Design of a Universal Remotely Triggered Firing Actuator for Finger-Triggered Powered Hand Pieces

Capstone Senior Design Project

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Sponsor: Zimmer Inc.

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Section 1: Acknowledgements
Section 1: Acknowledgements

The team would like to thank Zimmer Advanced Technology Research for their sponsorship and support of this senior design project. We would also like to thank Dr. Donald Mueller for his participation with this project.
Section 2: Abstract
Section 2: Abstract

The purpose of this report is to document the final work completed on the design solution developed for a surgical hand piece triggering system. The ultimate goal of this project is to develop a universal system for securing and triggering a surgical hand piece to aid in the prototype development testing of surgical hand pieces. The system will replace the requirement for manual operation during hand piece durability and fatigue experimentation. The mechanism will also remove the operator from potential safety hazards associated with unproven hand piece prototype designs. After completing the entire conceptual design phase last semester, the team started the build, test, and evaluation phases of the design. During part fabrication, minor issues arose that the team addressed while avoiding major design changes for the project. The team drafted a testing procedure to validate the completeness of the system requirements. The design came in 46% under budget, while also meeting all necessary design specifications and passing all testing requirements.
Section 3: Detailed Design Description
Section 3.1: Design from Last Semester

The final conceptual design is represented in Figure 1 below, which includes the fixture and triggering mechanism that was selected to be built for Zimmer, Inc. The design was the result of combining the best fixture and triggering sub-systems during the conceptual design evaluation process last semester. The fixture sub-system is designed to accept pneumatic and battery powered hand pieces, and secure them in place with a hand torqued clamp. The actuator selected is rated to generate up to 20 lbf per the system requirement [1]. The triggering sub-system electronically translates the actuator, which moves the rail guided triggering block to trigger a hand piece. The entire design was made to be lightweight, portable, and function on a benchtop. The build process, critical components, and function of the design relevant to the system requirements are presented and analyzed in the following sections.

![Figure 1. Model of final design from last semester](image)

Section 3.2: System Requirements

System requirements are goals that the system must achieve. The design of the system will be broken into two sub-systems: a means of fixturing a hand piece and a means of triggering a hand piece. These two different sub-systems must interface to provide an effective mechanism.

**Fixture Sub-system Requirements**

The fixture design must be able to fit and secure both pneumatic and battery powered hand pieces regardless of grip geometry. This shall be evaluated as no macro-movement resulting in measurable alterations to the hand piece position and orientation within the device throughout all phases of operation. Macro-movement shall be defined as 1° or more of rotation and/or 0.02” in translation.
**Triggering Sub-system Requirements**

The triggering design must provide a length of stroke up to 1.00 inch, and an actuating force within the range of 2 – 20 lbf with the load applied at the middle of the trigger and exerted in a line parallel to the barrel of the hand piece.

**Section 3.3: Design Parameters**

Design parameters are the aspects of the system that cannot be changed. The design of the system must not require any modification or alteration of, nor impose any damage to the hand piece throughout all phases of operation within the design. Materials used to create this system must be able to withstand all testing procedures provided by Zimmer.

**Section 3.4: Design Variables**

Design variables are the aspects of the system that can be modified.

**Fixture Sub-system**

It is desired that the design be simple, lightweight, easily transportable, and capable of assembly and operation without the use of supplemental tools. To create a more simplistic design, the number of components that comprises the fixture sub-system should be minimized. The design is to be used for bench-top testing; therefore features promoting the ability for secure attachment to a work surface should be considered.

**Triggering Sub-system**

It is desired that the method of triggering be a standalone operation so that a test engineer does not have to be present to manually actuate each trigger pull cycle in order to increase operator safety and reduce operator fatigue during lengthy hand piece fatigue and reliability testing procedures.

It is desired that a method of triggering be designed that can provide two modes of operation. An intermittent duty mode capable of triggering and immediate release shall be considered. Additionally, a continuous duty mode capable of triggering, holding for a specified amount of time, and releasing shall also be considered. For the scope of this project, it is not required that these two modes of operations be designed or built, as long as the triggering sub-system design is capable of accommodating these modes of operation.

