Design and Analysis of Pneumatic Exo-Skeleton Arm

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Abstract - *A wearable mobile device known as an Exoskeleton or Exposit is powered by a system of electric motors, pneumatics, hydraulics, or a mix of technologies that enable limb movement with greater strength and endurance. The pneumatically powered upper body Exoskeleton prototype being developed for assistive load-lifting is the main emphasis of this project, which also focuses on modelling, basic analysis, development (using Solid works), analysis (using ANSYS), and testing. There are a wide range of potential applications, including those in MSMES (Micro, Small and Medium Scale enterprises), the automobile industry, search and rescue operations, transportation and logistics, the medical industry, the construction industry, and many other small-scale enterprises. A powered exoskeleton, also known as power Armour, powered Armour, powered suit, exo frame, hard suit, or exosuit, is a wearable mobile machine that is powered by a system of electric motors, pneumatics, levers, hydraulics, or a combination of technologies that enable limb movement with increased strength and endurance. Its construction seeks to support the back, detect user motion, and communicate with the motors that control the gears. While reducing back strain, the exoskeleton supports the shoulder, waist, and thigh and facilitates movement for lifting and handling big objects. To lessen effort and exhaustion, exoskeletons shift weight from one part of the body to another, such as the core and waist.*

Key Words: Exoskeleton, Pneumatic Exoskeleton, Structural Analysis

1.INTRODUCTION

In order to move the limb with greater strength and endurance, powered exoskeletons are portable, mobile machines that are powered by a system of electric motors, pneumatics, levers, hydraulics, or a combination of technologies. The exoskeleton provides shoulder, waist, and thigh support, facilitates movement for lifting and handling big objects, and lessens back strain. Exoskeletons transmit weight from one part of the body—such as the arms and shoulders—to another—such as the core and waist—to lessen strain and exhaustion.

1.1 Classification of Exoskeletons

Several feasible exoskeleton types are suggested by the broad categorisation. Due to the vast variety of exoskeletons that exist and the differences between them in terms of construction, body part targeted, action, power technology, purpose, and application area, these categories have generic classes.

Exoskeletons can be made more broadly for only one hand, one leg, or even the entire body. They are not just made for certain body parts. The division of classes therefore illustrates the most typical body portion for which exoskeletons can be constructed. Exoskeletons designed to support all of the limbs or the majority of the body are classified as full-body exoskeletons. The exoskeletons for the upper limbs that cover the chest, head, back, and/or shoulders are referred to as the upper body. The lower body category includes exoskeletons designed for the thighs, lower legs, and/or hips. Exoskeletons classified as rigid have rigid structural parts that are attached to the user's body. Metals, polymers, fibres, etc. are examples of such materials. Contrarily, soft exoskeletons, often referred to as exosuits, are constructed from materials that permit the structural elements to move freely. Although not exclusively, fabrics are frequently used to create exosuits.

Exoskeletons are classified into active and passive action under the action category, which outlines the kind of assistance the device offers to the wearer. Exoskeletons that provide "active" assistance to the user are classified as belonging to the active class; in other words, they carry out the actions without the user having to exert any energy.

1.2 Working of Pneumatic Exoskeleton

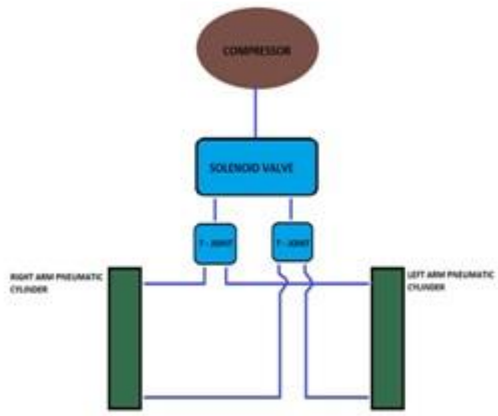

Fig -1.1: Block diagram of the Pneumatic Exoskeleton

The main parts of a pneumatic Exoskeleton suit are: -

1. Compressor unit
2. Solenoid valve
3. Double-acting cylinders
4. Frame

The pneumatic cylinders, solenoid valves, and joints that offer each part varying degrees of freedom enabling simple motion for the person wearing it are entirely responsible for the exoskeleton's operation. The cylinder is made to work by the compressor's air, which also aids in lifting the weight.

