DESIGN AND FABRICATION OF PRE-CHARGED PNEUMATIC DOUBLE ACTING RIFLES

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ABSTRACT

This invention correlates to CO2 air rifles and air pistols, where air rifles being filled with carbon dioxide gas, allowing to adjust the muzzle velocity according to the preference of the user, by manually adjusting the pressure at which they can shoot pellets reducing the recoil formed during the shoot and thereby preserving the shot accuracy of the rifle. This design-based on a double-acting cylinder which pushes the pellet inside the chamber and then releases in the retraction stroke. This is not a high-pressure model which runs at around 850 Psi-900 Psi, it can run on low pressure such as 60 psi to 145 psi hence it is safe to use for anyone.

Keywords – Sequence Valve; Pneumatic components; Magazine; Barrel; Stock; Pellet, double acting cylinder;

I. INTRODUCTION

Pre-charged pneumatic (PCP) air guns represent one of the oldest air gun power plants of all time. They have been around since at least the early 1600s and most likely a bit longer. With air rifles lead soft pellets are used which are less harmful in comparison to the traditional firearms and with that they are less prone to hurt someone in a lethal way unless intended otherwise. [4]...

With black powder, speed is directly dependent on barrel length. The same is true for compressed air. Both power sources continue to accelerate a projectile as long as the pressure behind the projectile is higher than the pressure in front of it (ambient air pressure, plus the pressure wave in front of the accelerating projectile). Of course, in this example, it must be understood that friction is also always a reason to contend with. [4]

What we get from these two facts is a simple rule: A longer barrel in a pneumatic gun increases speed (to a point), and higher air pressure also increases speed (to a point). As those points are approached, the gains from longer barrels and higher pressures have diminishing returns, so designers must balance that against making a gun too long or using pressures too high for safe and convenient operation [4]…

II. CONCEPT & METHODOLOGY

The concept of the project is to use make a pneumatic rifle based on an air gun by using CO2 gas as a pressurized gas to a junction where a projectile (Diablo pellets) in the air like a bullet. This is a trial and error method in which multiple designs have been made and tested out to meet a desired effect/result. Usage of already existing devices has been made which has been altered to our desired form to meet the desired effects.

This is done to make a modern pneumatic weapon that can be used for target practice which acts and works as a modern automatic rifle. Modern air guns have a magazine of about 20-30 bb's in them which are in a cylindrical shape and not Diablo. Making a magazine that feeds about 10-25 diablo pellets into the pneumatic rifle so that an air gun would work in a consecutive manner without the need for reloading (Traditional one by one-shot).

Existing devices are used and modified for the sole reason that they exist in the market and work properly without any problems, the price of the pneumatic rifle is also low because of this reason. A double-acting cylinder is used in this system which works at a maximum pressure of 10 bars now since its double-acting cylinder would have two ports for extraction and retraction. During the retraction period, the gas inside the pneumatic cylinder would go back to exhaust port 2 and during extraction, it would come out from exhaust port 1. So using the exhaust energy and then combining them together injunction by a Male Y pneumatic fitting we would be able to launch a projectile at a constant pressure. [11]

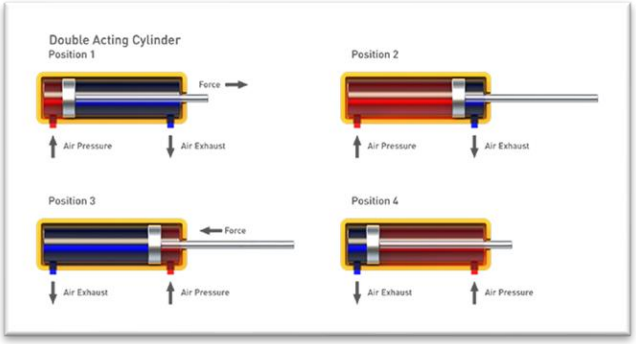

Fig.1: Double Acting Cylinder Concept

Air pressure is applied alternately to the opposite ends of the piston. Application of air pressure produces a thrust in the positive (push) stroke and thrust in the negative (pull) stroke. [11] Double-acting cylinders are typically used in all applications where the thrusts and stroke lengths required are in excess of those available from single-acting cylinders. [11]

III. DESIGN AND IMPLEMENTATION

1. Pressure release valve

A high-pressure tank which is capable of 2500 PSI pressure or a higher tank can be used for this modeling. We have used a 1.3kg clear line 140 bar pressure tank in our modeling that is having a poppet type valve. To bring out the pressure from the tank a soda machine (Co2) is used which is then cut and modified to make the system compact and made the soda machine valve accordingly.

