DESIGN AND FABRICATION OF LOWER LIMB EXOSKELETON

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ABSTRACT: Exoskeletons are defined as standalone anthropomorphic active mechanical devices that are worn by an operator and work in concert with the operator's movements. Exoskeletons are mainly used to increase performance of able-bodied wearer, and to help disabled people to retrieve some motion abilities. The idea of this study is to develop a portable device capable of providing knee-joint mechanical assistance during walking without using external power from onboard actuators (i.e. an 'energy-neutral' solution).We hypothesized that a passive wearable device using pneumatic damper during walking cycle which is capable of recycling a significant portion of knee joint mechanical work and could reduce the metabolic activity of walking.

The constructional goals and features of each and every components used have been considered for its light weight, durability, portable framework without motors or an external energy source to provide an ease in gait cycle. We set out to develop a passive 'energy neutral' system with following key design objectives:

1. Provide support to the knee joint following a pattern similar to the normal joint moment during walking.
2. Recycle damping energy provided by the pneumatic damper during the gait cycle.

Keywords: Achilles tendon, Actuators, Dampers, Exoskeleton, Gait Cycle, Pneumatic Piston.

I. INTRODUCTION

An Exoskeleton is a wearable mechanism, usually with an anthropomorphic configuration, capable of tracking the movements of the user's extremities. In most applications, exoskeletons are designed to produce forces that assist the user in performing a motor task. Different types of lower-limb exoskeletons and powered orthosis are currently being developed as tools for gait rehabilitation and mobility assistance. Gait trainers are exoskeletons designed for physical therapy and neuro-rehabilitation. Another category is formed by autonomous wearable exoskeletons for human force augmentation .A common application for such devices is increasing the load-carrying capabilities of the user. A general goal in the design of lower-limb exoskeletons should be reducing the metabolic cost of walking. These have applications for military and service personnel as well as for patients with physical impairments. They also have the ability to reach the terrain where wheels vehicles cannot reach. Exoskeletons allow people to run farther, jump higher and bear larger loads while expending less energy and hence reducing metabolic activities. The leg exoskeleton mechanism is portable, wearable and adjustable for patients doing home rehabilitation training. Through using the finite element software (ANSYS), the main components of the leg exoskeleton are studied by force simulation analysis. And it shows that the exoskeleton device have the ability to resist deformation and sustain patients' fingers to implement rehabilitation training. The gait cycle begins when one foot contacts the ground and ends when that foot contacts the ground again. Thus, each cycle begins at initial contact with a stance phase and proceeds through a swing phase until the cycle ends with the limbs next initial contacts.

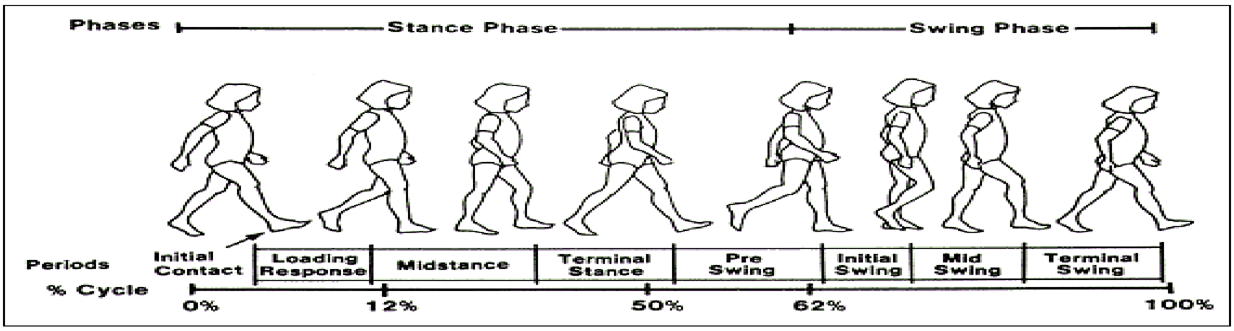

FIG.-1.1 GAIT CYCLE

1.1 MOTIVATION

The disable persons have been increased significantly. More than 10 percent of the world population disable persons have spinal cord injury, which are unable to control their lower part of body. Those spinal cord injured persons always stay in the same posture, or normally use wheelchair for their movements. Lacking of mobility for a long time can contribute medical complications, such as, pressure sore, atrophy, joint stiffness and thrombosis. Moreover, psychological problem can be occurred in the same group of patients. To relieve the symptoms, several procedures of physical therapy for rehabilitation have been treated to the patients. The progression of science and technology is presenting the robotic exoskeleton to be an alternate rehabilitation device, which also increases the patient’s mobility.