The solenoid valve receives air from the compressor and, depending on the position of the forearm, either expands or contracts the cylinder rod. A dc source and a switch button are used to operate the solenoid valve. The forearm revolves around the pivot point as a result of the cylinder rod's extension and contraction.

The pneumatic cylinder is mounted to the frame using cylinder mountings. Air enters the cylinder when the forearm is in the lower position, forcing the rod to lengthen. The forearm rotates around the pivot as a result of the force generated by the rod's extension, lifting the weight.

1.3 Objectives

Designing and analysing a pneumatically powered exoskeleton that can be controlled by signals from the user is the goal. The following are the many goals.

1. To calculate the bore size and stroke of the Pneumatic cylinder required to lift the load.
2. To calculate the stress-induced and total deformation in the frame and the material that can be used.
3. Using a 5/3 double solenoid valve to control the movement of the Exo-arm.
4. 3D Modelling of the Exo-arm using Solid Works and using ANSYS for numerical analysis.
5. Evaluating the overall performance of the integrated system using standardized arm/hand function tests.

2. LITERATURE SURVEY

Abdulla AL Momani et al. provided an overview of the pneumatic exoskeleton idea, including its advantages, the theoretical foundation of exoskeletons, and the design process. Steel and aluminium were primarily used to construct the exoskeleton arm construction. A group of fluidic muscles supplied the power system [1]. The use of robotic exoskeletons in upper limb rehabilitation was studied by Boris et al. (2014). They provided an overview of the rehabilitation robotic system's architecture and key components as well as its use in rehabilitation [2]. In their 2007 study, Michael Scott Liszka et al. exclusively considered the design of an exoskeleton for shoulder rehabilitation. They suggested design, kinematics, actuators, gearbox, and mechanical analysis processes [3]. Simone Marcheschi et al. (2011) conducted research on the kinematics and dynamic properties required for a full-body wearable robot with power augmentation that is capable of lifting large things. Bowden cable-based mechanical structure and actuator design for the upper limb soft exoskeleton was proposed by Conor James et al. in 2006. The delicate exoskeleton is very light and barely scrapes skin [4]. Kazeroni, H., et al Additionally, the wearer of this soft exoskeleton is free to move through their whole range of motion without any theoretical restrictions [5]. The study conducted by de la Tejera et al. (2020) offered details on metabolic analyses and human body joints that are used to create exoskeleton joints that mimic human natural joints. For this hip and knee exoskeleton, they had created a state machine control technique based on joint angle and ground exoskeleton force detection [6].

3. DESCRIPTION OF THE COMPONENTS

3.1 Pneumatic System

Pneumatic technology focuses on the analysis of compressed air's behaviour and uses in several aspects of daily life, including manufacturing automation. Air is a resource that is widely available and can be vented into the atmosphere through pneumatic systems once the activity at hand has been finished.

3.2 Basic components of Pneumatic System

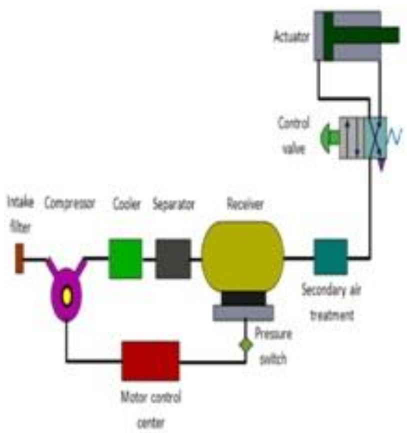

Fig -3.1: Components of a Pneumatic System

Important components of a pneumatic system are shown in Figure 3.1 are:

a) Air filters: These are used to filter out the contaminants from the air.

b) Compressor: Compressed air is generated by using air compressors. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressors may be used.

c) Air cooler: During compression operation, air temperature increases. Therefore, coolers are used to reduce the temperature of the compressed air.

d) Dryer: The water vapor or moisture in the air is separated from the air by using a dryer.

e) Control Valves: Control valves are used to regulate, control, and monitor for control of direction flow, pressure, etc.

f) Air Actuator: Air cylinders and motors are used to obtain the required movements of mechanical elements of the pneumatic system.

g) Electric Motor: Transforms electrical energy into mechanical energy. It is used to drive the compressor.

h) Receiver tank: The compressed air coming from the compressor is stored in the air receiver.

i) These components of the pneumatic system are explained in detail in the next pages.

