Design of a Trigger Mechanism for a Sniper Rifle

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Abstract

In their paper, authors design a trigger mechanism for a 20 x 102 mm calibre sniper rifle. Authors analyse kinematic and dynamic quantities of the sniper rifle trigger mechanism. The analysis of the individual component load of the trigger mechanism was carried out by applying the finite element method. The proposal of the design was developed by means of CAD software.

Key words: trigger mechanism, trigger resistance, trigger lever, hammer stop, angular displacement

1. Introduction

Army and special troops are equipped with and use high calibre sniper rifles in combat operations. They are of high combat value as they are capable of destroying valuable targets while not necessitating to deploy own forces. A trigger mechanism design has a significant impact on the weapon properties. In the paper, we attempt to design a trigger mechanism for a 20 x 102 mm calibre sniper rifle.

2. Weapon Concept

We have designed a trigger mechanism for a 20 x 102 mm calibre repeater sniper rifle with a rotating retractable breech. We have also outlined the weapon frame together with the breech and its carrier since all the constituents of the trigger mechanism are closely interrelated and interdependent.

3. Trigger Mechanism

3.1 Technical description

We deal with a release trigger mechanism with a support. Its key components include a trigger with a rod and a trigger lock lever, both in a position of fulcrum in the trigger frame. After firing, the trigger lock lever returns to its original position by means of the lock spring 8. The first trigger resistance is adjustable with the screw 13, the second trigger resistance can be adjusted with the screw 14. The adjusting screw 15 serves to set the length of the trigger run after firing. The shape of the trigger lever is adjusted to avoid raising the trigger lock lever.

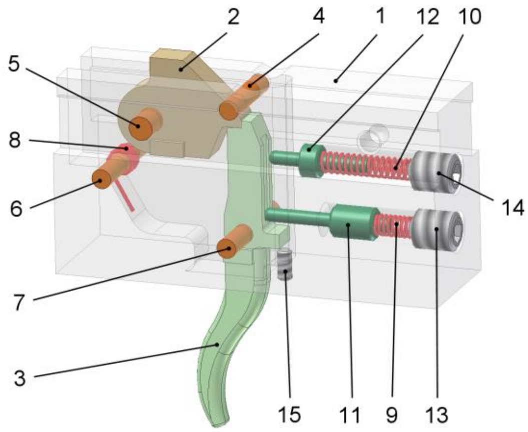
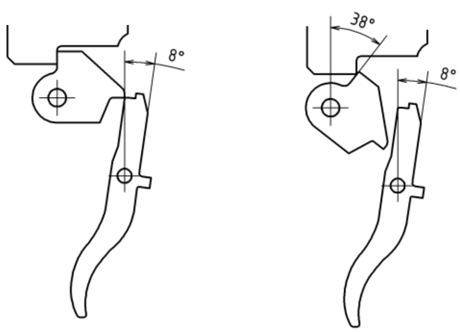


Fig. 3.1 Trigger mechanism

1 – trigger mechanism frame, 2 – trigger lock lever, 3 – trigger lever, 4 - stop pivot of the trigger lock lever, 5 – trigger lock lever pivot, 6 – stop spring pivot, 7 – trigger lever pivot, 8 – stop spring, 9 – spring of the first trigger resistance, 10 – spring of the second trigger resistance, 11 – pressure rod, 12 – pressure rod, 13 – set-screw to adjust the initial compression of the first trigger resistance, 14 – set-screw to adjust the initial compression of the second trigger resistance, 15 – set-screw to adjust the drag of trigger after firing

3.2 Determination of significant kinematic quantities of the trigger

For the purposes of the kinematic analysis of the trigger mechanism designed, it is necessary to identify the angular displacement of the trigger lever, which makes the trigger lever stop supporting the firing pin lock lever and the firing pin lock lever turn. The following angle of importance is the angular displacement of the firing pin lock lever due to the trigger impact. As both the trigger lever and the firing pin lock lever are of complex shapes, we developed a trigger mechanism design in CAD *Autodesk Inventor 6* in order to identify the required angular displacements. By changing the mutual position of the trigger lever and the firing pin lock lever, we identified values of the angular displacement.



a) b)

Fig. 3.2 Angular displacement of the trigger lever and the firing pin lock lever

Angular displacement of the trigger lever when the stop is located on the edge $\alpha_{SP} = 8^\circ$ (*Fig. 3.2a*). Upon firing, the firing pin lock lever will turn by the angle of $\alpha_{ZU} = 38^\circ$ (*Fig. 3.2b*) due to the striker action.