1.2 OBJECTIVE

1.2.1 PRIMARY OBJECTIVE

To develop a portable exoskeleton for mechanical assistance during walking without using external power from onboard actuators.

1.2.2 SECONDARY OBJECTIVE

- The device we set out to build should be light weight, portable and user friendly.
- The device should not hamper normal gait cycle of an individual but should only enhance it.

II. DESIGN PROCEDURAL OF EXOSKELETON

The Exoskeleton was designed and modeled virtually on 3D-Designing software Catia-V5 with a solution to shape design, styling, surfacing workflow and visualization to create, modify, and validate design.

2.1 FRAME DESIGN

The Frame of the exoskeleton was designed by keeping the following parameters:-

- Design has to be low in weight.
- Design should be wearable and portable.
- Design should not create problem in normal Gait cycle but should enhance it.
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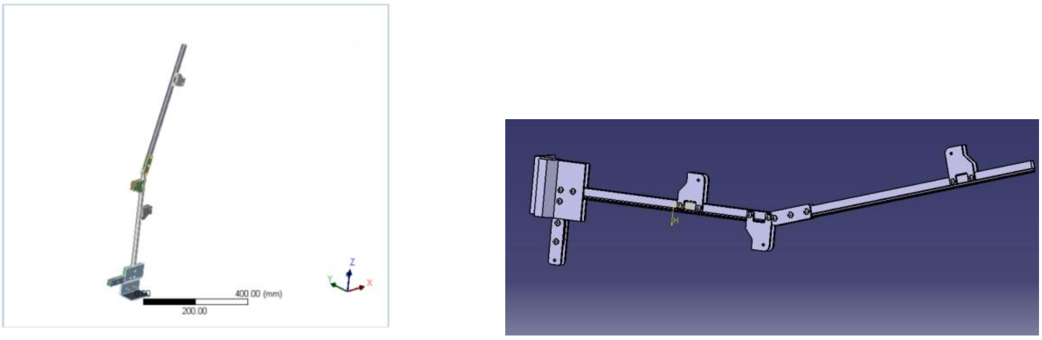

FIG-2.1 FRAME DESIGN

2.2 DAMPER SELECTION

2.2.1 SPRING DAMPER DESIGN:-

FIG-2.2.1 SPRING DAMPER DESIGN

- Spring was considered as a damper in the exoskeleton as it has properties same as the Achilles tendon in our legs.
- The Achilles tendons is a tough band of fibrous tissue that connects the calf muscles to the heel bone and pulls the heels for natural moment, this moment allows us to stand on our toes when walking, running or jumping.
- The spring acts as a recoil moment while walking and assists the Achilles tendons which is vulnerable to injury, due to its limited blood supply and the high tensions placed on it.
- But spring has shortcoming because it gives the recoil moment at a time and doesn't assists Gait cycle.
- One more shortcoming of spring is it gets loose when used continuously.
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2.2.2 PNEUMATIC DAMPER DESIGN:-