3.3 3D Modelling

The Three-Dimensional CAD models of the chassis are designed based on the requirements using SOLID WORKS.

4. INTRODUCTION TO SOLIDWORKS

Solid Works is a computer programme developed by Dassault Systems for use with solid modelling in computer-aided design (CAD) and computer-aided engineering (CAE).

Solid Works is a 3D mechanical CAD programme that runs on Microsoft Windows. It was created by the USA-based solid works corporation, a salt systems subsidiary. Solid Works gives engineers, designers, and other creative professionals the resources they need to create the best things ever.

SolidWorks is a solid modeller that builds models and assemblies using a parametric future-based method that was first developed by PTC (Creo/Pro-Engineer). Software is created using the Parasolid-kernel platform.

The shape or geometry of the model or assembly is determined by the values of the parameters, which are constraints. In addition to geometric terms like tangent, parallel, concentric, horizontal, and vertical, parameters can also be numerical terms like circle or line diameters. Through the application of relations, it is possible to link together numerical parameters and convey design intent.

How the part should react to updates and modifications is outlined in the design intent. For instance, you would like the hole at the top of a beverage can to remain there no matter how tall or large the container is. No matter what height the user later gives the can, SolidWorks allows the user to indicate that the hole is a feature on the top surface and will thereafter obey their design intent.

The components of the feature are referred to as features. The part is built using these operations and forms. Typically, shape-based features start with a 2D or 3D sketch of shapes like bosses, holes, slots, etc. The material is then added to the portion or removed by cutting this shape. Features like fillets, chamfers, shells, applying draught to a part's faces, etc. are examples of operation-based features that are not sketch-based.

4.1 Creating Parts

Each chassis component—the side and cross members—was constructed using the SOLIDWORKS programme as a separate element. As a result, creating 2D sketches is typically where SOLIDWORKS model creation begins. Points, lines, arcs, conics, and splines are among the geometric elements present in the sketch. The geometry's size and location are specified by adding dimensions to the sketch. Attributes like concentricity, parallelism, perpendicularity, and tangency are defined through relations.

ARM:

Fig -4.1: Arm

FOREARM:

Fig -4.2: Fore-Arm

FORK-END:

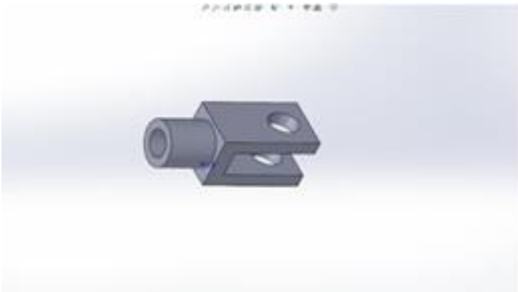

Fig -4.3: Fork End

MALE CLEVIS:

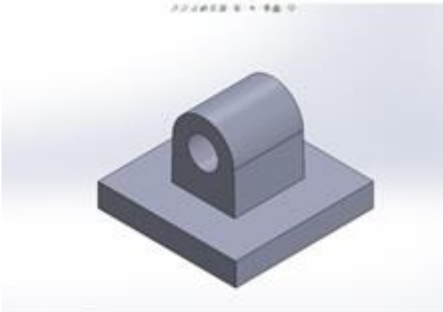

Fig -4.4: Male Clevis

BACK:

Fig -4.5: Back Design

4.2 Making Assembly

As illustrated in the pictures, an assembly was created after each item and subassembly had been finished. The equivalents of sketch relations in an assembly are called mates. Assembly mates create equivalent relations with respect to the individual parts or components, enabling the simple creation of assemblies, just as sketch relations define sketch geometry's sketch geometry's tangency, parallelism, and concentricity criteria.

