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DOI: https://doi.org/10.64388/IREV9I7-1713723

Force Analysis of Tractor Beam Magnetic System.

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Abstract- This paper shows detailed two-dimensional analysis of the tractor beam magnetic arrangement. It also shows that 3D analysis is not necessary for basic level. The paper highlights that the equilibrium distance will not depend upon the strength of the test magnet, unless the size of it is too large. The paper also shows that the vector forces around the equilibrium position are almost exactly point towards equilibrium point.

Index Terms- Tractor Beam Magnetic System, Two-Dimensional Force Analysis, Equilibrium Position.

I. INTRODUCTION

The tractor beam magnet experiments are quite new and started about the year 2015. Many attempts have been made in the direction of analysis of Forces in three dimensional and also in two dimensional.[1],[2]

In 2022, The National Institutes of Health (NIH) publishes research demonstrating the use of a magnetic tractor beam to steer a catheter over a distance of 100 mm with high precision.[3],[4]

This paper clearly shows that all around the equilibrium position the vector resultants are almost directed towards the equilibrium position.

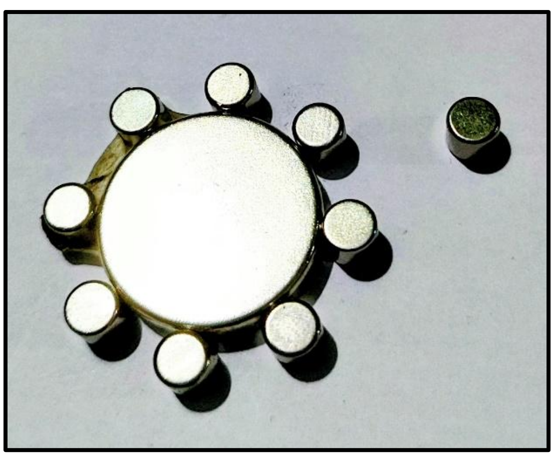

Figure 1- The tractor beam magnetic arrangement

Also the magnets that are in nearer to the test magnets (the two small magnets) are only contributing for the major force and the remaining magnets (figure-2) around the bigger magnet are not necessary for the analysis.

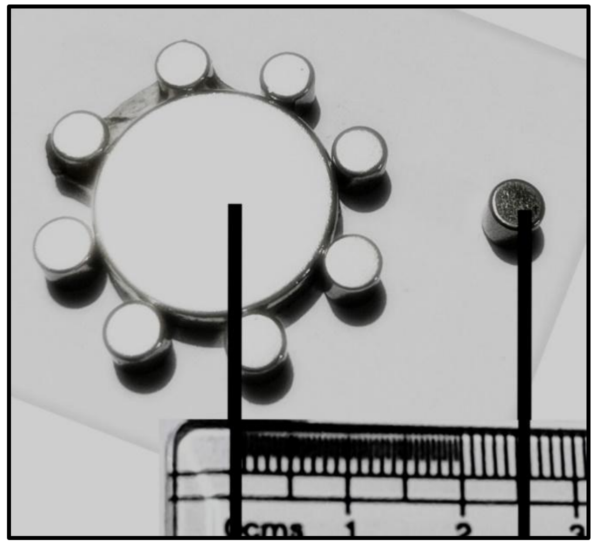

Figure 2 -The equilibrium distance is same with all other magnets

Hence, in this experimental analysis, only a bigger magnet and the two other magnets are only used along with the test magnet.

II. EXPERIMENTAL ARRANGEMENTS

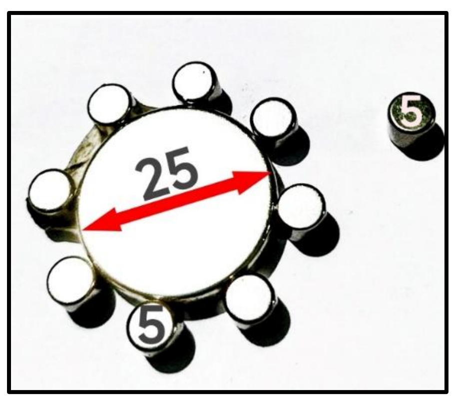

Figure 3- Sizes of magnets.
Figure 4 Sizes of magnets

The experimental setup includes a central magnet of 25 mm diameter and 5 mm height, attached with two small magnets with 5 mm height and 5 mm diameter, at 48^0 apart. The poles are such that the poles of small magnets are opposite to that of the central magnet. The test magnet is also of 5 mm height and 5 mm diameter and all are niobium silver magnets.