**Section 3.5: Limitations and Constraints**

Limitations and constraints are restrictions of the system. The design should be compatible with standard control and data acquisition systems for future incorporation not included within the scope of this project. The cost of the project shall be kept to a minimum by selecting off-the-shelf products when applicable.
Section 3.6: Additional Considerations

Additional considerations are design considerations not previously mentioned. The design should not introduce any new safety concerns to the testing environment. A simple and robust design should be sought in order to minimize the need for maintenance and calibration efforts.
Section 4: Building Process
Section 4.1: Building Process

Zimmer has an excellent fabrication shop with a qualified machinist who assisted with this project. All parts were fabricated to the specifications outlined in the engineering drawings that the team created. All of the plate parts were machined on a vertical mill and the cylindrical parts were machined on a manual lathe. The fasteners, ACME threaded rod, and plastic parts were purchased from McMaster-Carr and modified by the Zimmer machinist when needed. The team assembled the parts with available tools to finish the assembly of the design.

Section 4.2: Changes during the Build Process

When the engineering drawings were released to the machinist, it was observed that the interface between bushings and the triggering blocks could be modified to assist with fabrication.

Figure 2. Previous triggering block design

Figure 3. New triggering block design

Figure 2 shows the initial design, with the triggering block as two separate pieces. Two bolts fastened the triggering blocks together, and the sleeve bearings were held into their machined cavity. The machinist recommended a design change based on the ability to manufacture the trigger block as a single component. This alteration reduced machining time and associated cost, and created a more robust and stable component. Figure 3 shows the new design. The triggering block is one solid piece with tapped holes to thread the sleeve bearings into. This was easier to fabricate and proved to function as the team desired with the initial design. The new design also eliminated the need for the two bolts in the previous design.
As assembly started, it was realized that the bolt pattern on the actuator bracket did not match the actuator. Figure 4 shows the original bolt hole pattern circled in red and the correct hole location circled in green. This error was from an incorrectly dimensioned engineering drawing from last semester. The dimensioning was based off a solid model of a similar actuator from the manufacturer’s website [1]. To resolve this issue, the correct bolt hole pattern was milled into the actuator bracket according to the correct measurements from the correct linear actuator print. The approach of modifying the existing actuator bracket was chosen to avoid remanufacturing the component. The correction and modification of the actuator bracket does not affect its intended function. Figure 5 shows the corrected actuator bracket. In the final assembly, four washers are used to cosmetically cover the error. The original engineering drawing was corrected and added to Appendix 2.

During design last semester, a socket head cap screw was selected to mount the actuator base plate to the fixture sub-system. During fabrication it was realized that the heads of the screws were obstructing the assembly of the triggering rail supports, so a flat head socket cap screw was selected as a substitute. This required that a countersink be machined into the bolt holes of the actuator base plate. This deviation resulted in improved ease of assembly. A small portion of the flat head socket cap screw hangs over the actuator base plate, creating a cosmetic error to the design. The slight imperfection does not affect the function of the fastener or performance of the design. This blemish can be seen in Figure 6.
Section 4.3: Completed Build

Assembly began once the team received the last component from fabrication. Figures 7 - 17 below are snapshots of the components and build process that took place at Zimmer. All team members were present for this build process, and no issues other than those listed in Section 4.2 arose during assembly. For the elastic padding on the clamping faces, 40 Shore-A durometer .063" thick adhesive backed, transparent silicone was installed. Holes were manually cut into the elastic padding at fastener locations. The build started by constructing the clamping assemblies (Figures 10 – 11) and the triggering platforms (Figures 12 – 14) independently. The clamping assemblies were then assembled onto the fixture base plate (Figures 15), and then the triggering platform was assembled onto the stationary clamping assembly (Figures 16). With all of the fasteners tightened, the build was complete and ready for integration with the linear actuator controlling software.

