Design of Electromagnetic Weight Lifting Gym Equipment

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Abstract –*The aim of this project is to design and simulate the electromagnetic weight lifting equipment. A traditional type of training equipment are free weights. But this requires more space. So the design of electromagnetic weight lifting equipment is proposed in this project. The current required to increase the weight of the sample by increasing the pull force is calculated and a method to supply constant current irrespective of the distance between the sample and the electromagnet is incorporated. The CAD models of the components to be used for this setup are modelled using Solidworks software. To avoid damage in the setup when the lifter drops the sample on the electromagnet the drop test analysis is done and two obstructs are put in place to counter the damage and lastly, with the help of the simulating software, the stress and deformation analysis are carried on the obstruct and the belt. Due to large amount of heat generated in the electromagnet, a cooling fan is introduced in the setup for cooling. CFD analysis is done on the electromagnet using Ansys Fluent software to predict the air flow requirement to cool the electromagnet. Based on the results of the analysis, the cooling fan is designed. Finally the cost and the space required for the proposed setup is compared with the conventional weight lifting equipment.*

Key Words: **Electromagnet, Drop test, Cooling fan, CFD analysis, Ansys fluent.**

1.INTRODUCTION

Weight training is a common type of strength training for developing the strength and size of skeletal muscles. Conventional weight lifting gym equipment has been around for many decades and is still in use by many fitness enthusiasts and centres today. Examples of free weights include barbells, weight plates and dumbbells. Free weights are typically used with weight benches, which can be both adjustable or fixed. Wight training uses a variety of specialized equipment to target specific muscle groups various types of movements.

1.1 Problem Statement and Objective

Weight lifting gym equipment generally costs high and takes up most of the space, this would not be a problem for a largescale gym that is spread over 5000sq. ft or more, like the ones in abroad but from a domestic point of view, it is completely impractical. The objective is to design a low cost, space saving electromagnetic weight lifting gym equipment for domestic purpose.

1.2 Feasibility Calculation

Before you begin to format your paper, A sample of **5 kg** as primary weight is added. Electromagnet is placed below the sample. Weight is increased by increasing the current supplied to the electromagnet. Electromagnetic weight lifting equipment consumes approximately **2000 W/hr** to work in its maximum amperage. One-unit costs Rs.2 up to 100 units and then moves up to Rs.5/unit. Take **Rs.5** as the average unit cost. Therefore, this equipment consumes **Rs.10** to work for an hour. Therefore the operating cost is not much higher.

2. LITERATURE SURVEY

Following conclusions are made from the literature survey

i. **Aluminium** coil wound with anodized foils is recommended due to the absence of airspaces in between layers so that the packing factor and thermal conductivity gets improved.

ii. **Iron** is used as the core material for electromagnet because it can be easily magnetised and demagnetised.

iii. **U shaped core** is used as it provides wider window area for coil and eddy current induced is substantially less than the E-core magnets.

iv. **Higher number of turns** is used in the coil for making stronger electromagnet thus reducing the current by considerable amount. Also, transmission power losses are low.

v. **ANSYS Fluent** software is used for CFD analysis of electromagnetic setup for designing the cooling system.

3. Electromagnet Design

The dimensions of electromagnet are chosen as follows

- Slot width, w_s= 300 mm
- Wire window width, w_w = 260 mm
- Slot depth, d_s = 150 mm

- End width, w_e = 100 mm
- Back width, w_b = 100 mm
- Height, h = 120 mm
- Total surface area A = 0.232 m^2

Current required by the electromagnet to pull the weight is given by

$$I = \sqrt{\frac{F \times 2R^2}{N^2 \times \mu \times A}} \quad (A)$$

Where,

N - number of turns, I - current (A), μ- permeability constant (N/A^2), F - force required by the electromagnet to pull the weight(N), A - area (m^2), R - distance between electromagnet and sample weight (m).

