ROBOTIC

OVER - UNDER GUN

SELF OPENING – SELF CLOSING

AN INNOVATIVE CONCEPT

OF

Ballistic **RA**dical **IN**novations

BRAIN

A MECHATRONIC MECHANISM CONCEPTUAL STUDY

Executive Summary

This technical description reports on the conceptual design of a mechatronic mechanism for actuated barrel opening of a generic hunting gun, which requires almost no effort from a user. This system can be easily developed and manufactured with no substantial modifications of the production line, as the design is generic enough and does not affect existing designs and mechanisms.

The initial requirements of the design are clarified. An analysis of the main concept follows, including a variation from the basic one. The design is illustrated by CAD figures for better comprehension. To examine the feasibility of the design, a set of experimental measurements on a generic gun system were taken. These measurements were used to select the main system subcomponents such as actuators and batteries. The results suggest possible motor assemblies (including peripherals and power source). The appendix includes a detailed analysis of each part of the mechatronic mechanism.

Summarizing, this technical study focuses on the automation of a generic hunting gun, minimizing the required modifications from the current state. In fact, the mechanism fits well within the actual shape of a generic gun. An appropriate controlled mechatronic mechanism is proposed. Efforts have been made so that the system retains backward compatibility in terms of users' habits. An innovative concept has been derived during this process, which can form the basis for future designs.

1. GENERAL REQUIREMENTS

Typically, any user of a conventional gun must use the Top Lever to open the Barrel. By default this mechanism is not ambidextrous and requires effort by the user.

To automate the barrel opening, a novel mechatronic design is required. During opening and closing this mechatronic system should be able to override mistaken orders – such as double or continuous pressing of button - until the opening or the closing is completed (or an obstacle has been found).

The technical requirements for this design include:

- Opening time duration at Normal holding position : less than 1 sec (includes Action Bolt Unlocking and Barrel Opening)
- Opening time duration at Horizontal holding position (capability test) : less than 1.2 sec (includes Action Bolt Unlocking and Barrel Opening)
- Closing time : less than 1.5 sec.
- Barrel opening angle (normal) : 45°.
- Minimum automatic openings on the same battery without recharging : 2000.
- External modifications are allowed but in a minor degree.
- The system should be ambidextrous.
- Additional weight to be kept minimal.
- Robustness against vibrations of recoil.

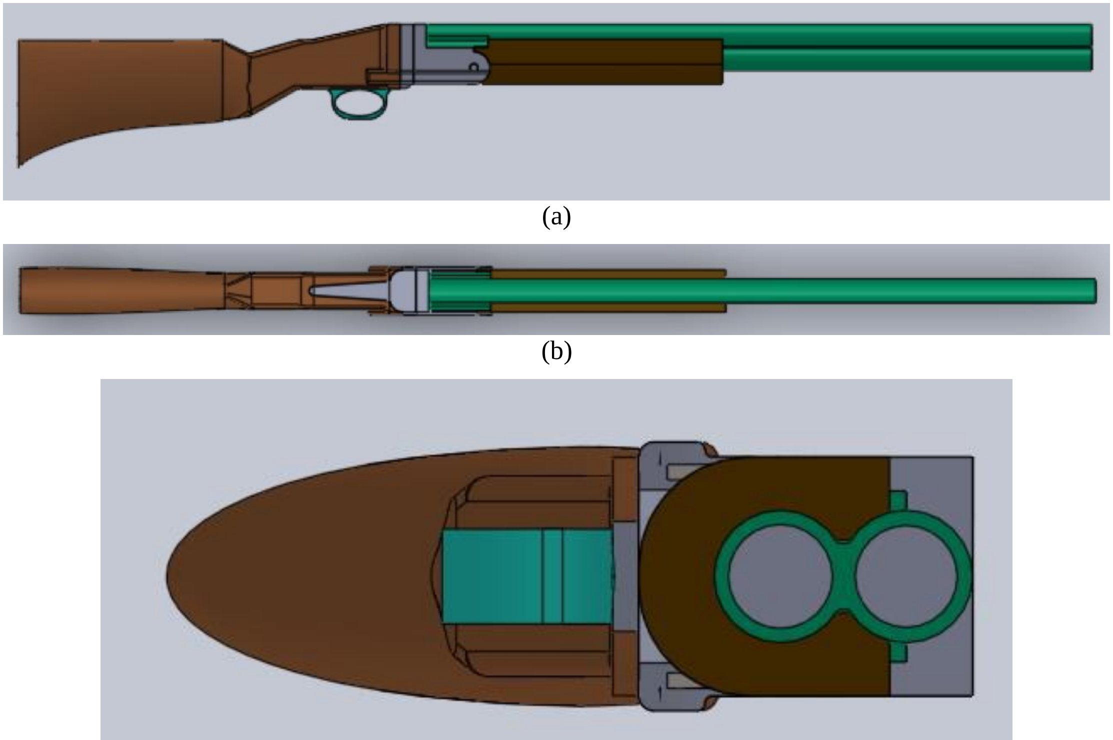
The programmatic requirements include:

- Development of a system capable of integration in a generic gun without imposing serious modifications to the initial system, and without affecting its firing capabilities , able to operate manually whenever needed.
- Cost to be kept to a minimum.

2. MECHATRONIC DESIGN DESCRIPTION

General

The main idea of the developed mechatronic design is that a microprocessor-controlled servomotor pushes the barrel to open or close through a novel transmission mechanism. The servomotor, the driving electronics and the batteries are located in the stock, and the motion reaches the barrel through a mainly translational mechanism. Two variations, called Variation I and II, have been developed, which share the same basic components. The two variations differ in the way the main motor is decoupled from the transmission. These will be discussed later. Inherently, the system has the capability to act in various modes, i.e. the barrel may open in (a) Automatic mode, (b) Semi-automatic mode and (c) Manual mode. It may also close in Automatic mode or in Manual mode .The user selects the desired mode by a switch. Although the mechanism needs electrical power (in the non-manual modes), it is designed so that it can operate manually in the case of a failure of the mechatronic system, despite the non-backdriveability of the transmission. The mechanism has a fail-safe design, so that it can be used manually even if the switch is not in the manual position, in case of emergency. A general view of the gun is shown in Fig. 1. Measurements of a conventional gun took place and the design dimensions are based on them. The figure shows that the external changes in the shape of the gun are minimal. The external shape corresponding to the two developed variations is the same. The new design's Action bottom is slightly thicker than that of the current design, see Fig. 2. However, this part may become thinner, if, analysis employing a Finite Element Method (FEM), shows that for the forces and torques in the mechanism and for the materials used, smaller cross sections of parts are required.



(a)

(b)

(c)

Figure 1. External view of the modified gun. (a) Side view, (b) top view, (c) frontal view.

Figure 2. Gun transparent top view. External modifications are contained in the black lines.

This point should be further clarified. The conceptual design in this report, places emphasis in the functionality of each part and not in optimizing its size. The reader will gain a clear picture of how the system will work, although some parts may appear to be over designed. A more detailed dimensional design, customized for a specific gun, is out of the scope of this report.

Variation I of the proposed mechanism is presented in Fig. 3. However later in this report, both variations are shown and explained. The mechatronic mechanism needs only a button to operate (and a Switch for Mode Selection), thus making it perfectly ambidextrous. Additionally the Opening or Closing time (including Action Bolt Unlocking, Barrel Opening or Closing and other operations) can be user-selectable among a number of options.

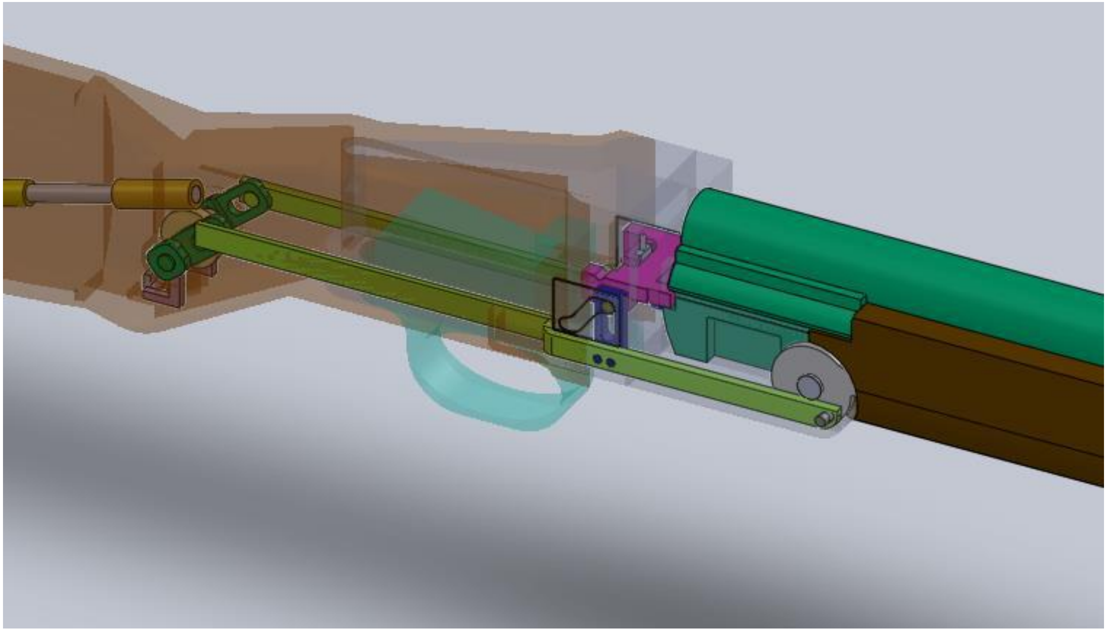


Figure 3a. The mechanism inside the gun (Variation I).

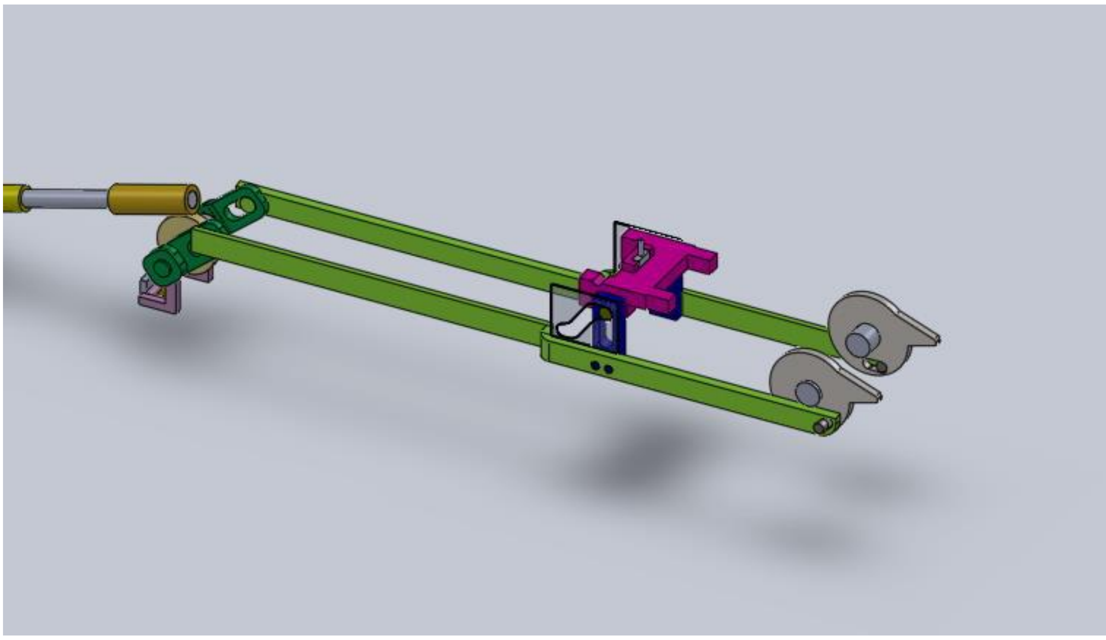


Figure 3b. The mechanism inside the gun (Variation I). The gun parts are omitted.

