Dynamic Analysis of a solenoid of chip kicker used in testing

The Dynamic Analysis of a solenoid which when fed by constant current was done using MATLAB 2013a and FEMM 4.2 softwares.

Initially we had 2 plunger designs. One with a thickness of 3.52 mm and length of 64mm (Plunger 1) and the other with a thickness of 2.67 mm and length of 70.75 mm (Plunger 2). Both plungers are 33.8 mm wide.

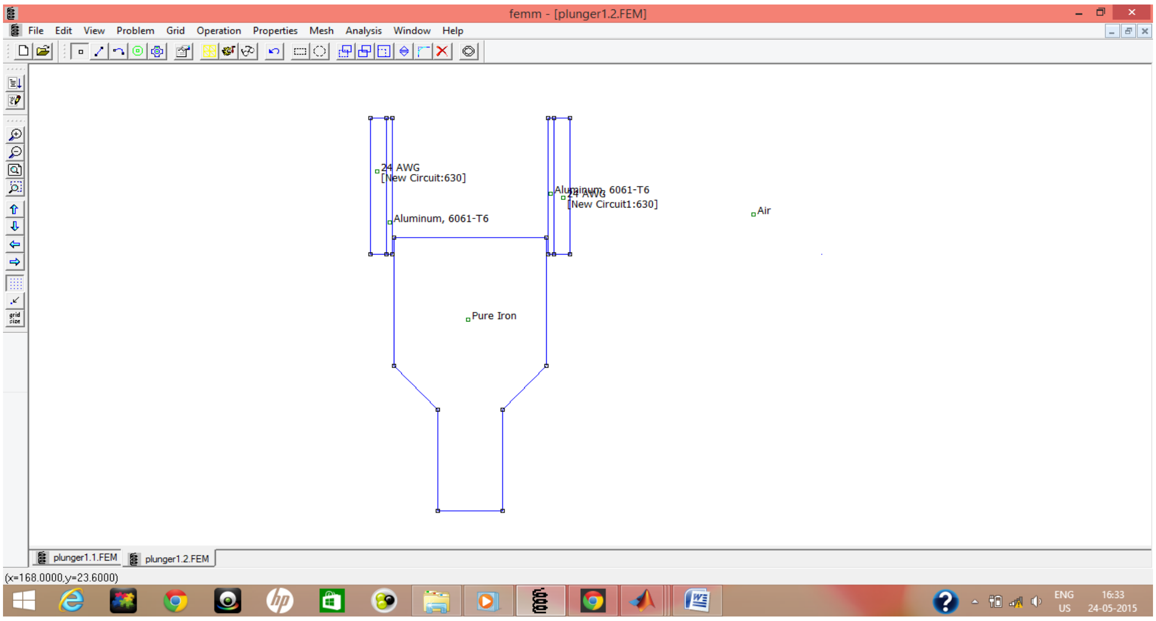
Approach: Using FEMM 4.2 software we created the image initial position of plunger in the solenoid across the two cross sections. Then using a code in MATLAB the plunger was made to move a distance of 1 mm into the solenoid in each iteration. In each iteration the force was calculated in the plunger and stored in an array f while its distance from its initial position was stored in x. The iterations were carried on till the plunger reached it's final position (here after 33 iterations). The force was calculated on both the cross sections and added. Finally the plot of force vs distance was generated. The area of the enclosed in the graph gave us the energy supplied by the solenoid to the plunger.

Solenoid: The solenoid is fed by constant current of **40 A**. Actually the current keeps varying in the solenoid and has a maximum value. Since we don't know the exact variation of current in the solenoid with respect to time/distance we are assume that a constant current of 40A is passing through it. Its structure is made of 6061-Aluminium alloy which is 1.25 mm thick. The wires are made of 24-AWG Copper and the number of turns is approximately 630. The outer dimensions of solenoid is 44.2mm × 32mm × 15.5mm while the inner hollow space is of dimensions 34.5mm ×32 mm × 4mm.

