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Lightweight Handheld EMR with Spring-Damper Handle

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ABSTRACT

Early versions of handheld (HH) electromagnetic riveters (EMR), while effective, were heavy. With the proven effectiveness of the EMR, the next step was to make the HH riveting system light and portable. To maintain the required output force in a small package, the upper limit of the voltage range was increased to 1000V, twice that of conventional 500V LVER systems. The 0-1000V range of the HH50s allows for the formation of rivets up to 3/16" diameter. Due to the lower mass in the HH50s, the riveting actuator was developed to strategically maximize output force and minimize recoil. Recent developments have been made to drastically reduce recoil by incorporating a spring-damper system integral to the HH50 handle.

INTRODUCTION

With the goal of producing a riveting system which would simplify, accelerate, and improve the quality of rivet formation in contrast to the traditional pneumatic hammer and bucking bar method, the handheld (HH) electromagnetic riveting (EMR) system was introduced. The computer controlled HH system provides the ability for rivet formation optimization with high repeatability by greatly reducing the dependence upon operator skill (2). Furthermore, the "single-shot" EMR impulsive force is significantly quieter than its pneumatic hammer counterpart. Research has shown that EMR noise levels are 20 to 26 dB less than pneumatic.

First generation handheld EMRs were heavy. Mass was added to the rivet guns (actuators) in order to reduce recoil, rendering the system large and difficult to maneuver. With the proven effectiveness of the EMR, the next step was to make the HH system light and portable, which lead to the HH50 spring-damper EMR system introduction.

HH50 EMR SYSTEM

MECHANICAL DESIGN - The HH50 actuator with the spring-damper system is similar in size and shape to a slightly oversized soda can. The mass of the actuator is less than 2.3 kg (5 lbs.). The primary design focus for the HH50 was to couple high energy output with small size and low weight. A basic analysis of the actuator function shows that the kinetic energy imparted to the driver (the ram/die that forms the rivet) is proportional to the ratio of the masses of the body and the driver (see Figure 1, Appendix). Efficient driver design is critical to ensuring a high output force while minimizing recoil (1). The HH50 driver was specifically tailored to have minimum mass, yet provide proper rivet formation. Because the HH50 is designed to form rivets up to ∅3/16", the required forming force can exceed 36 kN (8,000 lbs.). This must be resolved into a driver assembly, which has a mass of less than 0.187 kg (7 ounces). The HH50 driver is made from heat treated tool steel and is bored through the center for weight reduction. The die is also made from hardened tool steel to inhibit cup wear. Retention of the die in the driver can be configured for a threaded or snap connection depending on the buyers preference.

Recoil System - Previous HH50 models, though optimized to reduce recoil, still produced an unwanted "kick" when forming larger rivets or driving interference bolts. Development of the handle was undertaken on early models to reduce shock loads by tailoring the geometry and materials that would both deflect and dampen under vibration. Although this helped significantly, the problem was not eliminated entirely. The eccentric grip location (not in-line with the driver), aided to reduce shock, but also led to an undesirable vertical component to the recoil motion. Mass was then added to the gun which increased the total up from 1.4 kg (3 lbs.) to 3.6 kg (8 lbs.). Although this alleviated the recoil shock, operators were disappointed with the increased mass of the actuator. The necessity for a low-mass, in-line damping system was clear.

With the spring-damper system, the actuator can be broken down into three major sub-assemblies; the driver, the body, and the handle. The body consists of the coil, actuator shell, front plate, recoil mass, rear plate, spring rods, etc. The system efficiency increases and recoil decreases if the mass of the actuator is concentrated in the body (as discussed above). The handle remains stationary, and therefore, is designed to be as light as possible.

Figure 2 details the recoil system of the HH50. The body is constrained to allow for the forward/aft recoil motion. Calculations were made based upon the mass of the body, the impulse produced by the electromagnetic coil, and the linear recoil stroke distance to size the coil springs. Because the force impulse is user defined, the preload of the springs is adjustable. The linear motion of the body is produced from the upper and lower hardened steel rods that slide inside bearings mounted integral to the handle. The bearings are fixed alignment recirculating ball linear bearings with a stainless steel outer sleeve and a resin ball retainer. This low mass bearing assembly (0.04 kg [1.4 ounces]) provides exceptionally fluid motion and high rigidity.