Driving Subsystem

The components of the Driving Subsystem are described in Fig. 4 and shown in Table I. Figs. 5 and 6 present instances, which clarify, further the functionality. Appendix A contains all parts shown in Fig. 4, along with details about their design.

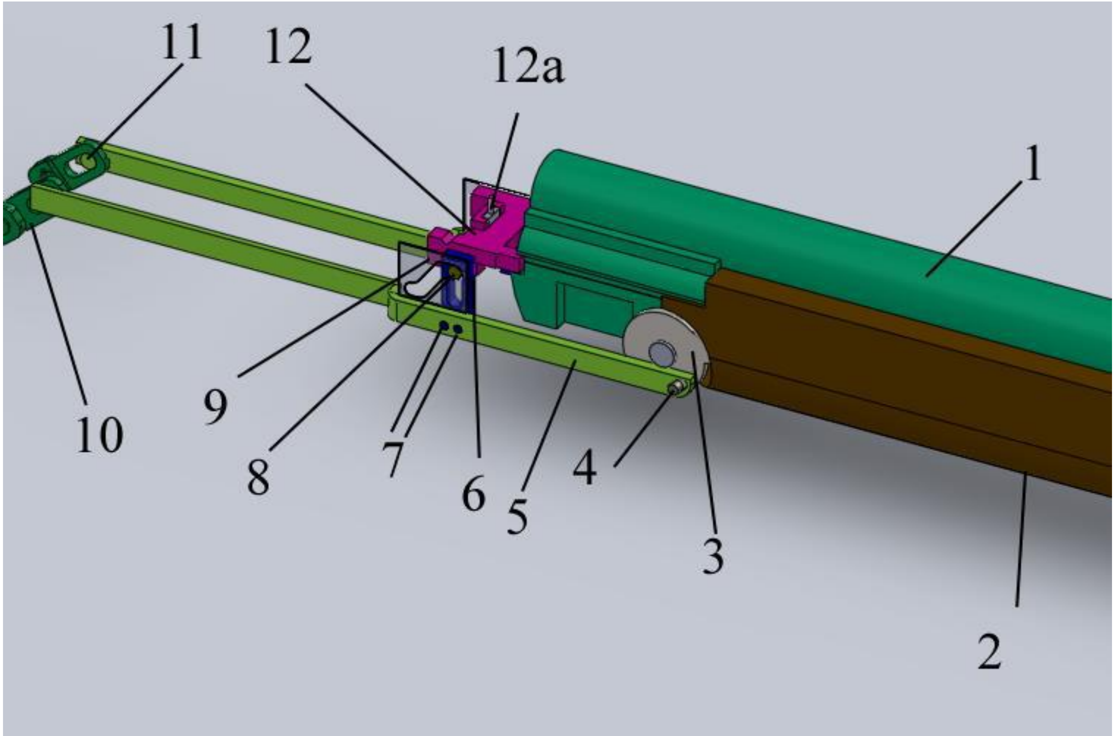


Figure 4. Driving Subsystem.

Table I: Parts list for Figure 4

1: Barrel	5: Bar	9: Engraving of Action
2: Modified Forend	6: Action Bolt Slider	10: Driving Sliders
3: Opening Wheel	7: Screws	11: Driving Pins
4: Wheel Pin	8: Action Bolt Driving Pin	12: Modified Action Bolt (12a: Manual Opening Extension)

Opening Sequence:

(i) Automatic Mode

The main motor transmits rotational motion to the axis of the Driving Sliders (10). The Sliders rotate Counterclockwise. Driving Pins (11) fixed on the Bars (5), are free to slide inside them. As the Sliders turn Counterclockwise, they force the Driving Pins (11) to follow them. However, the Bars (5) are constrained to move in one direction only, i.e. inside the side slots of both the gun Action and the Stock. The rotational movement of the sliders is transformed into linear with this system (which can be regarded as a simplified 4-link-bar mechanism).

Bars (5) move backwards (with respect to the direction of shooting), performing the following tasks: first releasing the Action Bolt (12) from the Barrel (1), and secondly turning the Opening Wheels (3) forcing the Forend (2) (and as a consequence the Barrel (1)) to open (e.g. turning them Clockwise).

The Bar (5) draws the Action Bolt Slider (6) backwards, which in turn draws the Action Bolt Driving Pin (8) backwards. The Action Bolt Driving Pin (8) is forced to follow the path engraved (9) at the inner of the gun Action. At the same time, the Action Bolt Driving Pin (8) forces the Action Bolt (12) to follow the motion, thus releasing the Barrel (1). However after releasing the Action Bolt (12), there is no need to force it anymore. So the path (9) forces the Action Bolt Driving Pin (8) to go downwards, because of the Action Bolt Slider (6) which continues to move with the Bar (5). The Action Bolt (12) in a conventional gun is forced to stay in this position by a (usually coupled with a spring) engager that acts in a notch of the Action Bolt (12), thus equalizing the spring which forces the Action Bolt (12) back into locking position. At the same time, an extruded Bolt Retaining System comes out from the face of the Action. This represents the system to be activated by the Barrel (1) at its complete closed position, so the Action Bolt disengages and moves to its locking position by its spring.

The Bar (5) initially acts no force to the Opening Wheel (3), as the Wheel Pin (4) is being dragged by the Bar (5), but it is free to slide within the Opening Wheel's (3) engraving. As the Action Bolt (12) releases the Barrel (1), the same time the Wheel Pin (4) reaches the face of the engraving (therefore it is in contact with the Opening Wheel (3)), and thus a torque to the Opening Wheel (3) is exerted. The Opening Wheel (3) turns Clockwise and the Wheel Pin (4) slides into the Bar (5) as it must rest at a higher position in respect with its initial one. The Opening Wheel (3) forces the Forend (2) down, thus finishing the opening sequence.

(i) Semi-automatic Mode

In the semi-automatic mode, the procedure is the same as that of the automatic mode, till the release of Action Bolt (12). The user then manually turns Clockwise the Barrel (1). Forend (2) is designed in a way that no force is transmitted to the Opening Wheels (3) and therefore to the rest of the mechanism. The designer can choose whether the motor will stop acting exactly at the time of Action Bolt release, or it will continue for a small fraction of time, to turn the Barrel Clockwise for a few degrees to assist the user.

(ii) Manual Mode

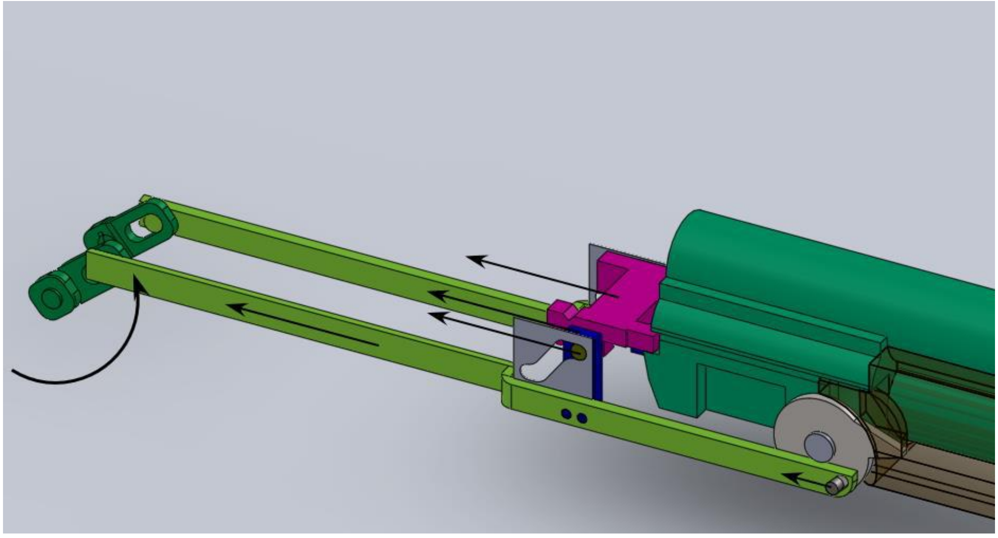
By moving the lever, its extension (12a) pushes the Action Bolt (12), which is being released, acting on the Action Bolt Driving Pin (8) thus forcing the Action Bolt Slider (6) and the Bar (5) backwards. Upon release, the user can rotate the Barrel as done in the Semi-automatic Mode.

Closing Sequence:

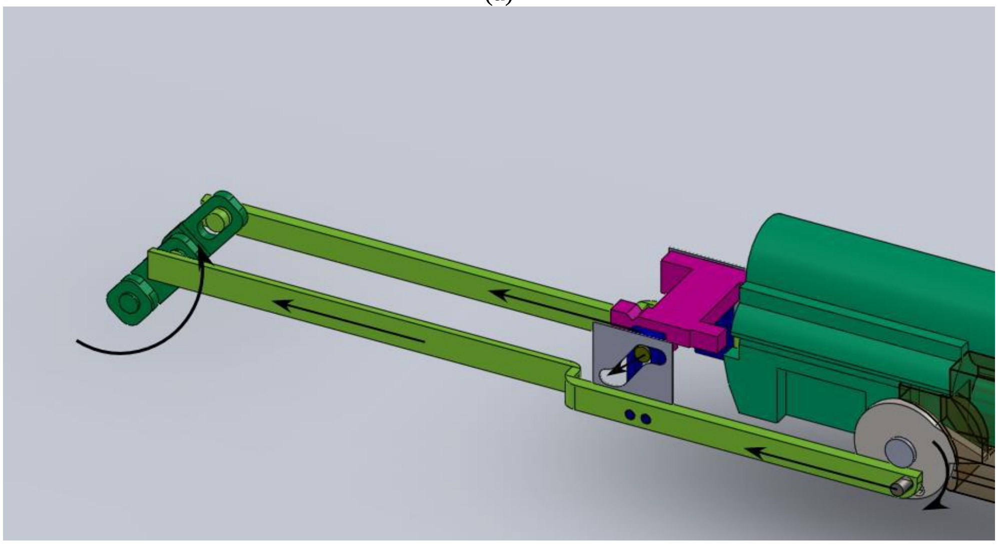
In case of Manual closing the user turns Counterclockwise the Barrel (1) and the Forend (2) thus turning the Opening Wheel (3) also Counterclockwise. The Wheel Pin (4) forces the Bar (5) to move forward, and as a consequence the Action Bolt Slider (6) and the Action Bolt Driving Pin (8) move forward. Driving Sliders (10) are forced to turn Clockwise. When the Barrel (1) is closed, the initial position should be reached.

