

Low Voltage Electromagnetic Lockbolt Installation

**John Hartmann, Michael Assadi,
Scott Tomchick, and John Barry
Electroimpact. Inc.**

**Andrew Roberts
British Aerospace**

Abstract

British Aerospace, Airbus Ltd., Chester, UK manufactures the main wing box assembly for all current Airbus programs. Titanium interference fasteners are used in large numbers throughout these aircraft structures. On the lower wing skin of the A320 alone there are approximately 11,000 of this fastener type. Currently, the majority of these fasteners are manually installed using pneumatic or hydraulic tooling. British Aerospace engineers recognized the significant potential which automation offers to reduce these current labor intensive installation methods. Electroimpact proposed extending Low Voltage Electromagnetic Riveter (LVER) technology to the automatic installation of these interference fasteners as well as rivets. Close liaison between Airbus and Electroimpact engineers resulted in the development of an automated LVER based lockbolt installation system, which is currently undergoing evaluation.

Over the past five years, Low Voltage Electromagnetic Riveting (LVER) has been gaining acceptance in the aerospace industry. LVER heads are impulse devices, which derive their power from the discharge of a bank of capacitors through a pancake coil. (1) LVER units are currently in production installing rivets in five major aircraft programs around the world. Besides rivets, the other primary type of fastener used in aircraft manufacture is the titanium interference bolt. Recent developments in LVER technology, have increased the reliability and quality of a complete LVER bolt installation system. An adjustable shock absorbing hardstop in the bolt driving head allows precise control of the point at which the driver stops at the end of the installation stroke. Other developments include innovative tooling for collar feeding and swaging. A compliant swaging die has been developed which will self-align to the bolt

eliminating alignment problems between the opposing heads.

The quality of the LVER bolted joint has been evaluated relative to currently used installation methods. Results from joint preload, ultimate tensile strength and fatigue tests are presented. These results indicate the quality of the LVER installed lockbolt is comparable to methods currently employed in the aerospace industry.

1.0 Introduction

The demand for higher quality at a lower cost has led aircraft manufacturers to move more and more toward automation. One area where automation has been shown to have a significant impact is in aircraft fastener installation. The introduction of the Low Voltage Electromagnetic Riveter (LVER) in 1986 (1) opened up new avenues for the automation of aircraft riveting. LVER technology is currently being used in production at a number of aerospace companies worldwide. Titanium interference bolts also make up a large percentage of the fasteners on large transport aircraft. A natural extension of LVER technology is to apply it to the installation of these two piece fasteners. Electromagnetic riveters (EMR) have been used for over twelve years to swage collars on lockbolts on the Boeing 767 ASAT machine. On this older machine pneumatic riveters are used to seat the bolts because it was felt at the time that the electromagnetic riveter could not "drive the bolt tight." (3) Recent developments in LVER technology, such as the integral hardstop, make LVER a viable multifunctional tool for the complete lockbolt and riveting installation cycles. Advances have also been made in collar feeding and swaging technology which increase the quality and reliability of the lockbolt installation process.

Testing has been performed to evaluate the quality of the LVER installed lockbolt. Preload and ultimate tensile strengths of the LVER swaged collars measure well within acceptable ranges as specified by the Huck International, manufacturer of the lockbolt. Fatigue studies indicate comparable quality between LVER installed bolts and those installed with conventional equipment.

2.0 Automation of Lockbolt Installation

Two piece fasteners are used throughout most aircraft for their high strength/weight ratio relative to aluminum rivets. Their strength is derived from the high shear strength of the titanium bolts. There are two primary types of these fasteners used in aircraft assembly, those which use threaded nuts and those which use swaged collars, such as the lockbolt. Both types of bolts are installed into interference fit holes. Lockbolts lend themselves more to automation since the collar is swaged rather than torqued onto the pin. Nut orientation and possible cross threading problems are therefore eliminated. Lockbolts come in two configurations pintails and stumps. Pintails are typically installed by hand using hydraulic pull type tools. Stump bolts are driven into the hole using pneumatic, hydraulic or electromagnetic force generators. Stump bolts are best suited for automation since they are more easily fed and can be installed using existing auto riveting equipment with only minor tooling changes.

LVER technology offers the aircraft manufacturers an automated fastening alternative to the conventional hydraulic squeeze machines. The lightweight and low recoil of LVER systems make them ideally suited for use with lightweight positioners. The electronic nature of LVER technology allows precise control and feedback of the forming parameters. LVER riveting technology is currently being used in production at a number of companies worldwide. One example is the Traveling Yoke Assembly System which rivets the skin to stringer joint on the upper skin of the Airbus A330/340 at Textron Aerostructures. (3,4). In this system, a lightweight yoke moves in five axes about a stationary part. Multiple parts are serviced by the same yoke system. In this fashion, the entire assembly process can be completed in one fixture with minimum part handling.

Automated lockbolt installation typically requires more machine functionality than does automatic riveting installation. Hole preparation is especially critical since the lockbolt does not expand in the hole as rivets do when driven. Hole roundness and diametrical tolerances are therefore critical to insure there is acceptable interference throughout the entire hole. At minimum,

each hole is drilled and reamed. In some cases, coldworking of the hole and sealant application is also required. The bolt must then be presented and driven into the hole. After the bolt is seated, the collar is positioned onto the bolt and swaged to apply the desired joint clamp. In many assemblies both rivets and bolts are used. It is therefore desirable to have one machine provide capabilities to perform both riveting and bolt installation.

For over twenty years EMR technology has been used on the 767 Automatic Spar Assembly Tool (ASAT) to install rivets and swage collars on lockbolts. On ASAT, the pins are seated using a pneumatic hammer. The EMR was not used to seat the bolt because at the time it was felt that EMR could not drive the bolt tight.(3) Recent developments in LVER technology however now make it a potentially viable means for the complete lockbolt installation process. The bolts are staked into the hole using an air cylinder with added inertia. The LVER bolt driver is then used to seat the bolt in one shot. The low voltage electromagnetic bolt driver can also be configured to perform riveting as well. This provides the manufacturer multifunctionality with a minimum amount of tooling.

