Light Cure Adhesives Enable Innovative Improvements in Stepper Motors

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Introduction

Every day more than 15 million electric motors are manufactured across the globe. While the specific performance requirements and manufacturing challenges for each individual motor design vary significantly, the challenges that manufacturers encounter are generally very similar:

- Global competition is creating severe pricing pressure in the industry
- Customization is more prevalent resulting in smaller manufacturing batch sizes
- Innovative new features or performance improvements are necessary to grow market share
- Motors continue to decrease in size and increase in performance, resulting in higher operating temperatures and rotational speeds

To remain competitive in this environment, innovative new product designs and lean manufacturing are becoming a necessity for motor manufacturers. Lean manufacturing focuses on eliminating all waste in manufacturing processes. To accomplish that, the design and manufacturing teams must work closely together to continually improve products and processes. Critical focus areas are decreasing the time to manufacture, reducing batch size and where possible moving to continuous flow processes; all while upholding the high quality standards of the industry.

A compellation of stepper motors and the adhesives used to manufacture them.

Adhesives in Motor Manufacturing

Loctite® branded adhesives and sealants have been used to enhance performance, reduce costs, increase quality and improve the manufacturability of electric motors and generators for more than forty years. Table 1 lists some of the common adhesive applications in motor and generator manufacturing and demonstrates the wide variety of adhesive technologies that are employed to meet the specific challenges of these applications.

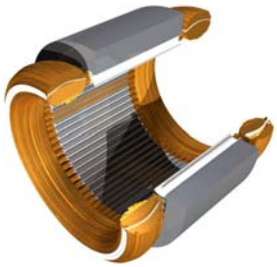
The application of adhesives and sealants varies significantly by motor type and motor size. To discuss all the different application permutations would require a book in itself. Thus, the remainder of this article focuses on how light curing adhesives have been used to improve stepper motor manufacturing. For a more detailed review of all adhesive applications in motors and generators, please request the Loctite® Design Guide for Electric Motors and Generators at motors.loctite.com.

Table 1: Adhesive Types Used for Typical Applications on Electric Motors

Motor Component	Application(s)	Adhesive Types Used							
		Acrylic	Anaerobic	Cyanoacrylate	Epoxy	Hot Melt	Light Cure	Polyurethane	Silicone
Bearings	Retaining to housing		X						
Bolts	Preventing vibrational loosening and corrosion		X						
Brackets	Bonding to stator or housing	X					X		
Brush holders	Bonding or reinforcing	X		X	X				
Commutators	Retaining to shaft	X	X						
Conduit boxes	Sealing		X						X
End plates	Sealing to housing		X						X
Fans	Bonding to shaft or rotor	X			X				
Fittings	Sealing threaded fittings		X						
Gaskets	Replacing or augmenting gaskets		X						X
Gear boxes	Sealing covers, sealing interface with motor		X						X
Insulation	Bonding to stator, rotor or wires			X	X	X	X		
Junction boxes	Sealing		X						X
Keys	Retaining in slot on shaft		X						
Laminates	Bonding lamination stacks and unitizing		X	X			X		
Lead wire	Bonding to stator or armature			X	X		X		
Magnets	Bonding to rotors or housings	X		X	X				
Printed circuit boards	Encapsulating				X			X	X
Rotors	Retaining to shaft		X						
Screws	Preventing vibrational loosening and corrosion		X						
Speed controls	Retaining to shaft		X						
Stators	Bonding to housings or mounting frames	X			X		X		
Wires	Reinforcing or insulating stator and armature wires				X		X		
Wire connectors	Sealing				X			X	X

Gasketing End Plates

Magnet Bonding



Insulation Tacking

Wire Reinforcement

Light Curing Adhesives

Light cure adhesives "cure on demand" eliminating the normal trade-off between open time and cure speed. At ambient conditions, all but the fastest light curing adhesives remain unaffected by ambient light for hours allowing for almost infinite part adjustment time. Upon exposure to light of the proper intensity and spectral output, the photoinitiator in the adhesive initiates cure, rapidly yielding a cured polymer. While cure times depend on many factors, 10 to 30 second exposure times to achieve full cure are typical and cure depths in excess of 0.5" (13 mm) are possible. Light curing adhesives are available with physical properties ranging from very rigid glass-like materials to soft, flexible elastomers.

While light cure acrylic adhesives are the most well known and commonly used type of light curing adhesive, four other chemistries that can be cured with light are anaerobics, cyanoacrylates, epoxies and silicones. Significant development has occurred on these light curing adhesives in the last five years and they may offer improved performance when compared to light cure acrylics in many motor applications. Table 2 compares and contrasts these five different types of light curing adhesives.