Figure 7. A view of the fabricated Buttress Plates and Clamping Plate
Figure 8. A view of the fabricated Fixture Base Plate

Figure 9. A view of the fasteners used for assembly
Figure 10. A portion of the Fixture Sub-assembly

Figure 11. The Fixture clamp assembled
Figure 12. Assembling the Triggering Rails into the Rail Supports

Figure 13. A portion of the Triggering Sub-assembly
Fixture 14. The completed Triggering Sub-assembly

Figure 15. The completed Fixture Sub-assembly
Figure 16. The completed design with a pneumatic hand piece installed

Figure 17. The completed design with a battery powered hand piece installed
Section 4.4: LabView Program

In order to better facilitate the testing of the project, a LabView program was developed to control the linear actuator for both intermittent and continuous duty operation. The work done with this aspect of the project was conducted in addition to the initial project scope, and engineering consultation at Zimmer was sought out to create a successful program.

Since the linear actuator consists of a bi-polar stepper motor which has a more complicated operating circuit than standard linear actuators, the wiring had to be carefully configured (Figure 18), and the LabView Program required the use of specific Data Acquisition Cards (Figure 19), which were already available at Zimmer [2, 3, 4]. Upon determining the appropriate wiring schematic, the LabView program was able to be configured. The block diagram for the program is shown in Appendix 3, and the operating panel below in Figure 20. The manufacturer sells accessory driver and controller components for this linear actuator that are specifically designed to maximize its function. The team chose not to purchase these components due to their high cost and long lead times for delivery.

![Hand drawn wiring schematic for the linear actuator, DAQs, and power supply.](image)

Figure 18. Hand drawn wiring schematic for the linear actuator, DAQs, and power supply.
Figure 19. DAQ card rack (NI 9172), and DAQ cards used to operate the linear actuator (NI 9474 & NI 9477).

Figure 20. Labview operating panel.

To interact with the program, the user has two control settings that can be manipulated. The “Manual Controls” panel allows the user to selectively turn on and off the motor and select a direction of travel. The “Release Trigger” button, when on (lit up), tells the program to move the actuator away from the hand piece. The function of the “Manual Controls” panel is to allow a user to manually set up the triggering block for different testing scenarios.
The “Test Setup Controls” panel serves as the operating panel for testing activities. Within this panel the user can select the number of cycles for intermittent or continuous duty testing, the stroke length for a specific hand piece, and the delay time at which the program holds the trigger for continuous duty testing.

The operating panel also has a “Test Status Indicators” panel that solely provides feedback to the user on the cycle count and the current displacement. One cycle is configured as one trigger pull and release event. The displacement begins at a tare value (zero) and displays the increasing positive displacement as the trigger is pulled. Once the actuator reverses direction to release the trigger, the displacement displays a decreasing positive value approaching the starting point (zero). This panel will provide the user feedback while operating in manual and testing mode. Since the actuator is configured in SI units, it was easier to utilize the same system for the program. Hence all displacements are entered and displayed in millimeters.

At the bottom of the operating panel, there is an “Advanced Controls” panel. For the current linear actuator, these controls should not be changed. This panel informs the user of the Data Acquisition Cards that are driving the program, the screw pitch (individual step length for the actuator), and the operating status of the circuit. The Drive Sequence indicator is a visual representation of the truth diagram for the actuator circuit, and will light up according to changing polarizations within the stepper motor windings (Appendix 2). Likewise the Data Acquisition Cards have operating status feedback indicators that flash according to the specific channel the signal is firing. This “Advanced Controls” panel serves merely as a high level indication that the program is setup and functioning properly. The user is not expected to interact with this panel, other than through observation.

For the user’s convenience a description and tip is included for all of the interactive elements of the operating panel. This feature was manually input into the program, and can be easily accessed by pausing the mouse over the element of interest. Information and guidance regarding the element of interest will then automatically be displayed under the mouse.
Section 5: Budget
Section 5: Budget

The overall budget for the project was estimated at $1039. Table 1, below shows the result of the actual project costs.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials</td>
<td>$20</td>
</tr>
<tr>
<td>Linear Actuator</td>
<td>$127</td>
</tr>
<tr>
<td>Fasteners</td>
<td>$10</td>
</tr>
<tr>
<td>Elastomeric Padding</td>
<td>$0</td>
</tr>
<tr>
<td>Sleeve Bearings</td>
<td>$4</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>$400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$561</strong></td>
</tr>
</tbody>
</table>

The total project cost came in 46% under the estimated budget, mostly due to our ability salvage aluminum stock material provided by Zimmer from previous projects, and the purchase of the linear actuator at a reduced cost. Manufacturing cost reflects machinist time in machining all required components. Total time for fabrication equated to approximately 14 hours.
Section 6: Testing
Section 6.1: Testing Overview

Purpose
The purpose of this testing is to validate the design project per the system requirements, design parameters, and design variables listed below. All testing was performed at Zimmer, Warsaw, IN. Test equipment and materials were made available by Zimmer at the time of testing. Testing and analysis were performed by the students.