3.0 Low Voltage Electromagnetic Bolt driver (LVEB) Design

In the past one of the primary concerns of using a one shot device for setting interference pins was proper seating of the pin. The amount of driving force required is strongly dependent upon the amount of interference between the bolt and the hole. If the driving force is set high enough to insure seating with cases on the high side of the interference tolerance band, there is a significant amount of excess energy when driving pins on the low side of the interference band. This excess energy can result in damage to the bolt head or to the surrounding material. Conversely, if the voltage is set too low, the bolt will not seat properly, which could result in a loose joint.

To overcome this problem, an adjustable shock absorbing hardstop was introduced, which prevents the driver from advancing beyond an acceptable point. The driving energy levels can therefore be set slightly higher than those required for the highest interference level because the excess energy is absorbed within the tool rather than by the part. A large mass in conjunction with a polyurethane pad is used to absorb the impact of the driver. Careful design of the hardstop is required to insure the shock waves which result from the driver's impact are sufficiently dampened.

Another primary issue of concern is the protection of the electromagnetic interface, i.e. coil/driver. When the driver reaches the apex of its stroke, there can be a significant amount of elastic energy stored in the hardstop. With no protection the driver rebounds into the coil. This can damage the electromagnetic interface and significantly reduce the coil lifetime. In a standard LVER riveting head, the amount of elastic energy stored in the formed rivet is minimal and therefore, the coil does not need protection. The LVER coil and driver are enclosed in single tube which recoils inside a stationary external tube. In the LVEB, this recoil mechanism is reduced. A rear driver hardstop has been incorporated into a stationary rear tube. Figure 1 illustrates this new design. Plate 1 shows the LVEB head. The coil protrudes in front of the hardstop prior to firing. After firing the coil recoils behind the hardstop, which protects it from the rebounding driver. These precautions significantly increase the LVEB coil lives.

4.0 Collar Feeding/Swaging

One of the common concerns with automation of the lockbolt process is the downtime required for the machine set up. Tooling changeouts between fasteners sizes and the tight alignment requirements between the opposing heads are the problem areas. Two recent developments, a quick change collar loading mechanism and a compliant swaging die address these concerns.

The quick change collar loaders are attached directly to the clamp arms of the back up side LVEB. This eliminates the need for a back side tool shuttle as was used on ASAT. (3) This collar loading mechanism is shown in Figure 3. This mechanism mounted on the riveting/swaging head is shown in Plate 2 Collars are blown directly to the collar loader where they are mechanically positioned on a transfer arm. The arm then rotates into the tool axis and the die is pushed against the transfer arm. The collar is positively transferred onto the die. Once the collar is on the die the transfer arm is retracted and the collar is pushed onto the tail of the bolt. This sequence is shown in Figure 4. The entire mechanism can be quickly removed and replaced to allow for installation of different collar diameters.

One of the primary causes for the long machine set up time is the high accuracy to which the opposing heads must be aligned to insure that the collar is positioned and swaged accurately on the bolt. This is especially true with the Lightweight Grooved Proportioned (LGP) collars due to the extremely tight clearances between the collar ID and the bolt OD, .001 5M minimum radial clearance. The low weight of the LGP collars make them a popular choice for

airframe fastening application. These close fitting parts require that the collar side ram be precisely aligned with the installed bolt. Slight misalignment can result in misfeeding, shaving of collar material on the bolt grooves or offset swaging of the collar on the bolt.

Alignment problems are virtually eliminated by introducing compliance into the swaging die. The Electroimpact two piece compliant die allows for up to .025" radial misalignment. The die indexes off the centering hole provided in the center of standard stump bolts. The collar is held onto the die with a tapered center pin. The tapered pin finds the center of the bolt and moves the die and collar into precise alignment with the bolt. Two axes of compliance are provided by the die. The front swaging die is tightly held against rear piece by a pin in a loosely fitting hole. The clearance between the pin and the hole determines the degree of compliance and is dependent upon the size of the fastener. A schematic of this die is shown in Figure 2.

5.0 Joint quality

A fastening process is evaluated by the quality of the produced joint. The term quality is defined by a number of parameters such as tensile strength, shear strength and microstructure in and around the joined material. These parameters are directly related to a joint's fatigue life and corrosion resistance in service. Lockbolts are typically used in areas where high shear fasteners are required. The pins are driven into interference fit holes which creates residual compressive stresses in the metal surrounding the hole. The compressive stresses shield the hole from tensile stresses which prolongs the fatigue life of the joint.

Lockbolts are designed with annular grooves rather than threads. The collar material is swaged into these grooves to fasten the joints. Lockbolts can either be pushed (stump bolts) or pulled (pintails) into the hole. For automation, stump bolts are preferable to pintails. Stump bolts are easier to feed due to the absence of the pintail. They also eliminate alignment problems between the grooves of the pulling mandrel and the pintail. Residual clamp is provided by the inherent design of the lockbolt swaging process and is not dependent upon whether the bolt is a stump or a pintail. When the collar material is swaged into the first annular groove, the collar and bolt are locked together. As the swaging die continues forward, the geometry acts to stretch the collar. Subsequently, the bolt is also stretched which puts the joint in tension. It is this action which provides the joint's residual clamp. High residual clamp is desirable for a quality

joint. When swaging with EMR, the power levels can be varied on either side of the bolt. The head side LVEB is discharged during swaging as well to provide backup. Typically, more energy is required on the collar side to compensate for the collar formation compliance. Tests per Mil-Std. 1312-16 were performed to measure the preload of both 3/16" and 1/4" diameter LVER swaged collars. Preload and breaking tension values are presented as a function of swaging voltages in Figures 5 and 6. Metallurgical analyses were performed to insure that the collar fill and collar microstructure were acceptable. No problems were seen. Plate 3 shows a view of the entire collar at 7X magnification. Plate 4 shows a comparison of the collar fill for hydraulically and LVER swaged collars at 50X magnification.