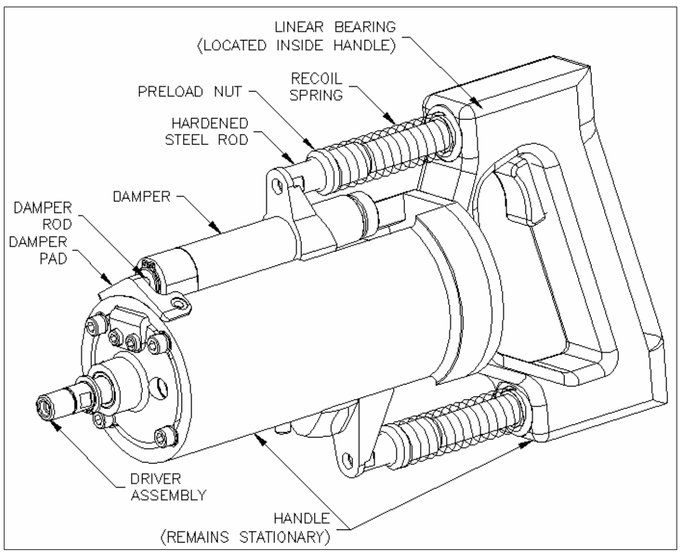

Figure 2. HH50 with Recoil System

The damper, shown in Figure 2, is critical to eliminating both double hitting springback and a secondary tug induced when the body is accelerated back to its rest position. When the actuator is fired, the body and damper move rearward, consequently increasing the distance between the damper and damper pad which allows the damper rod to extend. The damper exhibits a very rapid return rate in order to stay in contact with the pad when the body is set in motion. Once the recoil is complete, the springs push the body back to its rest position at a rate set by the adjustable damper.

Testing determined the optimal stroke to be 32mm (1.25"). The stroke was restricted to the minimum functional distance in order to reduce the overall length of the actuator.

ELECTRICAL DESIGN - In order to achieve the required forming force for a 3/16" diameter 7050 rivet with a 45mm (1.75") diameter coil, the upper limit of the HH50 voltage range was increased to 1000V from the more conventional 500V limit. Figure 3 (see Appendix) shows the force impulse generated by the 1000V HH50 and by the 500V HH100 system (1). Notice that the peak forces of both configurations are nearly identical, but the rise times are different. Since the area under the curve represents the total momentum, the HH50 configuration produces nearly half the momentum while still achieving the same peak forming force. The 1000V capability yields a small, powerful package with minimized recoil.

The electromagnetic impulse is made possible by discharging large amounts of energy through the copper pancake coil. Subsequently, the output force is dependent upon to what voltage the capacitors are charged. Recent developments to the HH50 charging and control system has enabled the unit to reach full voltage in approximately one second. Because the coil acts as a resistor when current is passed through it, power is dissipated in the form of heat. At a one second cycle rate the coil temperature quickly rises, and if not properly cooled, will eventually break down. Heat is removed from the coil by way of forced air cooling. The coil is drilled radially through the copper conductor to enable air to extract the heat directly from the surface of the copper. The coil temperature is monitored using an RTD. The output of the RTD is interpreted by the controller and is used to shut the system down before the coil reaches an overheated state.

Coil heating not only potentially affects the longevity of the coil, but it also affects the output force. As the coil temperature increases, the resistance across the coil also increases. This consequently acts to reduce the output level. This decreased power level directly effects the formation of the rivet. To eliminate varying rivet formation, the controller reads the temperature of the coil from the RTD and compensates for the reduction in EMR force by slightly adjusting the voltage level of the capacitor bank (3).

