Contents Print

SPECIAL PROBLEMS INCURRED WHEN MANUFACTURING COILS WITH FINE MAGNET WIRE

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Abstract: Manufacturing coils with fine wire AWG # 36 to #46 requires special consideration to be given to every operation in the manufacturing process. Obviously, the main reason for such detailed considerations is the small size of the wire with very low tensile strength and small cross sectional area. Proper attention to each operation increases quality and reduces manufacturing cost. The most common operations are identified and discussed with the exception of winding because winding and tension are covered in many other technical references.

I. INTRODUCTION

Because coils are an essential part or component of the end product , the integrity of the coil and its reliable operation can determine the reliability and quality of the end product. Many of these products are manufactured in very large volumes and thus reducing rejects and field failures impacts the cost, and quality of the product as well as conserving raw materials.

Many types of coils wound today use small wire sizes. Electronic devices have reduced drastically in size and thus associated reduction in coils and wire sizes. Changes in technology and electro-magnetic controls have lead to manufacturing of other coils requiring small wire for typical products such as step down transformers used to recharge batteries or as direct AC input (AC adapter), relays and solenoids that operate appliances such as washing machines, dishwashers and other uses in the home and industry, as well as secondary or tertiary windings on high voltage output transformers for florescent , HID and other forms of lighting fixtures and flyback transformers to power CRT/televisions, monitors. The proliferation of electronics and new innovation in automobiles has lead to a multitude of sensors, and solenoids for many uses and new technology for ignition coils all with coils wound with fine wire.

II. DISCUSSION

For purposes of this discussion, AWG # 36 to 46 are considered fine wire sizes Nominal bare wire size for # 36 is .005" /0.127 mm and # 46 is .0015 " /0.040 mm. Nominal area in circular mils for # 36 is 25.0 and for # 46 is 2.46 The same issues and others apply to smaller wire sizes but the quantity produced is not typically as high. The same issues apply to wire sizes larger than this range and while equally important the results might not be so immediate or catastrophic.

A. Bobbin Design and Molding.

Coils with fine wire are typically wound on bobbins molded from multi cavity molds using a multitude of polycarbon compounds appropriate for the application. The bobbin needs to be designed and manufactured realizing the impact it could have on winding fine wire. The bobbin design should include suitable radius on all corners and edges that might be touched by the magnet wire. Sharp corners or edges will increase stress on the wire and make it more susceptible to failure immediately of after being placed into operation. Smooth surfaces are also important because rough irregular surfaces could abrade the insulation and/or damage the magnet wire.

The best designs can be deteriorated by poor manufacturing. The bobbin molding process can introduce problems that will effect the winding of a coil including those with radius corners and smooth flat surfaces. A single cavity bobbin mold needs to pass quality inspections for design tolerances but also for the quality and preciseness of the molding process. Note; multi cavity molds multiply these concerns by the number of cavities used for molding the bobbins. Each cavity produces a different bobbin all of which need to be suitable for winding the fine wire , as well as meeting the dimensional requirements.

Wherever the magnet wire contacts the bobbin even if temporarily during the winding or lead placing process it must be radiused and smooth. This includes the presents of any molding flash on any surface or corner that might be contacted by the wire. Small amounts of flash can break the wire and slow or stop production which makes the equipment less efficient and thus the product more expensive. It can also increases scrap and thus waste materials which also increases cost.

Flash along the parting line of the winding surface can easily break the wire as the first layer is wound across this surface. Flash on the insides of the flanges can also break or abrade the insulation on the magnet wire. The problem might not be detected by testing and can possibly become a field failure because hot spot can occur during normal usage and eventual burn-through in operation. The flash on the flanges can affect more than one layer of the winding because the last turn on each layer will possible contact the flash as the wire reaches the end of each traversed layer. This can happen at both flanges on each side of the winding.