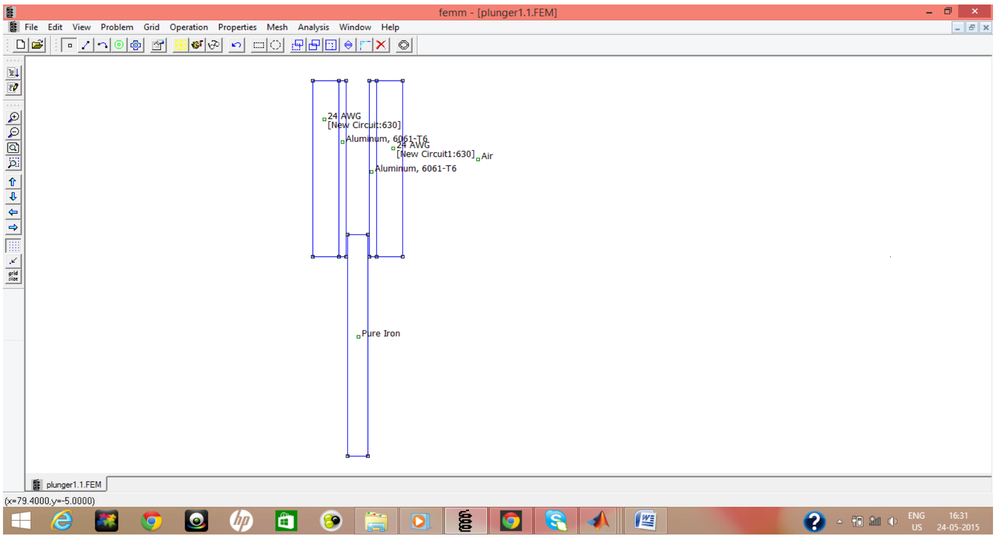
Plunger 1

The thickness of Plunger 1 is 3.52 mm and its complete length is 64 mm. In its initial position the plunger is 4mm inside the

The thickness of Plunger 1 is 3.52 mm and its complete length is 64 mm. In its initial position the plunger is 4mm inside the solenoid and in its final position the plunger has moved a distance of about 32mm inside the solenoid. The plunger is assumed to be made up of pure iron in FEMM simulation.



Across the other cross section the plunger is assumed to be of length 40.3 and we have neglected the thinner tail part and assumed the middle trapezoid as a rectangle.



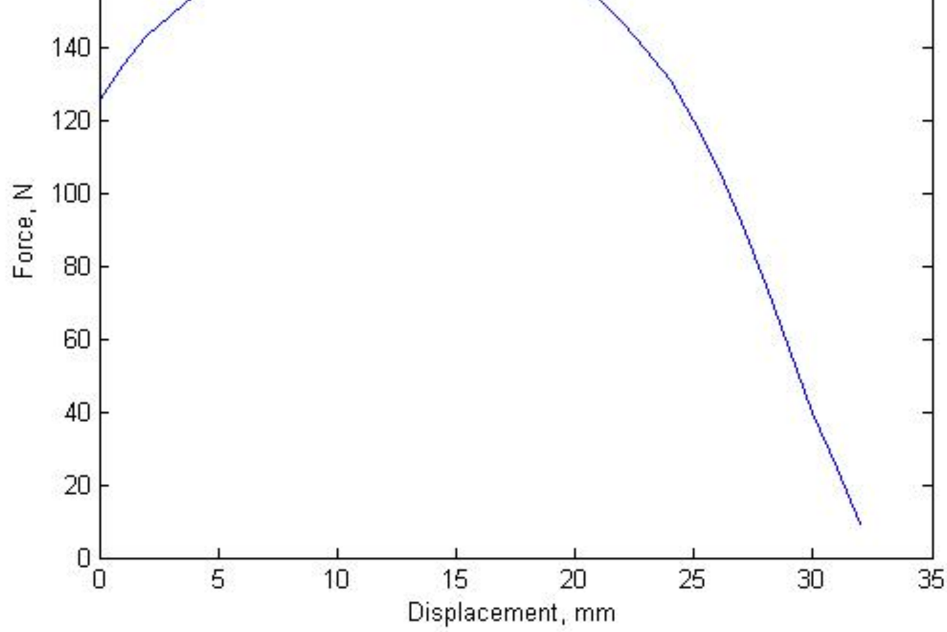
The boundary in FEMM simulation is kept sufficiently large in comparison with the solenoid dimensions (here a circle of 220 mm radius) .

The following Matlab code was used to generate the graph force vs displacement of the plunger.

```
openfemm
opendocument('plunger1.1.fem');
mi_saveas('temp.fem');
n=33;
y=zeros(n,1);
f=zeros(n,1);
mi_modifycircprop('New Circuit',1,40);
```

```
y=zeros(n,1);
f=zeros(n,1);
mi_modifycircprop('New Circuit',1,40);
for k=1:n
   disp(sprintf('iteration %i of %i',k,n));
   mi_analyze;
   mi_loadsolution;
   mo_groupselectblock(1);
   y(k)=(k-1);
   f(k)= mo_blockintegral(19);
   disp(sprintf('  force = %f',f(k)));

   mi_selectgroup(1);
   mi_movetranslate(0,1);
   mi_clearselected;
end
closefemm

openfemm
opendocument('plunger1.2.fem');
mi_saveas('temp.fem');
n=33;
mi_modifycircprop('New Circuit',1,40);
for k=1:n
   disp(sprintf('iteration %i of %i',k,n));
   mi_analyze;
   mi_loadsolution;
   mo_groupselectblock(1);
   y(k)=(k-1);
   f(k)= f(k)+ mo_blockintegral(19);
   disp(sprintf('  force = %f',f(k)));
   mi_selectgroup(1);
   mi_movetranslate(0,1);
   mi_clearselected;
end

plot(y,f)
xlabel('Displacement, mm');
ylabel('Force, N');
title('Plunger Force vs. Displacement');
a = trapz(y,f);
disp(sprintf('Area = %f',a));
closefemm
```

The following graph is generated. The area is calculated by trapz() function which uses trapezoidal method to find the area under the curve.

