Design, Analysis and Manufacturing of a Weight Lifting Human Sized EXO-Skeleton

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ABSTRACT – Lifting of various light and heavy objects is the tedious work done by many of the people on many occasions. Manpower is utilized in many areas where heavy materials are to be handled. Nowadays, this lifting of loads for hours together has become very common in every person’s life whether it may be bag or cup of coffee or books, laptop, tools which he works throughout the day, etc. At industries, heavy materials are to be machined and be loaded into the machinery, this requires a person to transfer uneven raw materials up to the cutting or crushing machines. With the EXO-SKELETON, a person can work freely by wearing it on his body and can lift heavy loads as easy without difficulty. The main objective here is to make a person to go through less strain while lifting heavyweights. This can be successfully used in production lines, weight transferring areas, military purposes, even in the medical field where when a person is unable to move his limbs, he can wear and easily can move his body parts. The main raw material used is Mild Steel as it is easily available and cheap. The movement occurs through the air compressor and pneumatic cylinders. The 3-D Modelling of the whole is done in Solidworks 2016 and the analysis of the parts was done in Ansys 18.1 workbench software.

Key Words: Exo-Skeleton, Industries, Medical, Military, Modelling, Solidworks, Ansys 18.1 workbench.

I. INTRODUCTION

Lifting operations are the core works in many fields in the construction industries, metal industries, production industries, manufacturing industries and so many areas. These operations can be performed manually i.e., by using humans or by using various types of lifting equipment. Both these methods can put a worker at greater risk of injury or disability or some may even seem to be fatal. The cost of accidents and ill health related to lifting operations is too high. This describes a brief explanation about the risks associated with the lifting operations in various industries. There is also a need for lifting operations other than in industries. Some of the lifting operations are also done in the medical field and also in the defence field. Some of the uses are to bring movement to a paralyzed person who is unable to move his body parts on his own. This person requires some external help to even move his hand. Such cases can be dealt with a suit type of armour. Even in military, there is a need to carry heavy loads through long distances and for so many hours. All these issues can be solved by using an exo-skeleton.

Generally, an Exo-Skeleton is an external skeleton that supports and protects an animal’s body. But here, the Exo-Skeleton is an electromechanical structure worn by the operator and matching the shape and functions of the human body. Moreover, this Exo-Skeleton will combine the intelligence of human and the power of the machine to give an ultimate power-intelligence to the human who operates it. The Exo-Skeleton is powered by electric motors, pneumatics, levers, hydraulics and or a combination of technologies which allows a free movement of the limbs of the human body.

II. WORKING

When pressurized air from an air compressor is regulated to the pneumatic cylinders through a solenoid valve, we will get the movement of the piston of the pneumatic cylinders which are connected to the limb-like structures of Mild Steel pipes and thus we will get the movement which we require. These Mild Steel pipes, when attached to the human body, will create the same motion as of the motion created by our limbs. The intermediate solenoid valve is also used to control these movements. When the pressure is released from the valve, the pistons in the front pneumatic cylinders will move to Top Dead Centre while the pistons at the rear pneumatic cylinders will move to Bottom Dead Centre. This will cause the motion to the limbs. This motion will be reversed as soon as the pressurized air is stopped at the valve. The total weight which is lifted by the hands will be transferred to the Metallic Legs which are also been made of Mild Steel. These Metallic Legs will take on all the loads and will allow the operator to feel less strain as he feels very less pressure even after lifting the heavy loads.

Fig. 2.1: Rough Assumption

III. MATERIAL SELECTION

The material which I have chosen for the completion of the frame is mild steel. The reason behind this selection is that, Mild Steel is: Cheap, Easily Available, Cost Efficient, Better Machinability, Better Weldability.
3.1 PROPERTIES OF MILD STEEL

Table – 3.1: Chemical Composition

| ELEMENT   | CONTENT                       |
|-----------|-------------------------------|
| Carbon, C | 0.14 – 0.20%                  |
| Iron, Fe  | 98.81 – 99.26% (as remainder) |
| Manganese, Mn | 0.60 – 0.90%             |
| Phosphorous, P | ≤ 0.040%                |
| Sulfur, S | ≤ 0.050%                     |

Table – 3.2: Physical Properties

| Physical Properties | Metric | Imperial |
|---------------------|--------|----------|
| Density             | 7.87 g/cc | 0.284 lb/in² |

