

MOTOR MANUFACTURING 101 - SHORT COURSE

While the basic process for assembling small motor stators has changed little over the past 30 years, increased international competition has driven manufacturers to seek significant process improvements in their facilities. Although many subtle improvements in assembly processes are ongoing (i.e. Lean Manufacturing), equipment modernization also needs to be implemented in order to achieve maximum product quality and minimize labor costs. In addition, drastic changes in motor control technology, coupled with the reduction in the cost of microprocessors, has given birth to an entire range of variable speed motors which were not available 10 to 15 years ago.

This paper will discuss the steps involved with assembling a stator for a small electric motor. It will also cover some of the recent advancements in technology implemented in many facilities that improved stator quality while minimizing labor, production and material costs.

STATOR CORE ASSEMBLY

Lamination Selection

Lamination stacking is either performed by hand selecting (by weight or height) or by automatic stack selection. Although automatic stack selection minimizes operator intervention with the core build process, most machines still require frequent operator attention. If the lamination process is inconsistent, automatic selection holds little benefit over hand selecting.

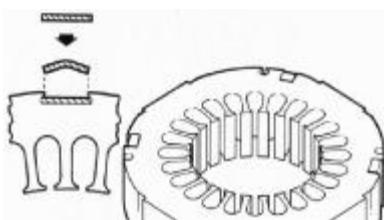
Manual stack selection still remains the most popular method, since an operator can easily compensate when selecting laminations with problems like adhering laminations from heavy burrs, oil or annealing oxidation. To assure stack height accuracy with manually selected laminations, motor manufacturers are using electronic gauges mounted to the core securing machine.

Welding

Welding is a popular and widespread method for securing stator cores. New welding machines offer flexibility and reliability since many have eliminated the need for hydraulic operation.

Despite recent advancements in machine design, welding has a number of drawbacks since a welding machine requires manual loading of the laminations and a high level of maintenance. This maintenance activity (including torch tip adjustments, the monitoring of argon and the sharpening of torch rods) usually requires the attention of a skilled operator or technician. This is an additional concern to the electric motor design since stator core loss could occur by welding across the laminations.

Cleating



This process “V” rolls and then flattens a strip of soft steel down a dovetail slot on the O.D. of the stator laminations. The cleating strip steel is low cost and the process is fast. Cleating machines are extremely flexible and require little setup. Unlike welding, cleating still leaves the stator with

good electrical properties and the cleats are easily stripped out to salvage rejected cores (thereby minimizing scrap). The drawback with small motors is that cleating still requires a machine, material (strip steel) and a relatively skilled operator.

Lamination Interlocking

During the lamination punching process, dimples are automatically placed in each lamination as they are stamped and collected at the end of the die. At this collection point, the laminations are counted and a stator core is assembled to preset lamination count and stack height.

This interlocking of the laminations provides motor manufacturers with a cost reduction because it can eliminate the need for both a core securing machine and one operator. The disadvantages to this process are that the die is more complex and annealing the assembled stator stack without core warp may be difficult. To eliminate annealing and potential warp; semi or fully processed height silicone steels are used but can add back much of the cost.

Loose Lamination

This is the most popular method for processing stators below six (6) inch stack height. The lamination stack is selected by the operator loose and placed directly on the slot insulating machine. A hold down ring is then either hand or machine placed on the laminations while cuffed slot liners hold the stator core together through further processing. After testing, the stator is pressed in a bore to face checking machine, and in some cases, clamped and placed in the resin process. This resin dip process not only coats and secures the wire, it also soaks into the laminations which bonds the stator core.

Loose laminations hold a number of advantages over other methods. Most obvious is the elimination of a stator core securing machine (and its operator). It offers inherent flexibility since the slot insulator operator selects and measures the laminations prior to insulating. We have also found that loose lamination stacks are less wearing on the stator process toolings because the loose stack is self-aligning.

The disadvantages to loose lamination stacking are twofold. First, clamping fixtures are sometimes required on larger O.D./taller stack stators. And second, some motor designs require that the excess resin be brushed from the O.D. of the stator so that they can be aligned in the rolled steel shell.