INTERFACE/CONTROL - Communication with the HH50 EMR system is accomplished through a touch pad/LCD interface located on the system control box. Information such as voltage levels, coil temperatures, delay values, etc. are displayed on the LCD, as well as any error messages that may occur. Operators use the touch pad interface to perform all parameter entry for forming and/or driving different fasteners.

The output force produced by the front and backside actuators is dependent upon each actuator's corresponding voltage setting. Further tailoring of the rivet formation is achieved by setting a delay between the firing of the actuators (3). Since the EMR pulse takes less than a millisecond to complete, the delay value is entered in the microsecond range. A unique set of voltage and delay settings exists for each fastener diameter, material, fastener type, length, etc. These values are obtained experimentally. Once these values are determined, they are stored in the controller under a user-defined name (e.g. grip, diameter, MS14186E6, etc.). This allows for efficient reconfiguration when changing from one fastener type to the next. A basic configuration change, including replacing both front and backside dies and loading new preset values, requires approximately 30 seconds to complete.

Riveting - Riveting with the HH50 EMR system is a two person process. One operator is responsible for the front side (head side) fastening and the other operator replaces the conventional bucking bar on the back side (tail side). For the system to work, both actuators must be fired at the same instant, or delayed slightly using the delay parameter as mentioned above. The timing of the discharge is not controlled by the operators, but by the system computer. In order for the actuators to fire, both triggers need to be pulled in a specific order. Basically, the team establishes a "master" and "slave". The system will discharge only when the master holds down his/her trigger, followed by the slave pulling his/her's. The triggering system can be set to either AB, BA, or AA with A being the head side, and B the tail side. Once the correct sequence has been established, the computer signals both actuators to fire (3).

In many cases, visual obstructions exist between operators making communication of ready/not ready status difficult. The HH50 actuators have been fitted with two LEDs to convey two critical messages. A green charge indicator is illuminated when the capacitor bank for the corresponding actuator is fully charged, and a second, yellow, LED illuminates on the slave actuator indicating the master is ready to fire.

Bolt Driving- Although originally designed for riveting, the HH50 system is also capable of driving interference bolts for use with threaded or swaged collars. Depending upon the application, bolt driving can be accomplished with either a single or multi-shot hit. Currently, HH50 systems are successfully being used for installing interference pins on the F/A-18 wing skin production line in St. Louis. A spring-loaded alignment tool was developed to keep the driver in-line with the fastener and to prevent the driver from contacting the workpiece. In contrast to using the manual phenolic block and mallet methods, using the EMR system for interference bolt driving significantly reduces assembly time, and also provides repeatable results. Because the impulsive force is highly controllable, research is currently underway for using the HH50s to install interference pins in composite/aluminum and composite/titanium stacks without delaminating the composite material.

CONCLUSION

The repeatability, computer control, and low noise characteristics of the handheld EMR system have made them a highly efficient and very effective tool in aerospace manufacturing. With the shock absorbing spring-damper recoil system on the HH50, operators can regain the maneuverability and comfort that was previously lacking in handheld EMR systems.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

EMR: Electromagnetic riveter

HH: Handheld (EMR)

KSI: kilo-pounds per square inch (6.9 MPa/KSI)

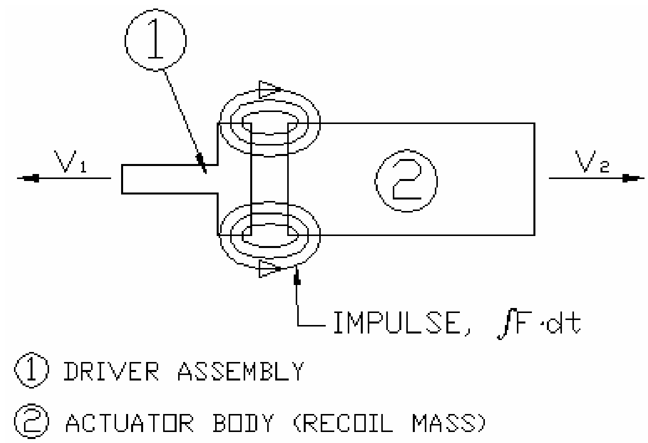
LED: light emitting diode

LCD: Liquid crystal display

LVER: Low voltage electromagnetic riveter

RTD: Resistance temperature device (difference in electrical resistance across a thin Platinum wire varies as a function of temperature)