Table – 3.3: Mechanical Properties

| Mechanical Properties | Metric | Imperial |
|-----------------------|--------|----------|
| Hardness, Brinell     | 126    | 126      |
| Hardness, Koop (Converted from Brinell hardness) | 145    | 145      |
| Hardness, Rockwell B (Converted from Brinell hardness) | 71     | 71       |
| Hardness, Vickers (Converted from Brinell hardness) | 131    | 131      |
| Tensile Strength, Ultimate | 440 MPa | 63800 psi |
| Tensile Strength, Yield | 370 MPa | 53700 psi |
| Elongation at Break (In 50 mm) | 15.0% | 15.0% |
| Reduction of Area     | 40.0%  | 40.0%    |
| Modulus of Elasticity (Typical for Steel) | 205 GPa | 29700 ksi |
| Bulk Modulus (Typical for steel) | 140 GPa | 20300 ksi |
| Poisson’s Ratio (Typical for Steel) | 0.290 | 0.290 |
| Machinability (Based on AISI 1212 steel, as 100% machinability) | 70% | 70% |
| Shear Modulus (Typical for Steel) | 80.0 GPa | 11600 ksi |

Table – 3.4: Electrical Properties

| Electrical Properties | Metric | English | Comments                  |
|-----------------------|--------|---------|---------------------------|
| Electrical Resistivity @70°C | 0.0000159 Ω-cm | 0.0000159 Ω-cm | Annealed Condition |
| @100°C/212°F | 0.0000219 Ω-cm | 0.0000219 Ω-cm | Annealed Condition |

IV. COMPONENTS USED

a) Air Compressor
b) Pneumatic Cylinders
c) Solenoid Valve
d) Metallic Square Pipes
e) Hose Pipes
f) Hose Pipe Fittings
g) Fasteners

V. CAD DESIGNS OF ALL THE COMPONENTS

Fig. 5.1: Air Compressor
Fig. 5.2: Pneumatic Cylinder
Fig. 5.3: Solenoid Valve
VI. DESIGN ASPECTS

Generally, the machines used to carry loads are heavy in weight and they occupy more weight as they are huge in dimensions. This will allow the operator to use them at a specified location and at particular times. This may cease the work at some times. To avoid such complications, we can use this Exo-Skeleton. It is wearable by anyone and can be carried as such. It does not occupy much space and light in weight.

VII. CALCULATIONS

Table 7.1: Design Attributes

| S No. | Symbol | Abbreviation/Nomenclature |
|-------|--------|---------------------------|
| 1     | Q      | Capacity at suction by customer requirement |
| 2     | P_{amb} = P_s | Suction Pressure |
| 3     | T_s    | Suction Temperature |
| 4     | T_d    | Discharge Temperature |
| 5     | P_d    | Discharge Pressure |
| 6     | n_s   | No. of Cylinders at the suction |
| 7     | L      | Stroke Length of Compressor |
| 8     | N      | Speed |
| 9     | F      | Frequency |
| 10    | P      | No. of Poles |
| 11    | P      | Pressure |
| 12    | D      | The diameter of the cylinder |
| 13    | F      | Force |
| 14    | A      | Area |

AIR COMPRESSOR
- Determining Minimum RPM Required
  \[ \text{Speed} = 120 \times \frac{f}{P} = 1500 \text{ rpm} \]

PNEUMATIC CYLINDER
- Piston Diameter
  \[ d = 25 \text{mm} \]
- The surface of the drive piston
  \[ A = \frac{d^2 \pi}{4} = \frac{25^2 \times 3.14}{4} = 490.87 \text{ mm}^2 \]
- Operating Pressure
  \[ p = 8 \text{ bar} = 0.8 \text{ N/mm}^2 \]
- Calculation of the Force
  \[ F = p \times A = 0.8 \text{ N/mm}^2 \times 490.87 \text{ mm}^2 = 392.696 \text{ N} \]

Thus, we have a theoretical force of 392.696 N
i.e., 392.696 kg*m/s² / 9.81 m/s² = 40.030 kg.
- Work = Force * Stroke
  \[ \text{Work} = 392.696 \times 200 = 78539.2 \text{ N-mm} \]
VIII. FINAL DESIGN

Fig. 8.1: Final CAD Model

Fig. 8.2: Final Project Output

IX. RESULTS AND DISCUSSIONS

As the chosen material is Mild Steel for the framework and the other parts of the body, the material may be subjected to various loads and changes which need to be calibrated accordingly. Below are some of the analyses done on the parts which will be subjected to loads and may be changed due to constant application of the loads.

| Weight Lifted in Kilograms | Time in Hours |
|----------------------------|--------------|
| 50                         | 1            |
| 45                         | 2            |
| 40                         | 3            |
| 35                         | 4            |
| 30                         | 5            |
| 25                         | 6            |
| 20                         | 7            |
| 15                         | 8            |
| 10                         | 9            |

From the above table and graph, 9.3 - it can be observed that by using the manual mode of lifting, there is a decrease in the weight lifting capacity of an operator as the time increases. In other words, the performance of the operator goes on decreasing as the day progresses and at the end of the days, the work done is much less than that of at the start of the day.
| Weight Lifted in Kilograms | Distance Travelled in Meters |
|---------------------------|-----------------------------|
| 10                        | 600                         |
| 15                        | 550                         |
| 20                        | 500                         |
| 25                        | 450                         |
| 30                        | 400                         |
| 35                        | 350                         |
| 40                        | 300                         |
| 45                        | 200                         |
| 50                        | 100                         |

Fig. 9.4: Time vs Weight Lifted through Weight Lifting by Exo-Skeleton

From the above table and graph, 9.4 - we can clearly observe that as time increases, the weight lifting capacity of an operator also increases by using an Exo-Skeleton. By altering the inlet working pressure to the pneumatics, which in turn will make the operator lift heavyweights. This shows us that there will be no reduction in the work carried out by the operator.