STATOR INSULATING

Most motor manufacturers use automatic slot insulating machines that coat the slots or place laminated materials in each stator slot. These machines are available for loading stator bore either vertically or horizontally. Automatic stator handling is a cost effective way to greatly improve productivity and reduce labor. The two methods of insulating stators in the size range are as follows:

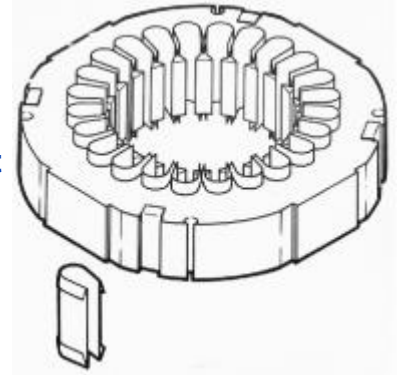
Epoxy Coating

The epoxy coating process requires that the stator be masked off to protect the working surfaces and be either preheated or electrically charged to adhere the insulation material. The epoxy materials were once limited by their heat rise capacity, which

narrowed the range of applications. The new epoxy materials can now exceed 150°C, but because of system investment and the process control problems (contamination, humidity and temperature changes), this process is rarely used.

Slot Liners

The placing of film or laminate material in the stator slots is by far the most common insulation for stators in this size range. Polyester film is the most preferred insulation material for cost, shelf life and temperature capability. Another benefit of using slot liners is that changing from a polyester film to a Dacron-Polyester-Dacron or Nomex (just by changing rolls of material) can quickly increase the temperature ratings. It is also a very easy process to control with a simple cam or gear driven punch and die machine.



To further improve the slot insulating area, there are new developments to reduce the tooling complexity. With the integration of servo motor material feed and stator index, slot cell insulators can be changed over within minutes.

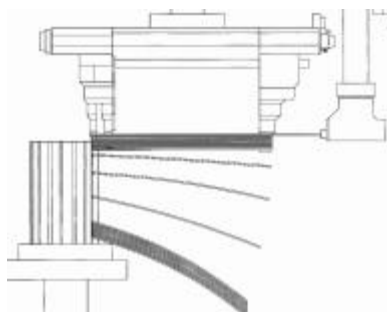
STATOR WINDING/INJECTING

The most common method of placing wire within the stator is by winding a concentric coil and automatically injecting it into the insulated core. The coil injection process has dominated the electric motor industry for over 40 years because of the level of quality and high production that a motor manufacturer can achieve.

In recent years, many advances have been made to this process to increase automation and machine utilization by decreasing changeover and machine down time. The use of servo motor drives to automate machine set-up eliminates the need for operator intervention in the changeover process. Not only do our customers see an increase in quality and consistency of their products, but they also report that their machines exceed 95% utilization. This is not only because of faster, more consistent set ups--it's through the elimination of "crashes" caused by inexperienced operators.

Coil Winding

Partnering with the coil injection process, most of the electric motor industry uses the "shed" type coil winders. The principle of the "shed" winder is that it wraps wire around a tapered coilform step and then pushes this wire down the taper into the tooling as the next turn of wire is wrapped above it. Stand-alone "shed" winders will wind coils into a "transfer tool". The operator then will use this tool to manually transfer the coils to the injection machine.

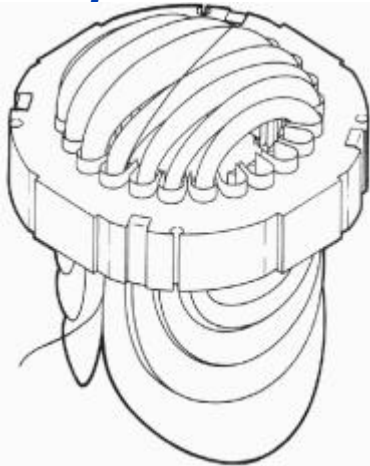


The "shed" type winder uses short, multiple step coilforms, which means a small flyer can be used to obtain higher winding speeds; however, a high winding speed is not synonymous with a reduced cycle time. Using a servo motor to drive the flyer yields great advantages over variable frequency drives. Although both systems can provide for +/- 0 turn count, variable frequency drives can only do so by winding the final turns at a very slow speed. Typically, a

machine using a variable frequency drive is approximately five (5) seconds slower per pole than a machine using a servo motor drive. When winding a typical 4 pole stator, a servo motor driven “shed” winder can produce approximately 25 more stators per hour (depending on turn count).

With the advent of improved machine tool controls, the “shed” type winder has become more versatile providing the motor manufacturers with additional savings on smaller production runs. A standalone “shed” winder can be changed from one lamination to another within two (2) minutes. Stack height changes and pole configuration changes can be made automatically. This flexibility is crucial in JIT/Lean Manufacturing environments since the winding process sets the pace for the entire stator assembly line.

