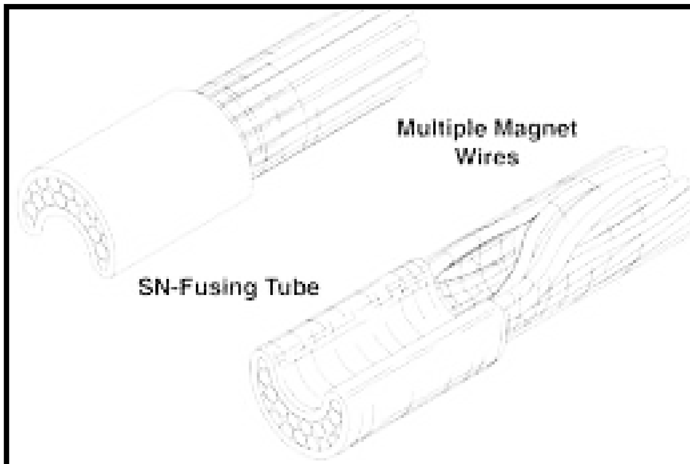
The Strip'N-Fuse system is used for joining conductors to insulated flexible circuits, welding or fusing through covered materials, such as zinc or vinyl coated metals, or through painted surfaces.

Tube-Fusing

When many (theoretically unlimited) individual magnet wire leads, by themselves, must be joined together or to stranded or solid wire, a tinned tube can be used. The tube acts as a gathering device, as well as a mechanical terminal. The wires are placed into a tinned copper tube. Electrodes then engulf the tube and it is fused.

The advantage of the tube is that the Tin, inside the tube, cannot easily be removed from the joint area, during heating, as the tube holds it in place. Therefore, the Tin tends to wet all of the wires inside the tube before it is driven out of the joint. This means that most, if not all, of the conductors inside the tube will be cleaned by the Tin. Another advantage of the tube is that it acts as a mechanical terminal. The wires are gathered and trapped inside the tube.

The tube is made from copper tubing that is cut to length



A top and bottom view of a group of magnet wires that are terminated in a tube that is designed for SN-Fusing

and deburred at the internal circumference of the tube. Tube diameters are available from an internal diameter of 0.125 inch (3.1 MM) to more than 2.0 inches (50.8 MM). The tube, of course, must be either coated or electro-plated with Tin. A tube that includes a flag, or a large crimp terminal that has a tube shaped bore can also be used. If the tube is made from flat stock that is rolled into the tube shape and brazed, special tooling must be used for fusing, but it can be fused.

Two types of Tube-Fusing machines are available. One is a bench type machine where the work being fused is brought to the machine. The other is a fusing gun type machine where the machine is brought to the work being fused. The Tube-Fusing system is designed to terminate from moderate size connections to extremely large connections. Automatic tube feeding systems are available for presenting the tubes to fusing electrodes. These systems speed up the joining process as the tubes do not have to be handled manually.

Tube Fusing of Litz Wire

Litz Wire, short for the German word “Litzendraht”, is a construction of fine individually insulated strands of wire (usually film insulated magnet wire) that are specially woven or braided together in a predetermined pattern into a bundle or group of wires, in order to reduce the “Skin Effect” and thus lower resistance in high frequency currents.

In an alternating current system, a phenomenon that occurs at elevated frequencies causes an increase in the resistance of the wire and forces the outer surface or skin of the wire to carry most of the current. This phenomenon, also called the Skin Effect, increases in intensity as frequency increases. To avoid the detrimental effects of this phenomenon, Litz wire is used.

As Litz Wire has many individually insulated conductors, sometimes into the thousands, some method must be used to terminate this type of wire. Solder can be used with Litz Wire that uses low temperature film insulation.

However, the trend, recently, has been to use high temperature film insulation in the range of Class F (155° C) of Class H (from 180° C to 220° C), which molten solder cannot break through. Crimp terminals cannot make a satisfactory connection, because the terminal’s insulation piercing teeth cannot reach every strand in the Litz Wire bundle. Another method is to use fused salts. This does not work well as the chemical residue cannot be completely removed from inside the Litz Wire bundle.