This happens through the spring that holds the Action Bolt (12) into position when gun is closed and already exists in a conventional gun. Specifically, as the Barrel (5) closes, it acts on the extruded part of the Bolt Retaining System, which is connected with the engager. The engager releases the Action Bolt (12), which is forced to lock the Barrel (5). As Action Bolt (12) moves, it acts on the Action Bolt Driving Pin (8), the Action Bolt Slider (6) and the Bar (5). The Bar (5) forces the Wheel Pin (4) and the Driving Slider (10) to stop at their initial positions. Thus the closing is completed and the gun is ready for use.

In case of Automatic closing, the Forend should have retractable covers at the upper position of the inner engraving. When these covers are used, the Opening Wheels (3) can act with their upper side of their extruded part on the Forend. This way the Barrel (1) can move Counterclockwise and close.



(a)



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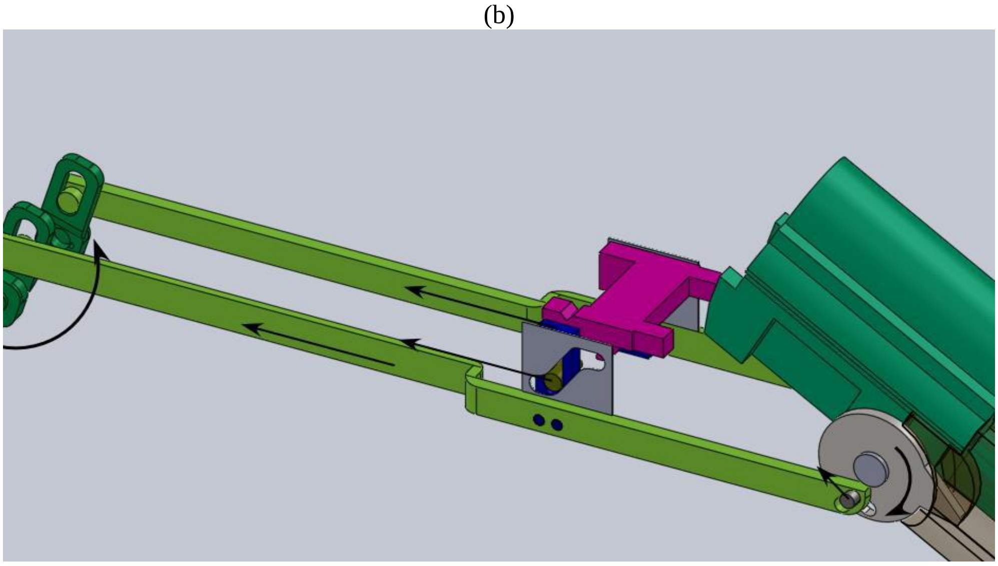


(c)

Figure 5. Sequential movements of the various parts of Driving Subsystem: (a) Release of Action Bolt, (b) The Opening Wheels start to turn, (c) The Opening Wheel have turned 30º.

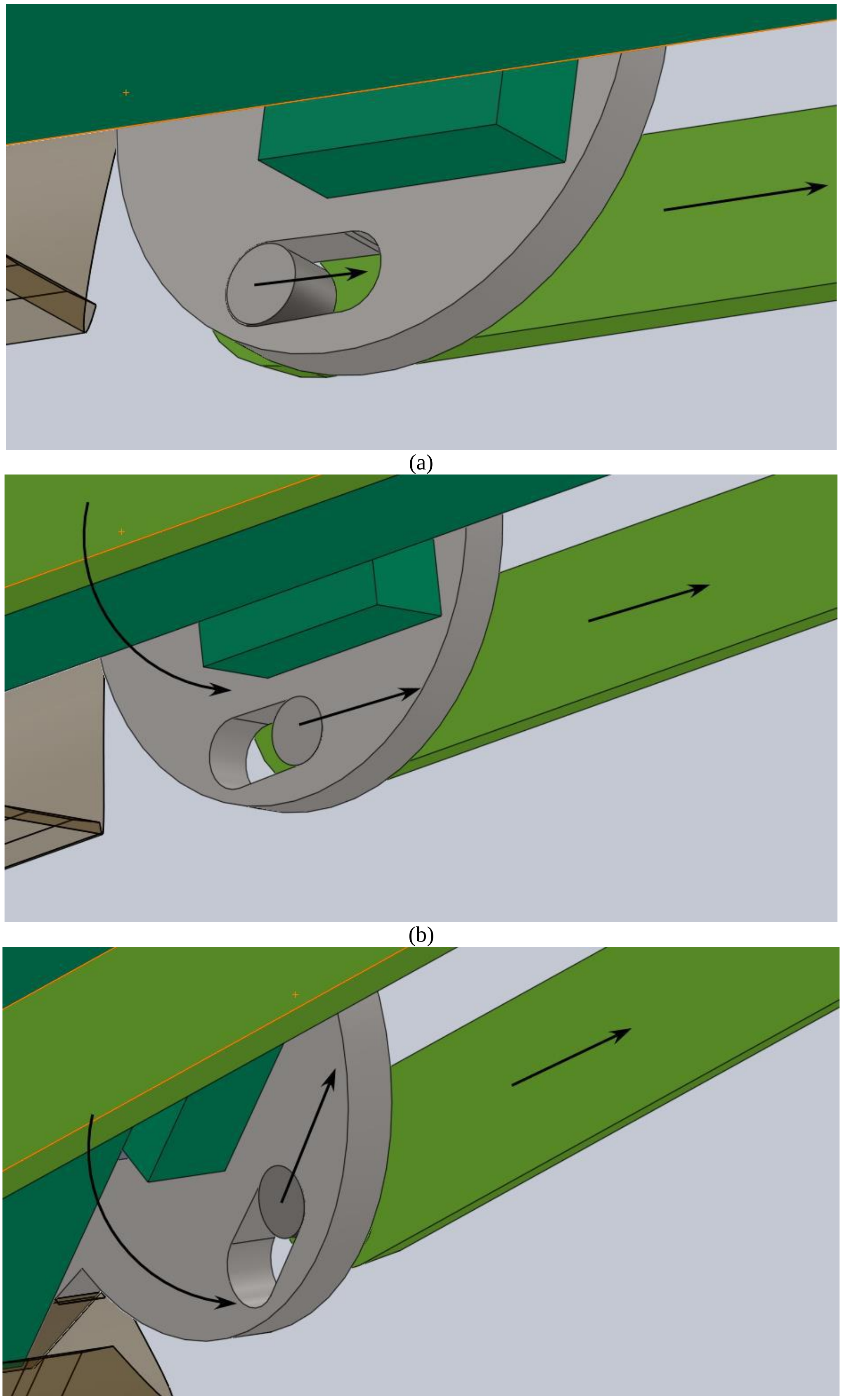

(a)
(b)
(c)

Figure 6. Sequential movements of the Opening Wheel and the Wheel Driving Pin: (a) Release of Action Bolt, (b) Opening Wheels start to turn, (c) Opening Wheel has turned 30^{o}.

Mechanical Transmission Subsystem

Shafts positioned inside appropriate extruded cuts of the Driving Sliders (10) force them to rotate. The main motor provides the motion to these shafts through a Worm-Gear (the Gear (19) is shown in Fig. 7) transmission, which is not backdriveable. This would create a problem when the barrel returns to its closed position manually. To address this potential problem, the motor is decoupled from the remaining transmission using two clutches, as shown in Fig. 7. The clutches are controlled either with a spindle motor (Variation I), or with a voice coil (Variation II).

Variation I

Whenever the Button for opening is pressed, the microcontroller sends a signal to the Spindle Motor (18) to close the Clutching Arms (16). For this reason, it acts through a screw mechanism to the Driving Cone (17), transforming the rotational motion (of the motor) to translational (of the Cone). The Clutching Arms (16) are obliged to move following the peripheral of the cone. It must be noted that the Arms (16) are inside drawers of the Stock, which forces them to move only linearly, to and from the Driving Sliders (10). On the Arms (16) preloaded springs act, thus retaining continuously contact between Arms (16) and Cone (17).

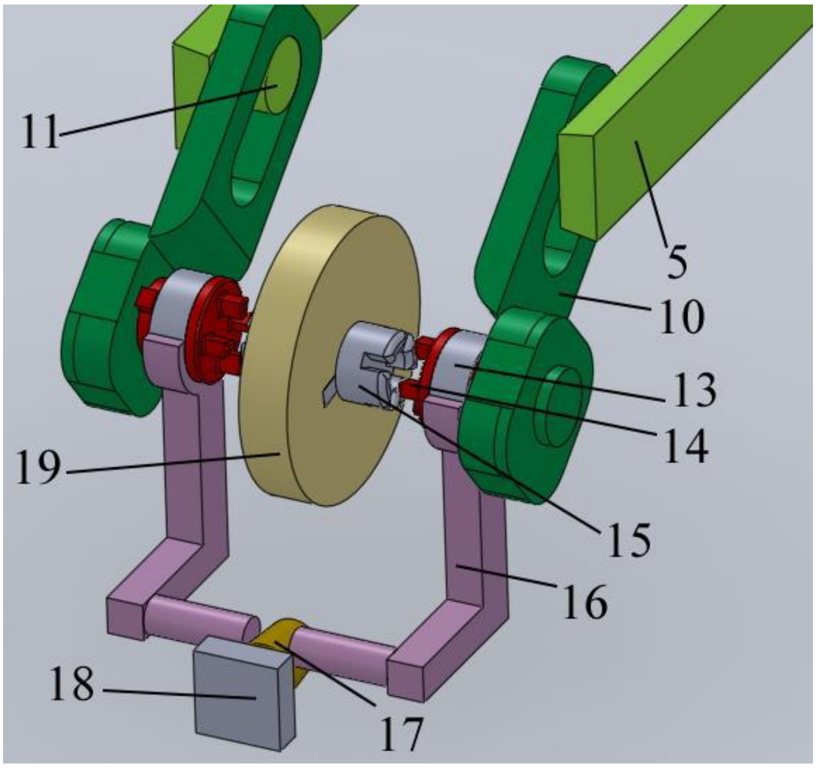


Figure 7. Conceptual design of the Clutching Mechanism for Variation I.