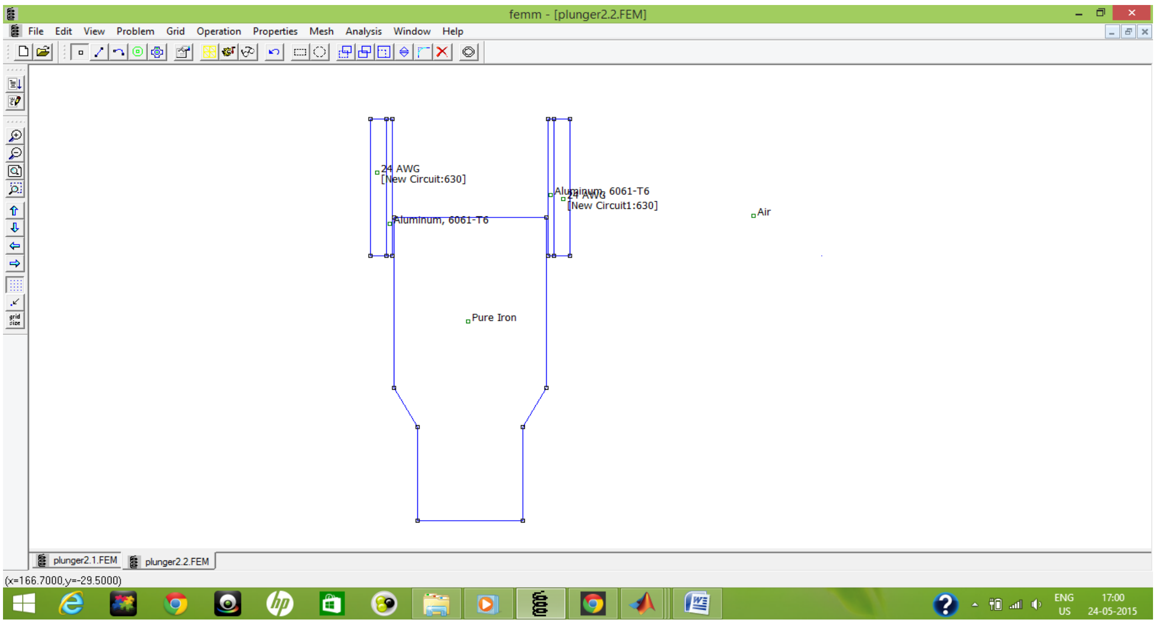


The area enclosed by the graph = 4386.895186 units

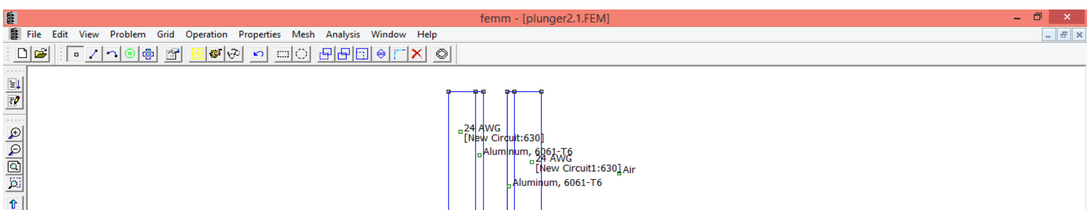
Thus **Energy = 4.387 Joules** (approx).

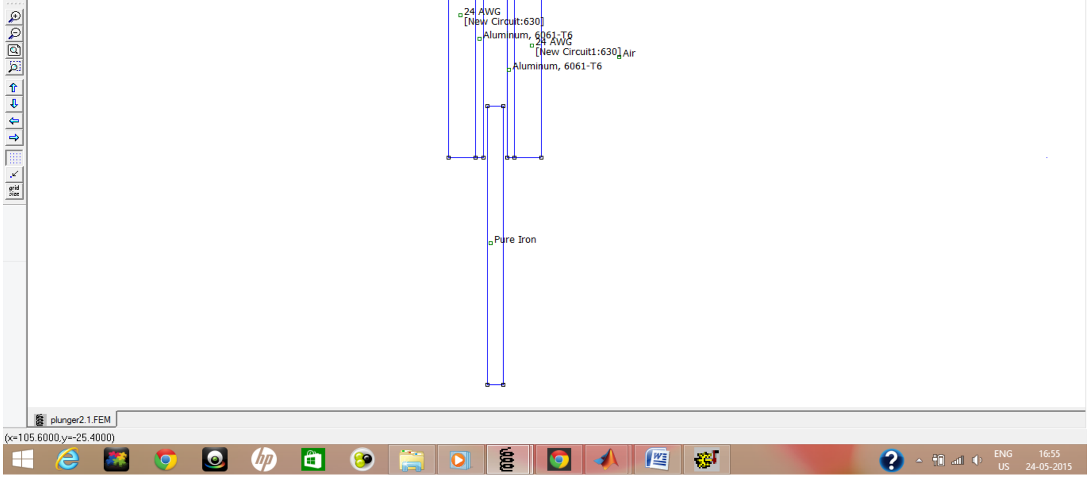
Plunger 2

The thickness of Plunger 2 is 2.67 mm and its complete length is 70.75 mm. In its initial position the plunger is 9mm inside the solenoid and in its final position the plunger has moved a distance of about 26 mm inside the solenoid. The plunger is assumed to be made up of pure iron in FEMM simulation.