Acceptance Criteria
System Requirements
The design of the system will be broken into two sub-systems. A means of fixturing a hand piece and a means of triggering a hand-piece. These two different sub-systems must interface to provide an effective mechanism.

Fixture Sub-system Requirements
The fixture design must be able to fit and secure both pneumatic and battery powered hand pieces, regardless of grip geometry. This shall be evaluated as no macro-movement resulting in measurable alterations to the hand piece position and orientation within the device throughout all phases of operation. Macro-movement shall be defined as 1° or more of rotation and/or 0.02” in translation.

Triggering Sub-system Requirements
The triggering design must provide a length of stroke up to 1.00 inch, and an actuating force within the range of 2 – 20 lbf with the load applied at the middle of the trigger and exerted in a line parallel to the barrel of the hand-piece.

Design Parameters
The design of the system must not require any modification or alteration of, nor impose any damage to the hand piece throughout all phases of operation within the design. Materials used to create this system must be able to withstand all testing procedures provided by Zimmer.

Section 6.2: Testing Preformed

Equipment
Universal Remotely Triggered Firing Actuator
Battery powered surgical hand piece
Pneumatic surgical hand piece
Table clamp
Power Supply
National Instruments 9127 DAQ card rack
National Instruments 9474 & 9477 DAQ cards
Laptop with installed LabView executable file
Photron SA4 digital high speed camera
Chatillion digital tensiometer
Linear and protractor scales
Digital weight scale
Procedures
The testing procedures below are sub-divided into equipment set-up procedures and testing procedures.

Fixture Set-up
1. Ensure the proper and complete assembly of the design.
2. Set the design up on a bench-top, lab table, or other solid working surface by clamping the base of the design to the table. Any available style of clamp may be utilized.
3. Set up a powered surgical hand piece in the design.
   a. Place the hand piece between the clamping plates in the correct height and location so that the triggering block has full and direct access to the trigger.
   b. Clamp the hand piece into the design by tightening the ACME rod. One handed operation should be utilized to avoid over tightening and damaging the hand-piece.

High Speed Camera Set-up
1. Power-up the high-speed camera (Figure 21) and associated software.
2. Set up the camera to record at the desired operating parameters (resolution, frame rate) capable of recording a full trigger pull event. **NOTE: the camera is capable of recording 500,000 fps, and can achieve full resolution (1024x1024) at 3600 fps. At these high resolutions and frame rate combinations the record time is short and the file size is massive.
3. Ensure the image is in focus, and the lighting is adequate.
4. Set the trigger to ‘Start Trigger.’
5. Calibrate the image using the ‘Shading’ button.

![Figure 21. Photron SA4 high speed camera](image)

LabView Program Set-up
1. Supply power to the Data Acquisition Card Rack (NI 9172) (Figure 22) and the Independent Power Supply (Figure 23).
2. Plug in the USB cable to a computer loaded with the appropriate software for running the program.
3. Open the .vi file titled “ATC” within the folder titled “Automatic Trigger Controller” located on the desktop.
4. Confirm the recognition of the correct National Instruments Data Cards (NI 9474 & NI 9477).
5. Turn on channel 1 of the power supply and set it to 5 volts and 0.08 amps.
6. Using the “Manual Control” settings, set up the triggering block and determine and set the stroke length for the test according to the specific hand piece.
7. Set the test parameters in the “Test Controls” panel to the desired cycle count and delay time.