Fig.2: Soda machine

Fig.3: Modified Soda Machine Valve

2. Support Structure & Arm Rest

A structure is required to support the weight of the pressurized tank which is when full (1.6 KG), and along with a support structure, it also requires looking as a pneumatic gun and gives an aesthetic feel as well. A stainless steel plate has been used for the support of the tank which has been brazed onto the soda machine valve firmly. Below the plate, an aluminum channel has been installed which works and acts like a channel (guide) for the Stock which is used to give a firm position on our shoulder.

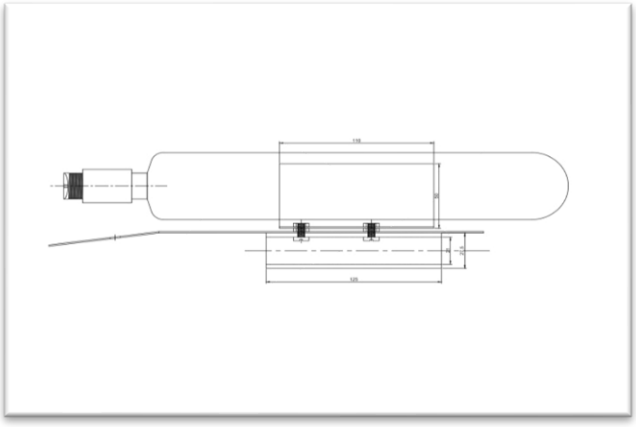

Fig.4: Support plate with the channel

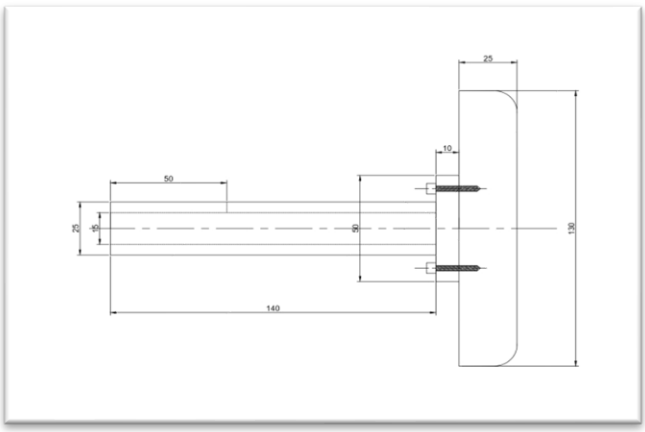

Fig.5: Arm rest

3. Pressure Regulator

The pressure coming out of the tank is unregulated at this stage, and to bring it to a controllable level (10bar pressure) a pressure regulator has to be installed but as in the market there were no such device available to drop the pressure from 140 bars to 10 bars and that also which are compact in size. So space was created and utilized around the PCV pipe and trigger [shown in Fig. 2]. A hole was created and using a 6mm bolt and some springs a pressure regulator was made around the space which used a winged nut as a knob [as shown in Fig 3].