Table II: Parts list for Figure 7

5: Bar	14: Minor Shaft	18: Spindle Motor
10: Driving Sliders	15: Major Shaft	19: Gear
11: Driving Pins	16: Clutching Arms	
13: Friction Ring	17: Driving Cone or Engraved Cylinder	

As the Arms (16) close, they force the Minor Shafts (14) to couple with the Major Shaft (15) in order torque from the Worm-gear to be transmitted to the Driving Sliders (10).
When there is no need to transmit any more torque from the motor, the microcontroller gives a signal to the Spindle Motor (18) to move the Cone (17) backwards, so the Arms (16) disengage the Shafts.
This way the manual closing and the Semi-automatic and Manual modes can work without transmitting torque to the Worm Gear and the Motor Assembly.

It is important to include the Friction Ring (13) between the Arms (16) and the Minor Shafts (14).
The latter can rotate however the Arms cannot. The Friction Ring (13) allows this. One more important thing is the shape of the teeth of the Minor and Major Shafts.
It is possible because of small inaccuracies, when the system is in rest, their faces not to match. However with proper machining the surfaces may slide to each other.
Thus, during clutching, if they cannot completely mate, the inevitable rotation from the Worm Wheel will result them to mate.

Instead of a Driving Cone (17) which acts on the Clutching Arms (16) by its helical movement, an Engraved Cylinder can be used.
The Cylinder can be set on the shaft of the Spindle Motor and will have appropriate engravings which the Arms must follow, thus creating their movement.
In this case no spring for Arms will be necessary and the movement of the Cylinder will be strictly rotational.

Variation II

The only difference between Variation II and Variation I is the use of Voice Coil (20) instead of the Cone and Spindle Motor, in moving the Clutching Arms (16). Upon pressing the Button from the user, the microcontroller sends a signal to an amplifier circuitry that activates the Voice Coil (20). A magnetic field is created forcing the metallic ends of the Clutching Arms (16) to move inside the Coil (20), thus engaging the Major with the Minor Shafts.

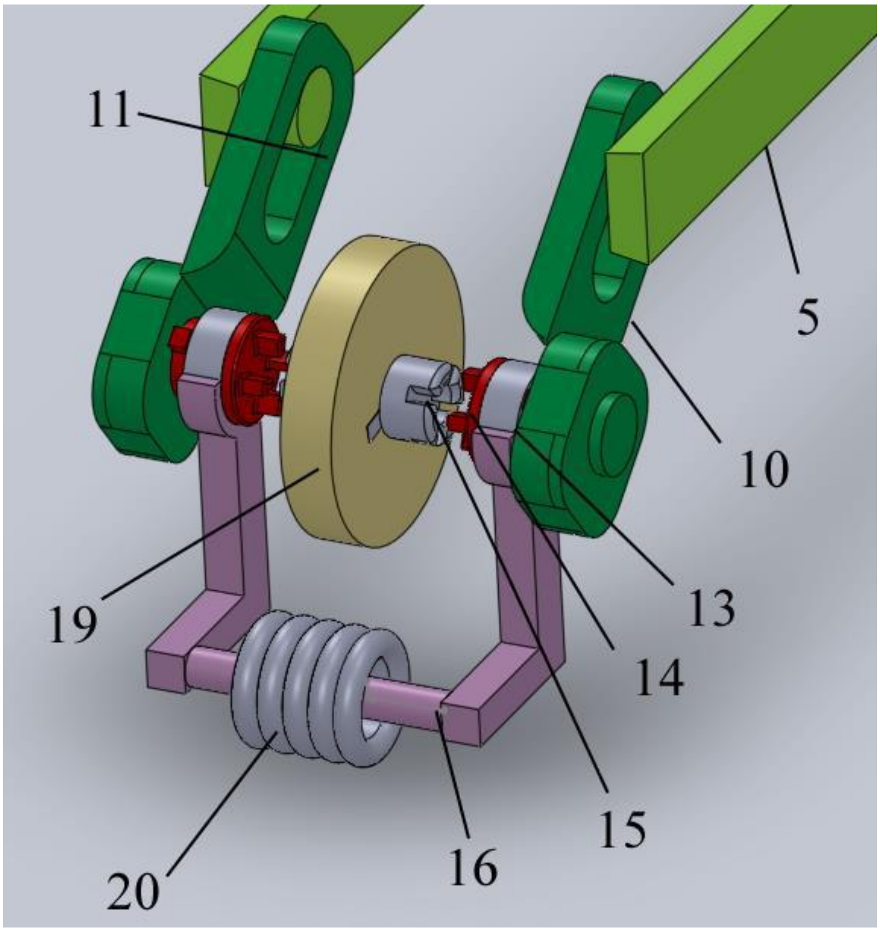


Figure 8. Conceptual design of the Clutching Mechanism for Variation II.

Table III: Parts list for Figure 8

5: Bar	13: Friction Ring	16: Clutching Arms
10: Driving Sliders	14: Minor Shaft	19: Wheel
11: Driving Pins	15: Major Shaft	20: Voice Coil

Motor Subsystem

The Motor Assembly (22) includes the Main Motor, which produces the necessary rotational motion, an Encoder to transmit the Motor's Shaft position to a microcontroller, and a Gearbox to reduce the rotational speed of the Motor's output shaft thus increasing the torque. The output shaft of the Gearbox is coupled with a Worm-Gear (19, 24) through a Coupler (23) in order to absorb any vibrations. The Motor Assembly and the Battery parts are located inside the Stock. Their exact position depends on specific requirements such us: exact dimensions of the necessary Motor Assembly and Battery, weight, center of mass, etc.

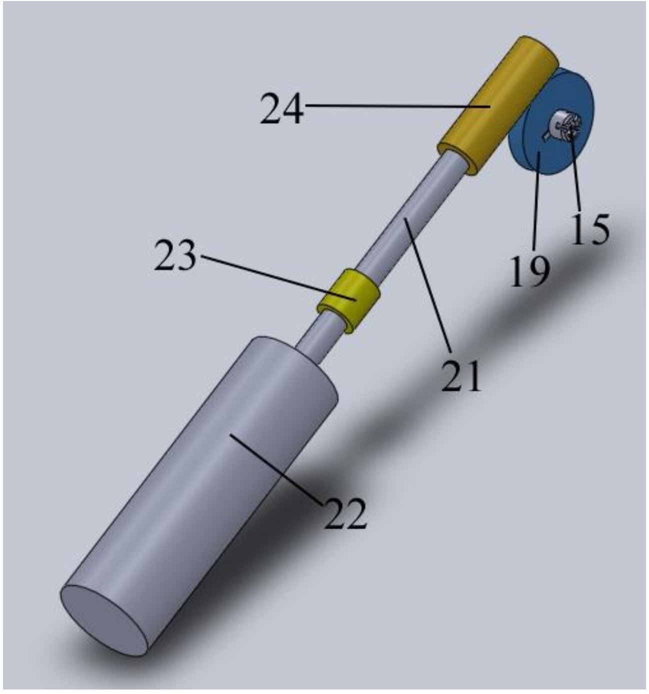


Figure 9. Motor Assembly.

Table IV: Parts list for Figure 9

15: Major Shaft	21: Shaft	23: Coupler
19: Wheel	22: Main Motor Assembly	24: Worm

Electronics and Control

A microcontroller (MCU), see Fig. 10, with the necessary electronics is attached in a small Printed Circuit Board (PCB). The PCB can be located anywhere in the interior of the gun, as it requires minimal space. Electronics may have the form of THT or SMD forms, with the latter being extremely small.

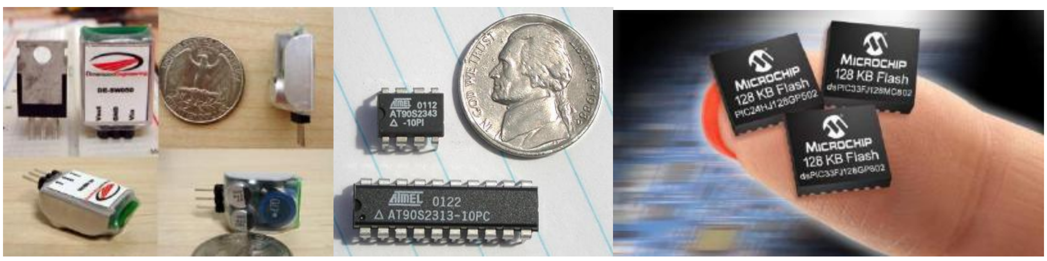


Figure 10. Some electronic components. (a) Voltage Regulators, (b) Atmel MCUs and (c) Microchip PIC MCUs.

The microcontroller controls the entire system. It can be programmed using a PC easily. In specific:

- It receives the signal from the Button when the user wants to open or close the Barrel (ignoring false commands such as multiple pressing during operation etc).
- It recognizes whether the user has selected the Automatic, Semi-automatic or Manual Opening mode and the Automatic or Manual Closing mode (by a Switch) and acts correspondingly at Button press.
- When in Manual Mode, the selection switch opens the circuit for the power transmission from MCU (and the other electronic parts). This is the “off” state for electronics.
- It controls the Spindle Motor or the Coil for the Clutching.
- It controls the Motor Assembly through an H-bridge and Pulse Width Modulation (PWM) signals.
- It can be easily programmed to change the profile of the motion of the Barrel. This can be achieved through appropriate programming, by setting a profile of rotation of the motor. Thus the motion starts and ends smoothly eliminating accelerations and decelerations that may result in undesired shocks to the user and damaging parts of the gun. The clutching can end some milliseconds after the end of motion, in order to avoid backward bouncing of Barrel because of its contact with the Action.
- It can be programmed in order to make the motion in various selectable time durations (this can be preprogrammed, or another Switch can exist).
- In case there is a Display, MCU controls the displayed signals.
- In case the barrel has not fully opened or closed because an obstacle was found (e.g. in the confined dimensions of a boat or a blind), a small circuit (and/or Hall sensors informing MCU if the barrel has reached the maximum position of its envelope) can protect the system from overloading (e.g. the motor tries to rotate, however it cannot because of the obstacle so it demands more power). In this case the system will decouple and the motion will stop.
- The MCU can be programmed to continue the motion, according to the information from the encoder. Another option is a small optical encoder (almost zero mass) which is located on the shaft of one of the two Driving Sliders or can be placed on the bar (encoder strips). This encoder informs continually the position of the mechanism to the MCU, which can act properly, according to preprogrammed scripts.
- The user after bringing the gun away of the obstacle can either complete the movement by hand or complete the movement from the present barrel position by pressing again the button (unless the MCU is programmed by him to ignore commands when barrel is not at fully closed or fully opened position) .

A basic connection between the various components is presented in Fig. 11. Voltage Regulators drop the DC Battery Voltage to nominal levels for each subsystem (for example from 11.1V Battery Pack to 9V for Motor and 5V for Electronics).