The unique balance of long open time and rapid cure make light cure adhesives ideal for lean manufacturing processes. Their almost infinite open time at ambient conditions makes them very easy to handle. This minimizes storage costs, line maintenance and waste. Because they achieve full cure in seconds, work-in-process approaches zero and it allows for immediate quality inspections. Since the adhesive is applied as a liquid, one adhesive can also be used on many different motor designs and sizes. This allows for almost

Table 2: Comparison of Light Cure Adhesive Types

Attribute	Adhesive Type (or Adhesive Chemistry)				
	Acrylic	**Anaerobic**	**Cyanoacrylate**	**Epoxies**	**Silicones**
Components	1	1	1	1 or 2	1
Viscosity	100 cP	15 cP	20 cP	5,000 cP	5,000 cP
Secondary Cure	May be activator or heat; many have no secondary cure	Anaerobic	Cyanoacrylate	Two-Part or Heat	RTV
Cure Intensity Required	25 mW/cm^2	100 mW/cm^2	<25 mW/cm^2	100 mW/cm^2	25 mW/cm^2
Relative Cure Speed	Fast	Slow	Very Fast	Moderate	Moderate
Max. Cure Through Depth	>0.25"	<0.010"	>0.25"	Varies	>0.25"
Temp. Resistance	-65 to 300°F	-65 to 350°F	-65 to 180°F	-65 to 350°F	-65 to 450°F
Adhesion to Metals Plastics Glass Rubber	 Good Excellent Good Fair	 Excellent Poor Poor Poor	 Very good Excellent Poor Very good	 Excellent Fair Excellent Fair	 Good Fair Very Good Good
Benefits	- Good general purpose light cure adhesive - Structural strength - Good flexibility - Wide range of formulations, viscosities - Fluorescent grades	- Excellent metal bonder - Structural strength	- Fastest cure - Best adhesion to plastics - Fluorescent grades	- High thermal and chemical resistance - Excellent adhesion to metals - Two component compatible with large depths (> 1")	- Highest temperature resistance - Best flexibility - Good adhesion to many substrates - Excellent outdoor weathering resistance - Fluorescent grades
Limitations	- May have tacky surface without high intensity cure	- For use on metals only - High intensity cure required - Low cure through depth	- Low temperature resistance - Not for structural applications - May be susceptible to corrosion on metals	- Slow UV cure - Two-component may complicate processing	- Not for structural applications - May have corrosive byproduct from RTV cure
Loctite® Product Examples	352, 3492, 3972	661	4306, 4307	3337, 3336, 3340	5031, 5033

immediate line change-overs and offers inventory cost savings when compared to mechanical alternatives such as gaskets that must be sized per each motor design.

The primary limitation of light curing adhesives is that light must reach the full bond line in order to be light cured. This may limit their use in motors when bonding metal to metal or two other opaque substrates. However, many manufactures have learned that by light curing the excess adhesive around the joint (also called the "fillet") they can very rapidly fixture the part. This allows the part to be subsequently handled while the adhesive cures between the opaque substrates via a secondary cure mechanism.

This innovative new light source uses an LED instead of a bulb. This offers higher intensity, lower cost, better portability and safer operation and when compared with previous technologies.

Another consideration when selecting a light cure adhesive is that equipment is required to cure the adhesive. Light curing adhesives require specific radiant energy (i.e. light energy) in order for the polymerization reaction to occur. It is, therefore, critical that the end user match the adhesive with the appropriate light source. Adhesive manufacturers can recommend the appropriate type of system. Typical low intensity systems can have a price of $800-1,000 while high intensity, custom systems can cost into the tens of thousands of dollars.

Stepper Motors

Stepper motors are used for a wide variety of high precision applications—to control critical medical equipment, drive industrial robots and control high precision video cameras just to name a few. They require high step accuracy, high resolution, and smooth motion all in a very compact size. Due to the broad range of applications they are used in, they must often be customized. Examples of design attributes that are commonly customized are winding patterns, shaft configurations, custom housings, and specialized bearings.

Their small size and high degree of customization makes the design and manufacture of stepper motors very challenging. To allow for this high level of customization and still offer short lead times, it is necessary for stepper motor manufacturers to develop processes that enable them to manufacture small, customized batches of motors very rapidly. As a technical leader in the step motor industry, Lin Engineering has developed innovative ways to leverage light curing acrylic adhesives to do this in their stepper motors.

Specific Applications of Light Cure Acrylics on Stepper Motors

The following are three applications that were implemented by Lin Engineering and will be discussed in detail.