Across the other cross section the plunger is assumed to be of length 46.25 and we have neglected the thinner tail part and assumed the middle trapezoid as a rectangle.





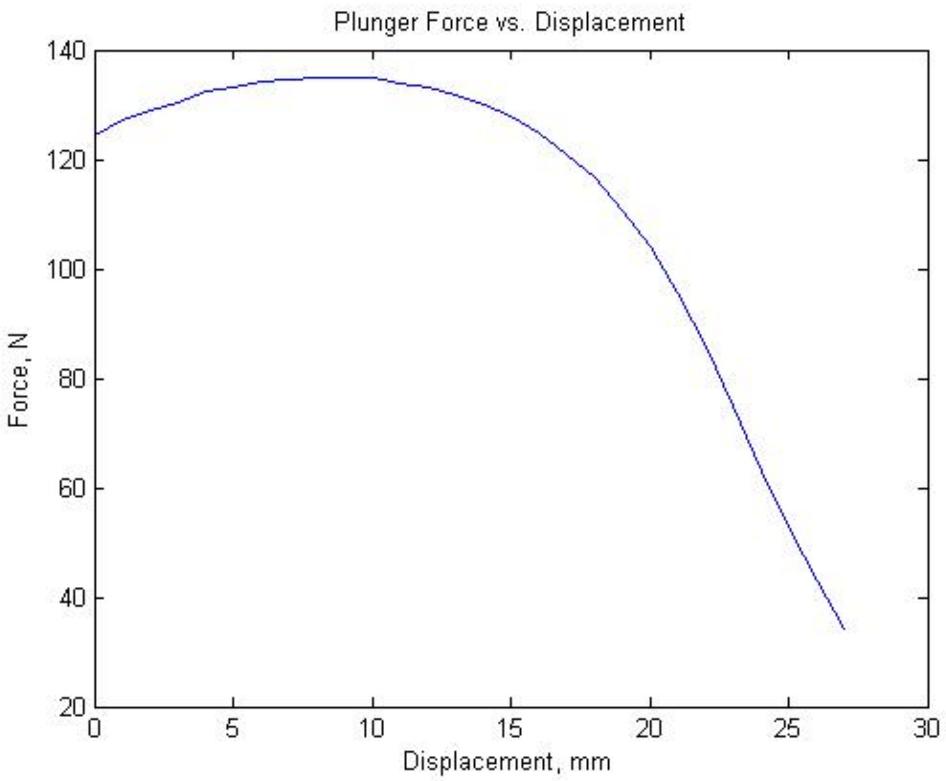
The boundary in FEMM simulation is kept sufficiently large in comparison with the solenoid dimensions (here a circle of 220 mm radius) .

The following Matlab code was used to generate the graph force vs displacement of the plunger.

```
openfemm
opendocument('plunger2.1.fem');
mi_saveas('temp.fem');
n=28;
y=zeros(n,1);
f=zeros(n,1);

for k=1:n
   disp(sprintf('iteration %i of %i',k,n));
   mi_analyze;
   mi_loadsolution;
   mo_groupselectblock(1);
   y(k)=(k-1);
   f(k)= mo_blockintegral(19);
   disp(sprintf('  force = %f',f(k)));
   mi_modifycircprop('New Circuit',1,40);
   mi_selectgroup(1);
   mi_movetranslate(0,1);
   mi_clearselected;
end
closefemm

openfemm
opendocument('plunger2.2.fem');
mi_saveas('temp.fem');
n=28;
for k=1:n
   disp(sprintf('iteration %i of %i',k,n));
   mi_analyze;
   mi_loadsolution;
   mo_groupselectblock(1);
   y(k)=(k-1);
   f(k)= f(k)+ mo_blockintegral(19);
```

```
    y(k)=(k-1);
    f(k)= f(k)+ mo_blockintegral(19);

    disp(sprintf('  force = %f at distance
                %f',f(k),y(k)));
    mi_modifycircprop('New Circuit',1,40);
    mi_selectgroup(1);
    mi_movetranslate(0,1);
    mi_clearselected;
end

plot(y,f)
xlabel('Displacement, mm');
ylabel('Force, N');
title('Plunger Force vs. Displacement');
a = trapz(y,f);
disp(sprintf('Area = %f',a));
closefemm
```

The following graph is generated. The area is calculated by trapz() function which uses trapezoidal method to find the area under the curve.



The area enclosed by the graph = 3053.359648units

Thus **Energy = 3.053 Joules** (approx).

Conclusion: Plunger 1 (length 64 mm and thickness 3.52 mm) is observed to provide more energy(4.387 J) than Plunger 2 (length 70.75 mm and thickness 2.67 mm) which provides 3.053 J.