III. ARRANGEMENT OF POLES

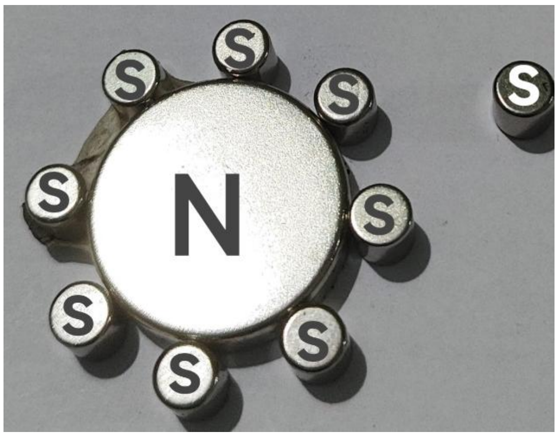

Figure 5-Arrangement of poles.

The poles are arranged as shown in the figure 5.

The central big magnet is the only magnet having north pole up. All the small magnets, including the test magnet, are having south pole up.

IV. THE EXPERIMENT

The small test magnet will be in equilibrium because of the repulsive forces from the two small magnets and the attractive force of the big magnet, as shown in figure 6

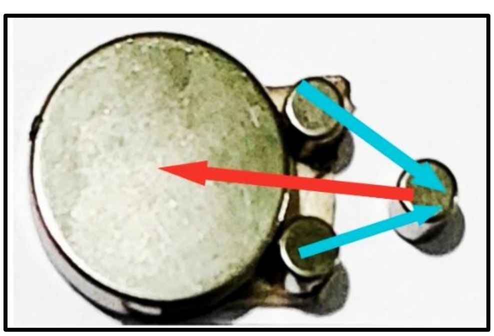

Figure 6- Forces acting on test magnet.

Also, the small magnets are fixed to the big magnet with the help of a glue tape, so as to have 48^0 angles between them.

V. CALCULATIONS

The experimental result shows that the equilibrium position is 25 mm from the centre of the 25 mm magnet

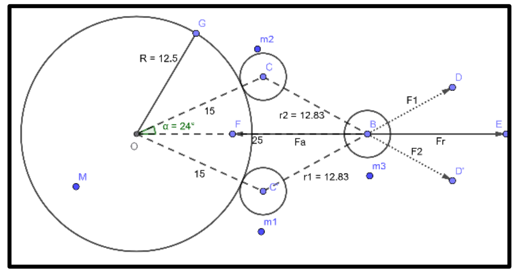

Figure 7-Forces and distances at point "p"

Magnets power ratio for this position the calculations are done as shown in the figures. The attractive force fa and the resultant repulsive force Fr are calculated at this equilibrium position.

In terms of the bigger magnet with M as the strength, smaller magnets as M2 as the strength and the test magnet MT as the strength.

T

he standard equation for force calculation of short magnets kept side by side is:

$$F = \frac{3\mu°(M)Mt}{4\pi r^4} \qquad (1)$$

Where, $\mu° = 4\boldsymbol{\pi} * (10)^{-7}$ H/m

Substituting this in above equation,

$$F = \frac{3(M)Mt * 10^{-7}}{r^4} \qquad (2)$$

For "r" in mm, we have to multiply the above equation by $(10)^{12}$

Hence equation becomes

$$F = \frac{3(M)Mt * 10^{5}}{r^4} \qquad (3)$$

The above equation gives attractive force F between big magnet and test magnet m_3.