APPENDIX



$m_1 \cdot v_1 = m_2 \cdot v_2$ (Conservation of Momentum)

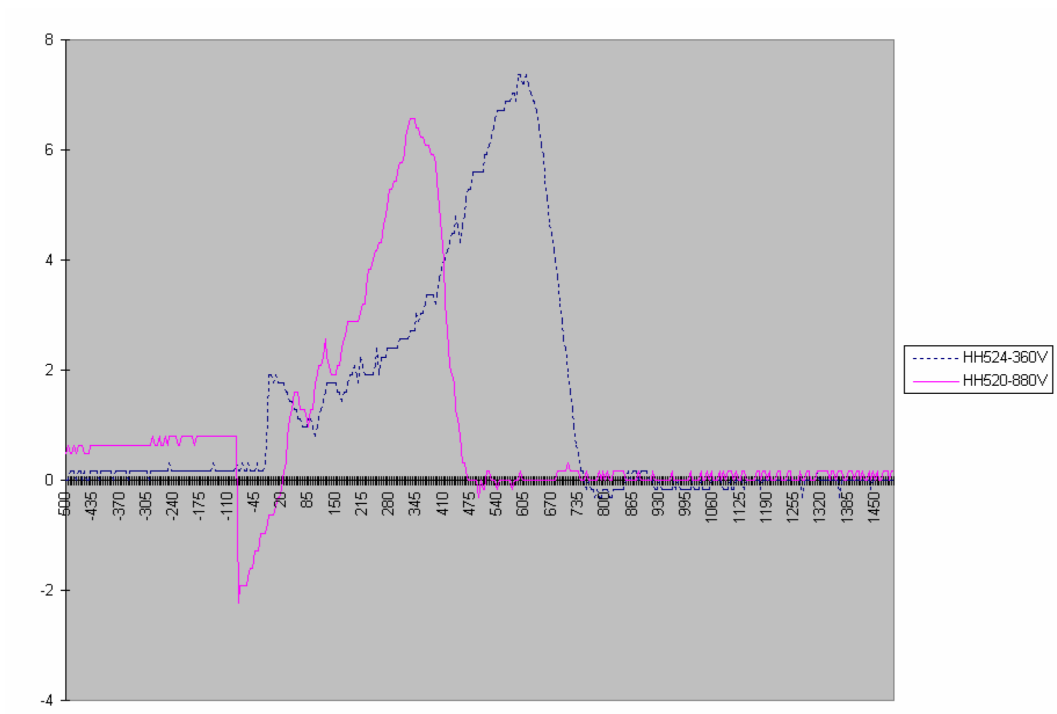
$$KE_1 = \frac{1}{2} \cdot m_1 \cdot (v_1)^2 = \frac{(m_1 \cdot v_1)^2}{2 \cdot m_1} \quad \text{or} \quad (m_1 \cdot v_1)^2 = 2 \cdot m_1 \cdot KE_1$$

$$KE_2 = \frac{1}{2} \cdot m_2 \cdot (v_2)^2 = \frac{(m_2 \cdot v_2)^2}{2 \cdot m_2} \quad \text{or} \quad (m_2 \cdot v_2)^2 = 2 \cdot m_2 \cdot KE_2$$

but $m_1 \cdot v_1 = m_2 \cdot v_2$ so $m_1 \cdot KE_1 = m_2 \cdot KE_2$

or $$\boxed{\frac{KE_1}{KE_2} = \frac{m_2}{m_1}}$$

Figure 1. Simple model of EMR function



Data: HH524 = HH100 System
HH520 = HH50 System

X Axis: Time (µs)
Y Axis: Volts (1235 lbs./Volt)

Figure 3. Force impulse comparison