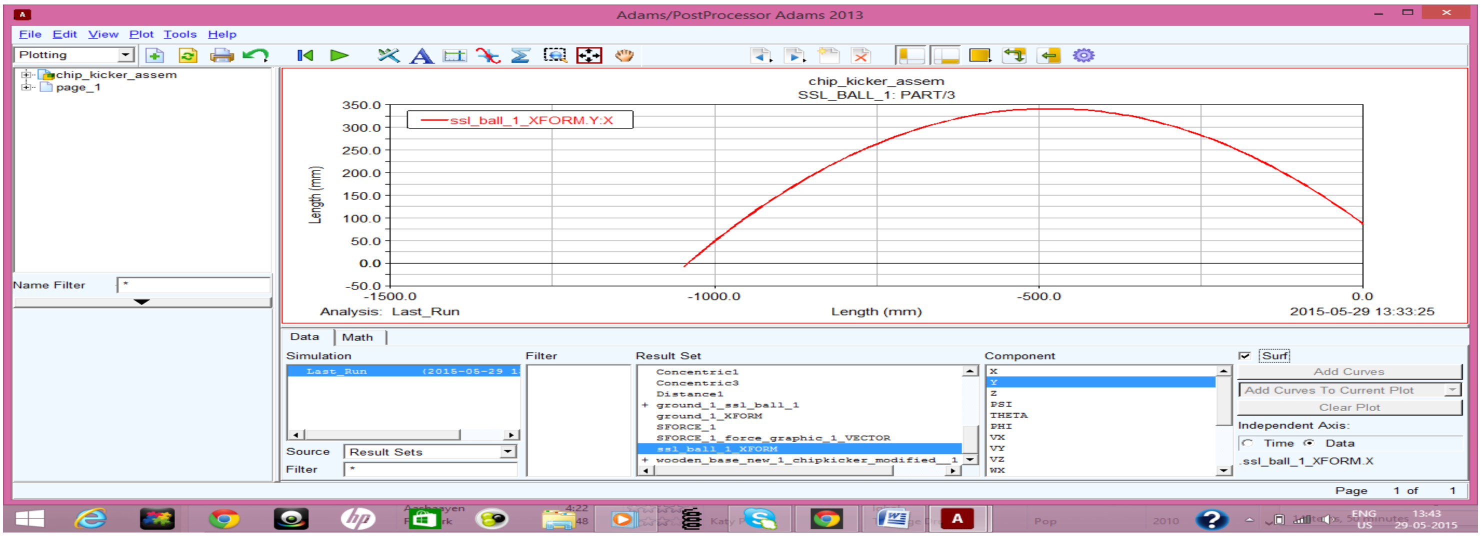
Plunger 2 (length 70.75 mm and thickness 2.07 mm) which provides 3.053 J.

Overall its observed that a plunger with greater length and thickness keeping width constant for the same solenoid and current possess more energy.

Testing of chip kicker on a wooden base

The chip kicker was tested on a wooden base. We used adams software to run the simulation .The range and height of the ball was calculated by the adams software based on force equation which was generated by matlab and fed into adams. The kicker setup was replicated and tested on a wooden base to test wether the original results matched with the results we got from the software.

The trajectory of the ball which we got in the simulation:



However in this plot we have applied the force in negative x axis so the ball is moving towards the negative x-direction i.e. the all moves from a point with x co-ordinates 0.0 to a point with x co ordinates about -1100.

From this plot we get that :

Distance which the ball travels in horizontal direction: 1.1 m (approx.)

Maximum height attained by the ball : 0.35 m (approx.)

The actual results which we got by testing the chip kicker on the wooden base :

Distance which the ball travels in horizontal direction: 1.3 m the wooden base :

Distance which the ball travels in horizontal direction: 1.3 m

Maximum height attained by the ball : 0.27 m

Hence the actual results and the observed results are quite similar. The differences are due to several assumptions we have taken during the simulation.

Dynamic analysis of solenoid for chip kicker in ssl bot

The solenoid and plunger which we used for testing was different from the one which we used in the actual bot.

In addition to the above procedures we also used ADAMS software to simulate the chip kicker and to predict the trajectory of the ball. For using ADAMS we have to import the solid works model of the chip kicker along with all the contact forces acting on the various components of the model. Then using MATLAB we generate the best fit polynomial of force as a function of x which is the distance moved by the plunger. MATLAB generates at max. a 10 degree polynomial for the estimation of a curve. We use this polynomial and apply it to the plunger and then find the trajectory of the ball.

Apart from the above arrangement we are also using a shell which is made of steel/iron. It is found that using a shell significantly increases the energy of the solenoid. The shell which we are using is 2mm thick.