![Figure 22. DAQ card rack.](image)

![Figure 23. Independent Power Supply.](image)

**Fixture Sub-system Test**

1. Weigh the assembled design, and record the mass.
2. Record the integrity of the surgical hand piece with a photograph of the surfaces contacting the fixture clamps.
3. Demonstrate that the fixture subsystem fits both the pneumatic and battery powered surgical hand pieces by following the Fixture Set-up procedure above.
4. Demonstrate that the fixture is capable of securing each hand piece in the correct orientation for a trigger pull.
5. Record any hand piece compatibility issues, and needed hand piece or device modifications.
6. Record, with a photograph, each hand piece secured in the fixture.
7. Set up an engineering scale and protractor within the viewing window capable of capturing any hand piece movement for supplying the viewer a frame of reference.
8. Follow the High Speed Camera Set-up and LabView Set-up procedures above to prepare for and conduct a trigger pull event.

9. Conduct the test for both intermittent and continuous duty triggering. To demonstrate the ability to achieve intermittent duty testing, parameters should include 3 cycles with a 0 second delay between cycles. To demonstrate the ability to achieve continuous duty testing, parameters should include 1 cycle with a hold time of 10 seconds.

10. Activate the camera trigger just prior to starting the linear actuator movement.

11. When the triggering event is finished, remove power from the linear actuator by turning off channel 1 on the independent power supply.

12. Observe the video file to ensure the entire event was captured. If it was not then retest. Note, the camera settings may have to be altered (frame rate and/or resolution) to provide a sufficient record time.

13. If the video file is acceptable, then crop and save as an .avi file to an external drive.

14. Repeat the test again until both hand pieces have been tested under both the intermittent and continuous duty parameters.

15. Remove the surgical hand piece from the design and record its integrity with a photograph.

**Triggering Sub-system Test**

1. Follow the High Speed Camera Set-up and LabView Set-up procedures above to prepare for and conduct a trigger pull event.

2. Use the “Manual Controls” panel to locate the triggering block at its most forward position (direction of trigger pull).

3. Place an engineering scale behind the triggering block for visual verification during filming of the linear actuator stroke length.

4. Using the “Manual Controls” panel, extend the triggering block through its entire stroke. **NOTE: pay attention to the length of actuator rod engagement with the motor.**

5. Observe and record the stroke length achieved both on the scale, and displacement value output in the “Test Status Indicators” panel.

6. Verify that the linear actuator was able to satisfy the system requirement of 1 inch (25.4mm) stroke length.

7. Remove the engineering scale.

8. Attach a digital tensiometer to the triggering block.

9. With the fixture sub-system secured to the bench top, stabilize the tensiometer in line with the triggering motion, so that it can record the tensile force at a representative point of trigger contact on the trigger block.

10. Activate the linear actuator and allow it to complete its cycle. **NOTE: a short displacement should be chosen (2 – 3mm) to avoid overload damage to the linear actuator.**

11. Record the maximum force value output from the tensiometer.
Section 6.3: Test Results

<table>
<thead>
<tr>
<th>TEST</th>
<th>RESULTS</th>
<th>REQUIREMENT MET?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand piece compatibility</td>
<td>Both battery and pneumatic hand pieces easily fit into the fixture, were able to be lined up with the trigger block, and were able to be secured. No compatibility issues to report.</td>
<td>Battery: YES Pneumatic: YES</td>
</tr>
<tr>
<td>Macromovement</td>
<td>Battery</td>
<td>Pneumatic</td>
</tr>
<tr>
<td>Linear Translation</td>
<td>Disp.(in) .0108 ± .0078</td>
<td>Angular Disp. .63° ± .16°</td>
</tr>
<tr>
<td>Scale: 382.3 px/in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke length</td>
<td>33.1 mm (1.3 inches)</td>
<td>YES</td>
</tr>
<tr>
<td>Trigger force</td>
<td>Maximum Force: 6.6 lbf</td>
<td>YES†</td>
</tr>
<tr>
<td>Weight</td>
<td>7lbs - 8.4oz</td>
<td>ACCEPTABLE</td>
</tr>
<tr>
<td>Hand piece integrity</td>
<td>No damage was incurred to either the battery or pneumatic hand pieces from the testing device.</td>
<td>Battery: YES Pneumatic: YES</td>
</tr>
</tbody>
</table>

*Measured value plus tolerance equals .0275in.
†See Section 7.1
Section 7: Evaluations and Recommendations
Section 7.1: Evaluation of Test Results

The following evaluation steps were taken to assess if the system requirements were met. A summary of the testing results is presented in Table 2 of Section 6.3 Test Results.

