International Journal of Research and Review
www.ijrrjournal.com E-ISSN: 2349-9788; P-ISSN: 2454-2237

Research Paper

Biomechanical Foot with Double Wishbone Structure

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ABSTRACT

This paper introduces a mechanical structure of bionic foot with a shoe structure. Additionally, the stability control of this prosthetic joint in leg during the swing phase is achieved by a using specific type of motor. By adjusting the transmission ratio of ankle, a desired output has been obtained. This compact system consists of only shoe structure and rest of the leg is a structure only with required number of degree of freedoms. It uses elastic actuator made up of wishbone structure for stability, proper load distribution and vibration absorption. This system also shows the charging percentage for the convenience of disabled people.

Keywords: Biomechanics, prosthetic foot, wishbone structure, suspension foot.

INTRODUCTION

Recently many efforts have been carried out in advancement of prosthetic leg for the convenience of the disabled people. While locomotion is slower, less stable, and requires more energy in convectional prosthetic leg. This system of prosthetic shoe provides high level of comfort with the use of wishbone type suspension. Construction of complete leg makes bulky arrangement and also increases weight in conventional system. While this paper avoids the nerd of bulky arrangement by constructing frame if the leg up to the ankle with desired degree of freedoms.

Only shoe part is controlling all mechanisms with the help of various motors, actuators and sensing devices. [1] Advanced tactile sensors are used for conversion of all senses like touch or any feeling in leg. [3] Specially designed brushless DC (BLDC) servos with planetary gear box are used in this system in order to bring required torque. The motion is transferred using gear drives, as per the restricted area. Battery drain and charging level measurement is done with the help of charging indicators made up of certain LEDs. Overall this prosthetic shoe is the advancement of conventional prosthetic leg.

LITERATURE REVIEW

HYDRAULIC DAMPER

In this work, the hydraulic damper is designed for an above-knee prosthesis with the aim for controlling damping in the swing phase. Specific linear spring mass damper system is used to obtain the dynamic properties of the damper. With the help of this model, three control parameters which control the damping force and displacement of the damper have been identified. [4]

ARTIFICIAL ANKLE FOOT WITH VARIABLE DAMPING AND SPRING AND SERIES OF ELASTIC ACTUATOR

An artificial foot and ankle joint is made up of a curved leaf spring foot which is having a heel end and a toe end, and a flexible elastic ankle member that connects the foot member for rotation at the ankle joint. An actuator motor applies torque to the ankle joint to orient the foot when it is not in contact with the Support Surface and to store energy in a catapult spring that is released along with the energy stored in the leaf spring to propel the wearer forward. A ribbon clutch prevents the foot member from rotating in one direction beyond a pre-determined limit position. A controllable damper is employed to lock the ankle joint or to absorb mechanical energy. The controller and sensing mechanisms control both the actuator motor and the controllable damper at different times during the walking cycle for level walking, stair ascent, and stair descent. [8]

CONTROL ARCHITECTURE:
PID CONTROLLER

A PID controller is used in various industries as a control loop feedback unit. This PID function consists of the various variable used to calculate the error value by subtracting the measured value by the set point. In this controller the error is minimized by using the three control parameters they are called as the proportional, the integral and derivative values, usually, they are denoted by P, I, and D. [6]

The function is denoted as follows:

$$\boldsymbol{fa = Kp + Ki \int_0^t e\,(t)dt + Kd\ \frac{d\,e(t)}{dt}} \quad (1)$$

Where, F_a = Actuator force.

Putting the value obtain by the encoder of the actuator in the equation (1), we get the required PID control over the loop and thus the actuator provides the specific torque to the ankle for its actuation. In this way, the control function works.

LEG DESIGN:
DOUBLE WISHBONE SUSPENSION SYSTEM

Double Wishbone Suspension System consists of two arms as upper arm and lower arm and usually they are of unequal lengths. But in this paper, we are constructing the wishbone structure with equal lengths. There is a coil type spring used as a vibration absorbing element. This structure is used to control the stability of the whole body. [7]

DESIGN OF WISHBONES

Design of the wishbone structure consists of three steps as follows:

Material is selected based on the strength and weight required:

Wishbone structure is designed for the maximum load carrying capacity of 100 kg. Based on these values we have to select the material for the wishbone structure.

The material should satisfy these conditions:

1. Light weight
2. High strength
3. Easy to machine

Hence, we have selected the aluminum as it is light weight, its alloy gives high strength and also it is easy to machine as the material is ductile in nature.