3.1 Sample Measurement

For 10 kg weight i.e. (F=50N, since already the dead weight is 5 kg, extra force required to add 5kg to the dead weight is used)

R = 0.05 m (when the weight is not lifted)

$\mu = 4\pi \times 10^{7}$ N/A^2

A - Total Surface area (TSA) of the electromagnet

$$I = \sqrt{\frac{50 \times 2 \times 0.05^2}{5000^2 \times 4\pi \times 10^{-7} \times 0.232}}$$

I = 0.19 A

Similarly, the current required for different forces was measured. This measured current produces the required force only when the sample weight is not lifted, i.e, when the distance between the sample weight and the electromagnet is about 0.05m. This denotes the minimum value of current required to operate the setup.

Electromagnetic force required to be generated by the electromagnet is given by,

$$F = ((W - S) \times 10) \; (N)$$

Where,

S - Sample weight (kg)

W – Weight required (kg)

Maximum current required by the setup is when lifting the 30kg weight to a height of 1.5 metres. So, the wire design parameters and values are assigned based on this maximum current value. For 30 kg (250N) weight when R= 1.5 m, the current value I is found to be 12.42 A. Similarly, the maximum current required to pull a weight ranging from 10 kg to 30 kg to a height of 1.5m is calculated.

3.2 Analytical Validation

The analytical validation is done using Magnetostatic analysis in ANSYS. The distance between the sample weight and the electromagnet is given as 1.5 metres. Number of turns of coil is 5000 and current through the coil is given as 12.42A and corresponding force is analysed.

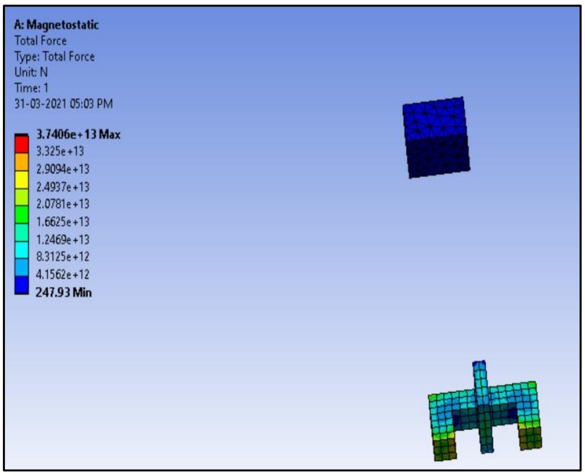

Fig-1: Magnetostatic analysis of electromagnet

From Fig 1 it is referred that the force produced for the current 12.42A is 247.97 N which nearly matches the results of theoretical calculation.

3.3 Specifications of Winding

For design of winding, two main parameters are determined which is the packing factor and the material. The packing factor is useful in selecting a transformer or inductor core with an eye towards optimizing the efficiency

or power transfer of the magnetic component. The packing factor should be greater than 0.7. Aluminium is preferred because of its low cost. Also, aluminium has high electrical conductivity and low resistivity.

Table -1: Aluminium wire selection chart- CMP Industries

Nominal diameter(mm)	Max diameter(mm)	Min diameter(mm)	Current (A)
2.650	2.677	2.623	14.14

The above table shows the nominal diameter of the wire to be chosen for the maximum current calculated. Since the maximum current is 12.42 A, for safety purpose the parameters next to 12.42 A is chosen. i.e, the nominal diameter for 14.14 A is chosen. Hence the nominal diameter of wire is chosen as 2.650 mm.

