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Development of Pneumatically Powered Upper Body Exoskeleton

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Abstract—A powered Exoskeleton or Exosuit is a wearable mobile machine that is powered by a system of electric motors, pneumatics, hydraulics, or a combination of technologies that allow for limb movement with increased strength and endurance.

This project focuses its efforts on the modeling, basic analysis, development (using CATIA) and testing of a pneumatically powered upper body Exoskeleton prototype which is cost-effective and meant specifically for assistive load-lifting.

The possible applications are numerous and spread across various fields such as in MSME's (Micro, small and medium scale industries, automobile industry, search and rescue operations, transport and logistics, medical industry, construction industry and many other small scale industries.

The team has successfully built a wearable prototype and achieved a lifting capacity of 17kgs per arm. A 5/3 double solenoid valve has been uniquely utilized for intermediate motions of the arms. Further work to improve lifting capacity, mobility, flexibility, controlled synchronized lifting and optimization of the performance of the Exosuit prototype is being contemplated.

Keywords—Exosuit; Pneumatic; Assistive Lifting; 5/3 Double Solenoid Valve; Air Compressor, MSME

I. INTRODUCTION

In general, a device which increases the performance of an able-bodied wearer is called an exoskeleton. A powered exoskeleton is basically a mechatronic system worn by a person. It comprises of wearable components such as a mechanical part, sensors, actuators and a power interface for controlling purpose. Dissimilar to a prosthesis that supplants a part of the human body, an exoskeleton is a wearable device used to restore, assist or improve motor skills of the user wearing it.

Nowadays the elderly population and individuals with limb dysfunction are mounting, medical staffs, caregivers, and medical resources are exceedingly in demand for providing assistance in walking, nursing care and everyday lives.

The registered number of MSMEs in India alone is around 700000. The arduousness of not having automation in Micro, small and medium scale (MSME) industries is a substantial problem. MSMEs follow batch production and are usually low on budget and hire mainly manual labor. A need to find a solution to succor small and medium scale industries is therefore acknowledged. An exoskeleton can be used for assistive load lifting. The workers can wear them during work and reduce burden on their bodies. It is comparatively cheaper and more flexible than a forklift truck and has similar applications.

Proper ergonomic design is obligatory to prevent repetitive strain injuries and other musculoskeletal disorders, which can grow over time and can lead to long-term disability. Ergonomics and human factors are basically concerned with the "compatibility" between the user, equipment and their environments. The user capabilities are identified and limitations in seeking to warrant those tasks, functions, information and the environment for each user.

II. OBJECTIVES OF EXOSKELETON

From the review of relevant literature carried out, it can be summarized that:

- Exoskeletons are advantageous for assistive lifting in industries and can help reduce the burden on the worker.
- The exosuit can be used in medical rehabilitation.
- There are various advanced technologies like electromyography and brain wave techniques which can be used to control the exosuit.
- The main power source that has been used is electrically powered motors or linear actuators.

- The pneumatic system is the safest, most economic and flexible power system and provides plausible power for lifting loads.

Therefore, the objective is to build, and study the incorporation of a powered exoskeleton controlled by signals from the user. The various objectives are:

i. Developing an exosuit having sufficient degrees of freedom for the arm, including releasing/grasping
ii. Setting up easy press of button for the electrical system
iii. Developing arm models for imitating the human arm joints' torques
iv. Using a 5/3 double solenoid valve to control the movement of the exosuit
v. Evaluating the overall performance of the integrated system using standardized arm/hand function tests

The proposed project includes developing an exoskeleton with a good performance which helps disabled subjects suffering from various neurological disabilities, such as muscular dystrophies, stroke, spinal cord injury and other neurodegenerative disorders and assist them to lift various loads without any strain on body or with minimal effort.