1. Qualitatively review and record any hand-piece compatibility issues with the fixture.

To accomplish this task, photographs of the test set-up and each surgical hand piece were recorded (Figures 24 – 25). No compatibility issues were apparent. Both hand pieces easily fit into the fixture and were functional while secured by the clamp. There was adequate room for the battery pack and air hose connection. Visualization was adequate for observation and filming.

![Figure 24. Test set up with pneumatic hand piece.](image)

![Figure 25. Battery (left) and pneumatic (right) surgical hand pieces secured in fixture.](image)
2. Review the video files captured in the Fixture Sub-system Test to check for macro-movement as defined in the System Requirements. Record the displacement of any noticed macro-movement of the surgical hand-piece using the appropriate scales as a reference indicator. Include photographs of the test.

Linear Translation
To accomplish this task, the intermittent duty video files were reviewed for each hand piece (Figure 26). The pixel coordinates of a selected point on the hand piece were recorded at the beginning of the test and at its point of maximum displacement. This point is represented by the yellow crosshairs in Figure 26, and captured in the bottom right hand corner of each screenshot. A 1/32” engineering scale was set up in the video to provide the user a reference to the macro-motion taking place and to aid as a known measuring reference in the video file to calculate the number of pixels per inch. The distance in pixels between the coordinates indicating the macro-movement of the selected point on the hand piece was calculated and then correlated with each respective video files calculated pixels per inch scale. Since this method has some subjectivity associated with it, we also calculated the width of a single tic mark on the engineering scale for each video. This value was then applied to the calculated displacement as the tolerance for the measurement. The scale, displacement, and tolerance values were recorded in Table 2 for each video file evaluated. The system requirement was considered successfully met if the measured value with the tolerance was under the system requirement value of .020”. If the measured value was under the required .020”, but the addition of the tolerance caused it to exceed that value, then the system requirement was considered met with note of the condition.

Figure 26. Photo representations of translations analysis. Battery hand piece before test (left-top) and at maximum displacement (left-bottom). Pneumatic hand piece before test (right-top) and at maximum displacement (right-bottom).

Angular Displacement
To accomplish this task, both the intermittent and continuous duty video files were reviewed (Figure 27) and the coordinates of a selected point on the hand piece were recorded at the beginning of the test
and at its point of maximum displacement. A ½° protractor was set up in the video frame to provide the user a reference to the macro-motion taking place. For each hand piece the point where the trigger shaft enters the grip was chosen as the origin for calculating angular displacements. A definitive point on the hand piece near the nose and centerline of the barrel was chosen and recorded for tracking macro-motion. Any movement caused this point to displace angularly, and this distance between these coordinates and the chosen origin was determined in pixels. The difference in these angles at the maximum displacement was then calculated and used to define the macro-movement of the hand piece angular displacement. Since this method has some subjectivity associated with it, we also calculated the angle contributed by the width of a single tic mark on the protractor for each video. This value was then applied to the calculated angular displacement as the tolerance for the measurement. The displacement and tolerance values were recorded in Table 2 for each video file evaluated. The system requirement was considered successfully met if the measured value with the tolerance was under the system requirement value of 1°. If the measured value was under the required 1°, but the addition of the tolerance caused it to exceed that value, then the system requirement was considered met with note of the condition.

Figure 27. Photo representations of angular displacement analysis. Battery hand piece before test marking origin (left-top), before test marking tracking coordinates (left-middle), and at maximum displacement (left-bottom). Pneumatic hand piece before test marking origin (right-top), before test marking tracking coordinates (right-middle), and at maximum displacement (right-bottom).
3. Record the stroke length and maximum force values from the Triggering Sub-system Test. Include photographs of the tensiometer and test.

Stroke Length
To accomplish this task an engineering scale was set up on the triggering fixture to record the stroke length. Since the program that controls the linear actuator records the displacement of the screw, it was used to verify the measurement (Figure 28). The stroke length was recorded in Table 2.