Fatigue studies were performed on a series of specimens to investigate the effects of different parameters involved in the installation process as well as to compare the LVER installation process with more conventional methods. Lap shear specimens made from 2024-T351 aluminum were used for these studies. The specimens were anodized. Sealant was applied under the bolt head and in the faying gap. Holes were drilled, followed by a ream/countersink operation. All holes were measured prior to the bolt installation. The interference level was between .004"-.005". The specimens were then subjected to alternating loads of approximately + 24ksi/ - 0.9ksi. Fatigue studies can be used to provide a comparative guide to verify that new process applications meet existing requirements. They can also be used to optimize system parameters. Figure 7 illustrates results of the fatigue tests used to compare: (1) Pintail lockbolts hydraulically pulled in and hydraulically swaged; (2) Stump bolts pneumatically driven and LVER swaged; and (3) Lockbolts driven and swaged with the LVEB. The results indicate that each process produces joints of

similar quality.

6.0 Conclusion

LVER technology offers aircraft manufacturers an automated fastening alternative to the conventional hydraulic squeeze machines. Recent developments have extended the potential capability of this technology to automatic lockbolt installation. The integral shock absorbing hardstop and the compliant swaging die are two examples of these technological advances. Test results indicate the quality of LVER bolted joints is comparable to that of joints fastener with more conventional methods.

Acknowledgement

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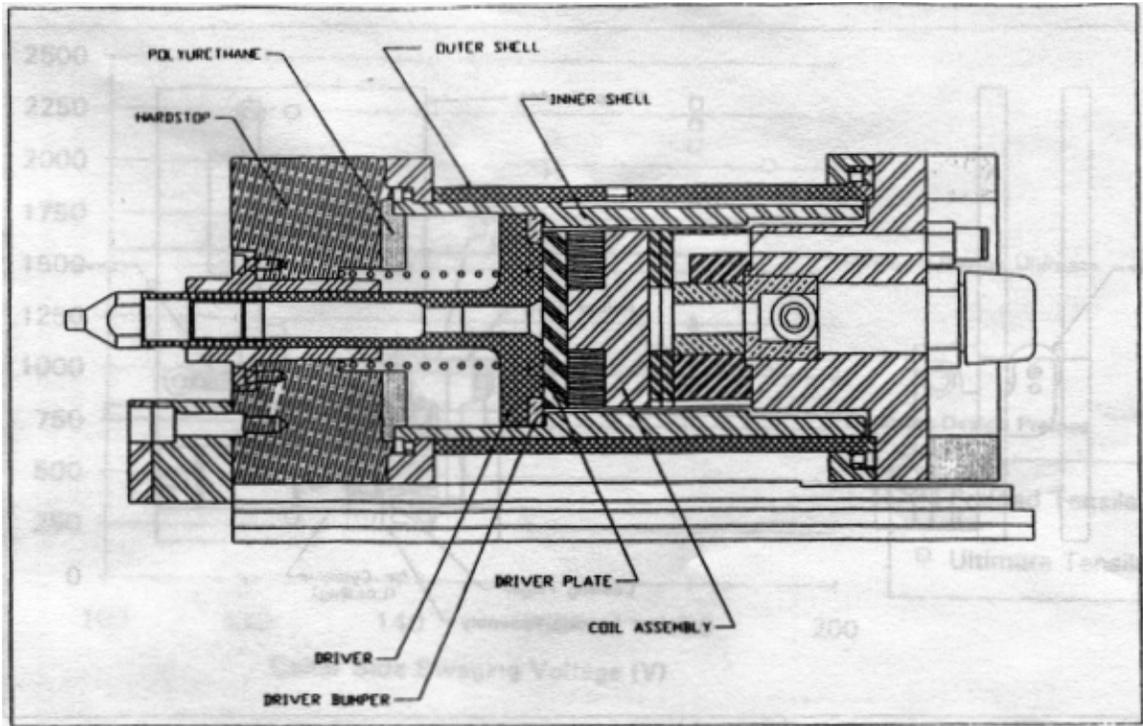