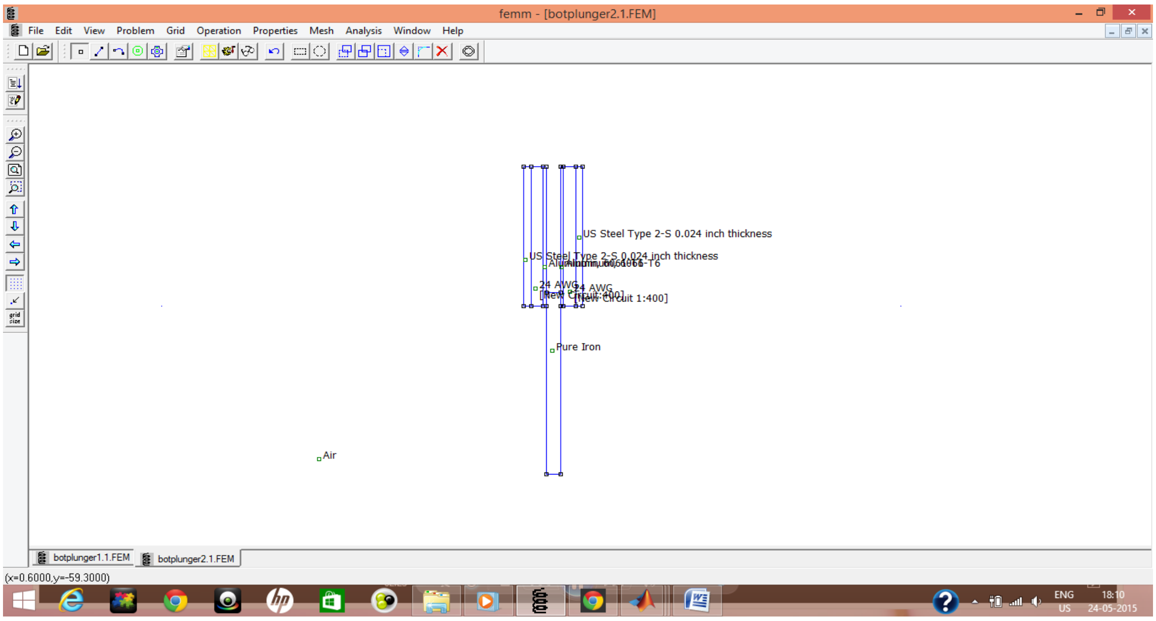
Solenoid: The solenoid is fed by constant current of 40 A. Actually the current keeps varying in the solenoid and has a maximum value. Since we don’t know the exact variation of current in the solenoid with respect to time/distance we are assume that a constant current of 40A is passing through it. Its structure is made of 6061-Aluminium alloy which is 1.25 mm thick. The wires are made of 24-AWG Copper and the number of turns is approximately 400. The outer dimensions of solenoid is 46mm × 43mm × 12mm while the inner hollow of turns is approximately 400. The outer dimensions of solenoid is 46mm × 43mm × 12mm while the inner hollow space is of dimensions 46mm ×38 mm × 4mm. There is also a 2mm thick steel/iron shell surrounding the solenoid.

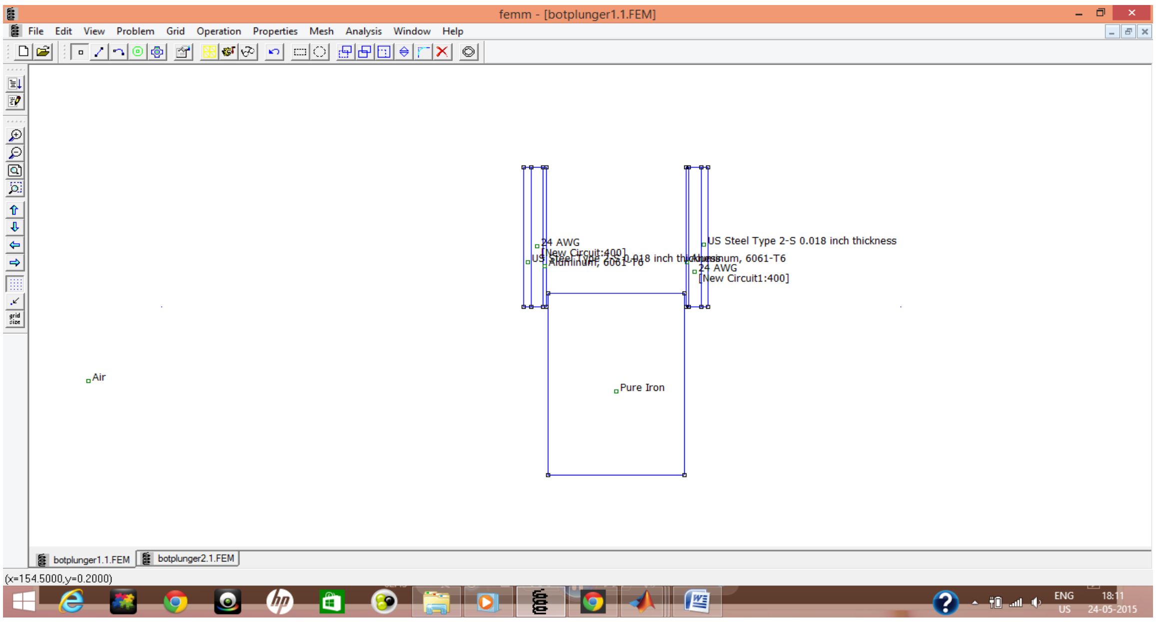
Plunger: The plunger is made of iron. It is assumed to be a cuboid though it is not. It's dimensions are 52mm × 37mm × 3.8mm.