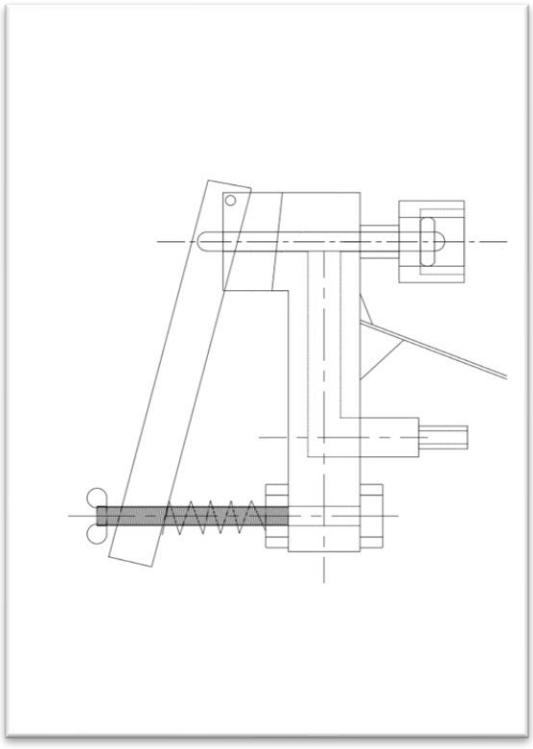

Fig.6: Pressure Regulator

A limit switch is also installed which can be seen in Fig 3. That is a bolt, now the length of the bolt can be adjusted to the degree of high pressure we require but since almost all pneumatic components work on 10 bar pressure, the bolt was set accordingly so that the regulator cannot be pressed more than that.

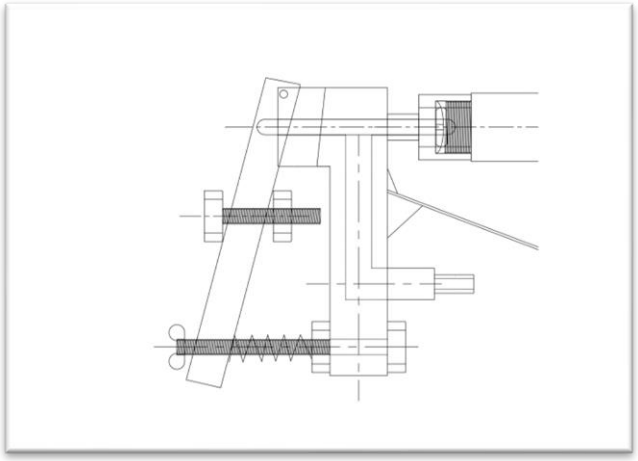

Fig.7: Pressure Regulator

4. Pressure gauge

To achieve an accurate flow of the pneumatic fluid (CO2) a required pressure was installed near the spacing of the soda machine valve, the reason behind using a CO2 tank was that with compactness it also cools the system further to sub temperature as it works more. Like a pneumatic system longer it works, cooler it runs [8] in a CO2 operated tank the temperature decreases to subcool temperatures.

Fig.8: Pressure Regulator & Pressure Gauge

5. Sequence Valve

Sequence valves can improve the operation, efficiency, performance, and safety of fluid power circuits in which they are used. Sequence valves are normally closed and usually allow bidirectional flow when equipped with a bypass check valve. Sequence valves always have an external drain connected directly to the tank. [9]

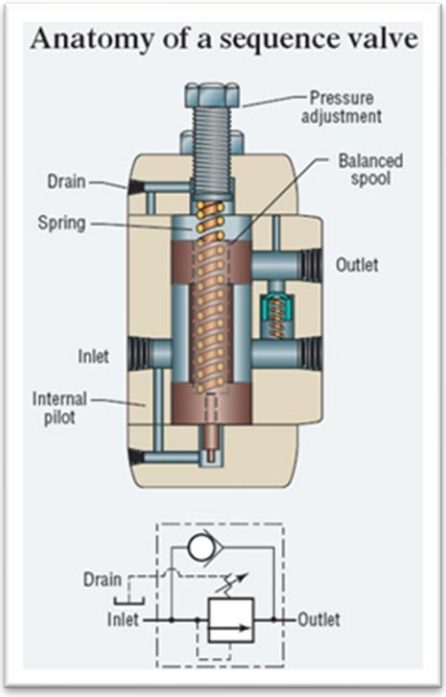

Fig.9: Anatomy of a sequence valve

When two or more cylinders operating in a parallel circuit must move in sequence, the only positive way to do this is with separate directional control valves and limits switches or limit valves. This setup ensures the first cylinder reaches a positive location before the second one begins to move. When safety or product quality will not be compromised if the first cylinder does not complete its cycle before the second one starts, a sequence valve can be a simple way of controlling cylinder actuation. [9]