4. CAD MODELS

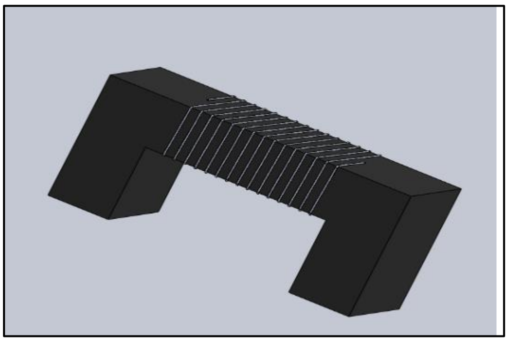

Fig -2: Electromagnet

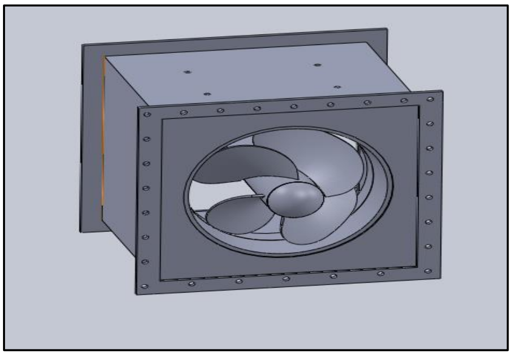

Fig -3: Cooling fan

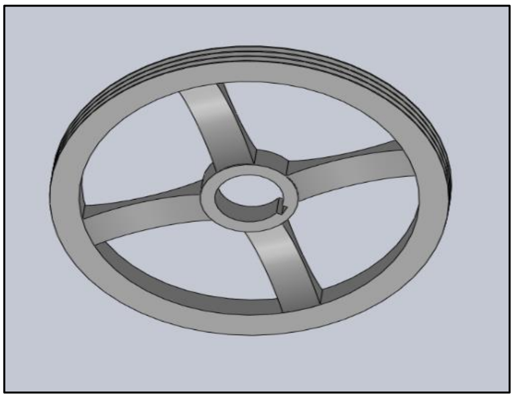

Fig -4: Pulley

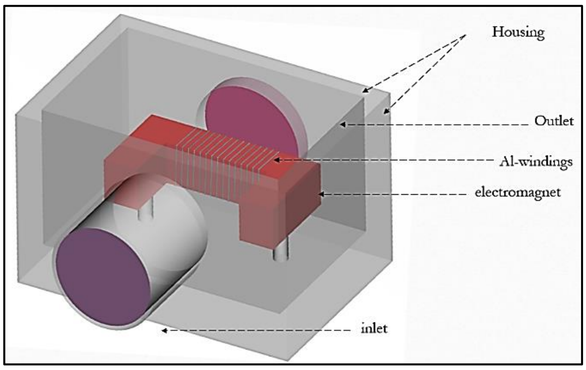

Fig -5: Housing

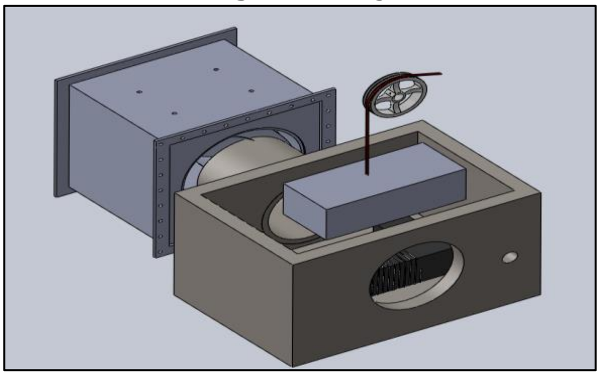

Fig -6: Final Assembly

Table -2: Specifications of model

Specifications	Electromagnet	Cooling Fan	Pulley	Housing
Material	Cast Iron	Stainless steel	Cast Iron	Stainless steel
Type	Clapper type electromagnet	Axial Cooling Fan	Fixed pulley	Top opened housing

5. DESIGN OF PULLEY

The Pulley is modelled in Solid works software with the diameter d=180mm, width w=63mm, thickness of rim t=4mm. The following input condition is given in Solidworks simulation software and maximum stress is calculated.

Material for pulley: Cast Iron, Circumferential Load: 300N, Load along the arms: 300N, Gravity: 9.8 m/s^2