The only proven successful production method is Tube Fusing using the SN-Fusing process. A terminal or tube is used and all of the film insulated on each and every Litz Wire strand is removed. Any outer coating insulation (holding the Litz Wire strands) can also be removed during Tube Fusing.

Sealing The Wire Termination

When SN-Fusing stranded wire, Litz wire or wire that is made from a bundle of many individual small wires, it has to be understood that the Tin in the joint might not be able to coat all of the wires in the bundle. This is because the amount of Tin (or gold or silver) that coats the terminal’s tube consists of an extremely small amount of material. There might not be enough of the coating material to cover all of the individual wires in the bundle. Under normal circumstances this lack of coating material is not a problem. Only a very small amount of coating material is needed to make contact to the outer layer of the individual strands of the wire bundle. Heat and compression will help achieve a more than acceptable termination for the wires in the bundle that do not become coated.

The Tin or other coating materials and the compression sealing of the joint help protect the termination from outside environmental pollution. This pollution is normally atmospheric gases as well as moisture. However, when the termination is in a liquid that has a very thin consistency, the liquid could be drawn into the termination through capillary action, where the non Tin coated material is not diffusion bonded to the wires in the center of the bundle, or at the ends of the tube where the wires enter the tube. Most liquids will not damage a diffusion bonded joint if the wires keep their tin coating just outside of the joint area. Certain fluids, such as human body fluids tend to corrode the wires at the point where they enter the termination’s tube structure. This corrosion weakens the physical integrity of the wire bundle as it enters the side (or both sies if using a pass through tube) of the tube. Eventually, the wire bundle could be weakened to a point where the wires actually break or they have lost enough strands so that the current passing through them over-heats as there is a high resistance area in the wire. As this over-heated area continues to heat the wire, it continues to destroy the electrical connection.

Another problem occurs when fluids enter the center bundle of the fused termination because of capillary action, and the fluids start to corrode, as well as erode the wires. This corrosion could chemically erode the wire's material to a point where the wires actually break. If this type of corrosion and erosion continues for some time, the electrical characteristics of the termination will be in jeopardy because of a change in the electrical resistance and physical structure of the wire's ability to conduct electrical power. This is what has happened to pacemaker or defibrillator leads that are inserted into a human body after some time. At the point of lead failure, the only solution is to replace the leads. Of course, this means that a surgical procedure has to be performed.

The description of the termination's failure that is described above could apply to both crimp type terminations as well as fused terminations. One solution is to possibly silver or gold solder or braze the termination's leads together with a torch, and then insulate the connection. As the leads are quite small, a skilled technician would have to perform the soldering or brazing.

An alternative would be to insulate the termination in such a way so that liquids would not be able to enter the termination. The insulation material would have to make an intimate contact with the outside as well as both ends of the terminal so as to seal the terminal's ends to avoid having liquids seep into it. This means that sleeves of insulation, or even heat shrink material could not be used, as liquids could still enter the terminal because of capillary action, as the seal would not be tight enough. Melted liquid insulation could seal the termination externally, but the application of this material would be difficult.

When terminating bare stranded wire, the individual strands can each be coated with Tin or some other coating that will facilitate SN-Fusing. As all of the wires can be fused to each other, there is a lesser possibility of wire corrosion. However, it is not possible to be fully assured that no bare wire is being held inside the tube, and that that the entire bundle of conductors are not diffusion bonded, which, in turn, means that liquids could enter the tube and corrode the termination. Considering all the alternatives, this is a relatively good method of making terminations that are not to be used in a human body.

The best method of making the termination is with SN-Fusing. It creates an intimate and clean joint, but does not seal the joint's ends from liquids. However, if the terminating process could automatically seal the terminal ends with a material that would make an intimate contact with the terminal's tube, as well as the wires entering the tube, then this would have solved the liquid corrosion problem. Using wires that are individually Tin, gold or silver coated, and then SN-Fused and additionally sealed would provide the most secure termination.