CYLINDER:

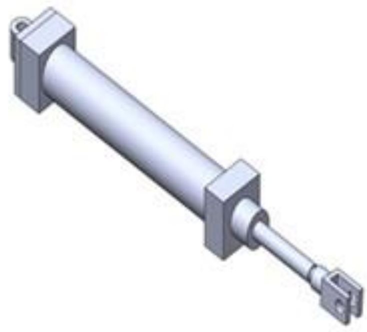

Fig -4.6: Cylinder

CYLINDER AND ARM ASSEMBLY:

Fig -4.7: Cylinder and Arm Assembly

FINAL ASSEMBLY:

Fig -4.8: Final Assembly

5. ANALYSIS USING ANSYS

The finite element solver ANSYS was used to do an analysis of the model made in SOLIDWORKS. A software programme for FEA, or finite element analysis, is called ANSYS.

A complex system can be broken down numerically into very tiny (and user-specified) bits, or elements, using finite element analysis. Equations governing the behaviour of various components are implemented by the software, which then solves them all to produce a thorough explanation of how the system functions as a whole. These outcomes can then be displayed in tabular or graphical formats. When designing and optimising a system that is too complicated to analyse manually, this form of analysis is frequently used. Systems that would fall under this heading are unsuitable because of their geometry, size, or governing equations. The preferred FEA teaching resource in mechanical engineering is ANSYS.

5.1 Generic Steps for Solving any Problem in ANSYS

➢ Build Geometry

Construct a two- or three-dimensional model of the object using a work plane coordinate system within ANSYS. The model of the object created in SOLIDWORKS may also be directly implemented in the ANSYS geometry modeler.

➢ Define Material Properties:

Now that the part exists, define a library of necessary materials that compose the object modelled. This includes mechanical and thermal properties.

➢ Generate Mesh:

At this point, ANSYS understands the makeup of the part. Now define how the modelled system should be broken down into finite pieces.

➢ Apply Boundary Conditions:

Once the system is fully designed, the next task is to burden the system with constraints, such as supports and physical loadings.

➢ Obtain Solutions:

This is actually a step because ANSYS needs to understand within what state (Steady, transient state…etc.) the problem must be solved.

➢ Present the Results:

After the solution has been obtained, there are many ways to present ANSYS results, choose from many options.

5.2 Static Structural Analysis of ARM

Static Analysis Definition By neglecting inertia and damping effects, such as those brought on by time-varying loads, a static analysis determines the effects of stable loading conditions on a structure. However, a static analysis can take into account time-varying loads that can be approximated as static equivalent loads, such as the static equivalent wind and seismic loads that are frequently specified in many building codes, as well as stable inertia loads (such as gravity and rotational velocity).

The following are the findings from an analysis done on steel using ANSYS in terms of equivalent stress, von-Mises stress, and total deformation.

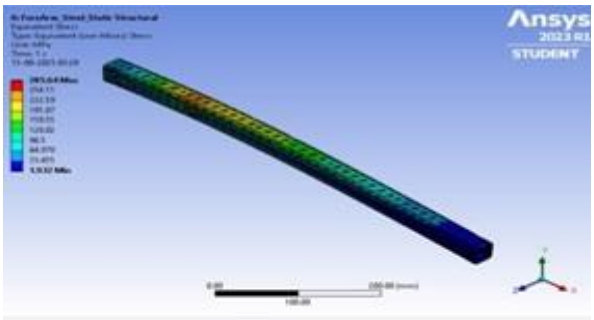

Fig -5.1: Von mises stress (structural steel)

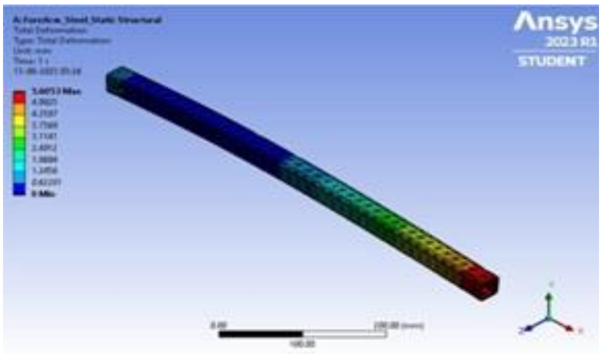

Fig -5.2: Total Deformation (structural steel)

The following results obtained from analysis performed on Aluminium material on ANSYS in Equivalent stress or Von-Misses stress and Total Deformation.