The FEMM files :

In its initial position the plunger is 4mm inside the solenoid and in its final position the plunger has moved a distance of 40 mm inside the solenoid.

The boundary in FEMM simulation is kept sufficiently large in comparison with the solenoid dimensions (here a circle of 220 mm radius) .





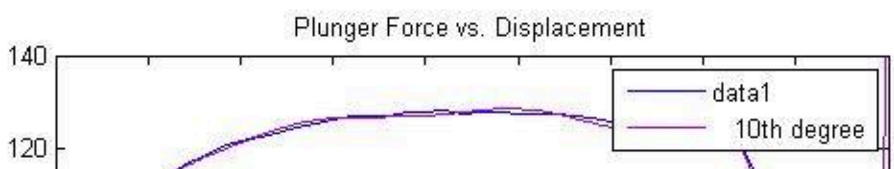
The MATLAB code used is :

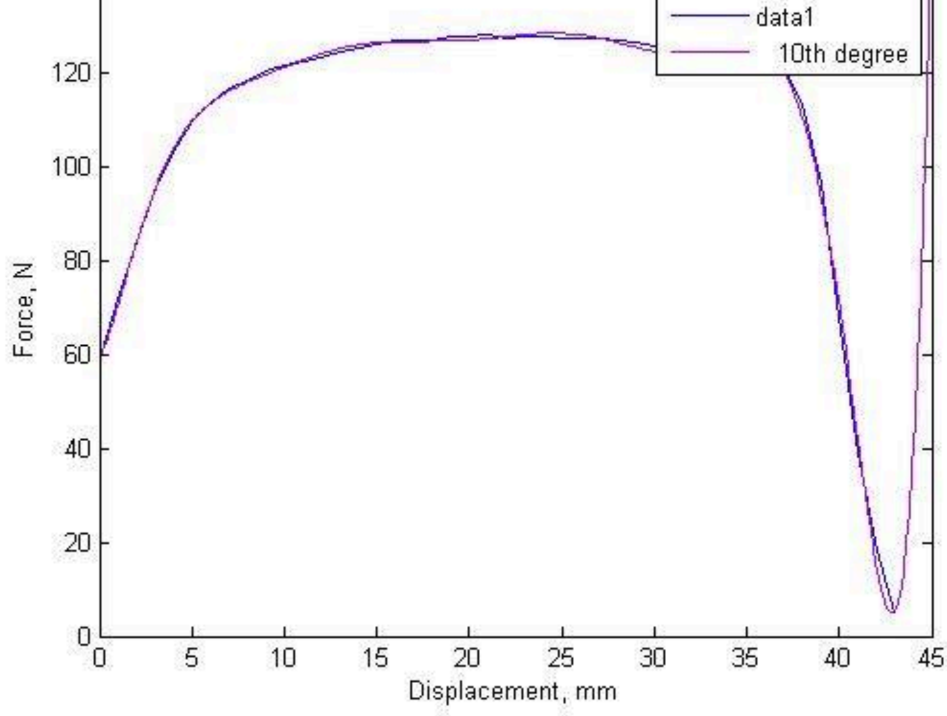
```
openfemm
```

The MATLAB code used is :

```
openfemm

opendocument('botplunger1.1.fem');% the file is opened
mi_saveas('temp.fem');% a temperory file is formed ..all the
changes will be reflected only in this file
n=44;% number of iterations
mi_modifycircprop('New Circuit',1,40);% the current in 'New
Circuit'is 40 A
y=zeros(n,1); % y i.e the distance array is initialised
f=zeros(n,1);% f i.e the force array is initialised
for k=1:n % the for loop starts
   disp(sprintf('iteration %i of %i',k,n));
   mi_analyze;
   mi_loadsolution;% meshing and analyszing has been done
   mo_groupselectblock(1);% group 1 i.e plunger is selected
   y(k)=(k-1);
   f(k)=mo_blockintegral(19);% the force in y direction on the
selected group
   disp(sprintf('   force = %f',f(k)));
   mi_selectgroup(1);% group 1 i.e plunger is selected
   mi_movetranslate(0,1);% group 1 is moved upwards by 1 mm
   mi_clearselected; % group 1 is cleared
end % for loop ends
closefemm
openfemm

opendocument('botplunger2.1.fem'); % new femm file is opened
mi_saveas('temp.fem');
n=44;
mi_modifycircprop('New Circuit',1,40);
for k=1:n
   disp(sprintf('iteration %i of %i',k,n));
   mi_analyze;
   mi_loadsolution;
   mo_groupselectblock(1);
   y(k)=(k-1);
   f(k)=f(k) + mo_blockintegral(19);
   disp(sprintf('   force = %f',f(k)));
   mi_selectgroup(1);
   mi_movetranslate(0,1);
   mi_clearselected;
end
plot(y,f) % a plot is drawn between y i.e distance and f i.e
force
xlabel('Displacement, mm'); % x axis is labeled
ylabel('Force, N'); % y axis is labeled
title('Plunger Force vs. Displacement');
a = trapz(y,f); % the area of the graph is calculated and
shown

disp(sprintf('Area = %f',a));
closefemm
```

The graph generated :





The area enclosed by the graph = 4824.456663 units

Thus **Energy = 4.824 Joules** (approx).