One method would be to apply a hot melt plastic material to both ends of the tube. However, this might not be easily done automatically. Also for an intimate seal to occur between the metal terminal and the plastic material, both materials would have to reach the temperature of, or above, the melted plastic. If the entire terminal's ends do not reach this temperature, the plastic will not make intimate contact with the metal.

Patent Applied for Sealing Process

Coating or inserting plastic inside the terminal's tube during the SN-Fusing process would result in sealing the terminal when fusing. During fusing, the heat generated would drive the plastic away from the fused area where heat is generated. The melted plastic would then accumulate around the ends of the tube. The fusing heat would heat the entire terminal to a temperature that would be above the melting point of the plastic.

Various types of plastic material could be used to accomplish the required seal in a known environment. The plastic's melting temperature, ability to withstand various chemicals, ability to adhere to metals and exist in various environments, would have to be considered when choosing the appropriate plastic.

A specific level of heat is required to create a fused connection. The plastic insulation should have a melting point that is below the temperature required to fuse the terminal. However, the plastic should not burst into flames at this temperature. Therefore, the plastic must be chosen so that it can stand the heat being applied during fusing. If the point of over-heating the plastic is critical, a device such as a Thermal Monitor/Controller should be used to control the heat generated by the fusing machine.

If a closed terminal is used, a pressure relief hole must be incorporated into the terminal to avoid expelling the wires and plastic from the tube. The melted plastic will also seal this pressure relief hole.

The thermo-plastic insulation can be sprayed or brushed into the inside diameter of the tube. A sleeve of plastic tubing can be inserted into the tube. The wire being terminated can be coated with a predetermined thickness of thermo-plastic. Plastic tube shaped washers can be placed on the wires being terminated at each end of the tube. A solid piece of plastic can be inserted in the tube with the wires being terminated. All of the plastic mentioned above in this paragraph will melt when the tube is heated. As the tube is heated in the middle of the tube, the plastic will be driven or flow away from the heat and both ends of the tube will be sealed. Thermo-plastic has a tendency to move away from heat, when it is molten.

The wires being terminated can be bare or coated with thermo-plastic insulation or magnet wire (aka winding wires) film insulation. When the wire is coated with film insulation, the film insulation must first be removed with a very high amount of heat in an extremely short period of time, and then a low level of heat must be applied to seal the tube with the thermo-plastic insulation over a longer period of time. Not all types of film insulation can be used as they might not be compatible with the thermo-plastic insulation or it cannot be removed with a reasonable level of heat.

This process can terminate either stranded or solid wire.

The tube can be coated with Tin (or gold or silver) as normal SN Fusing tubes are. The leads being terminated can be bare or coated with just about any metal, as long as the coating is compatible with the environment where the termination is used. The plastic insulation should also also be compatible with the end use environment.

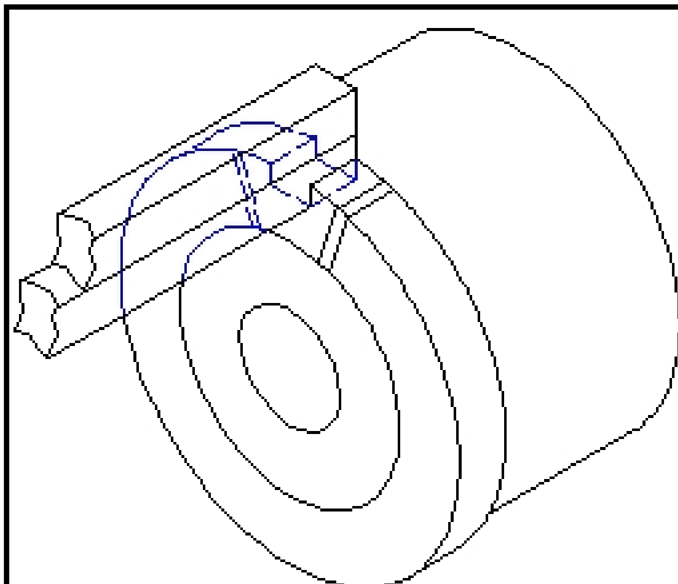
The process described above for sealing wire terminations has had a patent application filed with the United States Patent Office.