III. METHODOLOGY AND ERGONOMICS OF PROJECT

A. Methodology of the Project

i. Study and research on previous attempts
ii. Possible Innovations
iii. Planning based on availability and budget
iv. Basic CAD Drawing and Analysis of beam
v. Procurement of materials
vi. Testing and fabrication of single arm
vii. Attaching arm to main body
viii. Testing with two arms
ix. Final End Product

B. Operating States (Pneumatic Connections)

There are basically two possible operating states for the proposed system. The two states are the following:

1. Individual movement of right and left hand
   - Cylinder connection 1
   - Two 5/3 double solenoid valve required
2. Synchronous movement of hands
   - Cylinder connection 2
   - Only one 5/3 double solenoid valve required

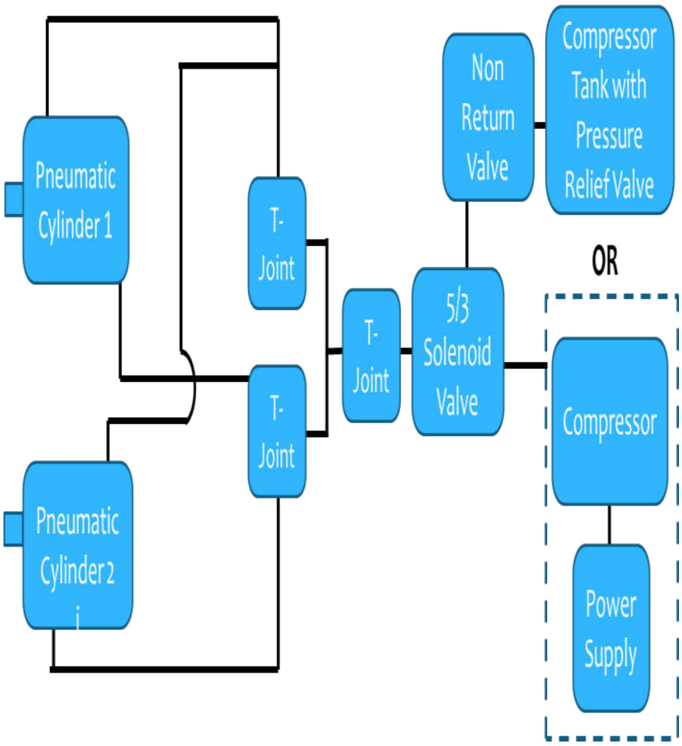

Fig.1: Pneumatic Cylinder Connection 1

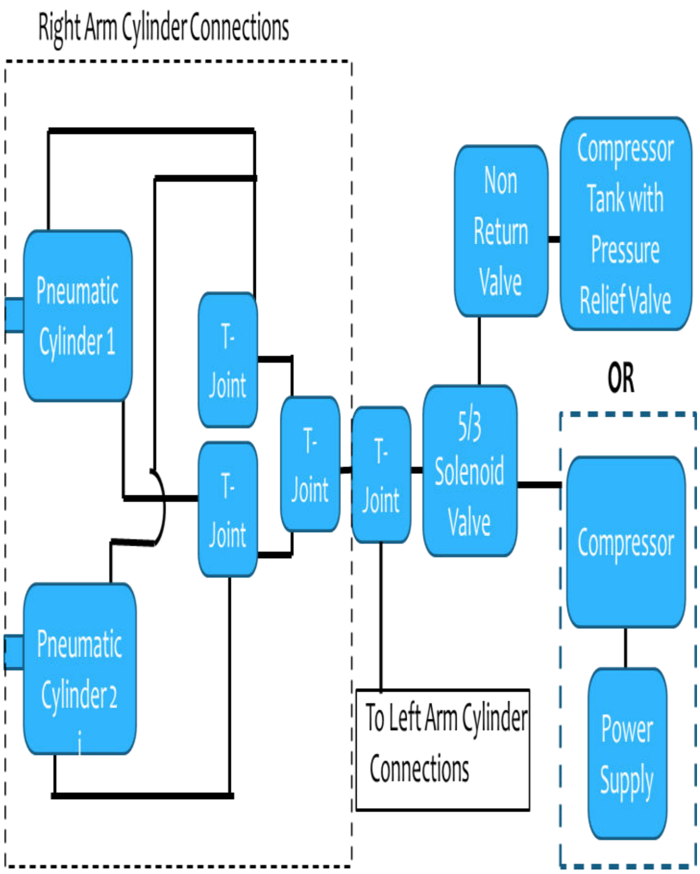

Fig.2: Pneumatic Cylinder Connection 2

C. Ergonomics

The model was made ergonomic to maximum possible extent to ensure easy wearing and use of the exosuit. Various measures were taken in this direction, such as

