Electromechanics Laboratory 1 and 2

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SUMMARY: This paper is about the first two electromechanics experiments, modelling an electrostatic system, which spheres are used and modelling an electromagnet, with coils. For the model of the elctromagnet, we have uncovered that, the original model struggles at higher currents, but the modification improves performance, especially with increased current flow.

1. ELECTROMECHANICS 1 Dual Spheres

Fig. 1 shows two conducting spheres, which simulates a sphere gap for high voltage measurement. Electric breakdown occurs between them at a defined potential difference, generating a spark. The complex electric field around the spheres is analyzed in this paper through computer simulation using numerical methods.

In this paper, two models, which will be hence forth be referred to as modified and unmodified, are used. The unmodified model is similar to the model presented in Fig. 1, with two spheres of the same size. The modified model is with spheres of vastly different sizes. However, ensuring result accuracy remains a challenge, addressed by comparing simulations with approximate analytical results for one configuration. The spheres in fig. 1 each have a diameter of 100 mm, and the gap between the spheres is 100 mm, so the distance between the centres is 200 mm. The spheres have potentials of –90 kV and +90 kV with respect to earth, and they are remote from any other objects.

Fig. 1: Oner, M. (2020). Electromechanics Module Pack. The University of Sussex.

1.1. Summary

The simulation followed the preconceived hypothesis and met the expectations that the theory provided for us with small but expected discrepancies that arrive from using numerical methods, which a computer will use. This part of the paper has checked the charges of the electrode, the values of the magnitude of E smoothed, the forces of both the modified and unmodified models, the stored electrical energy and the predicted fields and flux functions.

1.2. Objectives

Here are the objectives laid out by the brief[2]:

(i) To build a computer model of the system and examine plots of the electric field and potential
(ii) To compare the computed values of electric field strength with approximate analytical results
(iii) To obtain results for the capacitance of the system and the force of attraction between the spheres
(iv) To modify the model by changing the size of one sphere, and to compare the results from the two models.

1.3. Numerical Results

In these results, there are the electrodes charges, the —E— Smoothed Graph and the force acting upon them of both the unmodified and the modified models. In this section, the results are presented and whether the results should be expected or not is discussed.

Table 1 lists the charges of the electrode spheres which are equal in magnitude but opposite in direction, which is expected.

The values in Table 2 should be symmetrical but they aren't around the x-axis but they are not here. This is most likely due to numerical errors, but will be discussed further in the discussion. However the

[2] Oner, M. (2020). Electromechanics Module Pack. The University of Sussex.

Table 1: The table of charges of the two electrodes.

Electrode No.	Charge
Electrode 1	6.71e-07
Electrode 2	-6.71e-07

Table 2: The E Smoothed table at specified points of Y

Y	—E— Smoothed
-50	3.16e+06
-40	2.26e+06
-30	1.75e+06
-20	1.48e+06
-10	1.34e+06
0	1.3e+06
10	1.34e+06
20	1.48e+06
30	1.75e+06
40	2.25e+06
50	3.21e+06

values are close enough to symmetrical that the overall results can still be considered valid.

Table 3: The table of forces of the two electrodes.

Electrode no.	Y force	Magnitude
Electrode 1	-0.109	0.109
Electrode 2	0.109	0.109

Table 4: The table of forces of the modified two electrodes.

Electrode no.	Y force	Magnitude
Electrode 1	-0.0191	0.0191
Electrode 2	0.0191	0.0191

Table 3 and 9 lists the force of the electrode spheres upon one another as equal in magnitude but opposite in direction, which is again expected given newtons second law f=ma, even when one electrode is significantly smaller than the other. This is also because there are not any other actors acting upon either sphere. It also makes sense that the magnitude of the force in the unmodified version is far greater than the force in the modified electrodes, because of the equation:

$$E = F/A \tag{1}$$

Taking into account coulombs law, E remains the same in the modified model as it is in the unmodified and in the modified version the area of the electrode is becoming smaller, which means that the force must also become smaller to maintain the same value of E. In other words, the area is proportional to the value of force.