A sequence valve is the best choice for a pneumatic system but due to lack of availability of it in a compact size, a double-acting cylinder and a 5/2 mechanical push-pull valve were used in the system instead of a sequence valve. A sequence valve opens up the port 2 (in the figure) when a set pressure has been achieved and when the pressure exceeds that amount a sitting valve opens and pressure is directed towards the port 2 hence in our the system when the single-acting spring return cylinder extension rod would move forward due to port 1 being normally open after the desired pressure is set the port 2 would open and the pressurized air would flush out of the port assembled together 2 which is connected to the barrel. But due to lack of availability of it in size two more components have been used.

A 5/2 Solenoid valve can also be used in this but it is not that feasible because of the solenoid being 24V DC, the system would require 2 car batteries to operate it as it needs to be compact and portable. The weight of 1 car battery is around 1.8KG which would only increase the system weight and make it heavier nothing else. Hence the solenoid valve is not feasible for this system.

6. Pneumatic Components

Since it's a Pneumatic rifle is it only understandable that Pneumatic components would be involved, the pneumatic components used in this system are mentioned as below [10];

- Techno 16*100 Double Acting miniature Cylinder
- Male Studs Mini Fitting
- Techno 5/2 Mechanical Push Pull Valve
- Male Stud - Parallel Thread
- Male Stud Taper Thread
- Push Male Y
- Push Elbow Union
- Push Union Tee
- Swivel Elbow – Taper Thread
- Male Push Connectors
- Miniature Dial Gauge
- Blanking Plug
- 4 mm Polyurethane Tubing
- 6 mm Polyurethane Tubing

These above pneumatic systems were purchased and assembled together and infused in the pneumatic system. All the pneumatic fittings are having a maximum pressure capacity of 145 Psi handling capacity.

Steps to assemble the pneumatic components in a sequence is given as below.

1) In the Techno 16*100 double-acting miniature cylinder insert the Male studs after applying some Teflon to it for a firm grip. Use a spanner to tighten the fittings to prevent air leaks.
2) In the Techno 5/2 Mechanical, the push-pull valve insert the Male Stud in them using Teflon tape and

use the spanner to tighten the fittings.

3) Cut the Polyurethane tubing (6mm, 4mm) according to the size and length required.

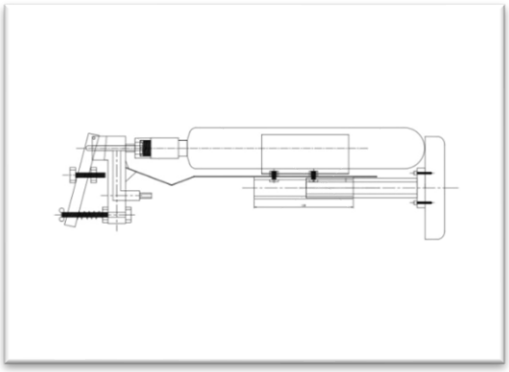

Fig.10: Pressure Regulator

Fig. 11: Pneumatic Fittings

4) Assemble the pneumatic fittings according to the image shown in Fig. 7
   - Fit the Swivel Elbow fittings in the Port A and Port B of the 5/2 mechanical valve.
   - And in the E1 port & E2 port connect the Male studs and in the Input port (I) also, connect the Male stud.
   - In the Input port (I) connect the 6mm Polyurethane tube and in E1, E2 use the 4mm Polyurethane tube which in turn is connected to the Push Male Y.
   - On port A & port B use the 4mm Polyurethane tube to connect the male stud mini fittings.

5) Use the spanner to tight the pneumatic fitting in their place as any gaps or untighten fitting would lead to leakages and pressure loss.