Coil Injection



This is still the most economical process for the quick, quality insertion of the coil groups into the stator slots. It uses highly polished tool steel to cover the saw tooth edged stator slot opening from the incoming wires. As the wire is pushed into the slots, the slot closure wedge follows the wire up through the tooling (additional information is available at <http://www.alliance-winding.com>).

Most stators can be simo-injected, which means that the main winding, auxiliary/start winding and even a multiple speed/tap winding can be injected together. This method can typically achieve slot fills up to 75%. For multi-phase applications and high slot fill requirements, multiple pass injection is typically employed. In this method, one layer of coils is injected into the stator core. These coils are drifted (intermediate formed) and the next layer of coils is injected. This method can produce a stator with slot fills exceeding 84%.

The trend in these motor sizes is toward the addition of lead end, cuff support tooling to protect the lower slot liner from the forces of coil injection. These cuff support tooling fingers are being used as slot fills increase and end turns decrease (a requirement to improve motor efficiency that reduces the material cost).

Although stack height changes can be fully automated, injection tooling does not lend itself to flexibility outside of the lamination for which it is tooled. In order to overcome this, Alliance supplies machines with quick release tooling features. This allows for a coil injector to be changed from one lamination to another within 10 to 15 minutes.

Winding/Injecting/Automation

One of the best ways to improve product quality while reducing direct labor in stator assembly is to integrate the winding and injecting operations into a common machine. Instead of winding into a transfer tool (for manual transfer of the coils to the injector tooling), these machines wind the stator coils directly into the correct slots of injection tooling. The insulated stator core is manually placed within the machine and its alignment is verified.

Many people believe that automation, flexibility and reliability are mutually exclusive

attributes in stator assembly. It has been the experience of Alliance that the opposite is true. Not only does an integrated wind/inject machine eliminate an operator (or two), but it also requires minimal training to operate compared to manual transfer machines. Although reduction of direct labor in low labor rate areas may not be a primary concern, many of our customers in these areas have a tremendous problem with employee turnover.

Alliance customers using these machines experience very high machine utilization and tooling life. This is due to the fact that operator error is practically eliminated since the machine automatically winds the stator coils into the correct slots and the stator alignment is automatically verified prior to it being placed on the injection tooling. When this technology is coupled with automated set-up features, the result is a highly productive, flexible and reliable cell at the heart of the stator assembly process. This is the goal of motor manufacturers regardless of their labor costs.

STATOR FORMING AND LACING

The end turn forming and lacing machines are important to improving quality, especially as the production rate increases. The machines for these processes can surpass many hand work operators with speed and consistency.

End Turn Forming

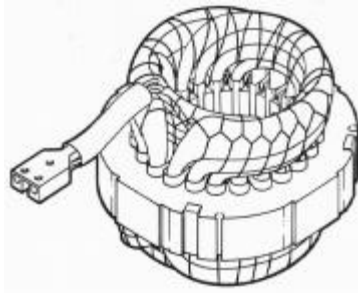
The end turn forming machine compresses the stator end turns which provides a tighter bundle of wire for resin impregnation. The most common tooling offers three (3) dimensional motion where the O.D. shoes compress, the I.D. shoes expand and the compression ring strokes to compact the end turns on both ends. Many motors are being formed down even further which reduces the overall length of the motor and the cost of materials. In the forming tooling, cuff support tooling fingers are important for protecting the slot liners from breakdown and providing access for the lacing needles. These cuff support fingers are either attached to the O.D. shoes or individually driven.

The machines we build offer standard tooling brakes to prevent tooling lift-off and direct more forming force to the high slot fill, low end turn stators of today's motors. Eliminating tooling lift-off not only reduces scrap stators—it minimizes downtime caused by damaged tooling.

In the past, final form machines have been dedicated to a lamination. While providing for "instant" changeover, this method greatly reduced floor space (especially in situations where a final form machine had to be dedicated to different pole configurations). Alliance has built a number of machines with quick change forming tooling. These machines use dove tailed OD shoes, "turn and lock" compression rings and modular ID shoes. Alliance has supplied turntable machines (with preform, final form and wedge set/automatic unload stations) that can change between laminations within ten (10) minutes.

End Turn Lacing

The lacing process is essential for tightly holding all of the magnet wire in the end turn through the resin bonding process and to secure lead bundles. The machines to end turn lace produce a diamond chain stitch of polyester cord around the end turns and the lead wire groups. This provides excellent coverage and constant cord tension that is unmatched by hand stitching.