Figure 1: Schematic of Quick Change Collar Loading Mechanism

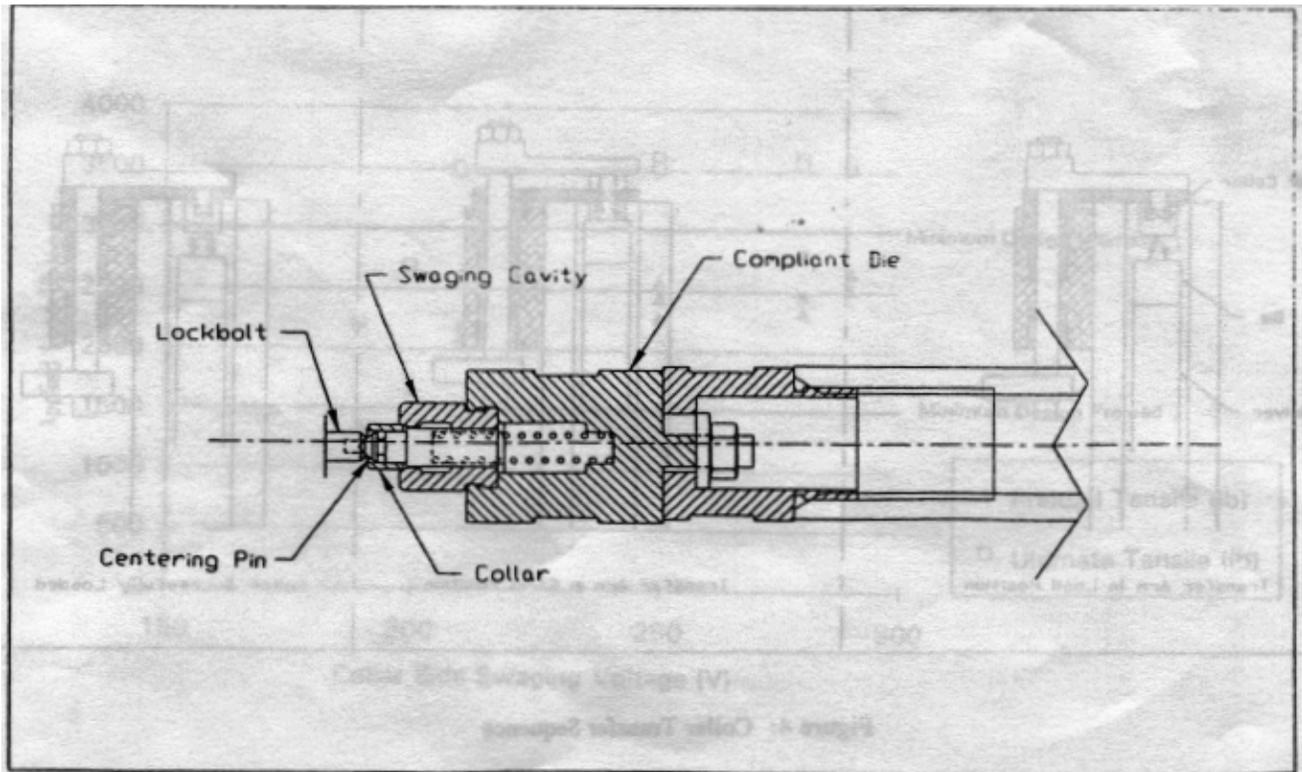


Figure 2: Collar Transfer Sequence
2099

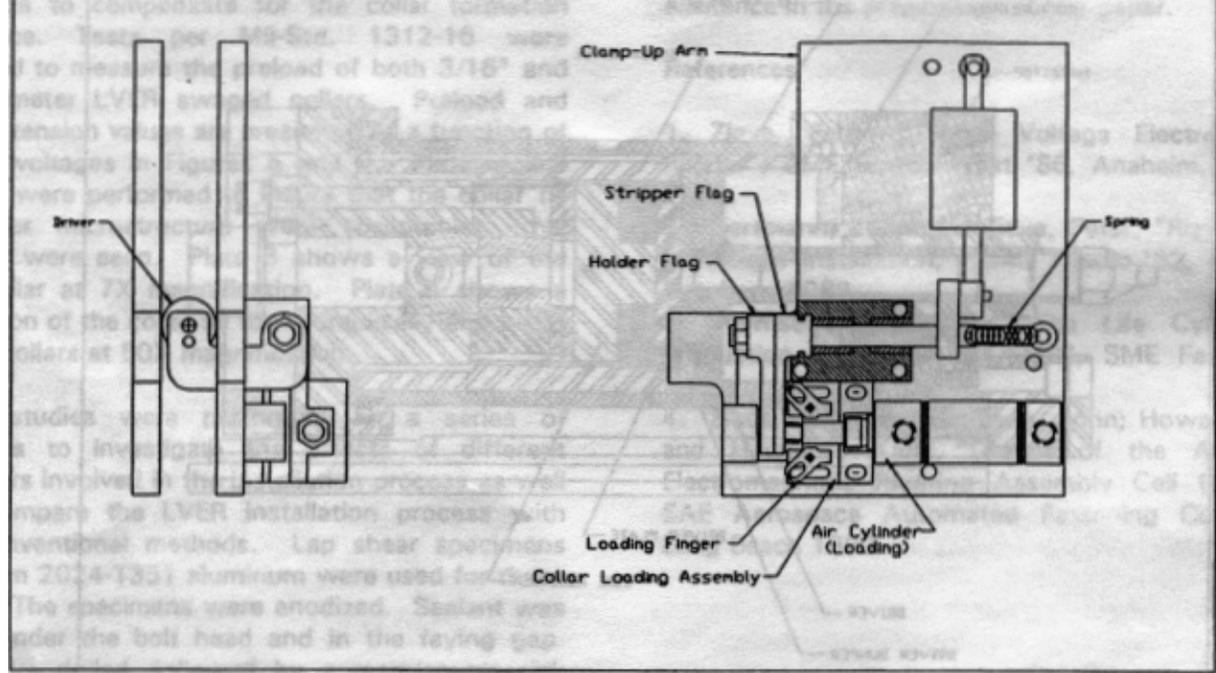


Figure 3: Schematic of Quick Change Collar Loading Mechanism

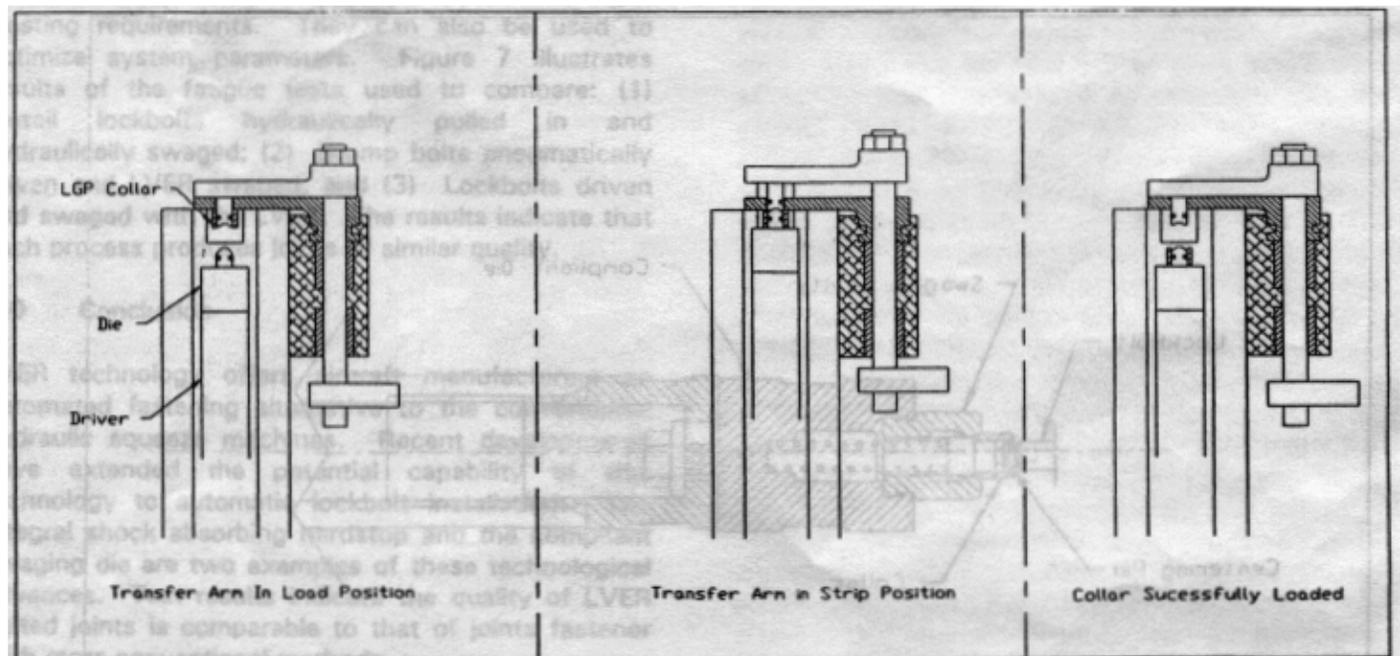


Figure 4: Collar Transfer Sequence

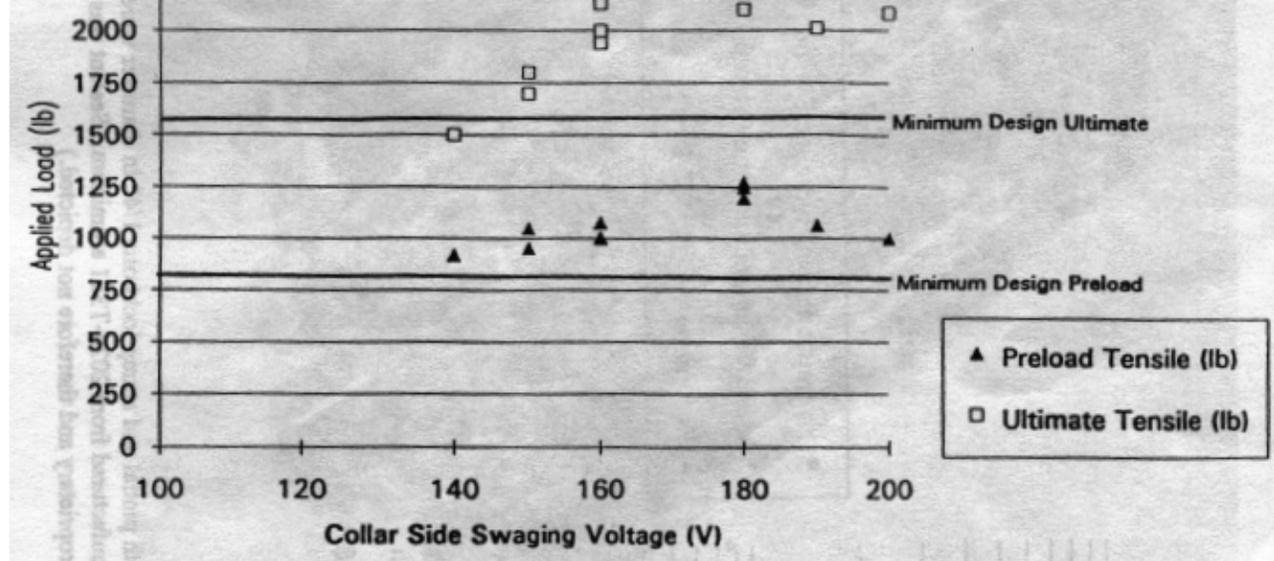


Figure 5: Preload and Ultimate Tensile Strength as a function of Collar Side Swaging Voltage. Fasteners used were 3/16" diameter Huck Lockbolts LGPLSCV. Collars were swaged using the Low Voltage Electromagnetic Boltdriver. Tests were performed per Mil-Std. 1312-16. (Note: Collars with low preload and ultimate values did not passed Huck gage standards.)