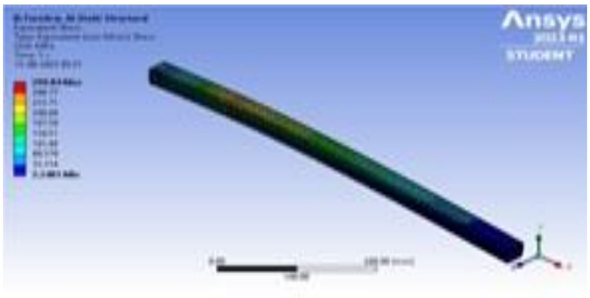

Fig -5.3: Von mises stress (Aluminium)

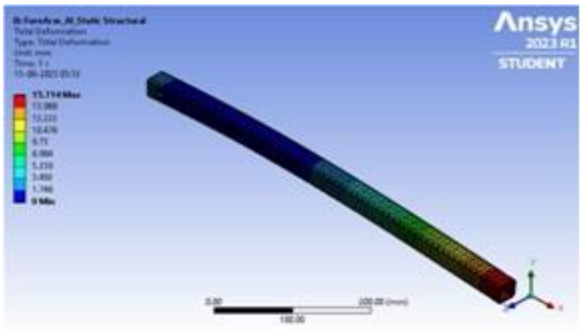

Fig -5.4: Total Deformation (Aluminium)

The following the results obtained from analysis performed on Carbon Fiber material on ANSYS in Equivalent stress or Von-Misses stress and Total Deformation.

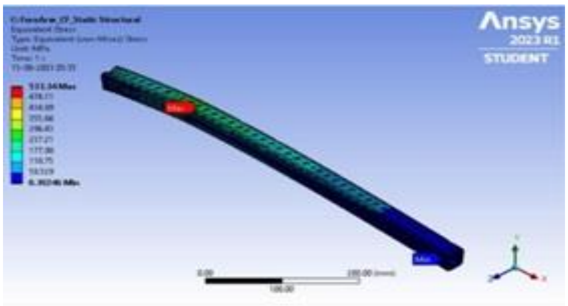

Fig -5.5: Von mises stress (Carbon Fiber)

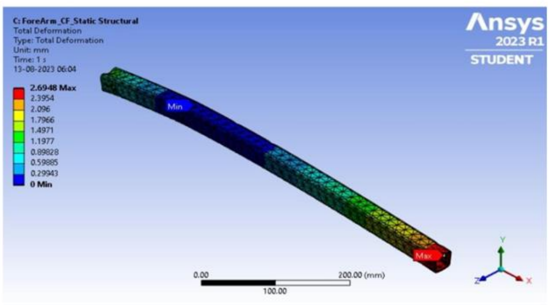

Fig -5.6: Total Deformation (Carbon Fiber)

Based on the studies done above on several materials, including steel, aluminium, and carbon fibre. The carbon fibre, which has a Von-Misses stress maximum of 533.34 MPa and a maximum total deformation of just 2.6948mm, is the most efficient of the materials mentioned above.

5.3 Rigid Analysis

We talked about using implicit and explicit approaches to solve rigid body dynamics problems in order to determine how structures respond to dynamic loads. The results included things like deformation, stress, and strain. The cost of computation to solve problems in large-scale and long-duration dynamics is substantial.

Ansys was used for rigid body dynamic simulation. The setup entails applying loads to the entire model in five steps. The Ansys mechanical programme that was necessary to run the simulation contained all the joints and connections that were needed. To mimic a real-world situation, standard earth gravity was also added. The bar deforms as it moves down in the first phase, returns to its original position, advances up, and finally moves back to its original position again, as shown in the image below, which is the outcome of the analysis.