Fig. 12: Pneumatic Assembly

7. Junction

The junction is designed in AutoCAD (2D) and PTC Creo wildfire 6.00 (3D). It is a component in which the pellet falls in a slot and then taken ahead towards the chamber of the barrel and inserted at the entrance of the barrel. Where the Male Y fitting is also attached to the junction from whom the compressed gas comes out and flushes the pellet out of the barrel with velocity.

The junction component is like a pipe which allows the gas/fluid to flow from point A to point B. On point A the gas enters which when reaches to the point B meets the pellet at the exit of the component and entrance from the barrel which pushes the pellet with velocity out of the barrel.

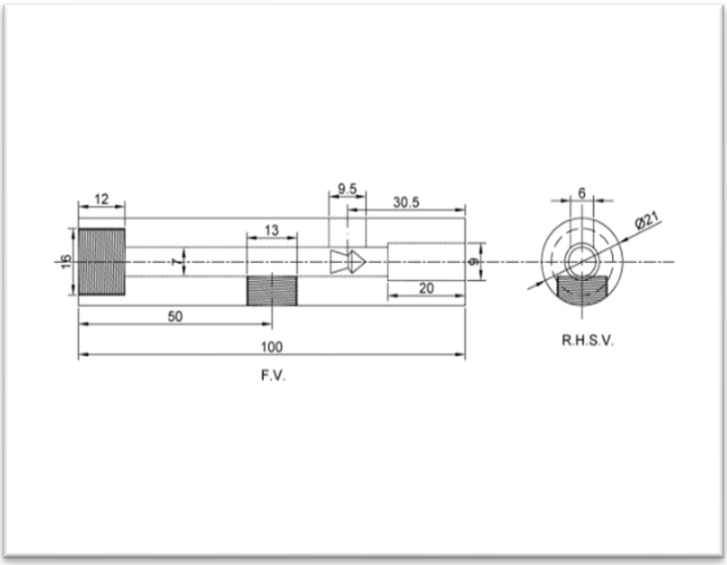

Fig. 13: Junction 2D (AutoCAD)

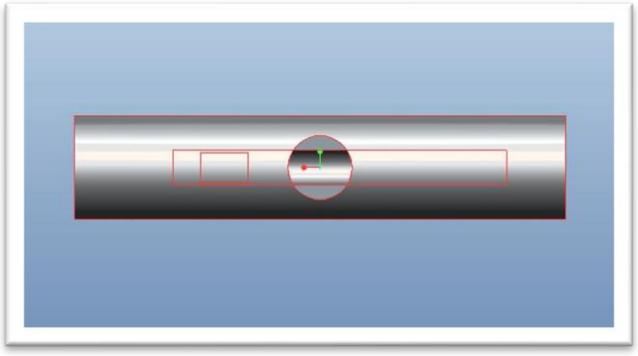

Fig. 14: Junction 3D (PTC Creo)

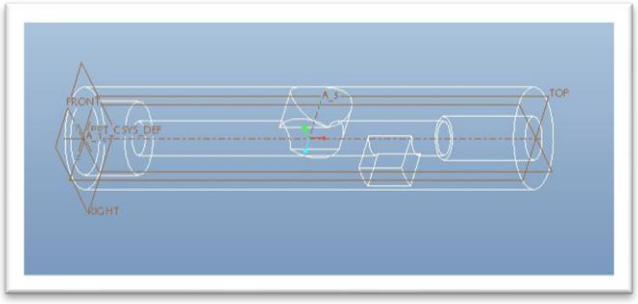

Fig. 15: Junction 3D Wireframe (PTC Creo)

Barlow's Formula –

Barlow's formula relates to the internal pressure that a pipe can withstand to its dimensions and the strength of its material.