1. Lead wire tacking / strain relief – Using Loctite® 352 light cure acrylic adhesive improved their motor reliability and facilitated encapsulation of the stator in plastic.

2. Bonding stator to housing – Using Loctite® 3942 light cure acrylic adhesive allowed unlimited mounting customization by bonding stators into any customer specified housing.

3. Sealing wires in housing – Using Loctite® 352 light cure acrylic adhesive extended motor longevity by sealing lead wires to protect the motor from environmental contaminants.

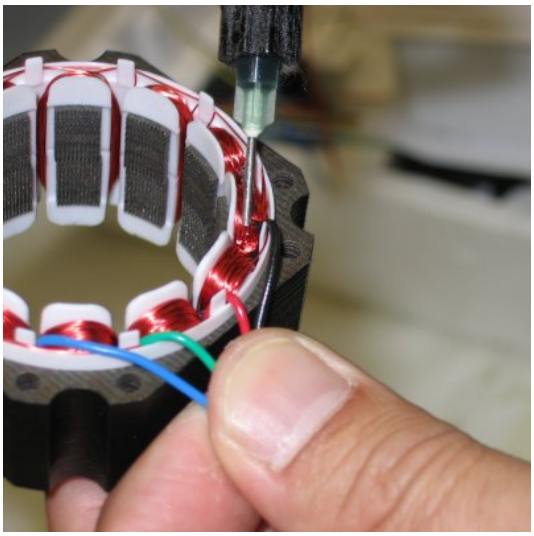
Typical Stepper Motor

Lead Wire Tacking / Strain Relief

The methods used to connect lead wires to the stator must be carefully considered to ensure reliability. The lead wires normally pass through the housing, external to the motor, and can be exposed to sharp pull forces or vibration that can degrade the solder connections if they are not properly secured or reinforced. Irregularities in the solder joint, such as solder balls or sharp peaks, can also result in shorts if the wires are free to move in the motor.

A variety of methods, such as adhesive tacking, grommets or specialty clamps, can be used to prevent lead wire failures. In the case of stepper motors, using grommets or specialty clamps is challenging due to the small size of the motor. The physical size of the grommet or clamp may require that a larger frame housing be used for a given motor, which is highly undesirable. The assembly of the grommet or clamp in the small stepper motor housing can also be a tedious process that slows the manufacturing processes and delays delivery to customers. The added cost of grommets and clamps also reduces the desirability of these two methods.

Lin Engineering determined that adhesively tacking the lead wires with a light curing acrylic adhesive was the optimum method for securing the lead wires based on performance and manufacturability. To accomplish this, the operator manually dispenses a bead of Loctite® 352 over the wire connections using a hand held syringe dispenser. The viscosity of the adhesive makes the dispensing process a quick and easy operation to accomplish. Since the adhesive can be dispensed in any pattern, the same process can also be used for all motor sizes and configurations. After the adhesive is dispensed, the coated motor assembly is then placed on a light cure conveyor where a 30 second exposure to light fully cures the adhesive. After the light cure process, the lead wire is fully reinforced and immediately ready for subsequent handling. Using the Loctite® 352 light cure adhesive has helped Lin Engineering prevent lead wire failures and provide both a high quality and cost effective solution for their customers.



Dispensing Loctite® 352 on Stator Lead Wires

Lin Engineering had previously wanted to encapsulate the stator in thermoplastic resin to extend the longevity of the motor. By developing this process for reinforcing the lead wires, it has also allowed Lin to mount the controller printed circuit board remotely which made it simpler and lower cost to encapsulate the stator.

Bonding Stator to Housing

When Lin Engineering encapsulated the stator in plastic it was originally envisioned that the motor could be direct mounted via bolt holes in the encapsulant. However, the wide range of mounting configurations requested by customers with established designs made it impossible to standardize on a mounting configuration that met every customer's needs. To increase the motor's relative degree of customization, Lin Engineering began bonding the molded stators into custom housings using Loctite® 3942 light cure acrylic adhesive. The custom housings were often machined from aluminum to meet a manufacturer's current mounting configuration.

Bonding Stators to Housing:
Left – Unassembled Parts
Center – Dispensing Loctite® 3942 to Stator to Housing Interface
Right – Final Bonded Motor

To bond the housing to the motor, the motor is manually inserted into the housing. A bead of Loctite® 3942 is then dispensed onto the interface between the stator and housing. The mated assembly is then placed on a light cure conveyor where a 30 second exposure to light fully cures the adhesive. After it exits the conveyor, the assembly is fully cured and ready to be handled.