Therefore, comparing the above tables and graphs, it can be stated that there are so many drawbacks of Manual mode of weight lifting when compared to the lifting through Exo-Skeleton. In manual weight lifting, the operator will be unable to work continuously throughout the day. The operator suffers from Fatigue Stresses such as body pains, back pains, etc. Because of these reasons, the production may be stopped. Thus, the ideal time of the operator increases, which in turn will lead to a decrease in production and unnecessary wage payments to the labour.

Fig. 9.5: Weight Lifted vs Distance Travelled through Manual Mode of Weight Lifting

Here, from the above table and graph, 9.5 - we can clearly observe that in Manual mode of lifting the weight, there is a drastic decrease in the distance travelled in meters as the carrying weight increases. This shows that the capacity of a human being in travelling long distances with more weight is very less.

Fig. 9.6: Weight Lifted vs Distance Travelled through Weight Lifting by Exo-Skeleton

Here, from the above table and graph, 9.6 - we can clearly notice that in lifting weights by using an Exo-Skeleton, there is no decrease in distance travelled with an increase in weights. In fact, there is an increase in distance travelled. This can be done by increasing the length of the pipe from the air compressor to the Exo-Skeleton body. After increasing the length of the pipe, we can increase the inlet working pressure to compensate the distance and as well as to increase the weight carrying capacity. Hence, by comparing the above tables and graphs, we can say that the Exo-Skeleton is used for weight transferring through long distances without any decrease in the production rate. Whereas by applying
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manual mode of weight lifting, once can only transfer the heavy loads to a certain distance and from there needs other person or any other external help to complete the rest of the distance. This will, in turn, decreases the production rate, giving a loss to the industry.

X. ADVANTAGES
1. Rapid completion of work.
2. Increased production rate.
3. Low maintenance.
4. Air is available in abundance as we will be using the pneumatic mechanism.
5. Used air can be disposed of easily.
6. No cost for raw materials such as Air.

XI. APPLICATIONS
1. In production lines where a worker has to carry heavy items from one end of the shop floor to the other end.
2. In medical fields where a paralyzed person who lost his/her hand or leg can be able to walk or work again.
3. In the military, this Exo-Skeleton is used where the soldiers need to carry heavy equipment for a long-distance and for so much time.
4. Used by firefighters to save civilians.
5. These are even used in construction sites to carry materials from one place to another without the use of any machinery.

XII. CONCLUSION
1) The Exo-Skeletons are classified into active and passive type Exo-Skeletons. These results show how to Design, Analyze, Develop and Manufacture an Exo-Skeleton mainly focusing on the Industrial Usage type. This still requires so many developments as the tests were a constraint to the student level. There are so many ways to develop this prototype model. This shows that the Exo-Skeletons have the capacity to drastically reduce the upper and lower back stress while working, allows a person to walk without any legs and moreover, it accelerates the production line.
2) From the model which we have manufactured, it can be clearly seen that the cost of manufacturing an Exo-Skeleton is less than the wages paid to a human operator.
3) Continuous work can be done by using an Exo-Skeleton when compared to the human operator.
4) The production rate will be increased when compared to normal human work.
5) Damage of the raw material can be prevented by using an Exo-Skeleton.
6) Speed of the raw material can be transferred by using an Exo-Skeleton when compared to the normal work of a human operator. Therefore, the profit of the company will be increased.

XIII. FUTURE ENHANCEMENT
This project is done to be pure mechanical as it is all mechanical inputs and outputs all over. However, this particular Exo-Skeleton can also be given motion by Artificial Intelligence. It is the next major stage of this product. The total Exo-Skeleton can be divided into 3 particular working parts such as the lower Exo-skeleton, the shoulder support Exo-skeleton and the hand supports Exo-skeleton.

(i) There is a wide scope of development that can be done in this sector as this is the future alternative for all the hard work that a person is doing now with great difficulty. This technology can bring a great change in the way work can be done. People’s perspective towards the heavy works to be carried out can be changed completely.

(ii) Making this system very feasible can bring tremendous changes in the Medical Field. These powered Exo-skeletons when attached to the paralysed human limbs, one can observe the movement of the system, simultaneously bringing a movement in the patient’s limbs when grabbed to it and the movements will be similar to that of a normal person can do. This will even act as an exercise tool for the people who suffer from the cease of limb movements.

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