Table 5: The Stored Electrical Energy of the two models

Model	Stored Electrical Energy
Unmodified	0.0604
Modified	0.0206

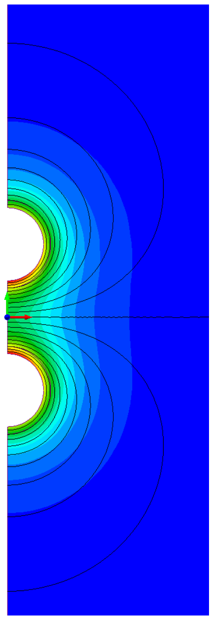

Fig. 2: Default fields view of unmodified electrodes

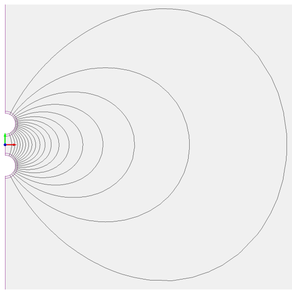

Fig. 3: Flux function contour

1.4. Calculations

For this section of the paper, the true value of capacitance of the system should hopefully be obtained, using the basic equations of capacitance.

$$C = q/V, \tag{2a}$$

$$W = \frac{1}{2}CV^2, \tag{2b}$$

$$C = 2\frac{W}{V^2} \tag{2c}$$

Equations 2 refer to the basic definition of capacitance and basic circuit theory to derive the third equation.

Original Model:
Magnitude of charges, q: 6.71e-07 (from Table 1)
Potential difference, V: 180 kV

$$C = 6.71e - 07/18000 = 3.73 \times 10^{-}12, \quad (3a)$$
$$W = \frac{1}{2} \times 3.73 \times 10^{-}12 \times 180000^2 \quad (3b)$$
$$W = 6.352 \times 10^{-}3 \quad (3c)$$

Modified Model:
Magnitude of charges, q: Same as the original model, 6.71e-07 C (from Table 1)
Potential difference, V: 180 kV

$$C = 6.71e - 07/18000 = 3.73 \times 10^{-}12, \quad (4a)$$
$$W = \frac{1}{2} \times 3.73 \times 10^{-}12 \times 180000^2 \quad (4b)$$
$$W = 6.352 \times 10^{-}3 \quad (4c)$$

The calculations yield the same capacitance values for the modified model as for the original model. This is expected, as the modification to the model doesn't alter the fundamental principles governing the capacitance calculation. Therefore, the capacitance values obtained using both Equation 1 and Equation 2 for the modified model should also be very similar to each other and of the same order of magnitude as the approximate result (4.17 pF) for the original model.

1.5. Discussion

1.5.1. Comparison with Approximate Values for the Original Model

For the magnitude of electric field strength and capacitance, compute the percentage differences between the computer results and the approximate values. If the values are close, it indicates that the computer simulation aligns well with the theoretical approximations. Any discrepancies may arise from numerical approximations or modeling assumptions.

1.5.2. Effect of the Diameter of Sphere 2

In the original model, a larger diameter of Sphere 2 might result in a lower electric field strength at its surface due to the inverse relationship between electric field strength and radius. Conversely, in the modified model with spheres of vastly different sizes, the electric field strength at the surface of the smaller sphere might be larger due to the smaller radius.

2. MODELLING AN ELECTROMAGNET 20th Febuary 2024

In this Experiment, an electromagnet is being modelled. The original model is a rectangular horseshoe shape and the modified model is extended outwards at the 'front' of the horseshoe. From there, the numerical simulation of flux density and relative permability was measured and the averages and percentage differences to the theoretical values calculated.

2.1. Graph

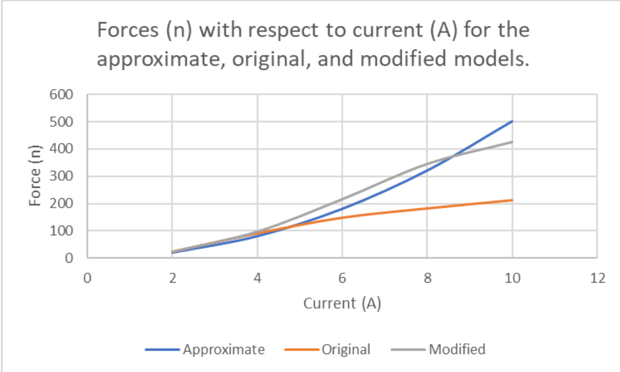

Fig. 4: Forces (n) with respect to current (A) for the approximate, original, and modified models

2.2. Numerical Results

Table 6 shows the Flux Density values for both the modified and original value at specified points.