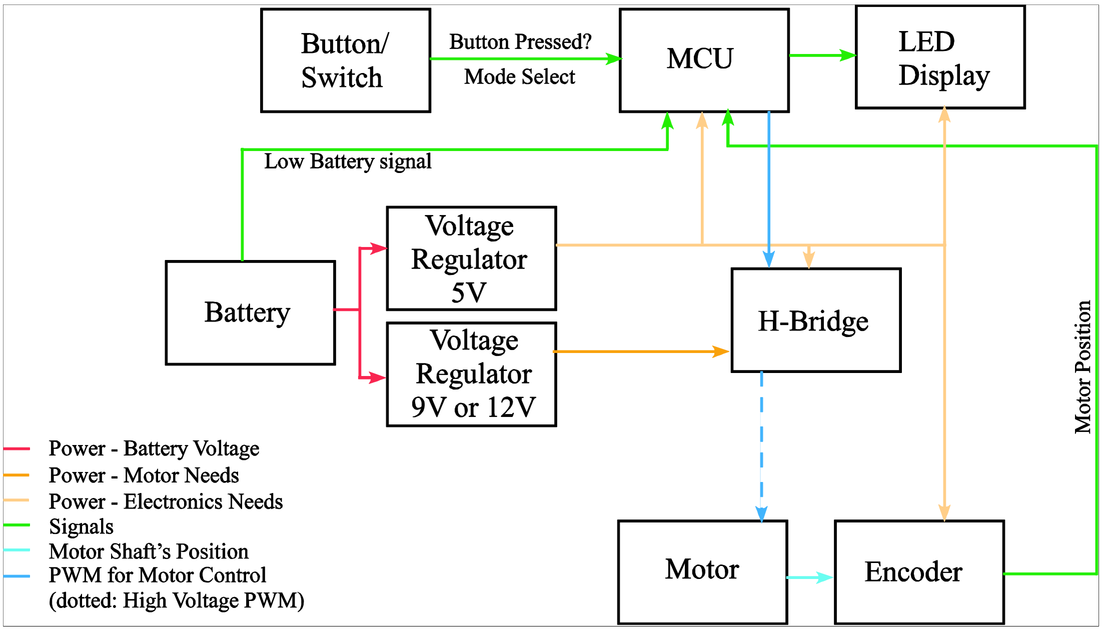


Figure 11. Basic interconnections between various electromechanical components.

3.EXPERIMENTAL MEASUREMENTS AND MOTOR ASSEMBLY SIZING

Experimental measurements took place in our laboratory, using a conventional over/under gun of a famous and well established maker. This gun was new “out of the box”(not a single round was fired with it), with very tight “fitting” compared to others of the same maker which were even slightly used, competition model, 12 gauge , with 75 cm barrel weigh 1.610 gr and “beaver-tail” forend weigh 360 gr (total weight 1.970 gr). That big weight supersizes the situation but is used for demonstration purposes.

Here must be noted that in the case of side-by-side gun, due to lower barrel-forend weight and smaller opening angle, the opening time and the required power are almost half.

The necessary forces, and therefore the necessary torques have been measured. Measurements for Opening were received at 30 cm from rotation center with the gun held in vertical (normal) position (therefore gravity acts to help in the opening) and (as a capability test) with the gun in horizontal position (held 90º around the axis of the barrel). At the latter case, gravity does not assist the user. Additionally the torque for the Action Bolt Unlocking has been measured also. This torque represents the necessary energy to overcome the spring force which holds the Action Bolt into Locking position. Before each measurement, both triggers were pulled so the force of all cocking springs is included. Note that calculations refer to various opening times, which are presented at each Table next. The total opening time includes Action Bolt Unlocking and Barrel Opening, and the values are based on the measured torque applied on the Top Lever and on the Barrel. Generally the opening times are divided in the proposed estimates: milliseconds for clutching (so it is not included in the total opening time), about 0.15 sec Action Bolt Unlocking and the rest (according to each case) Barrel Opening. Driving Sliders may have various rotational angles (it depends on the needs and the final design) which leads to various angular speed for them. However the power to perform Action Bolt Unlocking and Barrel Opening is derived by the physical properties of them.

Measurements and calculations performed also for Closing. In this case, the measurements were received by pulling the barrel from the bottom part of it , at 50 cm from rotation center, in order to keep the measuring instrument in a distance from the forend .The chosen Closing time is 1,35 sec due to the fact that ,during closing ,the gun stops on the soft area of the hand between the thumb and the pointing finger and a faster closing can cause an unpleasant shock (while, during opening, the gun is firmly held). A faster closing can also cause the emptying of the shotshells from the chambers and the wear of the fitting . It is also recommended during closing for the action of the gun to be held slightly downwards in order to keep the barrel pointing in a safe direction after the completion of the closing.

It is noted that the power requirements of the spindle motor or the voice coil is extremely low compared to the power requirements of the Motor Assembly. Additionally the driving force for the design concept was the mechatronic subsystem which unlocks the Action Bolt and opens or closes the Barrel. Thus the calculation for the power demands for the Clutching Subsystem is omitted. The Safety Factor is set high in order to cover also this.

Tables 5-8 summarize the findings and also calculations of some necessary values.

Table V. Experimental measurements and calculations for Action Bolt Unlocking (Angle 30º) . Mean value of 15 efforts. Unlocking time 0.15 sec.

Measured Force (kg)	2,41
Distance from Rot. Center (m)	0,06
Torque (Nm)	1,419
Angular Speed (rad/sec)	3,493
Power (W)	4,955
Safety Factor	1,20
Calculated Power	5,946

Table VI. Experimental measurements and calculations for Vertical (Normal) Barrel Opening (Angle 45^o) .Mean value of 30 efforts. Opening time 0.60 sec.

Measured Force (kg)	1,28
Distance from Rot. Center (m)	0,3
Torque (Nm)	3,767
Angular Speed (rad/sec)	1,309
Power (W)	4,931
Safety Factor	1,20
Calculated Power	5,917

Table VII. Experimental measurements and calculations for Horizontal Barrel (No gravity assist) Opening (Angle 45^o). Mean value of 30 efforts. Opening time 0.85 sec.

Measured Force (kg)	2,51
Distance from Rot. Center (m)	0,3
Torque (Nm)	7,387
Angular Speed (rad/sec)	0,924
Power (W)	6,826
Safety Factor	1,20
Calculated Power	8,191

Table VIII. Experimental measurements and calculations for Vertical (Normal) Closing of the Barrel (Gravity acts to the opposite direction of the movement) (Angle 45^o). Mean value of 30 efforts. Closing Time 1.35sec

Measured Force (kg)	2,60
Distance from Rot. Center (m)	0,5
Torque (Nm)	12,753
Angular Speed (rad/sec)	0,582
Power (W)	7,422
Safety Factor	1,20
Calculated Power	8,906

For the calculations the following formulas were used

Torque:

$$T = F \cdot r$$

Where

T (Nm) is torque

F (N) is measured force in kg ($1N = 1kg \cdot 9.81 m/\sec^2$)

r (m) is distance of Point of Force Application from Rotation Center

Angular Speed:

$$\omega = \frac{\Delta\theta}{\Delta t}$$

Where

ω $(rad/\sec)$ is the angular speed

$\Delta\theta$ (rad) is the opening angle

Δt $(\sec)$ is the opening time

Power

$$P = T \cdot \omega$$

Where

P (W) is power

T (Nm) is torque

ω $(rad/\sec)$ is the angular speed

The above mentioned power does not include a Safety Factor. Alternatively, it can be considered as the power when the Safety Factor equals 1.00. For design purposes, the necessary power with Safety Factor 1.20 (that means necessary power 20% more than the measured one) has been calculated also.

The CAD design for motor set (motor, gearbox, encoder), worm-gear and battery is based on the selection of the case of Horizontal Barrel Opening position with Safety Factor 1 as basic situation. It is an oversizing situation by default (the gravity does not assist the opening).

4. WORM GEAR SET

Worm Gear is the interface system between the motion that originates from the Motor Assembly and the motion imparted on the Driving Sliders (10). Additionally it lowers the rotational speed from the Shaft (21) after the Coupler (23) and the same time it increases the Torque to the Driving Sliders (10).

This mechanism allows the motion transmission from one direction only (e.g. from the Motor Assembly). This is added to the general problem of non-backdriveability, i.e. no motion from the Mechanism should be transmitted to the Worm Gear Set and the Motor Assembly. For this reason the Clutching Subsystem has been created.

Companies that make worm-gear systems are presented at the end of this Section. This is an indicative list, as globally many companies produce worm-gears including customized solutions. Therefore there was no point in referring to particular Worm Gear Sets. It is concluded that a Worm Gear mechanism with a reduction ratio of about 30:1 inside the volumetric permissible envelope of the gun, is feasible.

References:

(1) www.khkgears.co.jp/en/index.html
(2) www.framo-morat.com
(3) bostongear.com
(4) www.qtcgears.com

5. BATTERIES

After examination of various battery technologies, Li-Po batteries were selected as the best choice, since they are characterized by:

- Very high specific energy (about 140 Wh/kg, depending on the manufacturer)
- Capability of providing huge Amps, necessary for starting the motor
- Low mass and volume
- High cycle life (even more than 1000 cycles in some cases)
- Negligible memory effect
- Small charging times
- Generally accepted working temperatures from -20^{o}C up to 60^{o}C
- Loss of power in storage : less than 5% per month (almost 2 years from full)

Another crucial part is that by design, they can have any shape required, making them perfect for being positioned in the Stock, which is non-orthogonal. The battery producer can customize the battery according to the specific needs.

In case the temperature is below -20^{o}C, Li-Po still works just with lower capacity . The use of thermal insulation, especially with materials arising e.g. from aerospace technology will provide a stable environment for the battery packs. A thin sheet of this material around the battery, of some millimeters will solve any possible problem. Also the use of Heavy Duty Battery Packs, will ensure the proper function of the system according to the requirements in extreme conditions, however this design should be of such way in order not to change the physical characteristics of the Stock substantially.

Li-Po are established batteries, used in many applications that include laptops, mobile phones or RC models. Additionally there are special chargers that facilitate the charging process. In the near future, it is expected that Li-Po batteries will improve further due to the large R&D efforts in this area. In fact, recently MIT has discovered a method to charge Li-Po batteries in few seconds (depending on the capacity) which leads to designs with smaller batteries with lower mass, which however can be charged so fast rendering the drawback of capacity to a low importance matter.

To find the approximate number of opening cycles, we followed the following procedure. The necessary power to use the mechanism each time the Button is pressed is:

$$I_b(mAh) = 1000 \cdot I(A) \cdot \frac{t(\mathrm{s})}{3600}$$

Where

$I_b\ (mAh)$ is the necessary power each time the Button is pressed
$I\ (A)$ is the starting current for the motor
$t\ (\mathrm{sec})$ is the time the motor is working

Apparently the above mentioned equation over-computes the necessary power, as the average current drawn is only a fraction of the starting current of the motor.