- A belt strap at waist
- Two arm bands on each arm at upper arm and lower arm
- A cushioned back body
- Cushioned strap which is used to wear the exosuit
- Mellowed or covered edges to ensure safety
- Movement of the arm through intermediate positions to ensure safe movement
- Use of on board pressure regulator
- Switch placement near the thumb fingers
- Hook placement at end of arms

IV. PROJECT WORK DETAILS

A. Components of a Pneumatic System

i. Compressor: Compressed air is generated by using air compressors.
ii. Control Valves: They are used to regulate, control and monitor for control of direction flow, pressure etc
iii. Air Actuator: Air cylinders and motors are used to obtain the required movements of mechanical elements of pneumatic system
iv. Receiver tank: The compressed air coming from the compressor is stored in the air receiver

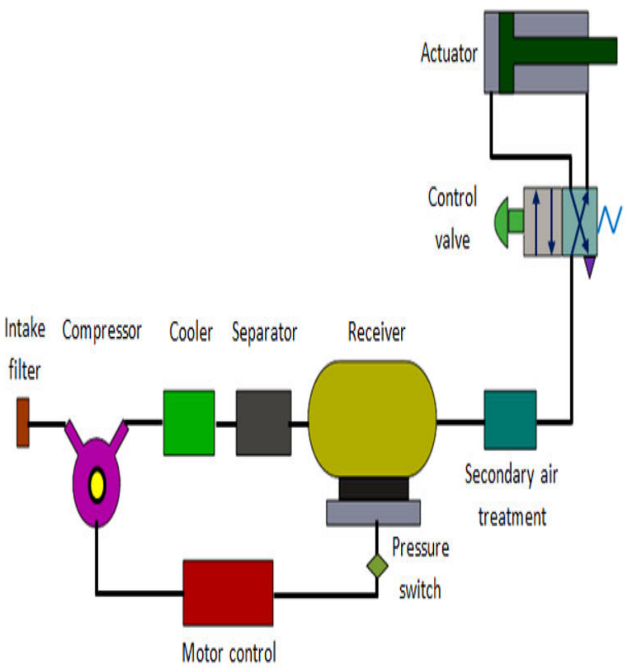

Fig. 3: Components of a Pneumatic System (Google Images)

B. Body Model

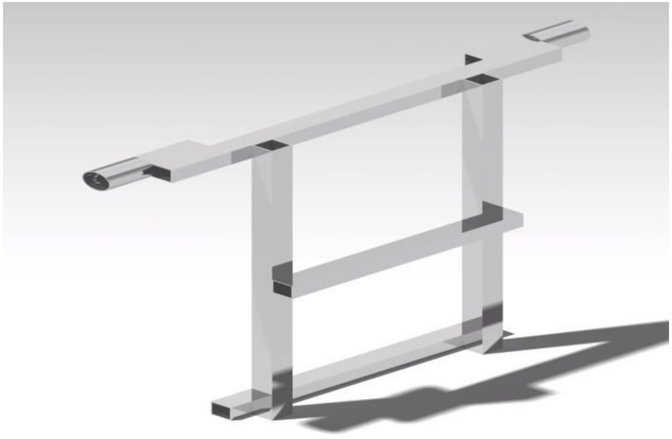

Fig. 4: Body CATIA Design

The model was accepted because:

- The stresses acting at the point intersection were well within the required values.
- This model provided proper back support to the person wearing the exoskeloton.
- It provided enough provision for placing various working components.