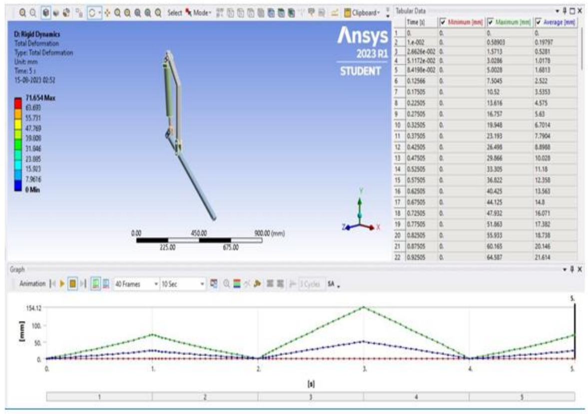

Fig -5.7: Rigid Dynamics

The arm's acceleration as it goes higher is depicted in the image below. The arm's acceleration as it travels up was studied in this scenario, which only took into account one step.

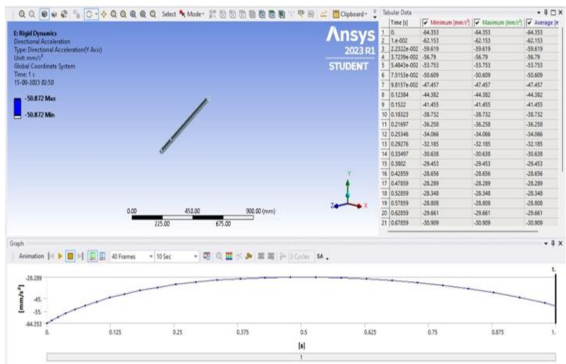

Fig -5.7: Directional acceleration

6. APPLICATIONS

6.1 Medical

Powered exoskeletons enable system-assisted walking, which can enhance the quality of life for those who have lost use of their legs. Exoskeletons might potentially be useful for ageing, spinal cord damage, and stroke recovery.

Healthcare, namely nursing, could be another form of application. Exoskeletons were created by numerous Japanese engineers to assist nurses in lifting and carrying patients due to the paucity of medical personnel and the rise in the number of persons requiring geriatric care.

6.2 Civilian

Exoskeletons are being developed to make stair climbing easier for firefighters and other rescue personnel.

Due to a delay in search and rescue efforts, almost 20 lakh people worldwide perish every year. Heavy equipment and crane systems are exceedingly inflexible and challenging to manoeuvre in order to quickly assist the sufferer. Utilising the proposed exoskeleton suit would undoubtedly be a positive step towards conducting effective and timely search and rescue operations.

6.3 Military

Exoskeletons can enhance a war fighter's present physical capabilities by allowing them to lift greater loads, run quicker, and reduce physical stress.

A soldier might lift heavy goods while jogging or ascending stairs, which is one of the principal uses for an exoskeleton. Soldiers are also capable of using stronger weapons and armour. Most versions now use a hydraulic system that is managed by an on-board computer. An internal combustion engine, batteries, or fuel cells can all power them.

6.4 Industry

The automobile sector is using passive exoskeleton technology more and more in an effort to reduce worker injuries (particularly to the shoulders and spine) and fatigue-related mistakes. Their potential for application in logistics is also being considered. There are about 700000 MSMEs that are officially registered in India alone. A major issue is how difficult it is for Micro, Small, and Medium-Sized (MSME) industries to operate without automation. MSMEs use batch production, have small budgets, and primarily employ manual labourers. This acknowledges the need for a solution to support small and medium-sized businesses. In order to lift loads with assistance, an exoskeleton can be used. They can be worn by the employees as they work to lessen the strain on their body. It has similar applications as a forklift truck but is cheaper and more adaptable.

6.5 Skeleton

Early exoskeletons were made of inexpensive, lightweight metals like steel and aluminium. The powered exoskeleton's efficiency is decreased because of the heavier weight of steel and the more effort required to overcome it. Although lightweight, aluminium alloys quickly wear out and fail. The strength to weight ratios of carbon nanotubes, carbon fibre, and fibreglass are significantly higher. Exoskeletons that are "soft" and that can be attached to flexible clothes with motors and controls are also being developed.