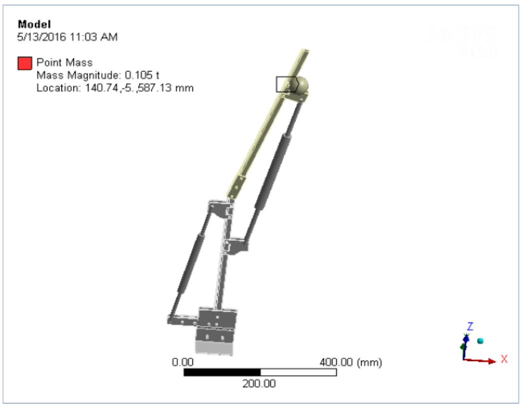


FIG-2.2.2 PNEUMATIC DAMPER DESIGN

- Pneumatic cylinder was considered as a damper in the exoskeleton as it has properties same as the Achilles tendon in our legs, has properties better than spring.
- The pneumatic cylinder acts as a recoil moment while walking and assists the Achilles tendons, supports the knee joint and carries the body.
- The shortcomings of spring of the recoil moment at a time is compensated by slow recoil of the damper when it retracts back slowly and gives continuous support to the leg movement and knee joint.
- The shortcoming of spring is it gets loose when used continuously is totally compensated by the pneumatic damper as the air pressure is constant and cylinder is leak proof.
- The pneumatic damper has better load carrying capacity then spring damper.

III. WORKING & METHODLOGY

3.1 WORKING MODEL

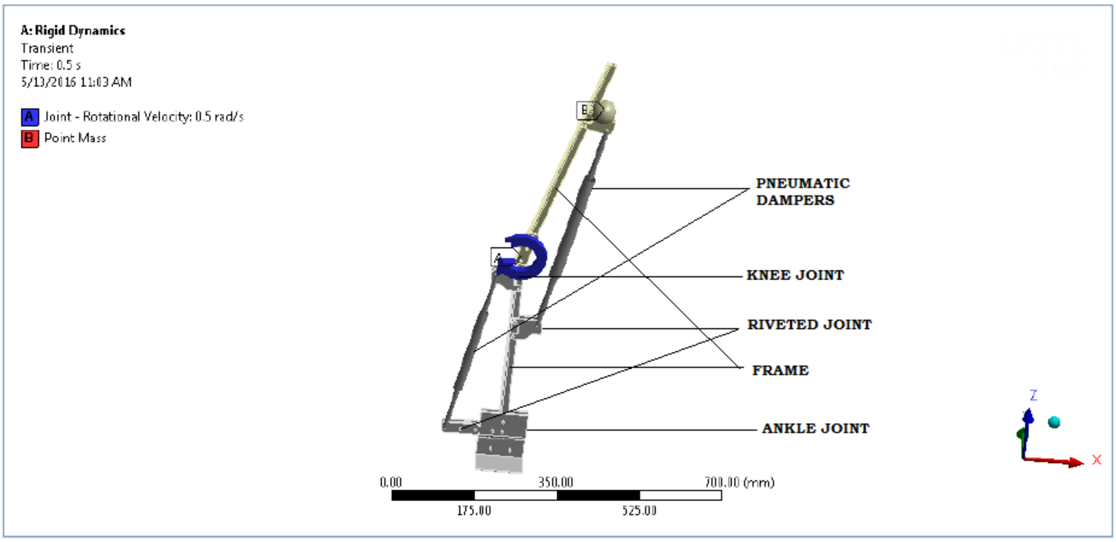


FIG-3.1 WORKING MODEL

3.2 DAMPING STRUCTURE

While walking the whole forces acts on the hip joint, knee joint and ankle joint. There is an impact force acting on the knee joint each time leg movement is there. So the pneumatic pistons (damper) are incorporated on the exoskeleton which gives damping effect to the force and directly reduces the load and force acting on the leg. The main area of work of damper is on the knee and the ankle as these are the area where most of the ruptures and injuries are caused. The cushioning effect of the recoil of the damper take away the force(30%) from the legs hence reducing metabolic activities and giving an aid in walking and load carrying.