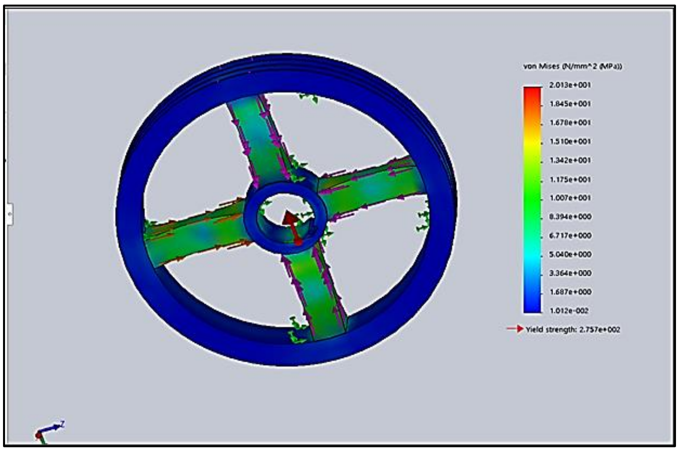

Fig -7: Stress analysis of pulley

From the stress analysis using Solid works simulation, it is found that maximum stress induced is 20.1 MPa which is less than the ultimate strength of the pulley i.e, less than 450MPa. Hence there will be no damage to the pulley.

6. DROP TEST ANALYSIS

Drop test is made in Ansys software to analyse the maximum stress induced in the dead weight and electromagnet when a person accidentally drops the lifted weight on the electromagnet. This test helps to predict the occurrence of damage to dead weight and the electromagnet. The following input condition is given in Explicit Dynamic analysis in Ansys software.

Material: Ductile iron, Drop Height: 1500mm, Target material: Rigid, Gravity: 9.8 m/s^2

Fig -8: Drop Test Analysis

The maximum stress induced on dead weight and electromagnet will be same and is found out to be 621 MPa from the Fig 8. The ultimate strength of ductile iron is around 450 MPa. Hence there will be damage to the dead weight and the electromagnet. In order to prevent the damage the base level of dead weight is kept above 50 mm from the electromagnet. So even if the weight is dropped accidentally the dead weight will not hit the electromagnet.

7. DESIGN OF COOLING FAN

The electromagnet generates a large amount of heat when a current is passed through the coil wound on electromagnet. This causes decrease in life of electromagnet and harmful effects on a person who is standing nearby. Thus cooling of the electromagnet turns out to be the best solution to avoid the damages.

The first step in designing a cooling fan is to find out the temperature rise of the electromagnet for the optimum mass flow rate of air using Ansys Fluent(CFD) software.

7.1 Software Used

- CAD model was created using Solidworks v2019
- Surface meshing is performed on ANSA v 19.1.7
- Volume meshing is performed using ANSYS Mesher
- Solver is performed on ANSYS Fluent 2020 R1.

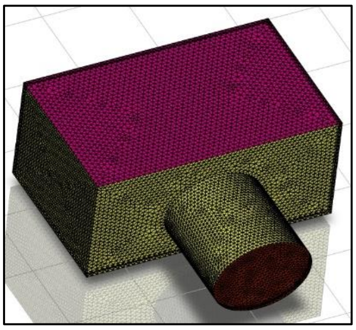

Fig -9: Surface meshing

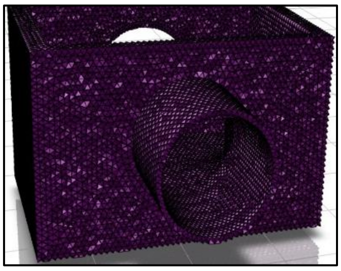

Fig -10: Volume meshing

7.2 Fluid and Solid Boundary Conditions

- Velocity inlet BC is imposed at the inlet of the computational domain with a velocity corresponding to its mass flow rate(m=ρAV).
- Current through the aluminium winding is given as 12.5A.
- The temperature of the air at inlet is 300K.
- Housing boundaries are assumed as wall with no slip, coupled BC.

7.3 CFD Simulations

The CFD simulation for 0kg/s, 0.15kg/s, 0.75kg/s, 1.10kg/s, 1.13kg/s and 1.50kg/s and the results are tabulated in Table 3.