By applying the Loctite® adhesive to the stator/housing interface, Lin Engineering is able to provide its customers any mounting configuration they require. The ability to customize the mounting bracket is a major benefit to the customer and often significantly reduces the assembly time for the customer. For example, some motors are configured with a bayonet type mounting bracket that allows for manual assembly of the motor in a blind location in a robotic device.

Applying the adhesive to the stator/housing interface also structurally reinforces the motor, allowing for a reduction in the overall thickness of the motor body. With a smaller overall size, the Lin motor's performance is able to provide the end user with better performance in a smaller package.

Sealing Wires in Housing

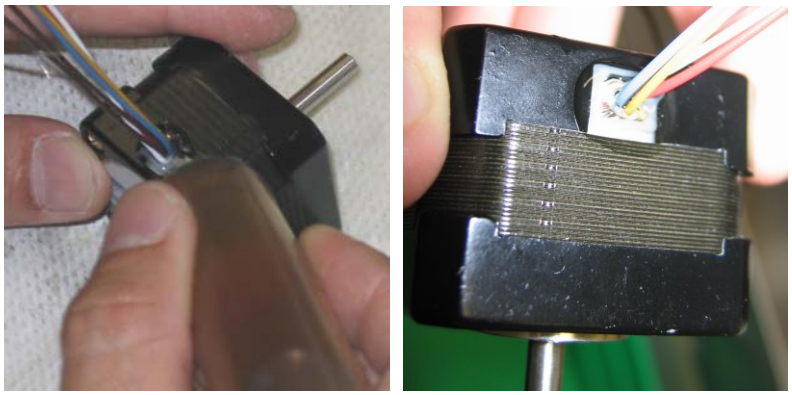
The lead wires typically pass through an opening in the motor housing which creates a leak path directly between the motor's service environment and the interior of the motor. This leak path must be sealed to prevent contaminants, such as dirt particles and moisture, from damaging the motor. Dirt particles can bind bearings or abrade wires. Moisture or other fluids can cause the bearings to rust or cause shorts.

Sealing these wire connections (also often called "potting") is a common challenge among motor manufacturers. There are a variety of methods that can be used to seal the wire connections, but the two most common are potting the connection with adhesives and using heat-shrink seals. Lin Engineering initially evaluated both methods.

When the heat-shrink seals were evaluated they did not seal effectively. The lead wires in Lin Engineering stepper motors typically have 4 to 8 lead wires. While the seal shrunk to fit snuggly around the exterior of the wires, they did not adequately seal between the wires.

When evaluating adhesives, it quickly became clear that the rheology of the adhesive was critical. In this motor design, the lead wires passed directly through the housing. As a result, there was no cavity that could simply be potted using a low viscosity adhesive. This mandated that the material be thick enough not to run into the motor contaminating the interior, but thin enough to create a seal. Since there were 4 to 8 lead wires, it was also required that the adhesive flow around the lead wires to create a complete seal.

Lin Engineering determined that Loctite® 352 light cure acrylic adhesive was the optimum adhesive for this application. Its 20,000 cP viscosity was just right to seal the opening without contaminating the interior of the motor.



Sealing Wire Connections in Motor Housing:
Left – Dispensing Loctite® 352 to Wire Connection
Right – Close Up of Sealed Assembly After Cure

In order to ensure the highest quality and most reliable step motors, Lin Engineering conducted extensive tests on a variety of other adhesive technologies that are commonly used for potting such as epoxies, polyurethanes, and silicones. When evaluating these alternatives, Lin Engineering found that they were harder to handle for this application and did not cure as fast as the light cure acrylics resulting in lower productivity and higher work-in-process. Exhaustive testing proved that Loctite® 352 light cure adhesive proved to be the optimum method for sealing the wires into the motor body.

Summary

Adhesives and sealants are used in many ways to improve motors and generators. Light curing adhesives have unique cure-on-command capabilities combining virtually unlimited open time with the ability to achieve full cure in seconds. This makes light cure acrylic adhesives extremely well suited for lean manufacturing operations.

Lin Engineering recognized the benefits of light cure adhesives and implemented light cure acrylics for wire tacking, bonding stators to housing and sealing wire connectors on their stepper motors. This facilitated customization, improved quality, reduced their manufacturing costs and decreased their time to manufacture stepper motors.

Additional Information

If you would like more information on adhesives and sealants for motors or generators, please visit motors.loctite.com to order the Loctite® Design Guide for Electric Motors and Generators.

If you would like more information on stepper motors, please visit www.linengineering.com.