![Figure 28](image1.png) Stroke length verification. Scale measurement with associated recorded displacement below.

Trigger Force
To accomplish this task a tensiometer was set up with a hook to catch the triggering block as it simulated a trigger pull. The tensiometer was braced against the trigger rail supports which provided stability of the instrument for accurate measurement (Figure 29). With the hook latched onto the trigger block the actuator was cycled through 2mm and 3mm displacements where the peak tension values were recorded. For both the cycle distances the peak force measurements resulted in a consistent value, which was recorded in Table 2. Since the system requirement stated the actuator should provide “an actuating force within the range of 2 – 20 lbf,” a peak force value within this range was considered as meeting the requirement. However, since the actuator did not provide values throughout the full spectrum of this range, the team wants to note that the system was unable to provide a triggering force across the entire range of the requirement. The chosen system requirement force range of 2 -20 lbf takes into account all pistol grip tools, instruments, and devices. For surgical use, research shows that lower values within this range are preferred for single finger trigger actuation [5]. According to the manufacturer’s specifications, the selected linear actuator is able to achieve 20lbf at a pulse rate of 200steps/sec, and a stroke length of 1.464”. The manufacturer’s specifications for the
linear actuator are located in Appendix 4 [1]. The incorporation of the appropriate manufacturer’s
driver and control system accessories for the linear actuator may aid in providing a better range of force
values since they are designed to operate the actuator at the appropriate pulse frequencies. The use of
our LabView program and computer to drive and control the actuator limit the pulse frequency of the
actuator to the speeds that the computer can process.

![Image 1](image1.png)

**Figure 29.** Triggering force verification. Note bracing of the tensiometer against the rail support for stabilization.

4. **Assess that the weight of the design is acceptable using a digital scale. Record this value.**

To accomplish this task the fully assembled device was placed on a digital scale and the weight was
recorded in Table 2 (Figure 30). It was determined that the device was easy to handle with an
acceptable weight.

![Image 2](image2.png)

**Figure 30.** Testing the weight of the device.

5. **Qualitatively assess the pre and post testing integrity of the surgical hand piece for any design induced damage. Record the hand piece integrity by capturing pre and post testing photographs.**

To accomplish this task, photographs of each hand piece were taken both prior to, and after testing
(Figure 31). If any damage appeared on the hand piece it was recorded. After completing the test, it
was observed that the fixture design did not induce any damage to either hand piece. Placement of the
tape on the pneumatic hand piece must be ignored, as it was previously applied and being used for other purposes.

![Battery powered hand piece pre-test (left-top) and post-test (left-bottom). Pneumatic hand piece pre-test (right-top) and post-test (right-bottom).](image)

**Figure 31.** Battery powered hand piece pre-test *(left-top)* and post-test *(left-bottom)*. Pneumatic hand piece pre-test *(right-top)* and post-test *(right-bottom)*.

### Section 7.2: Recommendations

The first recommendation would be to upgrade the electronics of the triggering system by investing in the dedicated controller and driver provided by the supplier of the linear actuator, Haydon-Kerk. The incorporation of the appropriate manufacturer’s driver and control system accessories for the linear actuator may aid in providing a better range of force values since they are designed to operate the actuator at the appropriate pulse frequencies. The addition of these accessory components would also allow the actuator to translate through the triggering stroke length at a faster rate. This would speed up the cycle time for intermittent duty hand piece reliability testing procedures. Incorporation of the dedicated controller and driver accessory components would eliminate the need for our LabView program, with which the computer drives and controls the actuator. Operating the actuator this way does limit the signal and pulse frequency to the actuator to whatever speed the computer can process.