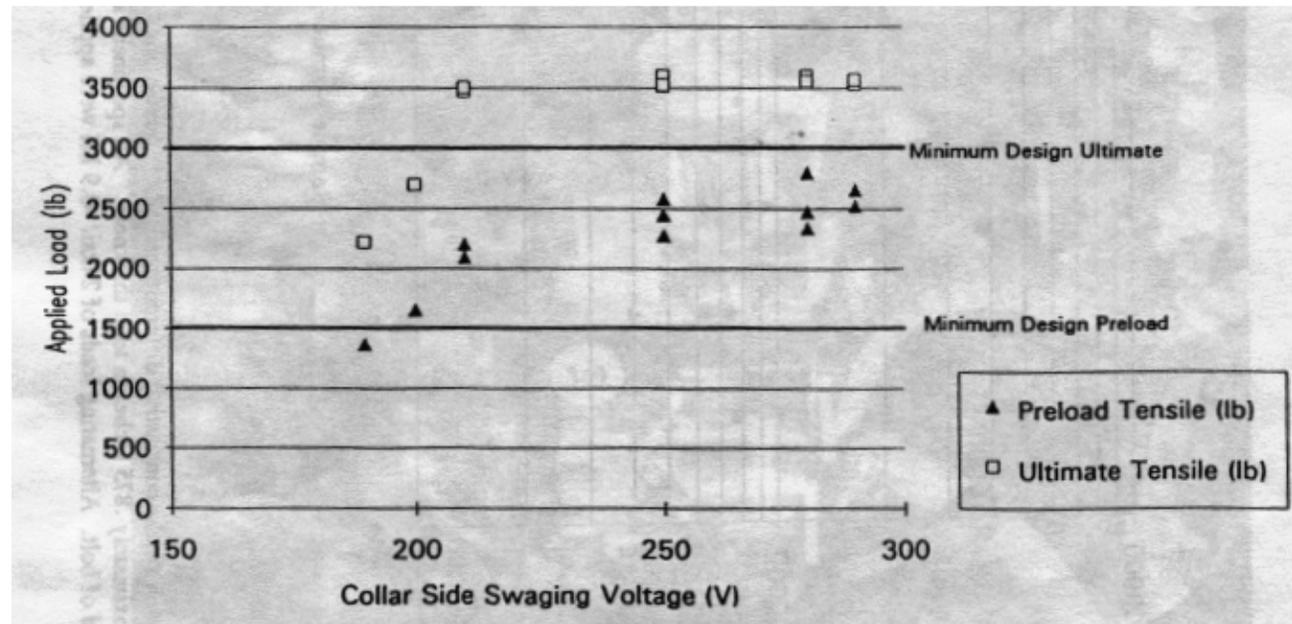


Figure 6: Preload and Ultimate Tensile Strength as a function of Collar Side Swaging Voltage. Fasteners used were 3/16" diameter Huck Lockbolts LGPLSCV. Collars were swaged using the Low Voltage Electromagnetic Boltdriver. Tests were performed per Mil-Std. 1312-16. (Note: Collars with low preload and ultimate values did not passed Huck gage standards.)

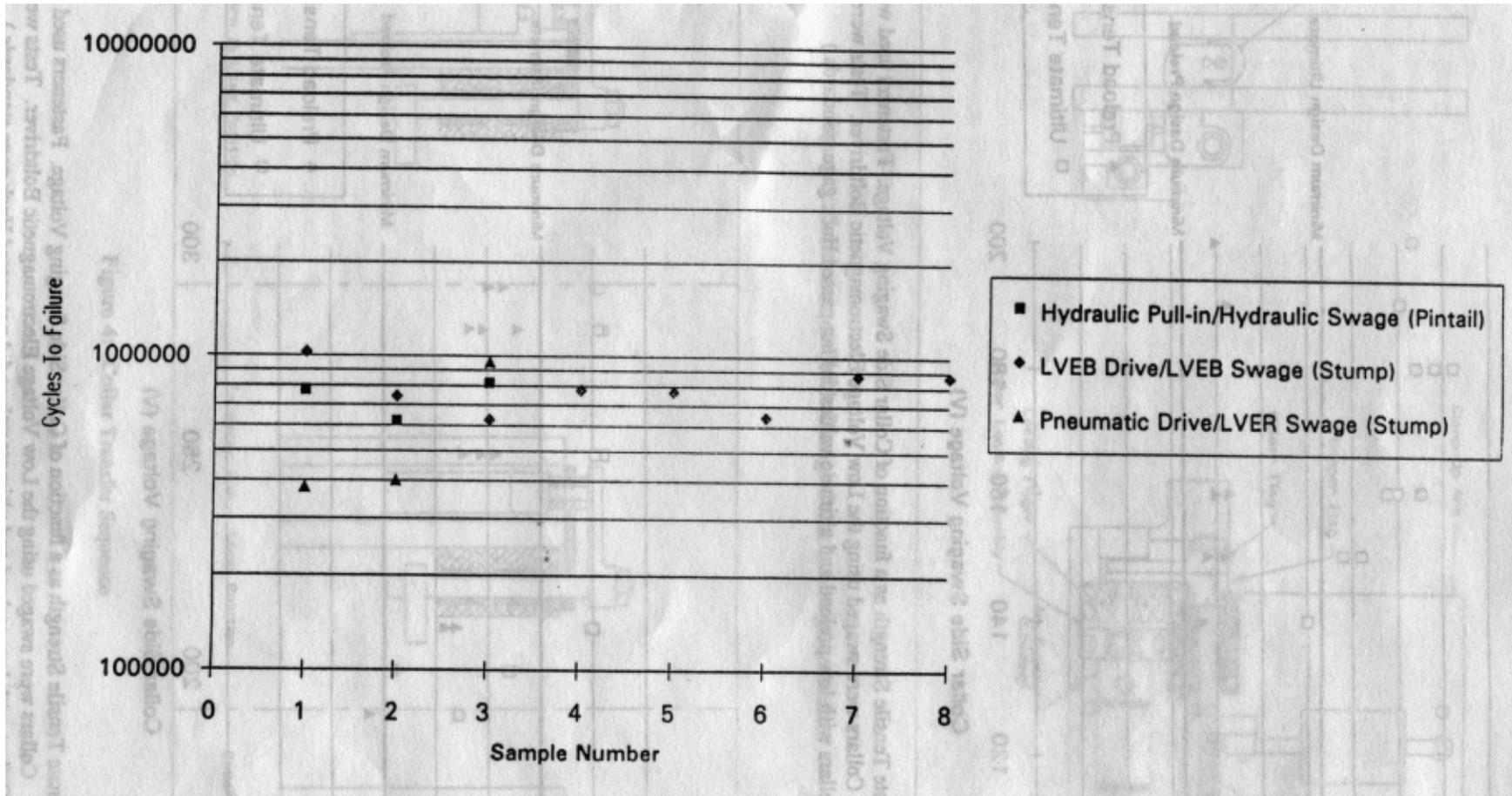


Figure 7: Fatigue test results contrasting different method of countersunk LGP lockbolt installation. Both pintail and stump lockbolts 1/4" in diameter were used in the tests. Stack up was approximately .875 inches in total thickness. All specimens are lap shear type and are manufactured from 2024-T351 aluminum. Sealant was applied in faying gap and under head of bolt. Alternating loads of 24ksi/ -0.9 ksi were applied. (Note: Actual shape is proprietary and therefore not depicted.)