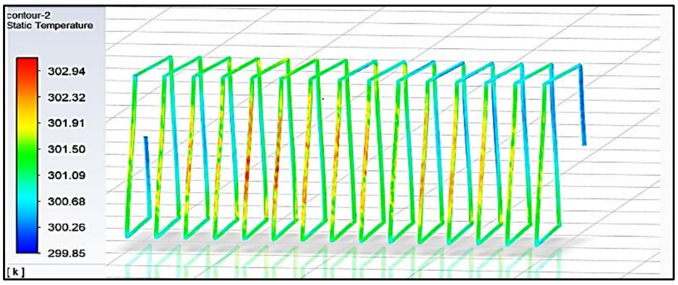

Fig -11: Static temperature distribution in winding at 10th sec for 1.13 kg/s

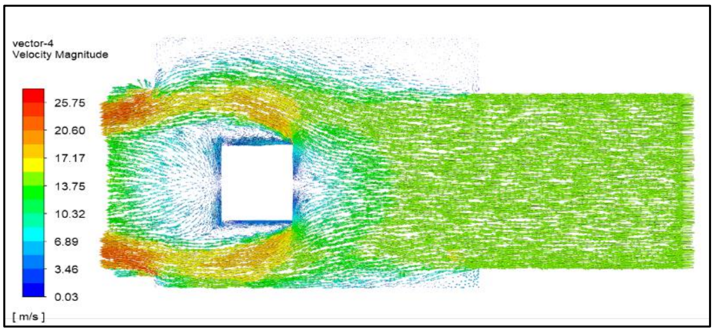

Fig -12: Velocity vector at 10th sec for 1.13 kg/s

Similarly the temperature distribution and velocity vector are found out for other mass flow rates also. The simulations are carried at 10th second because at this point only the the temperture of electromagnet becomes stable which is found in Ansys fluent software.

Table -3: CFD Results

Mass flow rate(kg/s)	Maximum surface temperature (K)	Maximum air velocity (m/s)
0	367.91	0
0.15	332.0	10.0
0.75	318.36	17.09
1.10	304.74	23.08
1.13	302.94	25.75
1.50	302.94	38.42

After several trials for different mass flow rates, mass flow rate of about **1.13kg/sec** gave the optimal results for a current of **12.5A** with a temperature rise of **2.94K** (**300K – 302.94K**). Beyond 10th second, there was no variation in the temperature rise upto the 18th second of the simulation and so on.

7.4 Theoretical Analysis of Heat Generation

According to Joule's heating effect, heat generated (Q) when a current (I) flows throw a coil of resistance R, for a certain time t, is given by **$Q= I^2Rt$.**

Here maximum value of current is chosen i.e. the current required to produce a pull force of 250N at 1.5m. Hence I=12.42A, t=10s, R = 7.47 ohm ,where R = $\frac{\rho l}{A}$

$Q = 12.5^2 x 7.47 x 10$

$= 11671.8$ W

Air flow requirement in CFM = (3.16 x Q) / (ΔT)

Where, ΔT= 2.94 K i.e.,ΔT= 5.86 °F

= (3.16 x 11671.8) / 5.86

CFM = 6294.04 ft^3/min

The cooling fan with the available size for the calculated CFM and obtained velocity has to be installed to the setup.

8. RESULTS AND DISCUSSIONS

The estimated cost of fabrication of the setup is around 27000₹ and the percentage of floor space saved is around 31.81% and the cost saved is around 35% compared to the commercial weight lifting equipment. Hence this designed product can be used in house by all classes of people as it is cheap and it occupies only less amount of floor space. Thus the product designed is economical and the objective of the project is achieved.

9. CONCLUSION

The basic design of the electromagnetic weight lifting gym equipment was finalised after the iteration process. The materials for the components were decided based on the requirements. The maximum current required to lift 10 to 30 kgs of weight to a height of 1.5 m is calculated theoretically and also analytically validated using Ansys software. The design for pulley is performed using Solidworks simulation software. To avoid damage in the setup when the lifter drops the sample on the electromagnet the drop test analysis is done and the base of sample weight is raised above 50 mm from the electromagnet. Due to large amount of heat generated in the electromagnet, a cooling fan is introduced in the setup for cooling. CFD analysis is done on the electromagnet using Ansys Fluent software to predict the air flow requirement to cool the electromagnet. From the CFD analysis, the mass flow rate of 1.13 kg/s with the velocity of 25.75 m/s is concluded as the optimum and chosen for the selection of cooling fan.. The designed setup saves 31.81% of space and 35% of cost compared to the commercial weight lifting equipment. Thus the objective of the project is fulfilled.

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