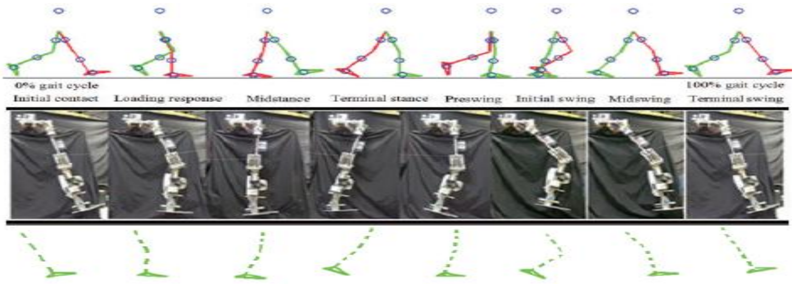


FIG-3.2 GAIT CYCLE WITH EXOSKELETON

3.3 STRUCTURAL SUPPORT FOR LEG

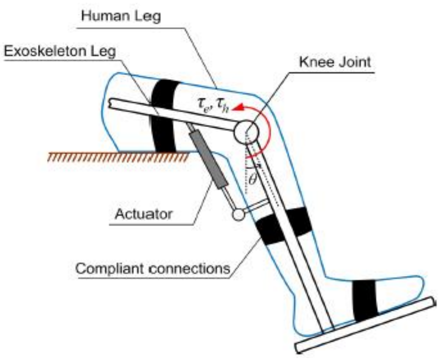


FIG-3.3 SUPPORT STRUCTURE

In order to give support to the knee joint and the whole leg of the body the structure is designed in a way that it gives strength and stability to the wearer while standing and walking. We designed a system of aluminum frame, links so as to provide constraints movement and adjustability of the structure with the leg. The exoskeleton is housed in the legs on three different positions i.e. the hip joint which controls the whole gait cycle, the knee joint moment which gives the necessary torque required for walking and the ankle joint link which controls the whole moment of walking as the legs moment is mainly controlled by the ankle.

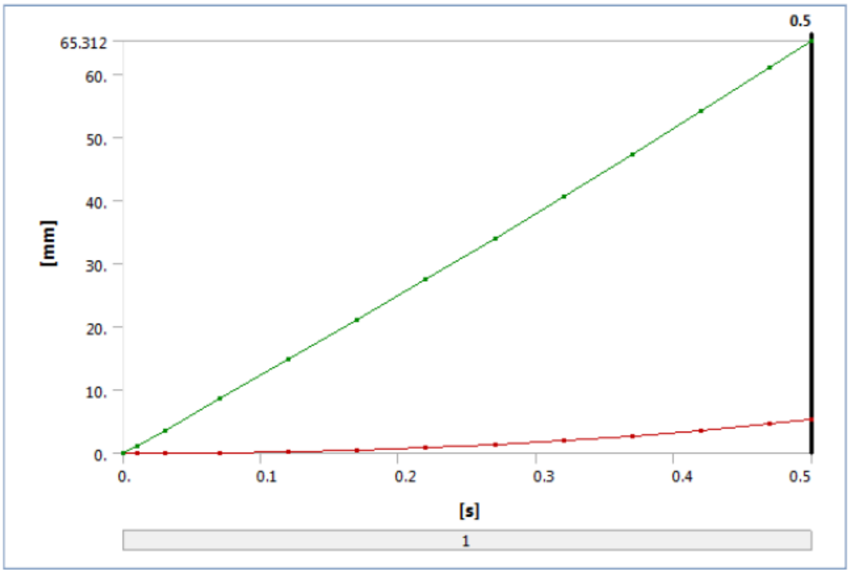
IV. RESULT ANALYSIS

4.1 STRUCTURAL DEFORMATION ANALYSIS

FIG:-4.1 DEFORMATION ANALYSIS

Time [s]	Minimum [mm]	Maximum [mm]
0.	0.	0.
1.e-002	1.7247e-003	1.2155
3.e-002	1.5663e-002	3.6563
7.e-002	8.6814e-002	8.5784
0.12	0.26074	14.809
0.17	0.5345	21.13
0.22	0.91382	27.543
0.27	1.4044	34.053
0.32	2.0117	40.662
0.37	2.7414	47.372
0.42	3.5988	54.187
0.47	4.5894	61.108
0.5	5.2498	65.312

TABLE-4.1 TIME & DEFORMATION



GRAPH-4.1 DEFORMATION vs. TIME

ANSYS finite modeling method analysis shows while using the exoskeleton for the time period of 0.5 sec and it shows that the structure will go under deformation in the range of minimum 5.2498 mm to a maximum of 65.312 mm which suggest that the design is safe and ready to fabricate.
The graph shows the variation from minimum (red line) to maximum (green line) deformation in mm for the load of 70kg acting on the exoskeleton for a time period of 0.5 sec.