Like final forming, the past trend was to permanently set-up a lacer for a specific specification. This is no longer necessary with the design of quick-change toolings that can go between laminations within ten (10) minutes. The trend in motor manufacturing is toward more automatic lacing, which

reduces labor and adds a margin of safety by keeping operators away from the lacing motion. Alliance has developed an automatic load/unload system that can be adapted to existing lacing machines within the plant.

MACHINE CONTROLS

Many of the above advancements discussed have been made possible through the implementation of standard, off-the-shelf programmable logic and motion controls. In the past, PLC's were rather limited in their capabilities. For this reason, many companies in the machine tool industry felt that the only way to accurately control their machines was to develop their own, PC based control systems. The major problem with this philosophy is that PC based controls are only supported by the vendor. The purchaser of the equipment was forever tied to the vendor for service and support (even for basic machine changes).

Commercial, off-the-shelf programmable controls and motion controllers are inexpensive and can be supported by various sources. Alliance has supplied machines with a variety of PLC's and motion controls including Baldor, Allen Bradley, Siemens, GE-Fanuc, Omron, Giddings & Lewis and many others. In addition, we have supplied automated cells with over 25 servo axis and linear systems with over 70 servo axis. These highly automated systems use off-the-shelf programmable logic and servo motor controllers.

Although some companies still produce their own control systems, the reasons are primarily to assure themselves of future spare parts business and service contracts.

STATOR/WIRE BONDING

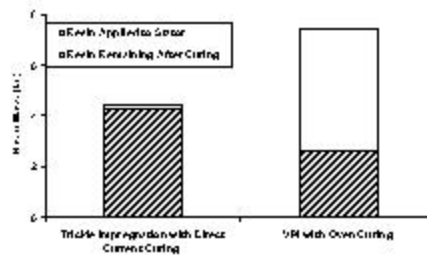
The most conventional method to bond stators is the resin dip tank and the oven system. However, there are several emerging technologies like dip and spin, trickle and bondable wire which reduce the emissions and waste.

Dip and Spin

The dip and spin machine is a lower cost machine when compared to a typical trickle system and it reduces the amount of resin wasted when compared to dip and drip system. The stators are loaded on a carousel and lowered into a tank where resin is pumped into it. After the tank is full and the resin has impregnated the stators, the tank is drained and the carousel spins the excess off the stators. There is a savings when the excess is pumped away and reused. The stators are then loaded into an oven for curing. The dip and spin process is difficult to control and has been know to spin resin back out of the stator slots. For this reason and oven emissions, trickle systems are becoming the emerging technology.

Trickle Resin

For small size stators, the automatic trickle systems can greatly increase the amount of resin applied to the stator, reduce emissions, and reduce the amount of wasted resin. The trickle system is usually a chain driven system that stators are loaded on and travel through the process. The system consists of a stator preheat area, a dispensing nozzle area and a final post-heat area to set the resin. These machines are expensive; but they put the resin directly where it is needed to solidify the coils and reduce waste. Typically, a stator that is trickle impregnated has a much higher resin slot fill than other impregnation methods (including VPI).



With the advent of precatalyzed resins and computer controlled digital power supplies, the resistance heated winding trickle systems are taking the process lead. With resistance heating, there are fewer stators in process, curing is more exact which significantly reduces emission and stators are cool enough that they can be assembled almost immediately.

Bondable Wire

An emerging technology in these stator sizes is where the wire manufacturer also pre-coats a polyester coated wire with a thermal epoxy. This wire is wound on the same “shed” type winders, but during the testing process, a resistance unit heats the windings and cures the epoxy.

Most of the development for this process has centered on the inexpensive, low torque or intermittent duty motors where humidity/rust is not a factor. This process is usually done in conjunction with final end turn forming on automatic turntables or linear lines. Alliance has been working to incorporate this technology into the stator process.

SHELL TO STATOR PRESSING

The presses for this area have been refined to reduce the cost and improve the quality of the finished motor. Many fractional horsepower stators are now being pressed into lower cost, lighter weight steel shells and the press tooling alignment is critical. These new shells are also being secured to the stator with dimples or other metal displacement methods to replace dowels or rivets. Most presses are still hand loaded, but a turntable machine with the pressing station and a separate load/unload station also greatly improves production rates. Further automation developments can be expected in this area in the future.

CONCLUSION

Electric motor manufacturers are under the pressure to increase product quality and consistency while minimizing scrap, direct labor and changeover times. These demands must be met with both modern manufacturing equipment and techniques.

Alliance continues to support meeting these demands by increasing the speed, automation, flexibility and reliability of our stator assembly systems.