3.3 Fundamental positions of the trigger mechanism

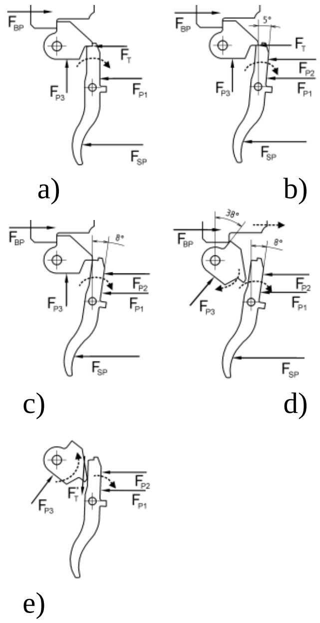


Fig. 3.3 Fundamental positions of the trigger mechanism

Position No. 1 ***(Fig. 3.3a)***
The weapon is in a stretched position. The shooter starts acting on the trigger and the trigger lever starts revolving. Trigger resistance F_{SP} is made up of the F_{P1} force (spring force of the first trigger resistance) and F_T friction force between the firing pin lock lever and the trigger lever. The following holds true for the angular displacement of the trigger lever $\alpha_{SP} = 0^\circ \div 5^\circ$.

Position No. 2 ***(Fig. 3.3b)***
The moment when there is $\alpha_{SP} = 5^\circ$ angular displacement of the trigger lever, the F_{P2} force (spring force of the second trigger resistance) starts acting on the trigger lever. F_{SP} trigger resistance is made up of F_{P1}, F_{P2} and F_T forces. The following holds true for the angular displacement of the trigger lever
$\alpha_{SP} = 5^\circ \div 8^\circ$

Position No. 3 ***(Fig. 3.3c)***
When the α_{SP} trigger lever angular displacement reaches the value of 8˚, the firing pin lock lever is situated on the edge of the functional area of the trigger lever.

Position No. 4 ***(Fig. 3.3d)***
Additional turns of the trigger lever ($\alpha_{SP}>8^\circ$) stop the firing pin lock lever to be supported by the trigger lever. Then, the striker travels a path of 6 mm and the striker spring force action makes the firing pin lock lever turn by the $\alpha_{ZU} = 38^\circ$ angle.

Position No. 5 ***(Fig. 3.3e)***
The shooter releases the trigger lever, turns the breech and pushes it backwards. In addition to the breech, the striker mechanism is moving as well. The striker spring force F_{BP} stops acting on the firing pin lock lever. The screw spring force F_{P3} makes the firing pin lock lever return to its original position and strike the stop pin of the firing pin lock lever. Then, the shooter begins to insert the breech forward, while the hammer gets caught on the firing pin lock lever and the striker spring gets compressed. Finally, the shooter turns the breech.

3.4 Calculation of the trigger resistance

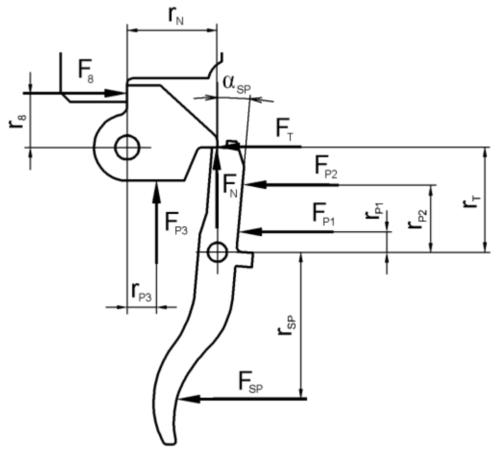


Fig. 3.4 Forces acting in the trigger mechanism

Input parameters (*Fig. 3.4*):