Formula – $P = \frac{2St}{D}$

Where, P = Pressure in psi
S = Allowable stress in psi
t = Nominal wall thickness, in inches
D = Outside Diameter in inches

Data present – P = 200 Psi
S = 36259.4 Psi
T =?
D = 0.82 inch

Formula - $P = \frac{2St}$ [Input the above data]
D

$\therefore 200 = \frac{2 \times 36259.4 \times t}{0.82}$ = 0.0022 inch ~ 0.058 mm

Considering minimum thickness to be 7mm + Re-boring allowance + safety we have taken all the internal dimensions < 10mm

Material selected - Aluminum 6082 T6 [12]

Properties and specification of material;

Density	2.70 g/cc
Hardness, Brinell	95 HB
Tensile Strength, Ultimate	290 MPa
Tensile Strength, Yield	250 MPa
Elongation at Break	10 %
Thermal Conductivity	170 W/m-K
Modulus of Elasticity	70 GPa
Melting Point	555 °C
Workability	Cold: Good
Machinability	Good
Shape	Round Bar

The above image represents how the Junction being all assembled and how it would take shape after assembly. The component is designed in such a way that the stroke length of 100mm from the pneumatic cylinder would end exactly on the entrance of the barrel delivering the pellet from the slot into the barrel for launch. Due to this very integration, this component is named Junction.

8. Pellet Magazine

The magazine is also another crucial part of the Pneumatic Rifle, to give it a continuous and consecutive pellet delivery into the slot of the Junction below designs were make;

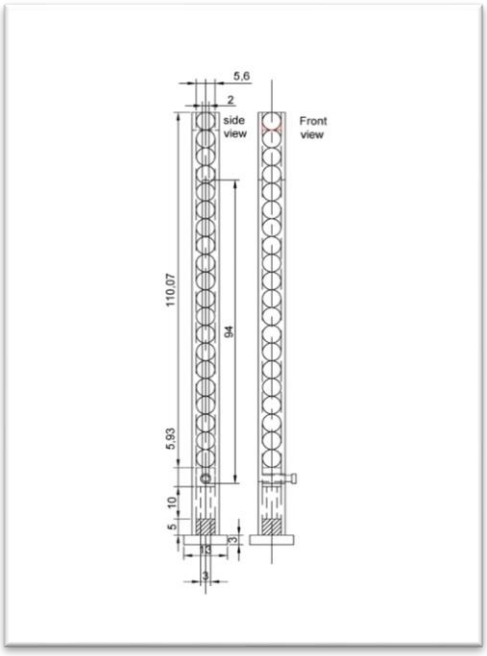

Fig. 16: Magazine Design

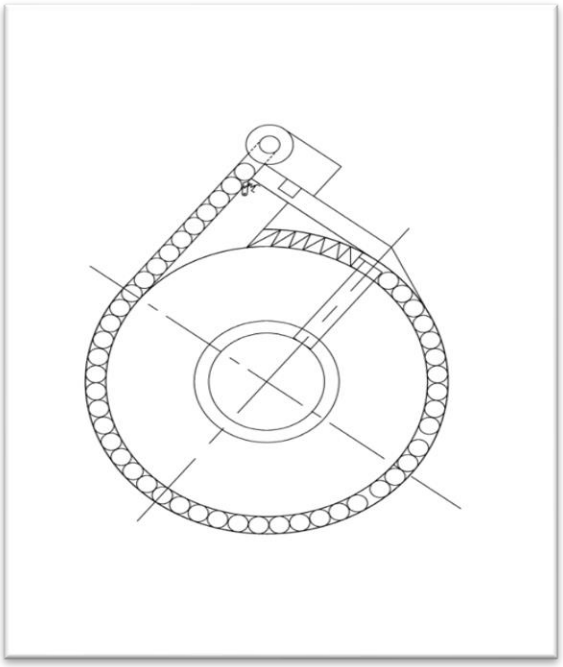

Fig. 17: Drum Magazine Design

Since the pellet size was small to manufacture, aluminum channels are used as magazines. The outer casing and the inner case make it a perfect selection for the 5.5 Diablo double head pellets.