A second recommendation would be to consider upgrading to a more powerful linear actuator if testing requirements do call for greater trigger force values. The system requirement force range of 2 -20 lbf takes into account all pistol grip tools, instruments, and devices. For surgical use, research shows that
lower values are preferred for single finger trigger actuation [5]. This recommendation may not be necessary if the above recommendation is installed. However, if Zimmer does intend to upgrade the linear actuator, attention to the geometrical alignment relationships of the triggering block and guide rails should be accounted for.
Section 8: Conclusions
Section 8: Conclusions

In conclusion, the Universal Remotely Triggered Firing Actuator resulted in a successful design and build. Minor design deviations were required through the build process to achieve a functional device. These design deviations were necessary for manufacturing and assembly purposes only, and did not affect the function or performance of the device. The cost of the project came in well under (46%) the estimated proposed amount, mainly due to the opportunity to salvage on-hand material, obtaining the linear actuator at a reduced cost, and redesigning the triggering block component for simplified manufacturing. Outside of the scope of the project, a LabView program was developed, with the aid of Zimmer engineering consultation, to best facilitate the testing and allow the device to function remotely and autonomously. Testing showed that the device was compatible with both pneumatic and battery powered surgical hand pieces. Testing also showed that the device is able to provide the stroke length, triggering force, stability, and non-destructive results outlined in the system requirements. Two recommendations were made by the team offering potential improved performance outcomes for the device. The final device is now located in Zimmer research labs and is scheduled for surgical hand piece reliability testing.
Section 9: References
Section 9: References


Section 10: Appendices
Appendix 1 – Master Material Properties Table

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§ MatWeb Material Property Data
□ McMaster-Carr
※ Shigley’s Mechanical Engineering Design 9th Ed.
Appendix 2 – Custom Component Drawings
Appendix 3 – LabView Program Block Diagram
Appendix 4 – Linear Actuator Manufacturer Specifications

28000 SERIES SIZE 11 STEPPER MOTOR LINEAR ACTUATOR

The Haydon™ Size 11 linear stepper motor actuators are one of our most compact additions to an extensive line of precision power motion stepper motors. The various powered versions deliver high performance, opening avenues for equipment designers who require performance and actuators in a very small package. These designs are available captive, non-captive and external actuator styles. The 28000 Series stepper motor based linear actuator is available in a range of lengths and a variety of resolutions—from 0.000125” (0.00175 mm) per step to 0.002” (50.8 mm) per step. The Size 11 stepper motor based linear actuator delivers linear of up to 25 lbs (11.3 kg).

Available with Integrated connector: Size 11 Integrated Connector

Part Number Information Guide:

- Captive
- Non-Captive
- External

Available in 3D Model:

- Download 2D/3D Model
- Download 3D Model
- Download 3D Model

SALENT CHARACTERISTICS - SERIES 28000 SIZE 11 STEPPER MOTOR LINEAR ACTUATOR

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Winding

- Bipolar
- Unipolar

Dimensions:

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<tr>
<td>0.0025&quot;</td>
<td>0.0035&quot;</td>
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<tr>
<td>0.005&quot;</td>
<td>0.007&quot;</td>
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| Insulation Resistance | 50 MΩ |

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<tbody>
<tr>
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<tr>
<td>Humidity</td>
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DIMENSIONAL DRAWING - 28000 SERIES SIZE 11 CAPTIVE STEPPER MOTOR LINEAR ACTUATOR

DIMENSIONAL DRAWING - 28000 SERIES SIZE 11 NON-CAPTIVE STEPPER MOTOR LINEAR ACTUATOR
Size 11 Series 28000 Force vs Pulse Rate
.187 in. [4.75 mm] Ø Lead Screw, Bipolar, Chopper Drive, 100% Duty Cycle

<table>
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<th>Pulse Rate: steps/sec.</th>
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<td>300</td>
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<tr>
<td>20</td>
<td>400</td>
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Performance Curves - 28000 Series - Force vs Linear Velocity Stepper Motor Linear Actuator

Size 11 Series 28000 Force vs. Linear Velocity
.187 in. [4.75 mm] Ø Lead Screw, Bipolar, Chopper Drive, 100% Duty Cycle

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<td>0</td>
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<tr>
<td>20</td>
<td>80</td>
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Ramping can improve the performance of a motor by increasing the speed of getting heavier load acceleration up to speed faster. Also, decelerations can be used to stop the motor without overloads.

NOTE: All data shown curves were tested with a 0 volt motor and a 40 volt power supply.

With LFT drives, peak force and speeds are reduced. Using a linear drive will yield a better 100% force reduction.