6.6 Actuators

Joint actuators must also contend with the difficulty of being both light and strong. Utilised technologies include electronic servomotors, hydraulic cylinders, and pneumatic activators. To imitate the control of limb stiffness and to offer touch perception, elastic actuators are being researched. Also utilised to improve tactile feedback is the air muscle, also known as a braided pneumatic actuator or McKibben air muscle.

6.7 Joint Flexibility

Traditional "hard" robots' rigid anatomy presents a design challenge. Human joints with the centre of rotation inside the body, such the hips and shoulders, include ball and socket joints. Since no two people are precisely same, it is impossible to completely imitate the degrees of freedom of a joint. As an alternative, the exoskeleton joint is frequently depicted as a set of hinges with one degree of freedom for each of the major rotations. Since the spine is essentially a stack of ball joints with restricted motion, spinal flexibility is a problem as well. No straightforward arrangement of external single-axis hinges can match the whole range of motion of the human spine. Devices frequently include the capacity to correct misalignment with additional degrees of freedom due to the difficulty of exact alignment. Some of these problems are addressed by soft exoskeletons, which bend with the body.

6.8 Power Control and Modulation

An effective exoskeleton should support its wearer, for instance by lowering the amount of energy needed to complete a task. A standardised device has trouble offering the proper amount of assistance at the right moment due to individual variances in the type, range, and force of motions. The creation of control parameter tuning algorithms to automatically optimise the energy cost of walking A few well-known instances of "neuro-embodied design" have also been used to provide direct input between the human nervous system and motorised prosthesis.

6.9 Adaptation to User Size Variations

Exoskeletons must either be adaptable or tailored to specific users because humans have a broad range of physical size disparities in terms of both skeletal bone lengths and limb and torso girth. This may be addressed in military applications by requiring the user to be of an acceptable physical size in order to receive an exoskeleton. Due to the difficulties in fitting extremely large and very small individuals into seats and controls, physical body size constraints already exist in the military for occupations like aircraft pilots. This is less of an issue with soft exoskeletons.

6.10 Health and Safety

Exoskeletons can lessen the strain of manual labour, but they could also be dangerous. The US Centres for Disease Control and Prevention (CDC) have requested research on the possible risks and advantages of the technology, pointing out potential additional risk factors for workers such a lack of mobility to dodge a falling object and probable falls due to a shift in centre of gravity.

7. CONCLUSIONS

The design and study of an affordable, straightforward, and pneumatically driven upper limb exoskeleton for weightlifting are the focus of our project.

We employed a 5/2 dc powered usually open solenoid valve in the proposed design, which will allow us to lift a load of 80 kg. lve to regulate the 50mm-diameter, 180mm-stroke pneumatic cylinders. The frame has a cross-section of a hollow square bar measuring 30*30*2mm, is made of structural steel, has a 210MPa Youngs modulus, and a 450MPa ultimate tensile strength. Our project is relevant in industry, the military, and rescue efforts in addition to weightlifting. Due to the maximum load carried by this pneumatic system, it forces people with physical disabilities to carry weights in their daily lives.

8. FUTURE SCOPE OF THE PROJECT

1. A connection between the main body and a lower exoskeleton. Transferring the weight to the ground will be aided by the addition of the lower body to the upper body. Because of this, the user won't be able to feel the weight of their own body or the load they are carrying. The leg movements could be aided by a similar design utilising pneumatic systems.

2. Employing brain waves to control an actuator. Better and simpler control systems are now possible because to the development of new technology. Movements of the exoskeleton can be regulated by brain waves. The helmet allows the user to mentally operate the exosuit while wearing it.

3. Electromyography Control (EMG) is used to control actuators.

4. Miniaturised power supply with high capacity. One major problem with powering the exosuit is the absence of technology in miniature high-capacity power sources. To increase the exosuit's power to weight ratio, more study and development are needed in this area.

5. More freedom of movement. While using the exosuit, the user shouldn't be subject to any limitations. During varied movements, it ought to be more elastic and less taxing.

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

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

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