Commutator Brazing and SN-Fusing

Commutator brazing machinery is similar to commutator fusing machinery, except that it is larger and must be able to handle even higher heat/current densities. Seconds are required to braze one joint. Therefore, the heat required to braze must be sustained for a longer period of time. The exact same machinery used to braze commutators can be used to possibly SN-Fuse the same commutators, or commutators designed specifically for SN-Fusing.

Heat is developed in a commutator brazing or SN-Fusing machine in the same way it is in a commutator fusing machine. The machinery used in commutator brazing or SN-Fusing consists of a brazing/fusing head, step-down transformer, and electronic control timer. The transformer's secondary winding is connected to the head, which brings the electrodes, which are part of the head, in contact with the commutator and coil leads. The control timer controls input (main line voltage) to the transformer. The control timer performs three functions: it times as low as one-half of one mains line cycle (0.0083 seconds on 60 Hertz current or 0.01 seconds on 50 Hertz current), turning the power to the transformer on and off, and it controls the current of each half cycle by means of the phase shift method of A.C. voltage control. In the timer, silicon controlled rectifiers (SCR's or thyristors) normally are used as contactors for switching power to the transformer's primary winding.

When SN-Fusing, brazing alloy is not required. The coil



A diagram that shows a 1/4 riser commutator and leads that are designed for SN-Fusing

leads must be bare and tinned. They are SN-Fused to the commutator, directly to a flush commutator's segment into a riser slot, or onto a quarter riser. SN-Fusing uses a higher level of heat than commutator brazing, but requires a level of pressure that is many times the pressure required for brazing.

There are two commutator configurations that are used for commutator brazing, the riser type and the flush type. The riser type contains a slot, into which the coil leads are placed for brazing. On the flush type, the leads are placed directly on the commutator's brush track (or a small projection to suit the armature's design). The flush and riser type commutators can also be used for SN-Fusing. However, a quarter riser type is the most acceptable. The quarter riser extends to half the height of one of the bottom leads. Normally, two leads are SN-Fused, one on top of the other. The wall of the riser extends only to one quarter of the height of the two leads.

The riser or quarter riser type gives the most secure connection. The coil leads are held on three surfaces of the slot. The riser, but not the quarter riser, however, acts to block air from circulating through the coils. With the flush type, there is no metal on the side of the coil leads. The bottom lead is SN-Fused to the commutator, while the top lead is SN-Fused to the bottom lead. As there is space on either side of the leads, air can circulate across the brush track, and through the coils. A motor, whose commutator is of the flush type or quarter riser type design, will run much cooler than one of the riser type. Various methods are used to keep the leads in place during SN-Fusing, such as alignment rings, alignment electrodes, an alignment clamp, etc. The electrode is placed on the top lead while the ground electrode is placed on the commutator's brush track, as close to the fused area as possible, but, of course, far enough away so as not to be joined to the commutator itself.

Some commutators are made with split bars where one commutator segment is made of two metal parts. When SN-Fusing with this type of commutator, it is possible to spread apart the two parts of the segment, permanently damaging the commutator. Unless special precautions are taken, it is, therefore, not practical to SN-Fuse split bar commutators. However, when brazing split bar commutators, lower forces are applied than when SN-Fusing. Also, the brazing alloy seeps into the crevice between the two parts of the segment, through capillary action, brazing them together. Such a brazed split bar commutator will have greater structural integrity, than if joined in any other way.

SN-Fusing replaces commutator brazing in moderate to high production environments. It is cost effective because it eliminates expensive brazing alloy. This relatively new method of commutator termination has been proven in the production of millions of automobile and truck starter motors. In the future, it will gain wider acceptance because of its cost savings and joint quality.