B. Start Lead

The start lead typically needs to be protected or covered as it enters the winding area. Most coils require a bobbin design with a start lead slot that allows the start lead to enter the winding area at the bottom of the start flange. Otherwise, the start lead is positioned against the inside of the start flange to reach the bobbin winding surface, or hub. The start lead slot is especially necessary for coils wound on automated machines where the machine terminates the start and finish leads as well as winds the coil. The start lead slot must be designed so the machine can automatically place the lead in the slot before the coil is wound. Before automatic machines existed and today in special low volume cases a piece of tape to provide protection is manually placed over the start lead and securing it against the inside of the flange. If the start lead is not protected it will be contacted by the ending turns of each even number of layers (2^{nd}, 4^{th}, 6^{th}) wound on the bobbin and thus be scuffed or abraded with each contact .

The ultimate catastrophic result is when the insulation on the start lead is sufficiently abraded or damaged and contacted by the ending traverse turn with sufficient voltage gradient to pass from the wound turn to the start lead and cause a shorted circuit. Testing can detect most of these instances but some could pass and possibly become field failures. If the voltage gradient between 2 turns is not sufficient to cause a short it can change the resistance value and thus possibly it's function.

The ending wrap of the start lead on the terminal needs to be as close as possible to the bottom of the terminal and the path from the terminal to the entry into the start lead slot or winding area needs to be placed against the bobbin so it does not span in open space and thus be subjected to breakage. If the start lead is broken after the coil is wound and terminated the coil is a reject and scrap because the remaining length typically is not sufficient to reach the terminal and make the connection again. It is not possible to unwind a turn to gain additional length because many layers of magnet wire are wound over it and thus the wound bobbin is not economically salvageable.

C. Finish Lead

The finish lead should exit the final layer as close as possible to the exit flange of the bobbin. If the exit flange is higher than the winding surface consider utilizing a finish lead slot. The finish lead must remain against the winding or bobbin as it exits the winding surface and winding area to a finish terminal or suitable securing point with the first wrap as close as possible to the bottom of the terminal. It should not span in open space where is could be snagged and broken. It must be sufficiently separated and kept separated from to the start lead. It must be secured to the bobbin or terminal, the tooling or coil (tape or adhesive) or it will permit loose turns or unwinding. A wrap of tape can be manually or automatically placed over the completely wound coil. This can protect the path of the finish lead, provide protection for the winding and/or secure the finish lead. If the finish lead is broken, turns can unwind to a degree where the coil might not be economically or technically salvageable.

If the lead connections to the terminals are tight and the terminals bent or flexed in a direction away from the winding, the leads could be stretched or broken. To help this situation the tension device can reduced the tension control when wrapping the terminals to reduce the stress on the leads. Incorporating features (typically a pin) in the bobbin holding tooling that requires the leads to have a longer path to the terminals. When the coil is removed from the tooling and thus the lead freed from the pin a stress relief or slack loop will remain. Two other techniques used after the coils are terminated and probably away from the winding machine includes bending the terminals toward the winding area and the other is to push the terminals farther into the bobbin to reduce the stress on the leads and or a slight slack loop.

D. Over- molding and Skeining

Additional consideration concerning slack loops or strain relief needs to be given to coils that are over molded. There are some conditions where the forced flow of the over-molding material will push against the slack loop and break the leads.

Skeining is the process used to strengthen the start and finish leads; standard skeining attachments are available on winding machines. Skeining involves looping several strands of magnet wire together and then twisting them to make one multi-strand lead, with increased strength. The skeined portion can consist of several odd number of strands, 3, 5, 7, 9 etc. and most skeining devices attachments today provide this selection as a programmable features. Also, note that the skeining process adds time to the production of the coil and thus reduces the production rate. The cycle time increases with the addition of the number of strands selected so it is prudent to determine the least number of strands that will provide the strength required for the leads. Skeining is

typical used for wire sizes # 38 and smaller, but depends on the application.
The skeined length must be long enough to enable 1 ½ to 2 turns of the skeined portion to be wound around the body of the winding so the reinforced portion is anchored to the coil. It also needs to reach and permit several wraps around the terminal. This provides an increased strength for the start & finish leads and thus reduces the possibilities of the leads breaking.