Constant parameters:

- striker spring force: $F_8 = 154\ N$
- arms of acting forces: $r_{P1} = 3{,}5\ mm$

$r_{P2} = 15{,}5\ mm$

$r_{P3} = 6{,}8\ mm$

$r_8 = 11{,}25\ mm$

$r_{SP} = 28\ mm$ $r_T = 22\ mm$

$r_N = 18{,}25\ mm$

- angle of the P_3 initial angular displacement of spring arms: $\varphi_{P3} = 119{,}8^\circ$

Variable parameters:

- initial spring compression P_1:

$x_{01} = 2 \div 4\ mm$

- initial spring compression P_2:

$x_{02} = 2 \div 6\ mm$

- angular displacement of the trigger lever: $\alpha_{SP} = 0^\circ \div 8^\circ$

Calculation:

- equilibrium of force moments acting on the firing pin lock lever:

$$F_8.r_8 = F_{P3}.r_{P3} + F_N.r_N \qquad (3.1)$$

- equilibrium of force moments acting on the trigger lever:

$$F_{SP}.r_{SP} = F_{P1}.r_{P1} + F_{P2}.r_{P2} + F_T.r_T \qquad (3.2)$$

- spring force of the first resistance:

$$F_{P1} = c_1.(r_{P1}.tg\,\alpha_{SP} + x_{01}) \qquad (3.3)$$

c_1 – toughness of the first spring resistance ($N.mm^{-1}$)

x_{01} - initial compression of the first spring resistance (mm)

- force of the second spring resistance:

$$F_{P2} = c_2.(r_{P2}.tg\,\alpha_{SP} + x_{02}) \qquad (3.4)$$

c_2 - toughness of the second spring resistance ($N.mm^{-1}$)

x_{02} - initial compression of the second spring resistance (mm)

- force of the torsion spring:

$$F_{P3} = \frac{k_\varphi.\varphi_{P3}}{r_{P3}} \qquad (3.5)$$

k_φ – moment toughness of the torsion spring (*N.mm.(°)*$^{-1}$)

- by (3.1) we get the normal force F_N:

$$F_N = \frac{F_8.r_8 - F_{P3}.r_{P3}}{r_N} \qquad (3.6)$$

- friction force F_T:

$$F_T = F_N.f \qquad (3.7)$$

friction coefficient f = 0,11

- by rewriting (3.5) and (3.6) into (3.7), we get:

$$F_T = \frac{F_8.r_8 - k_\varphi.\varphi_{P3}}{r_N}.f \qquad (3.8)$$

- by (3.2), we express F_{SP}:

$$F_{SP} = \frac{F_{P1}.r_{P1} + F_{P2}.r_{P2} + F_T.r_T}{r_{SP}} \qquad (3.9)$$

- by rewriting (3.3), (3.4) and (3.8) into (3.9), we get the resulting expression for F_{SP}:

$$F_{SP} = \frac{c_1.r_{P1}.(r_{P1}.tg\alpha_{SP} + x_{01}) + c_2.r_{P2}.(r_{P2}.tg\alpha_{SP} + x_{02})}{r_{SP}} + \frac{\frac{F_8.r_8 - k_\varphi.\varphi_{P3}}{r_N}.f.r_T}{r_{SP}} \qquad (3.10)$$

The expression (3.10) is the resulting relation to calculate the trigger resistance. We calculate the trigger resistance in two phases:

1. $\alpha_{SP} = 0° \div 5°$ in this phase, the force of the second spring resistance is not acting on the trigger lever-i.e. $c_2 = 0$,
2. $\alpha_{SP} = 5° \div 8°$ in this phase, the force of the second spring resistance is acting on the trigger lever-i.e. $c_2 \neq 0$.