C. Arm Model

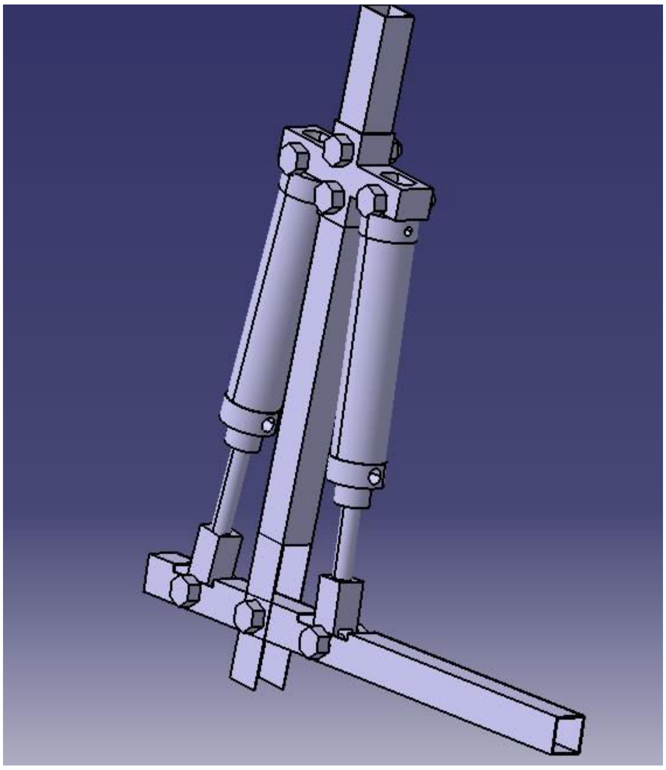

Fig.5: Arm CATIA Design

The arm was finally modeled with two pneumatic cylinders so that it could generate sufficient load carrying capacity at low pressures that are generated by commonly used air compressors.

D. Shoulder Joint

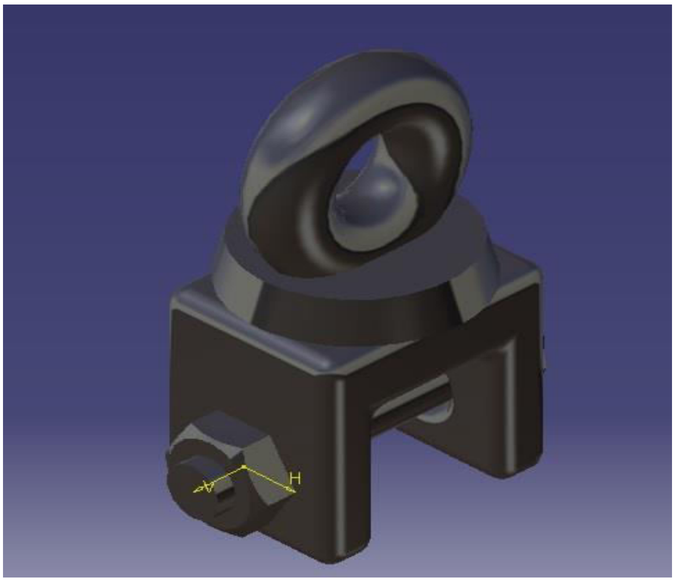

Fig. 6: Shoulder Joint

In order to support human arm-like movement, the above shown shoulder joint was modeled.