The number of times that the system will work without need of recharging (repeats) are:

$$R = \frac{I_c(mAh)}{I_b(mAh)}$$

Where

R is the number of repeat times
$I_b\ (mAh)$ is the necessary power each time the Button is pressed
$I_c(mAh)$ is the power capacity of the battery

References:

(1) Graupner, Instructions and Warnings Relating to the Use of LiPo Batteries
(2) KRC Newsletter Special Edition, “LiPo Batteries in Cold”
(3) www.3w-modellmotoren.com
(4) http://www.bikudo.com/product_search/details/104849/minamoto_3_7v_lithium_polymer_battery.html
(5) http://www.batteryuniversity.com/partone-15.htm
(6) http://www3.towerhobbies.com/

6. CASE STUDIES

According to the measured and calculated values 3 case studies have been selected. In each case, a number of necessary Motor Assemblies (Motor, Gearbox, Encoder) are selected and the appropriate Battery Pack.

The number of available repeated uses without recharging the battery has been found.

As it is obvious from the measurements (Section 3), power needs for Safety Factor 1.20 were well above corresponding values for Safety Factor 1.

Thus for demonstration purposes only SF 1.20 was chosen for the decision of Motor Assembly.

However when the Motor Assembly is chosen according to the power needs of Horizontal Opening or the Normal Closing, these power requirements are far above of the Action Bolt Unlocking power requirements, thus they are the selection drivers.

The use of SF 1.20 supersizes the selections, adding a safer margin to estimates.

Also supersizing exists for the energy consumption, as the starting current which is used for the calculation, acts only for the first milliseconds of movement, and then its value falls.

However for our purposes starting currents is used for the whole procedure (e.g. for the total motion time).

According to this, the following cases are presented:

(a) Action Bolt Unlocking 0.15 sec and Horizontal Opening 0.85 sec, Total time 1 sec. Opening power demands prevail.

(b) Action Bolt Unlocking 0.15 sec and Vertical Opening 0.60 sec, Total time 0.75 sec. Action Bolt Unlocking power demands prevail.

(c) Action Bolt Unlocking 0.15 sec and Vertical Opening 0.60 sec, Total Opening time 0.75 sec. 1.35 sec Closing Time. Closing power demands prevail.

Notes on the tables:

- Only Maxon Motors uses the term “Starting Current” in motor datasheets. Other firms provide “Nominal Voltage” and “Terminal Resistance”. In the latter case, the starting current is the division of Voltage to Resistance and has been computed.

- Necessary ratio field is the necessary gear reduction ratio of Motor Assembly, if the reduction ratio of Worm-Gear (see Sec. 4) is 30:1. The gearbox is selected based on this number.

- Some companies do not provide prices.

- Encoders have little information about weight and dimensions, so assumptions where used whenever possible. However this part adds no substantial weight or volume.

- Total numbers is a sum of the respective mass, length or volume of each part of Motor Assembly and Battery, whenever this was possible.

- The Spindle Motor (18) and Coil (20) consumptions, as well as the power consumption of electronics are not included. They are minimal compared to the Motor Assembly consumption.

See App. B for Spindle Motors information.

Information for Motor Assemblies can be found at:

(1) www.maxonmotor.com
(2) www.faulhaber-group.com
(3) www.micro-drives.com

(a) **Action Bolt Unlocking 0.15 sec and <u>HORIZONTAL OPENING</u> 0.85 sec, <u>TOTAL TIME 1 sec.</u>**

Motor												
SET	Company	Model	W	V	Nom. Torque (mNm)	St. Cur (A)	Diam. (mm)	Length (mm)	Volume (cm^3)	Weight (g)	Cost (€)	i (Nec. Ratio)
1	Faulhaber	2232009R	9.35	9	10.00	4.206	22.0	32.2	12.23	62	N/A	21.58

Gearbox								
SET	Model	i	Max Torque (Nm)	Diam. (mm)	Length (mm)	Volume (cm^3)	Weight (g)	Cost (€)
1	20/1	23	0.50	20.0	23.5	7.38	38	N/A

Encoder							
SET	Model	Counts	Width	Height	Length (mm)	Weight (g)	Cost (€)
1	IE2-400	100	13.0	N/A	N/A	20	N/A

Total of Motor Assembly				
SET	Weight (g)	Length (mm)	Volume(cm^3)	Cost (€)
1	120	55.7	19.61	N/A

Batteries List												
SET	Company	V	mAh	C	L (m)	W (m)	H (m)	Volume (cm^3)	Weight (Kg)	Repeats	Repeats (Unlock only)	Cost (€)
1	Flight Power	11.1	2500	25	0.129	0.040	0.022	113.520	0.208	2140	8559	94.92

Total			
SET	Weight (kg)	Volume (cm^3)	Cost (€)
1	0.328	133.133	N/A

(b) Action Bolt Unlocking 0.15 sec and VERTICAL OPENING 0.60 sec, TOTAL TIME 0.75 sec.

Motor												
SET	Company	Model	W	V	Nom. Torque (mNm)	Cur (A)*	Diam. (mm)	Length (mm)	Volume (cm^3)	Weight (g)	Cost (€)	i (Nec. Ratio)
1	Maxon	110158	6.00	9	6.52	2.380	22.0	31.9	12.12	54	33.27	13.04
2	Maxon	220427	6.50	9	10.70	2.210	24.0	31.9	14.42	71	56.07	7.95
3	Faulhaber	2232009R	9.35	9	10.00	4.206	22.0	32.2	12.23	62	N/A	8.50

Gearbox								
SET	Model	i	Max Torque (Nm)	Diam. (mm)	Length (mm)	Volume (cm^3)	Weight (g)	Cost (€)
1	134158	14	0.50	22.0	32.2	12.23	55	66.60
2	232766	14	0.30	22.0	29.5	11.21	35	38.27
3	20/1	9.7	0.50	20.0	23.5	7.38	38	N/A

Encoder							
SET	Model	Counts	Width	Height	Length (mm)	Weight (g)	Cost (€)
1	110520	100	33.7	22.0	N/A	20	48.53
2	110520	100	33.7	22.0	N/A	20	48.53
3	IE2-400	100	13.0	N/A	N/A	20	N/A

Total of Motor Assembly				
SET	Weight (g)	Length (mm)	Volume(cm^3)	Cost (€)
1	129	64.1	24.35	148.40
2	126	61.4	25.63	142.87
3	120	55.7	19.61	N/A

Batteries List												
SET	Company	V	mAh	C	L (m)	W (m)	H (m)	Volume (cm^3)	Weight (Kg)	Repeats	Repeats (Unlock Only)	Cost (€)
1	Thunder Power	11.1	1320	20	0.065	0.034	0.019	41.990	0.084	2662	7987	34.76
2	Thunder Power	11.1	1320	20	0.065	0.034	0.019	41.990	0.084	2867	8601	34.76
3	Thunder Power	11.1	1800	30	0.092	0.031	0.025	71.300	0.146	2054	6163	50.39

Total			
SET	Weight (kg)	Volume (cm^3)	Cost (€)
1	0.213	66.344	183.16
2	0.210	67.622	177.63
3	0.266	90.913	N/A

(c) Action Bolt Unlocking 0.15 sec and Vertical Opening 0.60 sec,
TOTAL OPENING TIME 0.75 sec. , CLOSING TIME 1.35 sec.

Motor												
SET	Company	Model	W	V	Nom. Torque (mNm)	St. Cur (A)	Diam. (mm)	Length (mm)	Volume (cm^3)	Weight (g)	Cost (€)	i (Nec. Ratio)
1	Faulhaber	2232009R	9.35	9	10.00	4.206	22.0	32.2	12.23	62	N/A	42.51

Gearbox								
SET	Model	i	Max Torque (Nm)	Diam. (mm)	Length (mm)	Volume (cm^3)	Weight (g)	Cost (€)
1	20/1	43	0.50	20.0	28.6	8.98	48	N/A

Encoder							
SET	Model	Counts	Width	Height	Length (mm)	Weight (g)	Cost (€)
1	IE2-400	100	13.0	N/A	N/A	20	N/A

Total of Motor Assembly				
SET	Weight (g)	Length (mm)	Volume(cm^3)	Cost (€)
1	130	60.8	21.21	N/A

Batteries List											
SET	Company	V	mAh	C	L (m)	W (m)	H (m)	Volume (cm^3)	Weight (Kg)	Repeats	Cost (€)
1	Flight Power	11.1	2500	25	0.129	0.040	0.022	113.520	0.208	1019	94.92

Total			
SET	Weight (kg)	Volume (cm^3)	Cost (€)
1	0.338	134.734	N/A

The additional mass due to the mechatronic mechanism will have a minimal effect in the total mass of a conventional gun. The volumes where the parts reside, substitute existing material, and there will be even some small gaps to enable the movements (linear and rotational) of the various components. Thus a small reduction of mass is possible.

Therefore the main mass problem is concentrated in the Stock, where in the wooden cavity the motor system plus the batteries and additional electronics are inserted. The total mass increase will be small (perhaps 50-100 g as a rough estimate), and it depends on the materials to be used and of course on the Motor Assembly selection. The use of novel light materials (but with approved strength and robustness), which can substitute the wood of the Stock, may lower substantially the mass increase.

7. CONCLUSIONS

A novel mechanism for automated movement of the Barrel with minimal effort from user has been presented. This mechanism can be easily adapted to the current form of conventional guns without any severe modifications. The normal functionality of guns is not affected in any case.

The description of the mechanism with relevant schematics was presented. Three Modes for Opening have been analyzed, namely (a) the Automatic Mode (Automatic Action Bolt Unlocking and Automatic Opening of the Barrel), (b) the Semi-automatic Mode (Automatic Action Bolt Unlocking, Manual Opening of the Barrel), and (c) the Manual Mode (Manual Action Bolt Unlocking and Manual Opening of the Barrel). Additionally, two Closing Modes have been examined, the Automatic Closing and the Manual Closing. Two clutching variations of the mechanism have been proposed also.

The design of the presented mechanism can be altered up to a high degree if needed, by using different types of parts and materials such as chains, transmission belts, steel threaded cables, levers, axes etc.

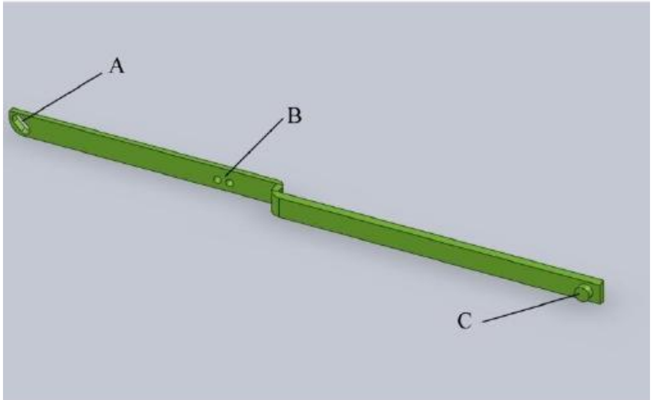
The experimental measurements in our laboratory were presented. According to them, proposals for the Battery and Motor Assembly are derived for three cases. The existence of solution is affirmed. The limit of 2000 repeats for opening can be easily achieved even if the gun is held in horizontal position. The case of Automatic Closing has been also examined.