On the basis of the strength, we have selected three grades of aluminum as follows:

7075-T6511 Aluminum

Elastic modulus 72 GPa
Elongation 5.8%
Tensile strength 590 MPa
Yield Strength 520 MPa

7075-T76 Aluminum

Elastic modulus 72 GPa

Elongation 8.1 %
Tensile strength 570 MPa
Yield Strength 490 MPa

7075-T76511 Aluminum
Elastic modulus 72 GPa
Elongation 5.8%
Tensile strength 580 MPa
Yield Strength 500 MPa
Thus, based on the maximum tensile strength we select the 7075-T6511 Aluminum material.

Allowable stress is calculated using sheer stress theory of failure:
We consider a factor of safety two for the aluminum material considering that it will absorb shock loads as well.
For ductile material, allowable stress is obtained by the following relationship:

$$\sigma = \frac{yield\ \ strengt\ h}{FOS} \qquad (2)$$

$$\sigma = allowable\ stress$$

$\sigma = \frac{520}{2}$ = 260 Mpa
This is the allowable stress value in the wishbones structure.

DESIGN OF SPRING

The spring is a shock absorbing element used for storing mechanical energy. They are made up of spring steel. This spring is cheaper, light weight and easy to manufacture. Thus because of this reason we select the spring as a damping element. Also there is not much load to carry thus need to use the simplest material and design accordingly.
[5] Based on the load carrying capacity and material used there are various types of spring in the market as follows:
Hard-drawn wire: This spring is made from cold drawn process, it is much cheaper spring steel. Generally used for the low stress and static load condition. [5]
Oil-tempered wire: This spring is made from cold drawn process followed by quenching, tempering, it is not suitable for fatigue or sudden load condition. [5]

As our application is of low stress condition we are using the hard-drawn wire.

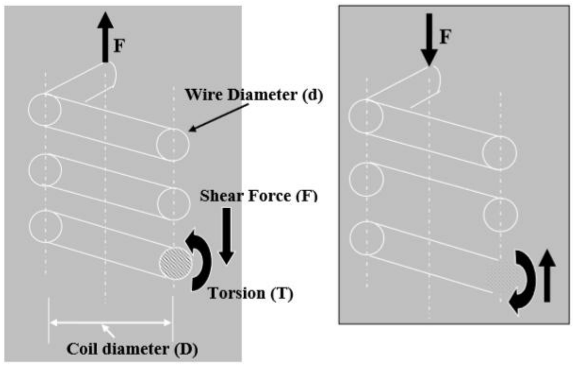

Figure 1: Helical Spring Free Body Diagram [17]

The radius of the spring is given by D/2.
T is the torque applied on the spring.
F is the lifting force
D is the mean diameter of the spring as shown in the figure 1
I_p is the polar movement of inertia
d is the wire diameter

τt *is the shear stress in spring due to torque*

τf *is the shear stress in spring due to force*

τ max *is the maximum shear stress in spring*

Now assuming the wire diameter as 6 mm and the spring diameter as 30 mm, as per the space available.