Table 6: Flux Density values at specified points

Point	Original Model	-	Modified Model
-	2A	6A	6A
A	-0.00260	-0.0066	-0.0083
B	-0.00265	-0.0066	-0.0085
C	-0.00274	-0.0072	-0.0099
D	-0.00265	-0.0071	-0.0099
E	-0.00300	-0.0075	-0.0103
F	-0.00300	-0.0084	-0.0102
G	-0.00286	-0.0085	-0.0084
H	-0.00160	-0.0042	-0.0053
I	-0.00152	-0.0041	-0.0053
J	-0.00232	-0.0058	-0.0078

Table 7 shows the Relative Permability values for both the modified and original value at specified points.

2.3. Calculations

2.3.1. Average Flux Density Values for specific cases

To find the average the following equation must be used.

Table 7: Relative Permability values at specified points

Point	Original Model	-	Modified Model
-	2A	6A	6A
C	1832.60	1235.68	997.43
D	1821.88	1192.69	996.31
E	1485.01	242.24	803.91
F	1485.25	242.66	803.79
G	1293.02	34.07	771.91

$$Av.Value = \frac{Og.Value \times Mod.value}{2} \tag{5}$$

In Table 8 the average values have been calculated.

Table 8: Flux Density Average values at specified points

Point	Original Model	Modified Model	Average
A	-0.0066	-0.0083	-0.00745
B	-0.0066	-0.0085	-0.00755
C	-0.0072	-0.0099	-0.00855
D	-0.0071	-0.0099	-0.00850
E	-0.0075	-0.0103	-0.00890
F	-0.0084	-0.0102	-0.00930
G	-0.0085	-0.0084	-0.00845
H	-0.0042	-0.0053	-0.00475
I	-0.0041	-0.0053	-0.00470
J	-0.0058	-0.0078	-0.00680

2.3.2. *Percentage Differences*

The following equation is about calculating Percentage difference in our results. The approximate value for 2A is given to us as 0.251 and 6A as 0.754.

$$\Delta\% = \frac{(Ap.Value) - (Av.Value)}{Ap.Value} \times 100, \tag{6}$$

Table 9: The table of forces of the modified two electrodes.

Model	Average	Δ%
Original 2A	-0.002625	-4.58%
Original 6A	-0.0066	1.25%
Modified 6A	-0.0084	-11.4%

2.4. Discussions

Based on the results obtained from the numerical simulations of flux density and relative permeability

at points E, F, and G, the following observations and explanations can be made:

2.4.1. *Original Model at 2 A*

The computed values of airgap flux density and force are close to the approximate values. This indicates that at a lower current of 2 A, the original model behaves as expected based on theoretical predictions. The flux density and force calculations align well with the approximations.

2.4.2. *Original Model at 6 A*

The computed values of airgap flux density and force are much lower than the approximate values. This discrepancy suggests that at higher currents, particularly 6 A, the original model doesn't perform as anticipated. There might be factors such as saturation effects or other nonlinearities impacting the magnetic circuit, leading to lower than expected flux density and force.

2.4.3. *Modified Model at 6 A*

The computed values of airgap flux density and force are close to the approximate values. With the modification applied to the model, extending it outward at the 'front' of the horseshoe, the behavior at 6 A seems to align better with the theoretical predictions. This modification likely compensates for the deficiencies observed in the original model at higher currents.

2.5. Conclusion

While the original model behaves reasonably well at lower currents, it shows limitations at higher currents, which the modification addresses effectively. The modified model demonstrates improved performance, especially at higher currents, suggesting that the modification enhances the magnetic circuit's ability to handle increased current flow, resulting in closer agreement between computed and approximate values of flux density and force.