Inverter DC Control

Normally AC Fusing control systems are used to supply AC electric power to the fusing electrodes. The use of either direct DC or Inverter DC systems is much more expensive and, under normal conditions, does not offer any real gain. Direct DC is very expensive and has no practical use in SN Fusing. Inverter DC is a little more reasonable in price than direct DC, but is still expensive. However, for Tube Fusing or Commutator SN-Fusing, there might be some practical use for the Inverter DC power supply, instead of the normal AC power supply.

AC power supplies use single phase AC power. When working with very large tubes or commutators, an extremely large single phase AC power line might be needed. The draw of very high electrical current can produce unbalanced mains electrical lines. By using a DC Inverter power supply, electrical power is drawn from all three phases of the three phase mains power line at the same time. Current is drawn equally from all three phases which results in a balanced mains electrical line, and draws less power per phase overall.

When using a portable Tube Fusing Gun, an Inverter DC power supply will allow for the use a much smaller and lighter high frequency fusing transformer that can be mounted directly on the Tube Fusing Gun itself.

Computer Control and SPC

There are various ways to control machine functions. A recent development has been to combine the PC (personal computer) with commercially available PLC (programmable Logic Control) for controlling assembly machinery. The PLC is used to actually control the SN-Fusing machine, while the PLC feeds variable information to the PC. The PC processes this information and acts as a front end for the PLC to interface with human operators and/or set-up personnel.

The PLC, such as one manufactured by the Allen-Bradley Company, can easily be programmed and re-programmed by most set-up personnel. These PLC devices use a type of ladder diagram logic, which most electricians can understand and even modify.

The PC computer, normally a Pentium-III 500 megahertz or faster unit, performs a number of functions. It can act as the PLC's front end, as mentioned above, can show the SN-Fusing process graphically in real time, can collect data for SPC (Statistical Process Control) manipulation and can process the collected SPC data to obtain process control and process capability indexes.

Process control (Cp) and process capability (Cpk) are the most accurate means of measuring production quality by statistical methods. Process control reflects the stability of the process, while process capability measures the built-in consistency of a product that is made by the process. The process is first brought under control by finding and eliminating special reasons for variation. The process is then predictable, and its capability to meet pre-defined expectations can be determined.

The PC would normally collect all or some of the following SN-Fusing machine data [assuming the fusing machine incorporates a constant current fusing control; a Thermal Monitor/Controller (TM/C), a load cell, an electrode displacement measurement system, as well as a cooling water temperature measurement system]:

- The actual peak current reached prior to terminating the fusing process
- The actual total fusing time used during the fusing process
- The actual temperature reached when fusing was terminated
- The actual peak fusing electrode pressure reached during fusing
- The actual final fusing electrode pressure that was reached when fusing was terminated
- The actual maximum depth the fusing electrode moved below the surface of the parts being fusing
- The average temperature of the machine's cooling water supply.

All of the above listed parameters, plus some others, can be collected for each fused connection. The date and time of the actual fusing can be captured. This data can be sent to an ink jet printing head, from which it will print the date and time or a code derived from this information, on the part, if the part is large enough. Part numbers or other information can also be printed at the same time.

At the same time, SPC data and graphics charts can be displayed on the PC's monitor. Calculations can be performed from the stored data using X-BAR-10, X-BAR-100 and/or R-BAR-100, to obtain a sigma index which will be a guide to production management, as to the relative quality of the output from the SN-Fusing machine.

The use of a PC computer as the front end of the PLC machine control system gives a number of benefits, but the SPC data capture and processing capabilities are added benefits that cost almost nothing. As manufacturers of electrical parts attempt to certify their quality control programs, SPC on SN-Fusing machines will become essential.

SN-Fusing and its sister process Gold/Silver-Fusing are economical and fast methods that deliver a high quality electrical and mechanical connection. In the future, these processes will help to replace manual compression type wire terminations.