$$T = \frac{F\ X\ D}{2} \qquad (3)$$

$$F = 100\ Kg = 100\ X\ 9.81 = 981\ N$$

$$Ip = \frac{\pi\ X\ d^4}{32} \qquad (4)$$

$$Ip = \frac{3.14\ X\ 6^4}{32} = 127.17\ mm^4$$

$$\tau t = \frac{8\ F\ D}{\pi\ d^3} \qquad (5)$$

$$\tau t = \frac{8\ X\ 981\ X\ 30}{3.14\ X\ 6^3} = 347.1337\ \frac{N}{mm^2}$$

$$\tau f = \frac{4\,F}{\pi\, d^2} \tag{6}$$

$$\tau f = \frac{4\,X\,981}{3.14\,X\,6^2} = 34.71337\,\frac{N}{mm^2}$$

$$\tau t = \frac{8\,F\,D}{\pi\, d^3} + \frac{4\,F}{\pi\, d^2} \tag{7}$$

$$\tau max = 347.13 + 34.71 = 381.2674\,\frac{N}{mm^2}$$

PART DISCRIPTION

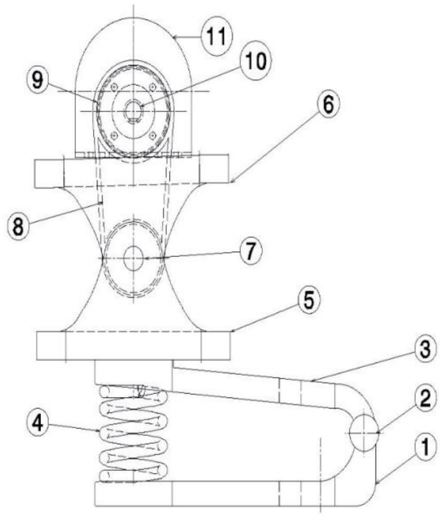

FIGURE 1: Side View of The Wishbone Structure Foot

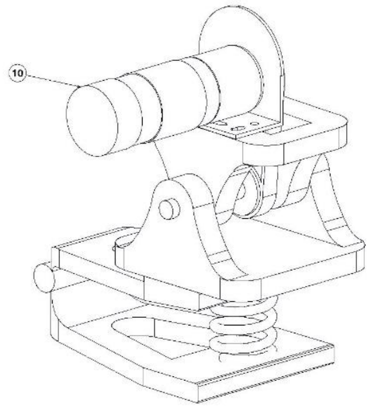

FIGURE 2: Isometric View of the Wishbone Structure Foot with Labeling

Part 1 Wishbone structure lower bone: This structure is used for bearing the total weight of the human body in comfortable manner. This bone is coupled with the upper bone part 3 of wishbone structure with the hinge part 2. This structure part 1 forms the supporting element.

Part 2 Hinge: This hinge plays an important role in joining the part 1 lower bone with the part 3 upper bone.

Part 3 Wishbone structure upper bone: This structure is used for bearing the total weight of the human body in comfortable manner and distributes it to the lower wishbone structure part 1 through hinge part 2. This bone is coupled with the upper bone part 3 of wishbone structure with the hinge part 2. This structure part 2 forms another supporting element.

Part 4 Spring: The spring is the shock absorbing element used to transfer the shock from upper bone part 3 to lower bone part 1 and provides the comfort to the user from this.

Part 5 holding block 1: This movable block is mounted on part 3 for the flexibility motion of ankle via chain drive. Sprocket is mounted on this block via shaft.

Part 6 Holding block 2: This stable block helps part 5 for providing angular degree of freedom. This supports the load of entire leg from knee.

Part 7 Sprocket 1: It is mounted on shaft. Sprocket is used for providing angular motion from ankle via chain drive.

Part 8 Chain: It is a drive used for transmission of angular motion of ankle with the help of sprocket (part 7)

Part 10 BLDC servo: This motor is equipped with planetary gear box used for power transmission to the sprocket 2.

Part 9 Sprocket 2: It is mounted on the shaft of BLDC servo motor for transmission of power.

Part 11 Motor clamp: It is used of mounting BLDC servo motor (part 10).

METHODOLOGY

The signals from the human brain are extracted from the surface electromyographic method. Thus, these signals are then amplified to certain limit which is then given it to microcontroller for the analytical calculation. Here the pattern is recognized and then gets ready to rotate the actuator accordingly. The wishbone structure is attached to the shoe. The prosthetic foot is designed in order to get the perfect stability and control and accordingly the shoe is designed. This foot is light weight and is driven by the planetary geared brushless DC motor. The motor is mounted on the holding block 1 and 2. This holding block performs the function of the ankle of the leg, by giving desired degree of freedom to the leg. The specially designed wishbone structure helps to provide the flexibility and comfort to the disabled person. The wishbone structure is also helping to absorb the vibration and thus it acts as a support element of the foot. When the controller realizes through the signals from the brain that the person wants to walk then controller recognizes the pattern and allows the motor to run. [2] The motor is used to generate specific torque at the joint.

CONCLUSION

This paper presents a new prototype of a prosthetic shoe using the wishbone system, which provides the patients with a better bionic performance and ankle trajectories with more appropriate walking. The feasibility of a biomechanics shoe is high. This avoids the use of bulky arrangement of complete leg. The energy consumption details are provided with the help of LED which would be beneficial for patients for long time walk. The entire system is in the shoe to hide the disability from the surrounding people.

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How to cite this article: Bairagi P, Meghani L, Panchagade DR et.al. Biomechanical foot with double wishbone structure. International Journal of Research and Review. 2018; 5(10):197-201.

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