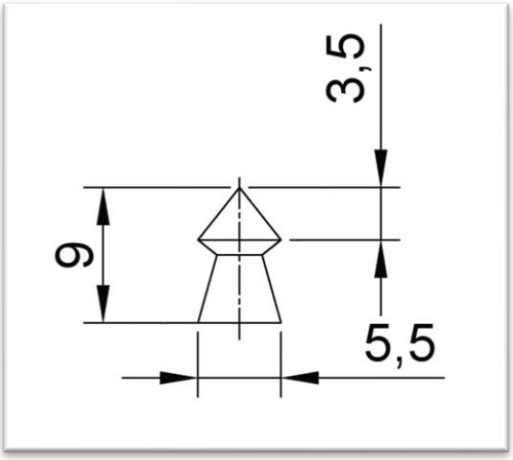

Fig. 18: Pellet

The springs used in this were manufactures and the specification for it is below;

Spring Material – Stainless Steel
Spring Thickness – 0.5 MM, 0.6 MM
Spring OD – 5.5 MM
Spring Length – 14 MM (Cut it if required)

Fig. 19: Channel Magazine

9. Trigger System and Barrel

The trigger system is attached on the 5/2 Mechanical push and pull valve, the idea is to utilize the push-pull mechanism, and adding a spring in the system would make it a spring return system. Short springs are used to give enough force to push back the connecting rod out again like a spring return system which in turn would act as a trigger mechanism.

A Stainless steel plate is used to make an attachment on the 5/2 mechanical valve as it has three holes in that it makes it easier to attach it on the plate horizontally by nut and bolts.
A hinge-like mechanism is used to provide an extension to the aluminum rod which is the trigger handle attached to the hinge by a nut and bolt.

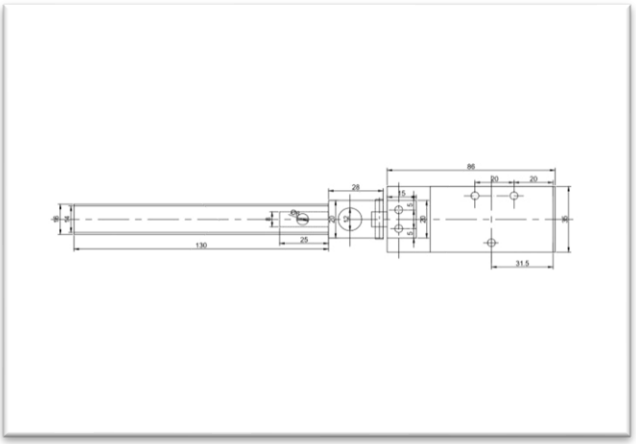

Fig. 20: Trigger Mechanism

The Barrel for the pneumatic rifle is an aluminum pipe of OD 9mm and ID 5.5mm which is highly suitable for this pneumatic as for two primary reasons.

1) The weight of the pipe is low as the material is aluminum.
2) The ID of the pipe is 5.5MM which of the same size as the pellet diameter making it a good choice of the barrel for this system. The length of the barrel is 200mm and OD is 9mm.

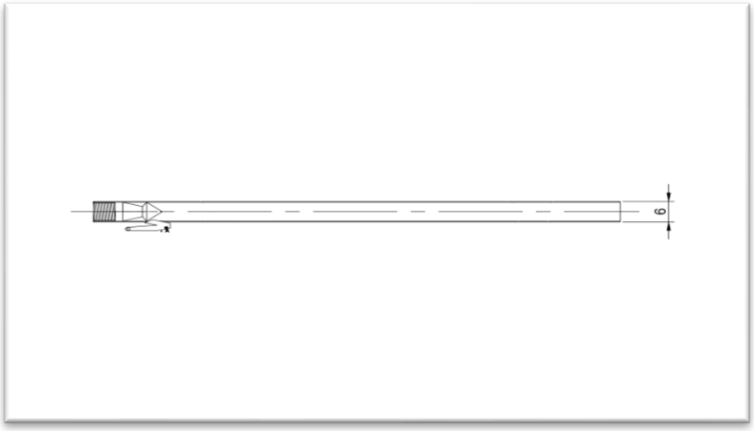

Fig. 21: Barrel

IV. TESTING

The testing was carried out and it was determined that the system does work as intended but it also exhibits few troubles such as the slot for the magazine from which the pellet is dropped has become a source for leakage since the inner rod can't be an exact fit hence there has to be given tolerance for it to move properly without being jammed in the system.