In order to calculate the trigger resistance by (3.10), it is necessary to determine toughness of all springs. As we wanted the trigger resistance to develop as required while not exceeding the value of 20 *N*, we proposed various spring toughness values and did repeated calculations. In order to simplify the processes, we programmed the trigger resistance calculation in *Matlab* software. By repeating calculations, we identified spring toughness values and used them to design the trigger mechanism springs:

$c_1 = 5$ *N.mm*$^{-1}$
$c_2 = 2$ *N.mm*$^{-1}$
$k_\varphi = 1$ *N.mm.(°)*$^{-1}$

The development of the trigger resistance is shown in *Fig. 3.5*. The trigger resistance can be set in the range of the minimum and maximum values.

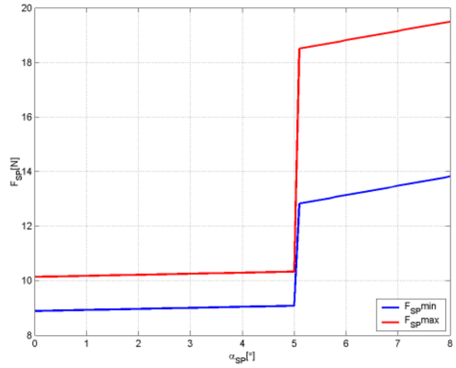


Fig. 3.5 Development of the trigger resistance depending on the angular displacement of the trigger lever.

3.5 Design of the trigger mechanism springs

3.5.1 Spring of the first trigger resistance

Selected parameters:

- type of spring:
- compression cylindrical spring
- spring material: 14 260
- allowed limiting twisting stress allowed boundary stress in torsion: τ_{Dm} = 1100 *MPa*
- shear modulus: $G = 8{,}04.10^4$ *MPa*
- mean diameter of the spring: $D = 4$ *mm*
- wire diameter: $d = 0{,}63$ *mm*
- number of end coils: $n_z = 2$
- number of machined threads: $n_0 = 1$
- spring toughness: $c = 5$ $N.mm^{-1}$

Calculation:

- winding ratio:

$$i = \frac{D}{d} = \frac{4}{0{,}63} = 6{,}349 \qquad (3.11)$$

- correction factor of torsional stress:

$$K = \frac{i+0{,}2}{i-1} = \frac{6{,}349+0{,}2}{6{,}349-1} = 1{,}224 \qquad (3.12)$$

- spring force in a boundary state:

$$F_9 = \frac{\tau_{Dm}.\pi.d^3}{8.D.K} = \frac{1100.\pi.0{,}63^3}{8.4.1{,}224} = 22{,}061\text{ N} \qquad (3.13)$$

- number of active threads:

$$n = \frac{G.d^4}{8.D^3.c} = \frac{8{,}04.10^4.0{,}63^4}{8.4^3.5} = 4{,}947 \approx 5 \qquad (3.14)$$

- spring compression in a boundary state:

$$s_9 = \frac{F_9}{c} = \frac{22{,}061}{5} = 4{,}412\ mm \qquad (3.15)$$

- total number of threads:

$$z = n + n_z = 5 + 2 = 7 \qquad (3.16)$$

- spring length in a boundary state:

$$l_9 = (z + 1 - z_0).d = (7 + 1 - 1).0{,}63 = 4{,}41\,mm \qquad (3.17)$$

- spring length in a free state:

$$l_0 = l_9 + s_9 = 4{,}41 + 4{,}412 = 8{,}822\,mm \qquad (3.18)$$

3.5.2 Spring of the second trigger resistance

Selected parameters:

- type of spring: cylindrical compressive spring
- spring material: 14 260
- allowed boundary torsional stress: $\tau_{Dm} = 1100\ MPa$
- shear modulus: $G = 8{,}04.10^4\ MPa$
- mean diameter of the spring: $D = 4\ mm$
- wire diameter: $d = 0{,}63\ mm$
- number of end coils: $n_z = 2$
- number of machined threads: $n_0 = 1$
- spring toughness: $c = 2\ N.mm^{-1}$