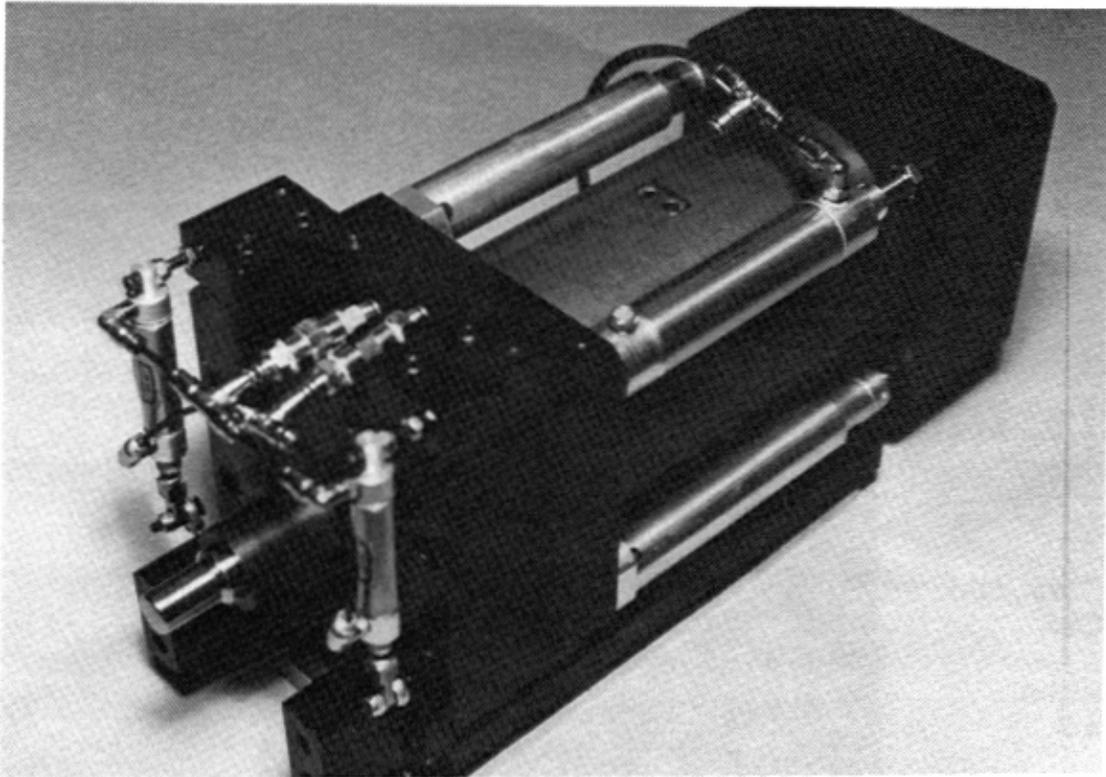


Plate 1: Low Voltage Electromagnetic Bolt Driver

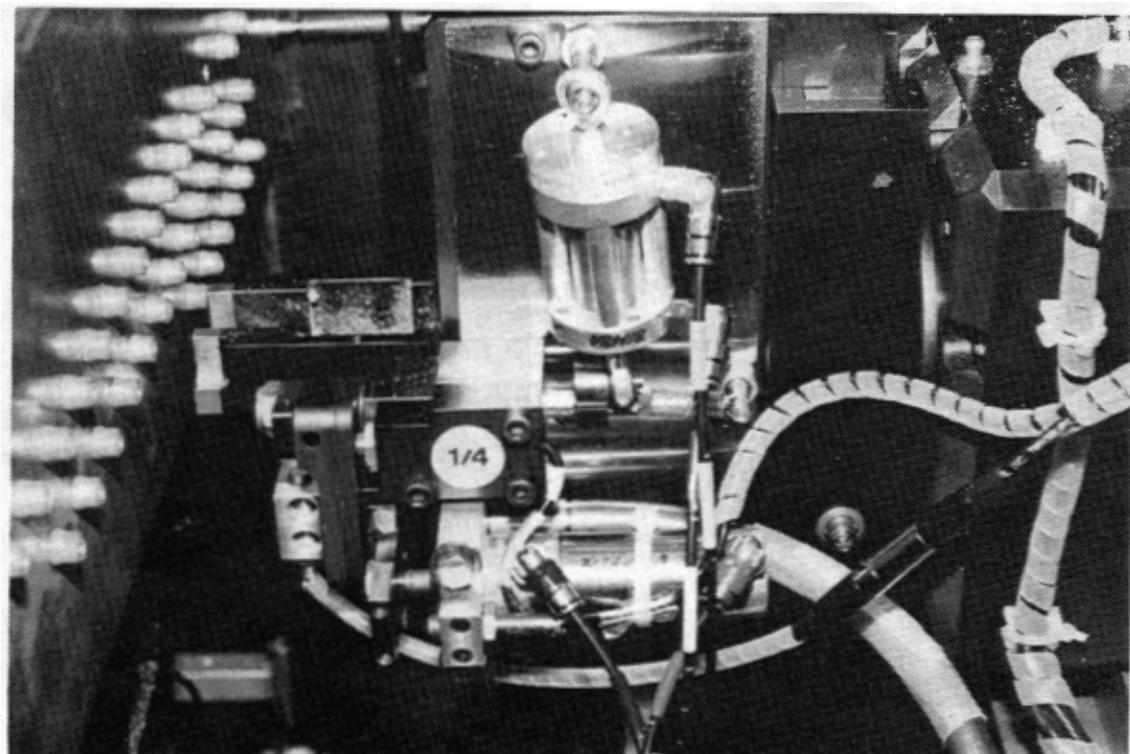


Plate 2: Collar Loading/Swaging Tooling

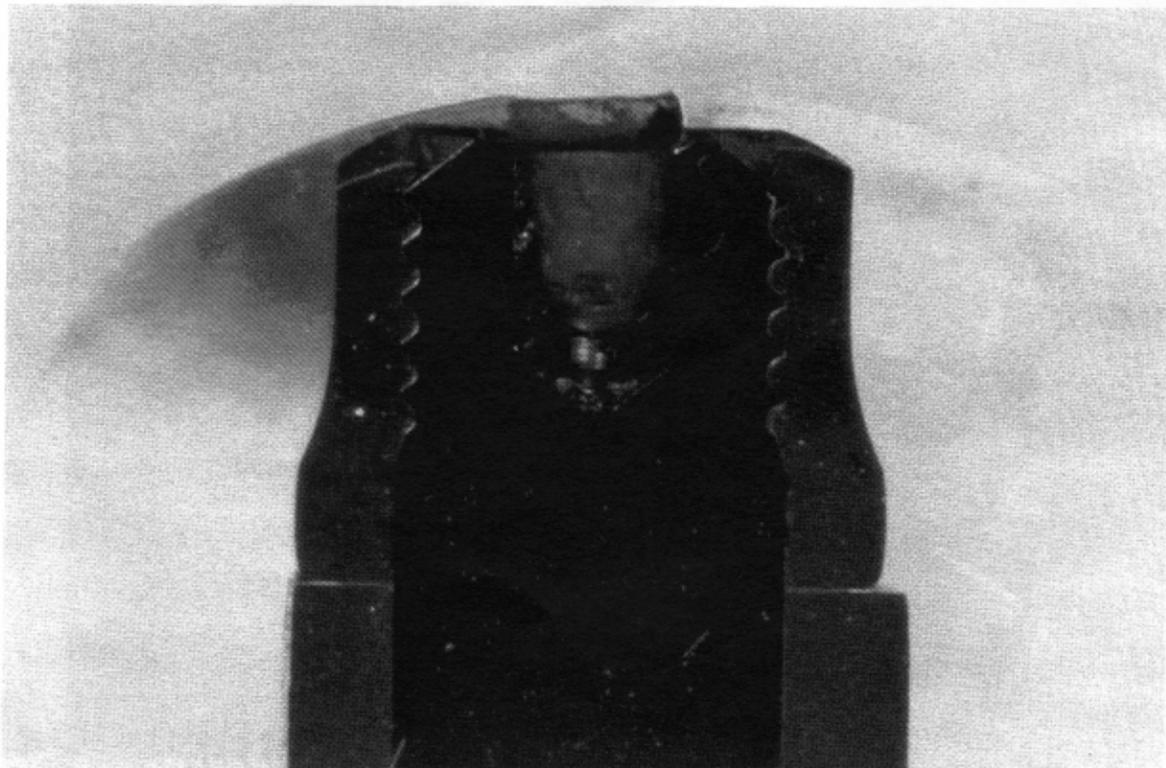
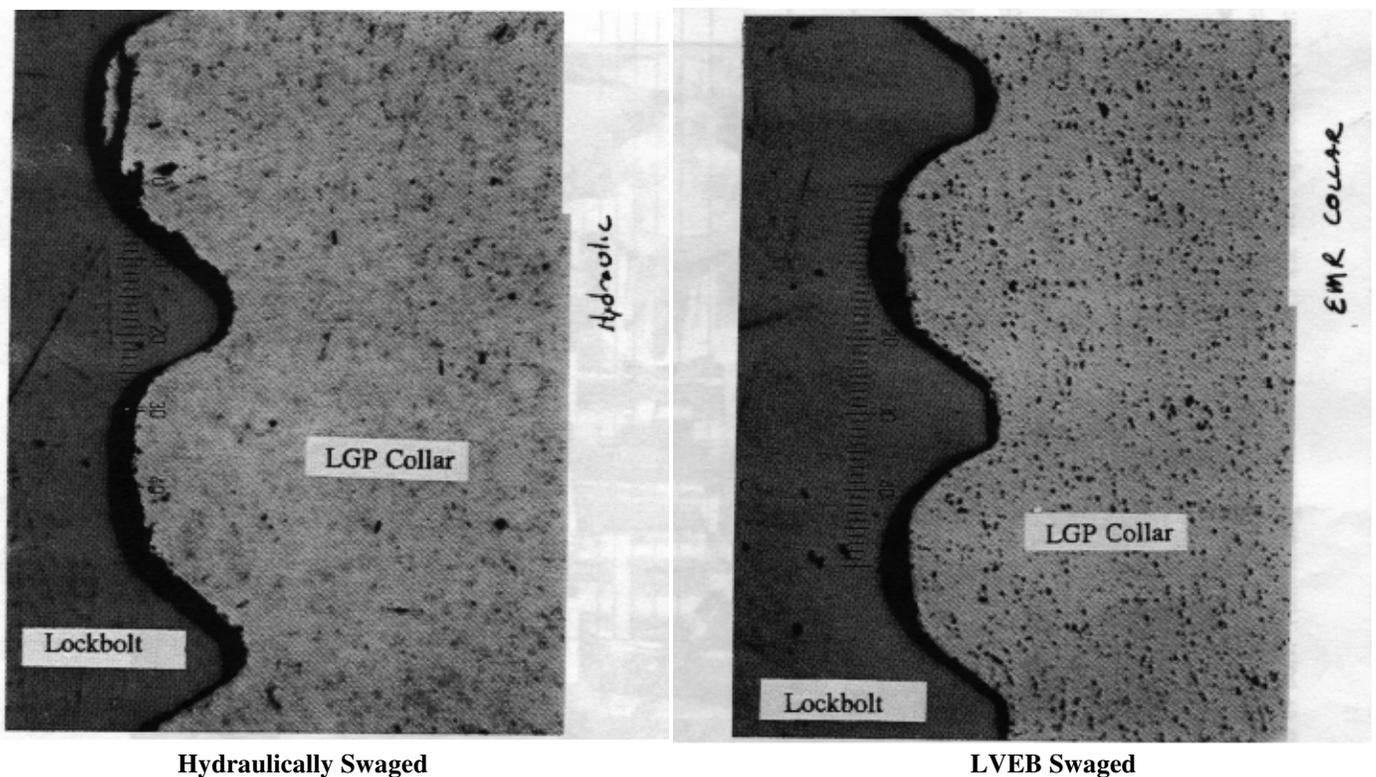


Plate 3: LGP Collar Swaged with the Low Voltage Electromagnetic Bolt Installation System (7X Magnification)



Hydraulically Swaged

LVEB Swaged

Plate 4: Collar Fill © 50X Magnification. Left view is collar swaged with hydraulic pull type tool. Right view is collar swaged with the LVEB system.