The polynomial generated :

y = p1*x^10 + p2*x^9 + p3*x^8 + p4*x^7 +p5*x^6 + p6*x^5 + p7*x^4 + p8*x^3 + p9*x^2 + p10*x +p11

Coefficients:

p1 = 6.1722e-11, p2 = -1.2511e-08, p3 = 1.0782e-06,

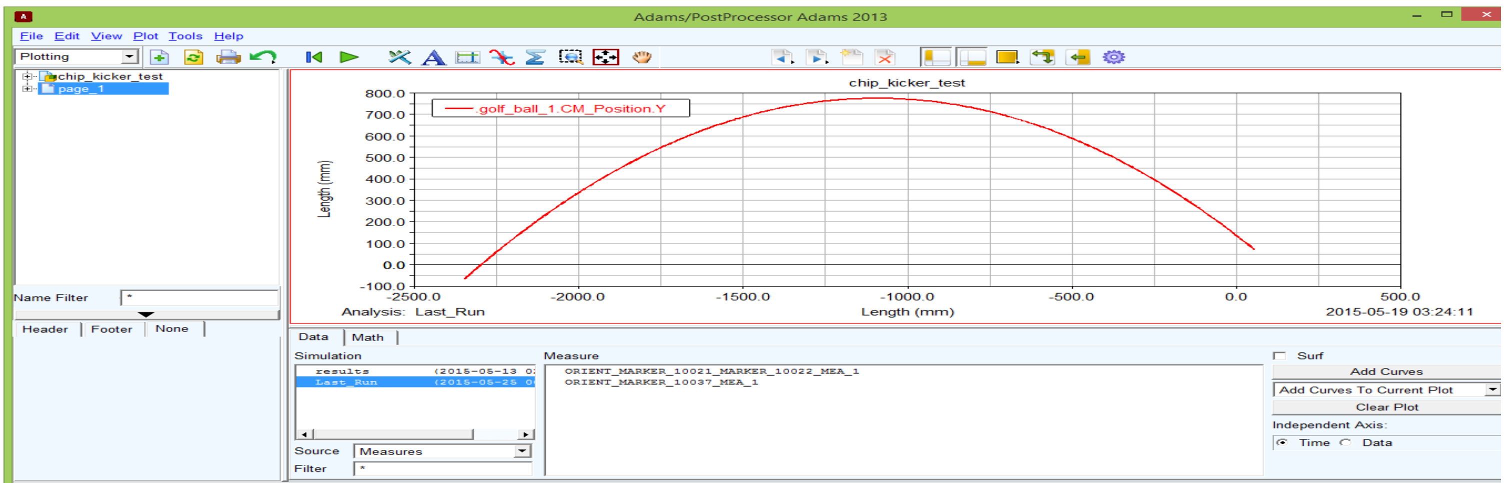
p4 = -5.1568e-05 , p5 = 0.0014976, p6 = -0.027101,

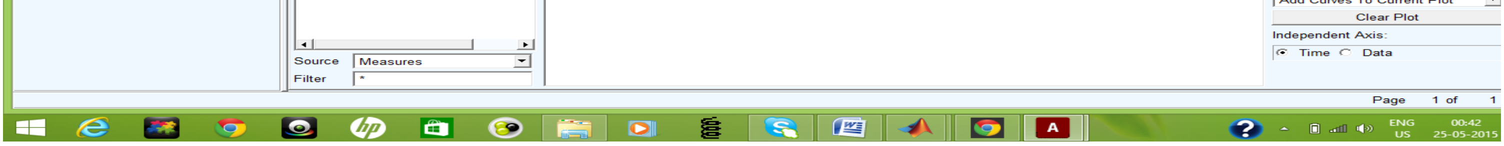
p7 = 0.30008, p8 = -1.876 ,p9 = 4.8921, p10 = 8.0266,

p11 = 59.327

This polynomial will be used in adams simulation and the trajectory of the ball will be generated from there.

The trajectory of the ball generated from adams :





However in this plot we have applied the force in negative x axis so the ball is moving towards the negative x-direction i.e. the all moves from a point with x co-ordinates of about 10 to a point with x co ordinates about -2300.

From this plot we get that :

Distance which the ball travels in horizontal direction: 2.3 m (approx.)

Maximum height attained by the ball : 0.75-0.8 m (approx.)

However in our calculations we have taken a whole lot of assumptions and the actual results may differ slightly from the calculated results.

The errors may be due to following assumptions:

- The current is kept constant at 40A. But actually it varies a lot.
- All type of frictional forces acting between various components of our model has been neglected.
- Proper and perfect alignment of the plunger, chip kicker and the ball is not always possible.