The two repulsive forces between m_1, m_3 and m_2, m_3 are f_1 and f_2 respectively, are equal and acting 23^0 above and below X axis. Hence the resultant repulsive force is given by

$$Fr = 2 * f1 * \cos(23) \qquad (4)$$

But

$$f1 = f2 = \frac{3 * 10^5 * M1 * Mt}{r_1{}^4} \qquad (5)$$

Substituting this in equation (4) and simplifying,

$$Fr = \frac{5.52 * 10^5 * M1 * Mt}{r_1{}^4} \qquad (6)$$

At equilibrium point, F = Fr.
Equating (3) and (6),

$$\frac{3(\mathrm{M})\mathrm{Mt} * 10^5}{\mathrm{r}^4} = \frac{5.52 * 10^5 * M1 * Mt}{r_1{}^4} \qquad (7)$$

By equation (7), we see that the strength of the test magnet, "Mt" has no effect on equilibrium distance, as it cancels out.
On simplification we get

$$\frac{3(\mathrm{M})}{\mathrm{r}^4} = \frac{5.52 * M1}{r_1{}^4} \qquad (8)$$

From the experiment, equilibrium distance was found as 25 mm form the centre of the big magnet. That is r =25 mm and r1 =12.8 mm

The ratio of strength to small magnet and that of the big magnet is calculated as below.
Re arranging the equation (8), we get

$$\frac{\mathrm{M}}{M1} = \frac{5.52 * \mathrm{r}^4}{3 * r_1{}^4} \qquad (9)$$

Substituting for r_1 and r, and simplifying, we get

$$\frac{\mathrm{M}}{M1} = 26.5 \qquad (10)$$

From here onwards, this ratio is used for calculations of forces.

VI. FINDING FORCES AROUND THE POINT "P"

The points "a", "b" ….to "f ", which are having co ordinates as shown in the figure, are considered for force analysis.

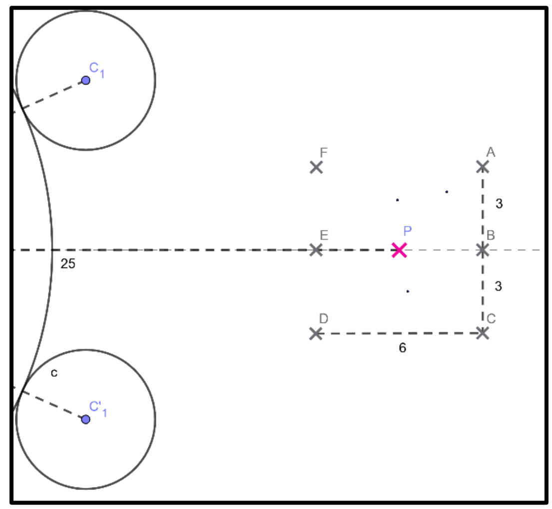

Figure 8- test points around "p"

VII. SPECIMEN CALCULATION FOR POINT "a"

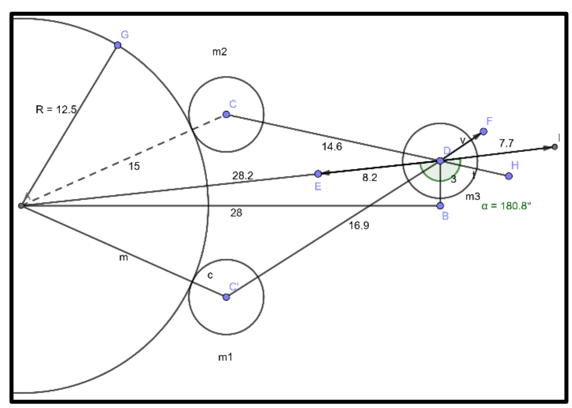

Figure 9- forces and distances at point "a"

$$F = \frac{3(\mathrm{M}) * Mt * 10^5}{r_a{}^4}$$

Here, r_a is the distance from center "o" to center of test magnet and is =28.2 mm. Also, the strength of the test magnet =Mt = M1 and for simplification, it is assumed as one unit. Hence M is 26.5 units.

$$F = \frac{3 * 26.5 * 10^5}{28.2^4}$$

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$$= 12.6\ units$$

$$f1 = \frac{3 * 10^5 * M1 * Mt}{{r_{a1}}^4}$$

Putting M1=Mt =1, ra1= 16.9 mm, we get

$$f1 = \frac{3 * 10^5}{16.9^4}$$

= 3.7 units

$$f2 = \frac{3 * 10^5}{14.6^4}$$

= 6.6 units

Figure -10 shows the force vectors acting on the test magnet at the point "p".