Calculation

- winding ratio:

$$i = \frac{D}{d} = \frac{4}{0{,}63} = 6{,}349 \quad (3.19)$$

- correction factor of torsional stress:

$$K = \frac{i+0{,}2}{i-1} = \frac{6{,}349+0{,}2}{6{,}349-1} = 1{,}224 \quad (3.20)$$

- spring force in a boundary state:

$$F_9 = \frac{\tau_{Dm}.\pi.d^3}{8.D.K} = \frac{1100.\pi.0{,}63^3}{8.4.1{,}224} = 22{,}061\,N \quad (3.21)$$

- number of active threads:

$$n = \frac{G.d^4}{8.D^3.c} = \frac{8{,}04.10^4.0{,}63^4}{8.4^3.2} = 12{,}369 \approx 12{,}5 \quad (3.22)$$

- spring compression in a boundary state:

$$s_9 = \frac{F_9}{c} = \frac{22{,}061}{2} = 11{,}031\ mm \quad (3.23)$$

- total number of threads:

$$z = n + n_z = 12{,}5 + 2 = 14{,}5 \quad (3.24)$$

- length of spring in a boundary state:

$$l_9 = (z + 1 - z_0).d = (14{,}5 + 1 - 1).0{,}63 = 9{,}135\ mm \quad (3.25)$$

- length of spring in a free state:

$$l_0 = l_9 + s_9 = 9{,}135 + 11{,}031 = 20{,}166\,mm \quad (3.26)$$

3.5.3 Firing pin lock spring

Selected parameters

- type of spring: torsion cylindrical spring
- spring material: 14 260
- allowed boundary bending stress: $\sigma_{Dmo} = 889\ MPa$
- Young's modulus: $E = 2{,}1.10^5\ MPa$
- mean diameter of the spring: $D = 5\ mm$
- wire diameter: $d = 0{,}8\ mm$
- moment toughness of the spring: $k_\varphi = 1\ N.mm.(^\circ)^{-1}$
- length of the working arm: $R_1 = 14\ mm$
- length of the support arm: $R_2 = 10\ mm$

Calculation

- winding ratio:

$$i = \frac{D}{d} = \frac{5}{0,8} = 6,25 \qquad (3.27)$$

- correction factor of bending stress:

$$K = \frac{i}{i - 0,75} = \frac{6,25}{6,25 - 0,75} = 1,136 \qquad (3.28)$$

- boundary spring load:

$$M_9 = \frac{\sigma_{Dmo}.\pi.d^3}{32.K} = \frac{889.\pi.0,8^3}{32.1,136} = 39,336\,N.mm \qquad (3.29)$$

- number of threads:

$$n = \frac{1}{\pi.D} \cdot \left(\frac{\pi.E.d^4}{3660.k_\varphi} - \frac{R_1}{3} - \frac{R_2}{3} \right) = \qquad (3.30)$$

$$= \frac{1}{\pi.5} \cdot \left(\frac{\pi.2,1.10^5.0,8^4}{3660.1} - \frac{14}{3} - \frac{10}{3} \right) = 4,19$$

3.6 Analysis of the load of the trigger mechanism components by using MKP

3.6.1 Static analysis of the striker stop lever load

In order to analyse the impact of the striker stop lever load in a stretched state, we used MKP and *ANSYS* software. In a stretched state, the striker stop lever is loaded by the striker spring force and torsion spring force. The striker stop lever is in the position of a fulcrum and supported by the trigger lever. The way the lever is loaded and positioned set up boundary conditions. Results of the analysis are shown in *Fig. 3.6* and *Fig. 3.7*.