E. Terminals/ Lead Cutting/Lead Breaking

Terminal materials, design and manufacturing need to be examined for the termination of small wire sizes. Round terminal stock poses no concerns about damaging the magnet wire during the wrapping process, but when the lead is cut there is the tendency for the magnet wire to spring-back which causes the wrapping to be come loose around the terminal and possible slide along the terminal and/or cause the last turn or two on the coil to loosen. Typically square or rectangular terminals are best because the 90 degree corners provide a bend in the magnet wire that minimizes the spring-back effect after the wrapping /cutting operations and thus less tendency for the wrapped portion to move or loosen. Often the corner of these terminals is used for breaking the wire but some tails can result. Some machines have a single cutting blade that can be programmed to temporarily position the blade adjacent to the terminal and thus the wire can be pulled against it for breaking of the wire. The blade technique is mandatory for round terminals because they do not provide a sharp edge to stress and break the wire at a consistent location. Sometimes the wireguide tube can be programmed to break the wire as well as a slight movement in rotation of the winding axis.

Note, that skeined leads cannot be pulled against a terminal or other sharp edge and broken. Skeined leads need to be cut and typically a sissor type cutter is best for this operation The 90 degree edge of the terminal material cannot be sharp or such that it breaks or damages the magnet wire as the magnet wire is wrapped around it. This is of particular concern when stamped terminals are used because as the stamping die wares the back of the cut surfaces becomes ragged and thus sharp or abrasive and can damage or cut the magnet wire.

F. Soldering

Soldering operation can be used to make a permanent mechanical and electrical connection between the magnet wire and the terminal, or other interface connection. Solder composition has moved from the eutectic 63/37 (or more often 60/40%) to less lead content. Copper will dissolve in molted solder and the cross sectional area is reduced and thus the tensile strength of the wire in reduced and the resistance increases. High resistance connection increases the operating resistance of the coil, increase the temperature at this point and perhaps lead to a “burn through” and a reject or field failure.

Therefore, it is best to solder at the lowest possible temperatures and expose the copper leads to the heat for the shortest practical time. Many insulation on magnet require a higher temperature to burn off than is necessary to actually solder the copper wire to the terminal. Soldering bare copper to a tin plated brass terminal can occur at about 430 degrees F. But temperatures necessary to burn-off NEMA 105 C degree class insulation can be more than 700 F. Higher rated insulation with 130 C, 155C and 180 C class solderable insulations can be above 900 degrees F. Therefore, depending on the mass of the magnet wire and terminal it is necessary to establish the minimum time required to bring the mass up to temperature and melt off the insulation, solder the connection and get the magnet wire out of the solder as soon as practical.

A single length or lead of the fine magnet wire leading to a terminal or otherwise exposed is a very small mass and thus it will heat faster than a larger mass of terminal and wire. Solder can wick along the magnet wire so this needs to be checked because a stress point can be created where the solder stops and if the lead is flexed it can be weakened. The soldered or tinned portion of the magnet wire is more rigid then the unsoldered magnet wire. The solder and heat from the solder can char or burn the insulation in unintended areas so protecting the portion of the leads not intended for soldering as well as the coil body need to be considered. Note; soldered coils absorb heat from the solder and thus will have a higher resistance when tested at that elevated temperatures. Resistance test that might be made soon after the coil is soldered need to consider this point.

G. Fluxing

Fluxing is typically required before soldering and an alcohol solvent Rosin Mildly Active (RMA) flux is generally used. Flux composition are best determined for each application but the more active a flux the more it can attack the copper wire and the more corrosions can be result. The soldering process subjects the flux and copper wire to very high temperatures and thus the corrosive effect can increased. It is important to remember that flux can remain on the magnet wire and thus be on the coil when it enters field operation. Depending on its application and if it is or is not over molded, corrosion can continue and possibly affect the integrity of connection and possibly create burn through and failure.