4.2 TESTING:-

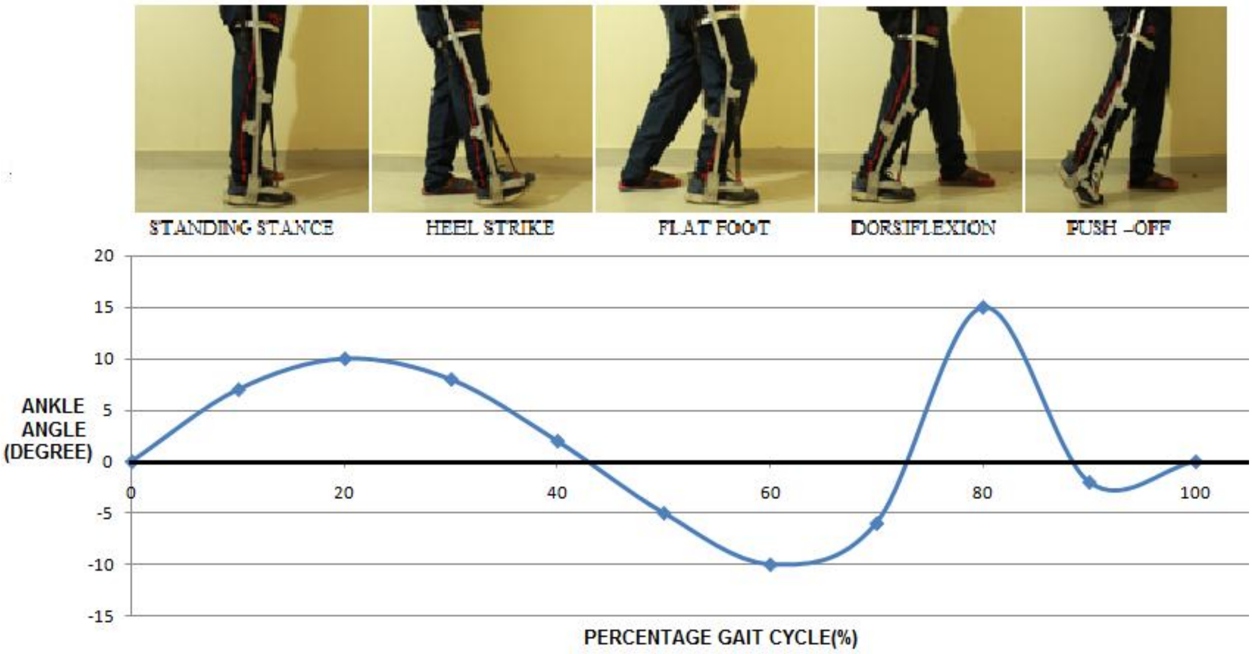


FIG-4.2 ANKLE ANGLE VS. GAIT CYCLE

- The above diagram shows the moment and position of the leg exoskeleton on different postures of walking i.e. standing, heel strike, flat foot, dorsiflexion & push-off.
- The comparison with the normal gait cycle shows a deflection of ankle angle to 5% which is negligible taking into account the support and assistance it will give to the wearer.
- The normal walking pattern is not hampered due to use of this device.

V. FUTURE SCOPE OF WORK

- We suggest using the 3-D printing technique since it greatly reduces the weight of the component. The conventional manufacturing constraints can be overcome by this method.
- Performing human walking tests on both impaired and unimpaired subjects to determine whether device at different speeds and pneumatic pressure.
- Perform biological test VO2 test to measure and optimize the cardiovascular fitness and maximize the training.

VI.CONCLUSION

In this paper a control strategy for a lightweight exoskeleton is presented. The exoskeleton runs in parallel to the human leg and transmits payload forces to the dampers. The desired control action by the variable-damper mechanism at the knee was based on knowledge of the current phase of the gait cycle of the wearer. The idea is to design and develop a new robotic exoskeleton with a control pneumatic damper on the Gait Cycle Analysis. A designed pneumatic damper mechanical system is introduced to compensate the metabolic activities and force impact on the leg. Each leg of the exoskeleton consists of 4 joints at hip, knee and ankle and at the connecting joint between both legs at torso of the patient. The detailed information on design, development and control has been discussed. The demonstration and its analysis show that the exoskeleton is able to perform assisting the walking steps by the pattern of gait cycle.

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