E. CATIA Model and Analysis

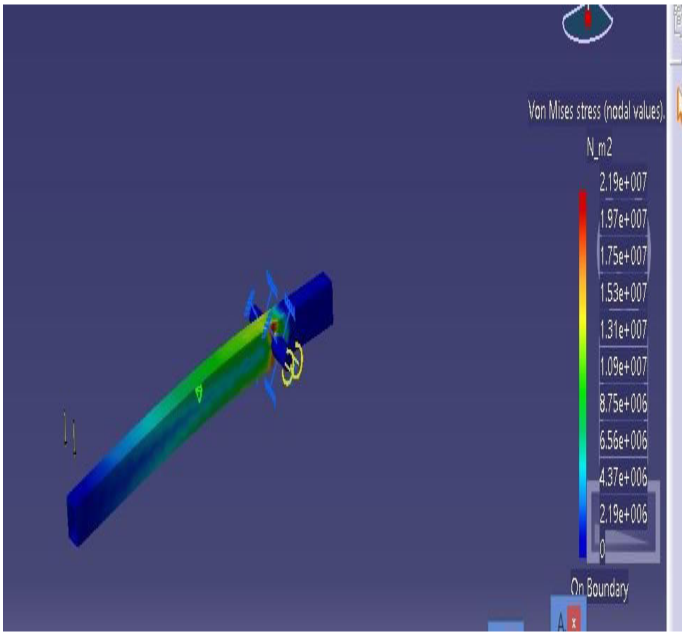

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Fig.7: CATIA Analysis for Lower Arm

Maximum stress possible found through analysis = 2.19×10^7 N/m^2
Aluminum Ultimate Tensile Strength = 3×10^8 N/m^2
Therefore it is Safe for use.

F. Electrical Connections

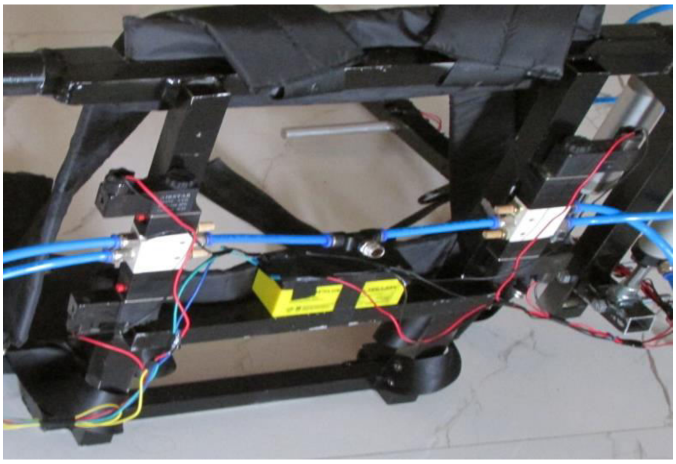

Fig.8: Electrical Connection in Exosuit

V. APPLICATIONS

In the following departments of automotive industries:

- Weld Shop
- Press Shop
- Assembly Shop
- Waste Management Department

i. Search and rescue Operations
ii. Construction Industry
iii. LPG Delivery Services
iv. Packers and Movers
v. Rehabilitation And Medical Treatment
vi. Warehouses
vii. Small Scale Industries

In the preset section of the welding departments of the weld shops, team members are required to perform spot welding to join the lower back to the underbody by operating a welding gun that weighs nearly 10 kg. This arduous task is inconvenient and team members often complain of back pain and discomfort. The proposed upper body exoskeleton suit can eliminate these problems by assisting them to lift the welding gun and reduce fatigue.

Every year around 20 lakh people die around the world because of delay in search and rescue operations. The heavy machinery and crane systems are very rigid and difficult to maneuver to help the victim in time. The use of the proposed exoskeleton suit would certainly be a step in the right direction towards carrying out efficient and timely search and rescue operations.
It is a known fact that the working conditions for masons and construction daily wage workers in India are terrible. Apart from the low wages, they are required to regularly carry and transport very heavy loads (sometimes over 30kg or more) all by themselves. The proposed pneumatically powered exoskeleton suit could alleviate their pains and discomfort by assisting them and reducing the strain they experience.

The door to door delivery of LPG cylinders can be a back breaking task. On an average an LPG cylinder meant for domestic use weighs 14.2kg. All the heavy lifting involved in this delivery and pickup service falls on the shoulders of ordinary men and they could certainly use some help. The proposed exoskeleton suit can assist them in lifting and carrying these cylinders and help prevent health related concerns.

Another sector that remains largely not automated is that of the packers and movers. Transporting furniture and other belongings of customers from one location to another does involve some strenuous effort. The proposed exoskeleton suit can definitely be useful here.

Many people in the world suffer from injuries which cause muscle weakness. For example, one such illness is a genetic condition known as muscular dystrophy. Patients suffering from this illness have limited muscle movement which can result in muscle hypertrophy and muscle pain. The proposed exoskeleton suit could help them during rehabilitation or treatment and empower them to try to lead a normal life.