Fig. 22: Testing the Rifle

A test has been conducted on effects on the pellet at a different pressure from a fixed parameters set. Below is the information is given;

Distance – 16.5 feet
Pellets – Marvelous shot (double head pellets)
Weight – 14.3 grains – 0.9 grams
Pellet Material - Lead
Target – 18mm Plywood
Gas used – Carbon dioxide

Fig. 23: Effects of different pressure on the pellet

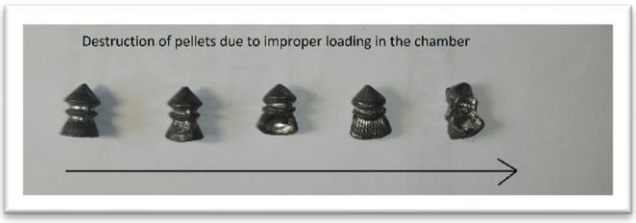

Fig. 24: Destruction of pellet due to improper loading

1. Muzzle Energy

Definition - Muzzle energy is the kinetic energy of a bullet as it is expelled from the muzzle of a firearm. Without consideration of factors such as aerodynamics and gravity for the sake of comparison, muzzle energy is used as a rough indication of the destructive potential of a given firearm or cartridge.

Formulae – $E_k = 1/2\ MV^2$

Where M = mass of bullet

V = velocity of bullet

Air guns formula [13] –

$$\frac{(\text{Weight of the pellet in grains}) \times \text{Velocity}^2}{\text{Constant}}$$

Where, Constant - 450240

Conversion to joules - 1 foot-pound = 1.35 joules

Pellet weight in grain – 14.3

Muzzle energy at different pressure				
Pressure (Psi)	60	80	100	120
Velocity (ft./sec)	422	519	626	742
Energy (Joules)	7.67	11.61	16.88	23.71
foot-pounds	5.65	8.55	12.44	17.48

The above table has been constructed on the based formula of air gun muzzle energy and done using the above parameters.

V. CONCLUSION

To conclude; following things were observed and mention as below;

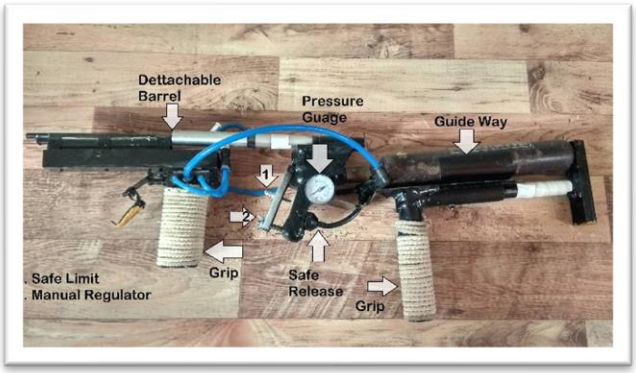

Fig. 25: Features

We can build an Air rifle based on double the acting cylinder in which the pellet enters the barrel in outwards stroke of the cylinder rod and during the retraction of the cylinder rod the gas from port E1 can push the projectile out of the barrel at a certain velocity.

We also noticed that using a double-acting the cylinder in an air rifle has a higher consumption of gas to fire a single shot, for example in normal air rifles only a single time the air is coming out of the barrel end; but in double-acting rifle the consumption is almost double for a single shot as it has to first have an outwards stroke and then during retraction stroke, it fires the round, which consumes double the energy. Even though the tank is of 300 gram of Co2 which is much larger than the 12 grams of Co2 canisters which are used in modern pre-charged pneumatics still given the exhaustion of the tank is on a similar rate due to the double consumption and manual on and off of the tank valve.

We have also noticed that during the testing if a pellet is improperly loaded it would jam the system and needs to be removed from the junction, a more refined design should be able to solve this problem.

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