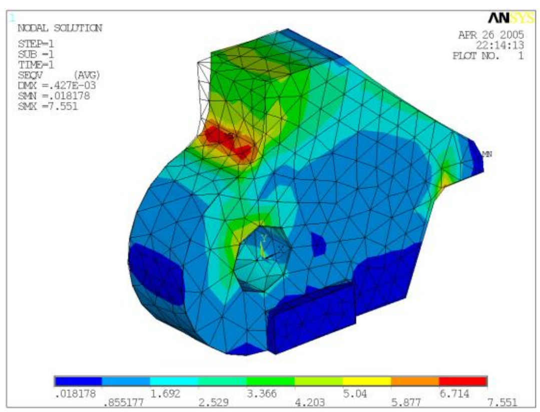


Fig. 3.6 Stresses in the hammer stop lever

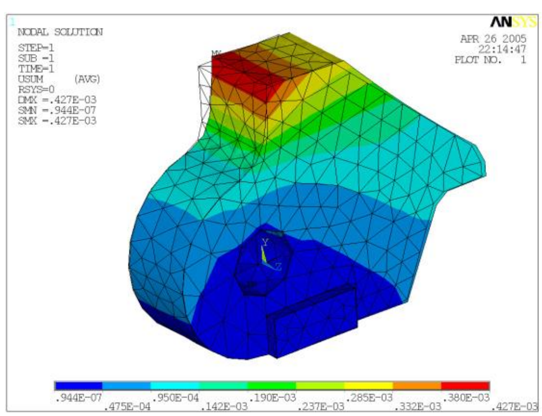


Fig. 3.7 Deformations in the hammer stop lever

3.6.2 Static analysis of the trigger lever load

In the stretched state of the weapon, the trigger lever is loaded by the striker spring force action transmitted to it by means of the hammer stop lever load and first resistance trigger force. The trigger lever is in the position of a fulcrum. The way the trigger lever is loaded and positioned set up boundary conditions. Results of the analysis are shown in *Fig. 3.8* and *Fig. 3.9.*

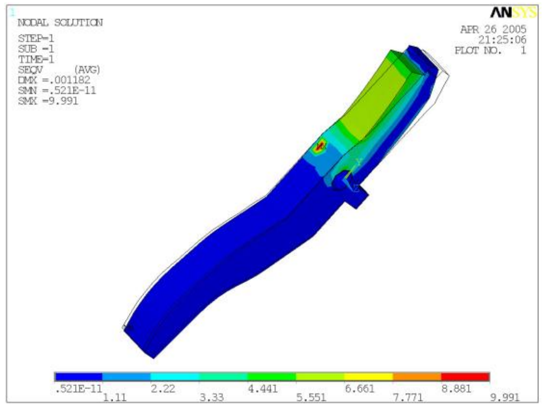


Fig. 3.8 Stresses in the trigger lever

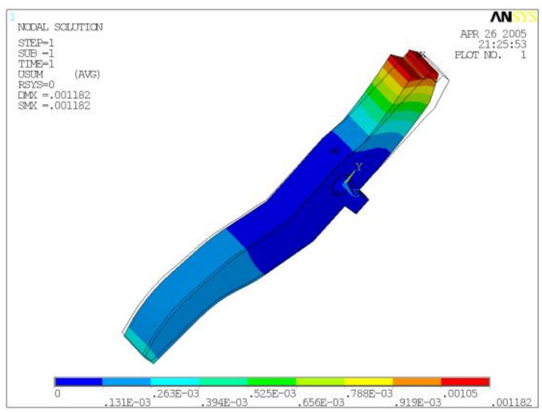


Fig. 3.9 Deformations in the trigger lever

4. Operation of the Trigger and Striker Mechanism

The weapon is in a stretched state and the breech is locked. The shooter turns the fuse lever, thus unlocking the hammer fuse. The shooter starts acting on the trigger lever which starts revolving. At some point, the striker stops to be supported by the trigger lever, thus making the hammer move owing to the striker spring force. The firing pin strikes the primer to start actuation. After firing, the shooter unlocks the breech by revolving it by 90˚ and shifts it backwards, while ejecting the cartridge. The hammer no longer acts on the striker stop lever which, in addition to the trigger lever, returns to its original position owing to the torsion spring. The shooter starts pushing the breech towards the barrel (new cartridge is being fed), at some point the hammer is caught at the stop and the striker spring gets compressed – the weapon gets stretched.

The shooter continues pushing the breech and when reaching the end of the path, the shooter turns it by 90˚ in order to lock it. The weapon is in stretched position ready to fire. The striker and trigger mechanisms are shown in *Fig. 4.1*. The striker and trigger mechanism within the weapon frame is shown in *Fig. 4.2*.