Note; if the coil is over molder or coated or encapsulated, it is important that the flux be compatible with over molding or encapsulating materials and conditions. Out gassing and other issues could be caused by flux

H. Welding

Welding in gaining in usage because of improved welding techniques using programmable controls for a continuously precise operation. Again, it is necessary to eliminate the insulation from the magnet wire so the electrode & anode must get a good electrical connection for sufficient current to pass to create sufficient heat to facilitate the welding process. With fine wire attention needs to be given to the pressure used in the welding process to prevent a high resistance connection and a possible burn through. Some of the best welding connections involve a terminal designed with a tang to capture the magnet wire very similar to the chnique used on millions of motor commutators for many years.

The tang is a “U” shaped extension to the terminal through which the wire is placed and the “U” closed against the wire. The anode contacts one side of the “U” and the cathode the other side for a good electrical connection and with a combination of heat and mechanical pressure, the insulation burns off and the continued heat and pressure fuse the wire to the terminal.

I. Insulation Displacement Terminals (IDT)

Insulation displacement terminals are available for some fine wire sizes. The use of IDT requires special pockets to be molded into the bobbins and precise routing of the fine wire. The most important point is to make all the bobbin surfaces smooth and radius the corners to prevent stressing or breaking the wire. The rest of the design details are the same and concerns mentioned above. IDT cannot be used with skeined leads.

J. De-reeling & Kinks

De-reeling fine wire from supply spools offers several challenges not as prevalent or pronounced with larger wire sizes. The wire is small and can be wound at higher speeds than larger wire sizes due to less resistance in the wire path and less imposed tension from a tension device and thus less torque is required to pull the wire. Coils with small wire sizes tend to have a higher number of turns and therefore higher winding speeds are desirable to reduce the cycle time and increase the production rate.

Wire supply spools are typically placed vertically setting on one flange. The magnet wire is de-reeled from the supply spool over the top flange (over-end dereeling), and tends to form a helix as it transforms from a round spooled geometric shape to a straight linear condition. This process is continuous and it can be very fast depending on the winding speed, diameter of the coil and the diameter of the supply spool. Occasionally, the helix does not elongate and straighten but creates a curl or pig-tail configuration with a continuously decreasing I.D., until the I.D. is eliminated and the kink or twist is formed. This kink can get caught as it passes eyelets etc. in the wire path or in the tension device, wireguide tube, etc. and break. This requires the machine to be stopped and the wire re-threaded through the machine. Occasionally it does not get caught and is wound into the coil and becomes buried by subsequent turns and layers. The kink can cause a high resistance point or hot spot and eventually burn through and the coil fails.

As the winding decelerates and stops the helix and loosened turns on the supply can fall vertically down to the bottom flange of the spool. When the next coil begins winding these loosens turns at the bottom of the spool are the first to leave the spool and when the loosened turns are consumed it is again necessary for the wire to be pull from the tighter turns around the spool and the sudden impact of the pulling force can break the wire.

One way to minimize the effects of this acceleration wire break is to use a commercially available brush-like disc that has small diameter nylon bristles extending radially past the edge of the supply wire spool top flange. The bristles help retain the loosened loops and prevent them from falling to the bottom of the spool and thus reduce the sudden impact of the accelerating wire. Another method is to position the spools on a 45 degree angle rather than at a vertical 90 degree position. This also reduces the tendency of the loosened loops to fall to the bottom of the spool. Winding is a major operation in the manufacturing of all coils. As mentioned above, this operation and tension control are not discussed because they are presented and discussed in many other technical references.

III. SUMMARY

Because of low tensile strength and small cross sectional area, manufacturing coils with fine wire sizes is more difficult than with larger wire sizes. However, if proper attention and development are given to each operation, these coils can be successfully manufactured with the highest quality and at reasonably high speeds to make large volume production practical and profitable. Each manufacturing operation is important and needs to be completed satisfactorily for the coil to operate as intended and for the proposed life cycles.