A novel mechanism using mechatronic components for the opening and the closing of a gun, retaining compatibility with user habits on conventional ones, is regarded as absolutely feasible.

APPENDIX A

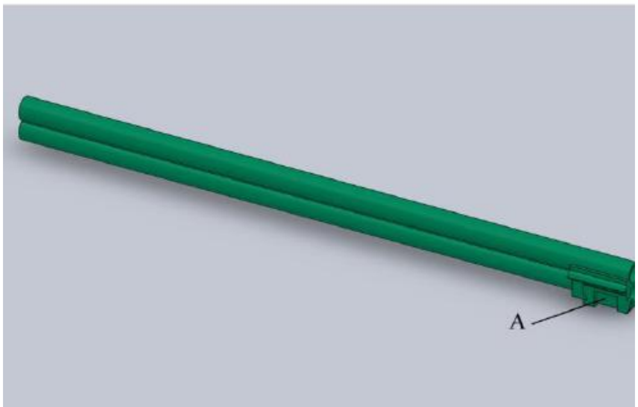
The following appendix describes one by one every component of the mechanism alphabetically.

Bar



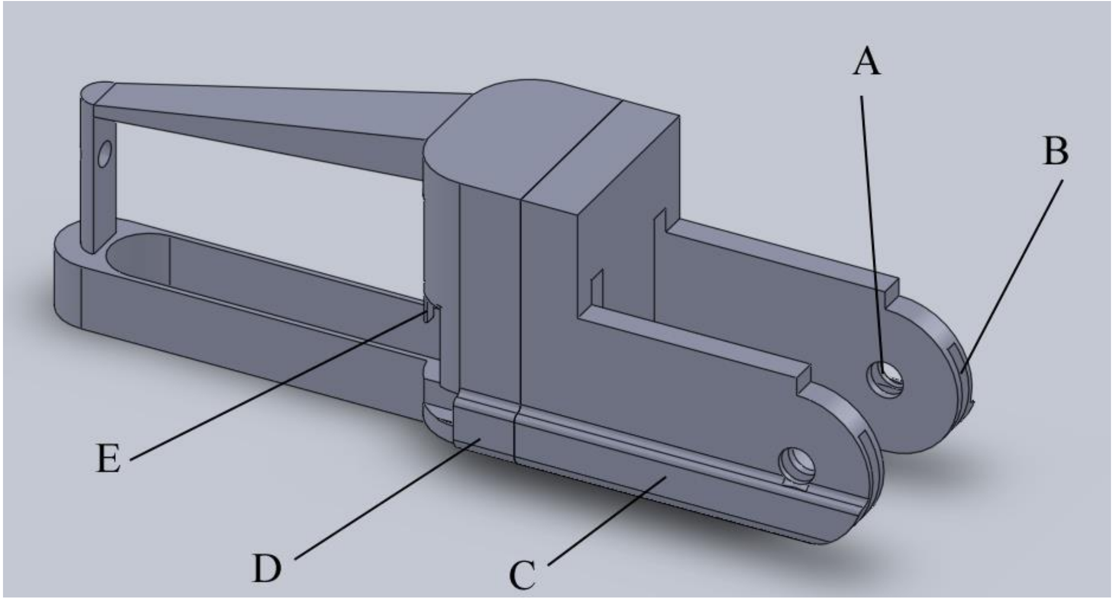
The Bar moves linearly inside cavities of the Action and the Stock, transforming the rotational movement of the Driving Slider to linear. (A) is the position where the Wheel Pin can move, (B) is the position where the Action Bolt Slider is fixed with screws and (C) is the extruded pin, which connects the Bar with the Driving Slider. (A) has diagonal shape, because as the Wheel Pin acts force to the Opening Wheel, the Pin must change its initial height.

Barrel



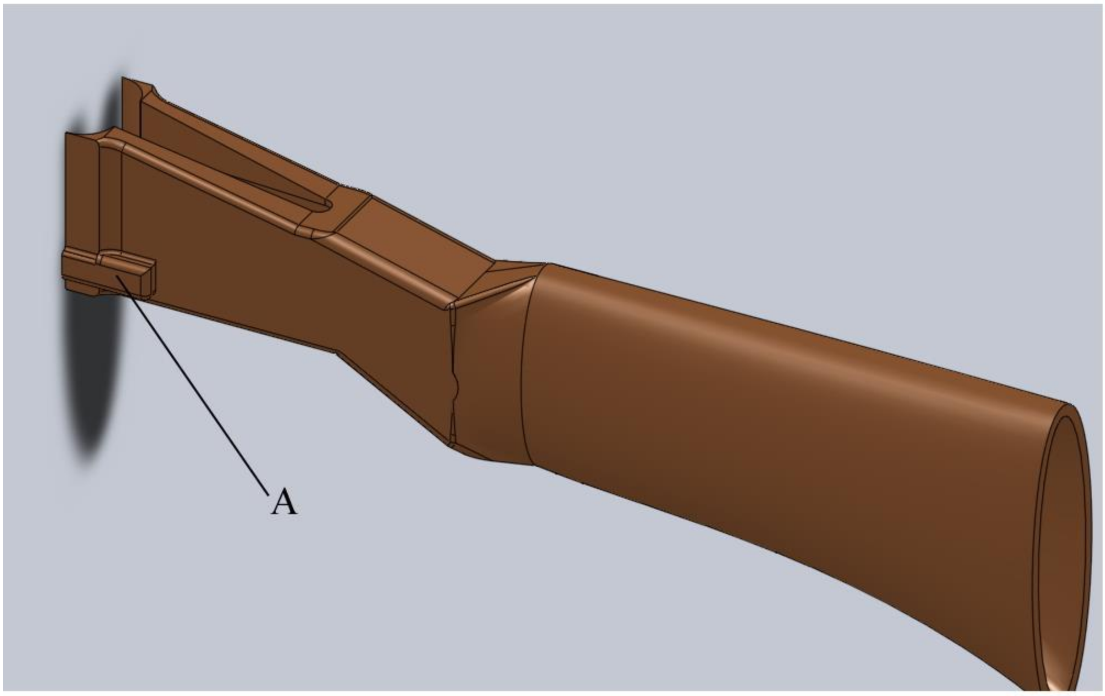
Barrel retains its conventional form. (A) is the point where it can rotate around the Pin of Action.

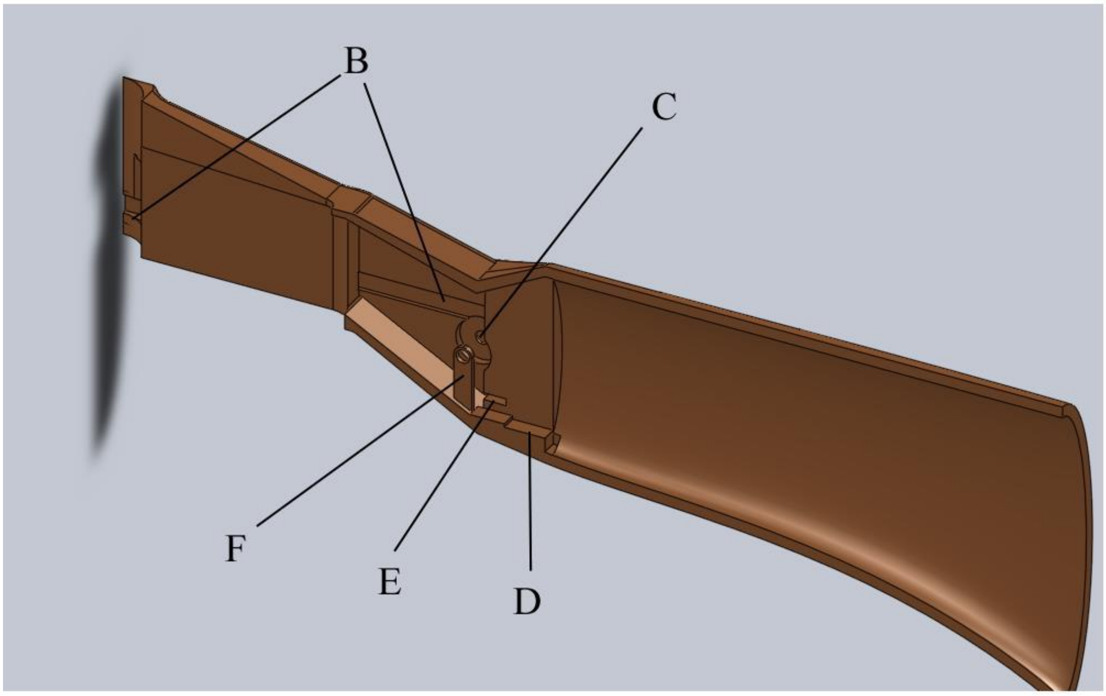
Action (modified)



The action is a conventional gun Action that has been properly modified. (A) Is where the Action Pin exists and the Opening Wheels can rotate. Additionally it is the point where the Barrel can rotate. (B) is the cavity where the extruded part of Opening Wheels moves. (C) is the cavity for the Bars, from outside. (D) is the cavity for the Bars from inside and (E) is a stop for the Action Bolt movement during Unlocking.

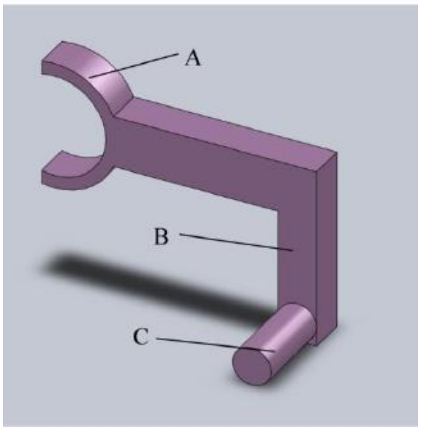
Stock (modified)





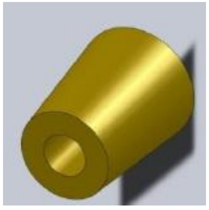
(A) is the outside modifications, allowing the Bar to move inside. (B) is the drawer where Bar can linearly translate. (C) is the position where the Driving Sliders can rotate, (D) is the position for Spindle Motor (only for Variation I), (E) is the location where the Clutching Arms can translate and (F) the support for the Major Shaft. The Motor Assembly and the Battery can be positioned in correspondence with requirements.