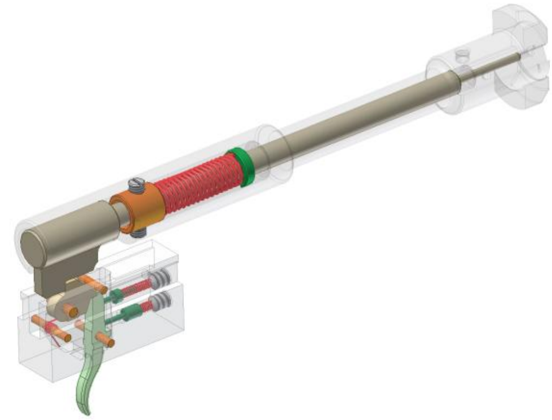


Fig. 4.1 Striker and trigger mechanism

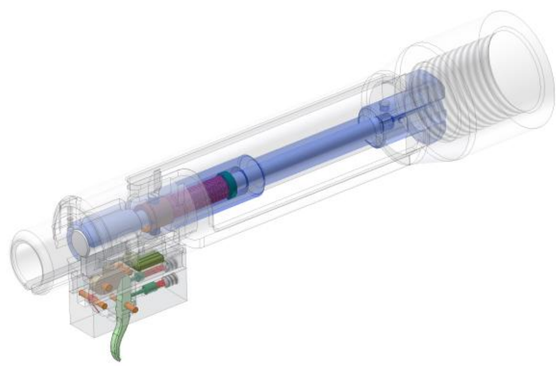


Fig. 4.2 Striker and trigger mechanism within the weapon frame

Enclosure 1

Matlab software used to calculate the trigger resistance

```
clear all
clc

% of spring toughness
c1 = 5;
c2 = 0;
kfi = 1;

% friction coefficient
f = 0.11;

% arms of acting forces
rp1 = 3.5;
rp2 = 15.5;
rp3 = 6.8;
r8 = 11.25;
rt = 22;
rn = 18.25;
rsp = 28;

% of force
F8 = 154;
```

```
% initial compression of springs
x01_min = 2;
x02_min = 2;
x01_max = 4;
x02_max = 6;
fip3 = 119.8;

alfa = [0:0.1:8];
Fsp_min = zeros(1, length(alfa));
Fsp_max = zeros(1, length(alfa));

for i=1:length(alfa)
  if alfa(i) > 5
     c2 = 2;
  end

  alfa_rad = (pi/180)*alfa(i);

  Fp3 = (kfi*fip3)/rp3;
  Fn = (F8*r8 - Fp3*rp3)/rn;
  Ft = Fn*f;

  Fp1_min = c1*(rp1*tan(alfa_rad) + x01_min);
  Fp2_min = c2*(rp2*tan(alfa_rad) + x02_min);
  Fsp_min(i) = (Fp1_min*rp1 + Fp2_min*rp2 + Ft*rt)/rsp;

  Fp1_max = c1*(rp1*tan(alfa_rad) + x01_max);
  Fp2_max = c2*(rp2*tan(alfa_rad) + x02_max);
  Fsp_max(i) = (Fp1_max*rp1 + Fp2_max*rp2 + Ft*rt)/rsp;
end

p = plot(alfa, Fsp_min,'b',  alfa, Fsp_max, 'r');
set(p, 'LineWidth', 2)
xlabel('\alpha_{SP}[\circ]')
ylabel('F_{SP}[N]')
legend('F_{SP}min', 'F_{SP}max', 4)
grid on
```

5. Conclusion

In our work, we have designed trigger mechanism for a 20 x 102 mm calibre sniper rifle. Simplicity of the design option and its applicability under real conditions were of utmost importance. When analysing the effects of loads acting on all the components of the trigger mechanism, we employed the finite element method and we used CAD Autodesk Inventor in the designing phase of the work. The use of cutting-edge technologies in the phase of design substantially increases the work efficiency.

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