VI. RESULTS AND DISCUSSIONS

After a number of tests, the exoskeleton was able to lift 35kgs of load easily under a compressor pressure of 120psi. The lifting capacity can be increased by increasing the compressor pressure supplied. The exosuit is built to withstand load up to 100kg without any problem.

Various problems had been dealt with during the project tenure and required knowledge of many mechanical engineering topics such as material science, mechanics of materials, Kinematics of machines etc. to overcome them. Overall, it was a very good learning experience.

Due to the use of 5/3 double solenoid valves, the achievement of intermediate positions and discrete motions of arm were also made possible. The movement is more difficult to control at very high compressor pressures. The arms are controlled by operating push-button switches provided near the wrist portion.
YouTube exosuit project working video link: - https://www.youtube.com/watch?v=qD3BgmOvlwQ

Fig. 9: Completed Model of the Proposed Exoskeleton

VII. CONCLUSIONS

i. A wearable prototype was made which can be adjusted to the user size accordingly
ii. The model is made keeping ergonomics in mind
iii. Safety was given foremost importance
iv. A test was conducted by lifting 350N with a compressor pressure of 120psi
v. No user effort was required to lift the load
vi. Load was equally distributed on the upper body through the exoskeleton

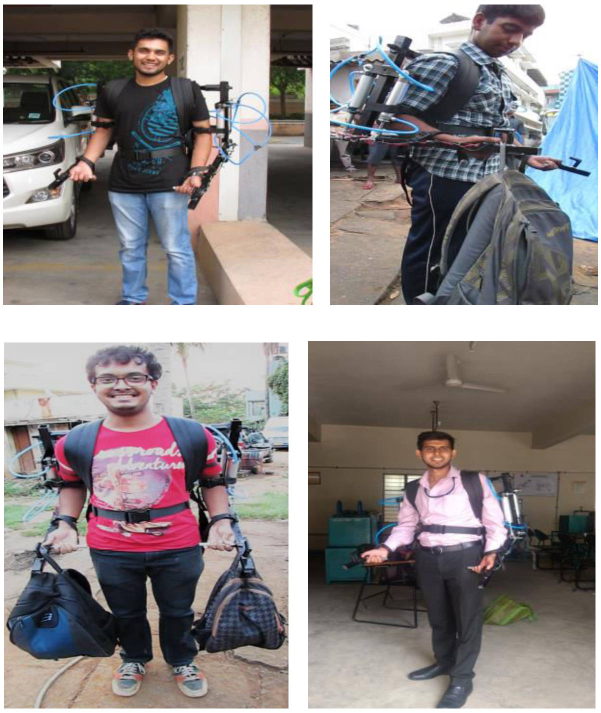

Fig. 10: Members Wearing Exoskeleton

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VIII. SCOPE FOR FUTURE WORK

i. A lower body exoskeleton connected to main body.
The addition of lower body to the upper body will help in transferring the weight to the ground. As a result the user will not be able to feel the weight of body and load being carried. A similar design using pneumatic systems could be used to assist the leg movements.

ii. Actuator control using brain waves.
The advent of new technology has given rise better and effortless control systems. Brain waves can be used to control the exoskeleton movements. The user can wear the headgear and control the exosuit through thoughts.

iii. Actuator control using Electromyography Control (EMG)

iv. High capacity and miniaturized power supply.
The lack of technology in miniaturized high capacity power sources is a major drawback for powering the exosuit. More research and development is required in this field to improve the power to weight ratio of the exosuit.

v. More freedom of motion.
There should be no restrictions for the user while wearing the exosuit. It should be more flexible and less strenuous during various movements.

vi. Stronger and lighter materials.
The material of the exosuit has to be lightweight and stronger to be able to lift heavy loads without failure.

vii. Investment in innovative control technologies
There should be more emphasis and investment given on developing more innovative and cheaper control technologies.

IX. ACKNOWLEDGMENT

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