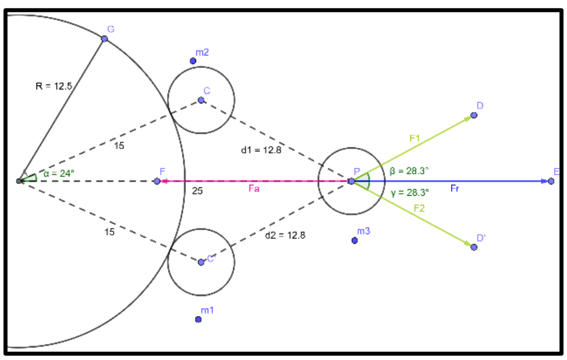

Figure 10- force vectors acting on test magnet at "p"

The 6 test points a, b, c, d, e and f are marked around the equilibrium point, each 3mm distance, as in figure -11.

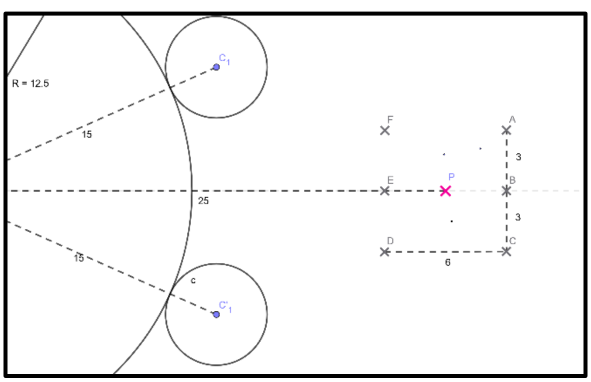

Figure 11- Test points around the point "p"

Resultant magnitude and direction calculations are done in a similar way to the positions shown in the above diagram at a different position.

VIII. RESULTS AND DISCUSSION

The calculated results are shown in table-1 below.

Table 1-Resultant forces and directions.

Test points	Net resultant force	Angle (in degrees)
a	5.42	216
b	2.9	180
c	5.42	144
d	31.8	75
e	10.1	0
f	31.8	285
p	0	0

As the test point move away from the equilibrium position, the magnitude of the resultant will be less compared to the position nearer to the magnet.

Vectors at points P, b and c are pointing towards the equilibrium position.

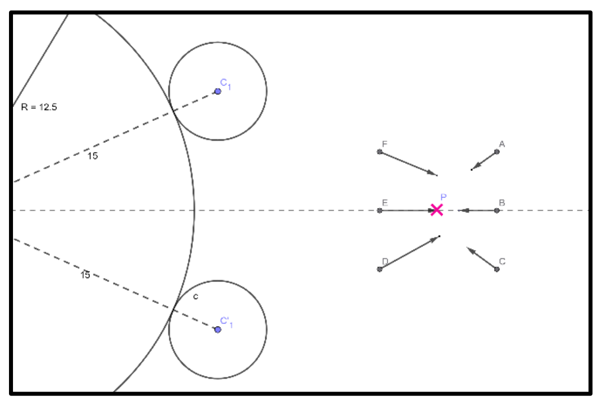

Figure 12-Direction of force vectors at test points.

Other vectors point little different direction, but as the magnet is moved towards equilibrium position, direction it tends to point the equilibrium position.

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Figure 13- very tiny magnet placed at "p"

The equilibrium position is almost unaltered when a different test magnet is placed.

Figure 14- Equilibrium point shifts whit large magnet.

But when the size of the test magnet is much bigger, then the equilibrium position will be little away.

IX. CONCLUSION

1. Tractor beam arrangement can be made with only four magnets.
2. The equilibrium distance is independent of the strength of the test magnet, but if the size is very big, the distance will increase.
3. All forces around the equilibrium point point almost towards the equilibrium position.
4. As the test point move away from the equilibrium position, the magnitude of the resultant will

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