Clutching Arms



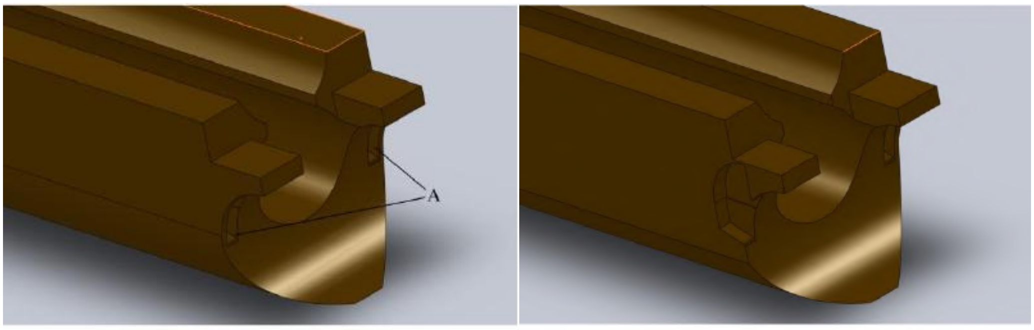
The Clutching Arm has a shape, (A), capable to drive the Minor Shafts. (B) is constrained into a cavity. (C) either follows the Cone (Variation I), or moves inside a Coil (Variation II).

Clutching Cone



This cone is used in Variation I to force Clutching Arms to open or close, thus engaging/disengaging the clutch. Alternatively it can have an engraving, which the Arms have to follow.

Forend (modified)

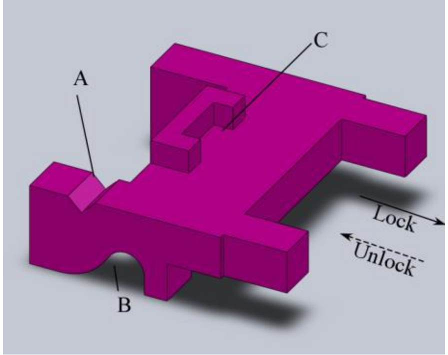


The Forend is connected with the Opening Wheel at (A) and assists the Barrel Movement. In Automatic Mode the Opening Wheels push the Forend downward during opening. During closing the force from user to the Forend is transferred to the Opening Wheels thus reversing the mechanism. In Semi-Automatic Mode however, the user opens the Barrel with hand, thus the engraving of (A) allows the rotation to be performed without acting force to the Opening Wheels and consequently to the gears and Motor Assembly. On the upper side of the engraving there are retractable covers to be used in the Automatic Closing Mode.

Engraving of Action

The engraving is actually part of the Action. It forces the Action Bolt Driving Pin to follow a certain path. This way the Action Bolt unlocks initially and the Pin moves with the Action Bolt Slider. At closing it reverses the movement.

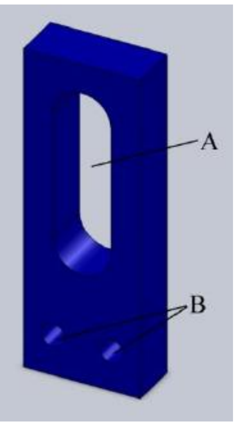
Action Bolt (modified)



The Action Bolt is a modified conventional one. The notch (A) is retained in order to allow the Bolt Retaining System to move in it freely. (B) is diagonal in one side to allow the Action Bolt Driving Pin to fall, following the engraving of the Action. (C) is the slot for the Top Lever Extension. (C) is in this position, so in Automatic and Semi-Automatic Mode the Action Bolt Unlocking acts no force to the extension, whereas in Manual Mode, the extension can act to the Action Bolt.

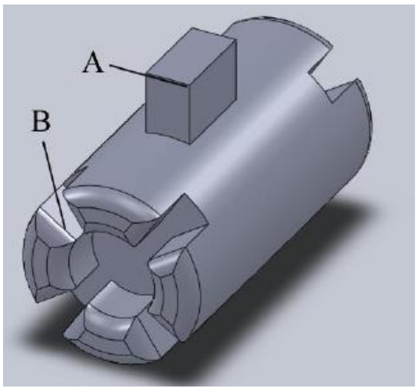
Action Bolt retains its original purpose, this of locking the Barrel. By default there is a spring that acts in order to keep it in locking position, and an engager is used to lock in a notch when opening the Barrel, thus equalizing the force of the spring. It is the force of this spring that is used to reset the mechanism to its original position, when the Barrel is closed and the engager unlocks from the notch .

Action Bolt Slider



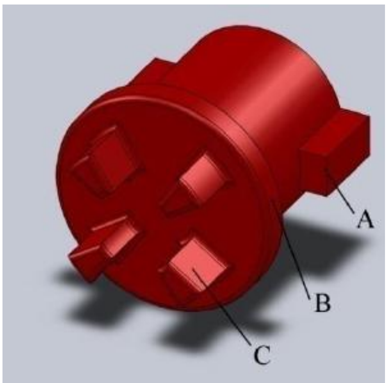
Action Bolt Sliders move with the Bar and force the Action Bolt Driving Pins to follow them. (A) is where the Pins are allowed to move, and (B) is the positions for Screws for fixing the Slider together with the Bar.

Major Shaft



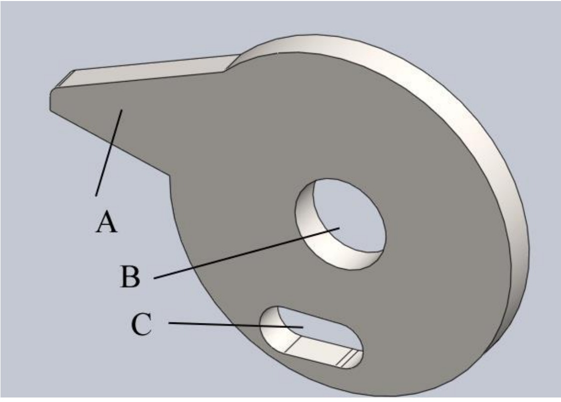
Major Shaft transmits the torque from the Worm-Gear to the Minor Shaft. (A) connects it with the Wheel. (B) exists in order to couple easier with the Minor Shafts.

Minor Shafts



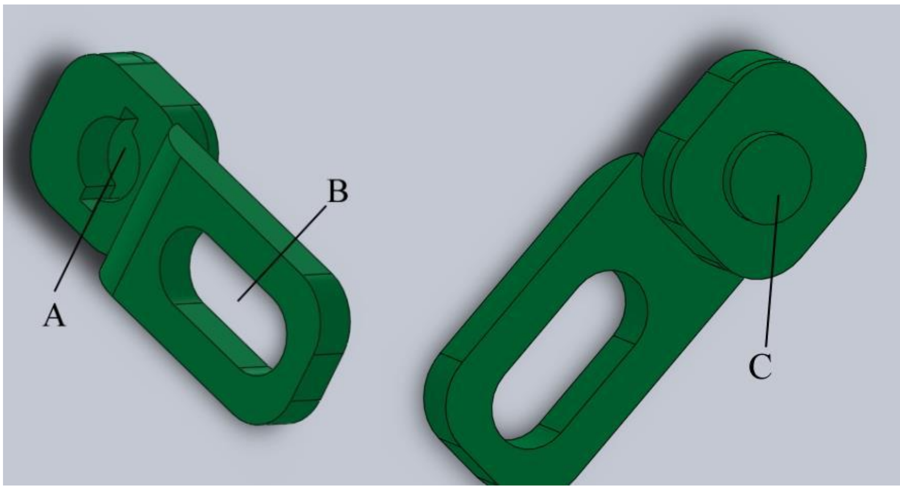
The Minor Shafts transmit torque form the Wheel to the Driving Sliders. (A) Allows the Shaft to cooperate with the Slider. (B) allows the Clutching Arms to operate for the translational movement and (C) allows the coupling with Major Shaft.

Opening Wheel



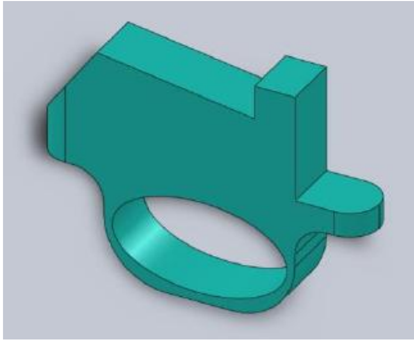
The Opening Wheel interfaces with the Forend. (A) is inserted in the Forend in order to act on it when rotating. Additionally, at Manual closing (in Automatic or Semi –Automatic Opening Mode), Forend forces the Opening Wheels to rotate in order to reset the mechanism ,while in Automatic Closing Mode the retractable covers of the Forend force the Forend to follow the Opening Wheels. (B) is the rotation point. (C) is the engraving of the Wheel, where the Wheel Pin moves.

Sliding Driver



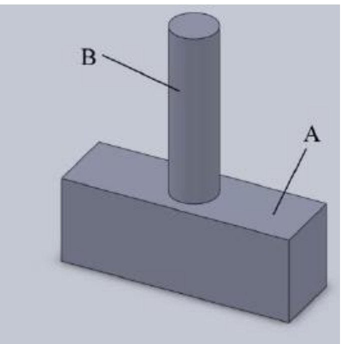
The Driving Sliders transform in conjunction with the Bar the rotational movement from the Motor Assembly and Worm-Gear to linear. (A) is the position where the Minor Shafts are positioned capable to move inside and outside during clutching. The shape allows the transmission of torque from Shafts to the Sliders. (B) is where the extruded pin of the Bars is allowed to move. (C) is used in the wall of Stock in order to position the Slider (small bearings can be used for greater robustness).

Trigger Assembly



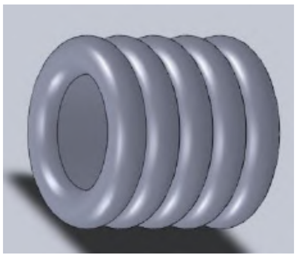
This part remains unmodified.

Manual Opening Extension



This is the extension of the Manual Opening. (A) has the shape of the Action Bolt slot. (B) is the extension from Manual Opening. Its shape allows the user only in Manual Mode to push the Action Bolt for Unlocking and does not follow the Action Bolt movement when the mechanism in non-manual modes.

Voice Coil



Voice Coil is used in Variation II. A magnetic field is created when current runs inside the cables, thus forcing the Clutching Arms to move.

APPENDIX B

Spindle Motors are small, have low power demands and provide adequate torque. Selections from Faulhaber Group have been made and presented in Table B-I. Two kinds interest: the one has the classical form with the ration of Length to Diameter higher than one and one flat form with the opposite. In any case the following list is just indicative. A rotational to linear mechanism should be included at the end of motor shaft. Starting Current is in most cases about 0.1A which is too low to impose any substantial problem. It is certain that motors with lower consumption can be found in the market.

Table B-I. Indicative list of Spindle Motors.

Model	**Type**	**Length(mm)**	**Diam.(mm)**	**Weight(g)**	**Power**	**St.Current(A)**
1506006SR IE2	Flat	7.8	15	7.1	0.170	0.123
1506006SR	Flat	5.5	15	4.3	0.150	0.109
0515006B	Classic	14.6	5	1.5	0.43	0.380