“EXPERIMENTAL STUDY OF EXOSKELETON FOR ANKLE AND KNEE JOINT”

PROJECT REFERENCE NO. : 37S0925

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Keywords: Achilles’ tendon, swing, stance, gait cycle, passive energy neutral solution, elastic energy

Introduction:

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. (e.g. for military applications), and to help disabled people to retrieve some motion abilities. (such exoskeletons are called “active orthoses” in the medical field). As we know, the normal motor capability of legs is crucial and important for human-beings daily life. Legs, however, are apt to be injured in accident. And the Rehabilitation is essential for the patients to recover after leg operation. Additionally, diseases, stoke for instance, can also result in the loss of leg function. In order to regain the motor capability, the leg rehabilitation is a fundamental therapeutic approach. This chapter deals with the background of various types of exoskeletons made till this day.

Basically Exoskeletons are of two types:

1. Active Exoskeletons
2. Passive Exoskeletons
**Active exoskeletons:** They are powered by external sources like a motor, battery powered etc. They work along with the passive exoskeletons to help in its functioning.

**Passive exoskeletons:** These are not powered by external power sources but work on the basis of mechanical linkages, pneumatic and hydraulic mechanisms, spring controlled devices etc. Since active exoskeletons pose a restriction to the amount of external energy that can be supplied in terms of quantity, quality and time we have focused purely on passive type of exoskeletons. Passive elements are implemented in the exoskeleton to either store or dissipate energy with the objective of reducing the residual energy that the human would have to expend for locomotion.

**Objective:**

To develop a portable device capable of providing ankle joint mechanical assistance during walking without using external power from onboard actuators. The device we set out to build should be light weight, portable and user friendly. The device should not hamper the normal gait cycle of an individual but should only enhance it.

Our goal was to provide all of the benefits of an actively powered exoskeleton but in a portable framework without motors or an external energy source to provide an ease in the gait cycle. We hypothesize that a passive wearable device using parallel elastic elements during the walking cycle is capable of recycling a significant portion of the ankle joint mechanical work and could reduce the metabolic cost of walking. We set out to develop a passive, ‘energy-neutral’ system with the following key design objectives:

1. Deliver torque to the ankle following a pattern similar to the normal joint moment during walking
2. Recycle elastic energy during the stance phase while allowing free ankle rotation during swing.

**Methodology:**

In this section we are going to discuss about the constructional features of each and every components used in this mechanism. We are going to deal with the specifications and the assumptions made while designing the mechanism. The working of the model is explained in a step by step manner as follows:
1. A clutch 1 and an elastic element 2 are coupled between upper portion and lower portion to control storage and release of mechanical energy by elastic element. Clutch 1 includes a housing formed by an inner portion and outer portion.

2. Clutch 1 includes a rotating drum formed by a back retainer 14 and a timing pin holder 4. Drum rotates about a rod (main shaft) via roller bearing assembly.

3. A pulley 15 is located between back retainer 14 and timing pin holder 4. Pulley 15 is attached to linkage 8 to allow extraction of linkage 8 from clutch 1 and retraction of linkage 8 into clutch 1.

4. A flat spring 27 applies a counter clockwise torque to drum to effect retraction of linkage 8 when the force applied to linkage 8 is less than that applied by flat spring 27.

5. In order to provide an engagement and locking mechanism to control energy storage and release by elastic element 2, clutch 1 includes a rotary ratchet 5 and a pawl 7.

6. Ratchet 5 is coupled to timing pin holder 4 and rotates with timing pin holder 4.

7. Pawl 7 is mounted on a shaft 18 that rotates with respect to inner and outer portions and of the housing. Roller bearing assemblies allow pawl 7 to rotate on shaft 18.

8. A pair of timing pins 17 control the engagement and disengagement of pawl 7 with ratchet 5.

9. A stopping pin 6 limits angular rotation of pawl 7 in a direction away from ratchet 5.

10. As stated above, spring 2 retracts linkage 8 into clutch 1. To effect this retraction, a portion of spring 2 is fixedly attached to and at least partially circumferentially surrounds pulley 15.

11. Another portion of spring 2 is fixedly attached to and surrounds a spring holder 10, which rotationally attaches spring 2 to a spring shaft 11.

12. When pulley 15 rotates in the clockwise direction, spring 2 is wound from its resting position, and spring holder 10 rotates in a counterclockwise direction about shaft 11.

13. This winding motion causes spring 2 to store mechanical energy.
14. When the force on linkage 8 becomes less than the reaction applied by spring 2, spring 2 unwinds, causing the portion of the spring that surrounds shaft 11 to rotate in the clockwise direction and effecting rotation of pulley 15 in the counter clockwise direction to retract linkage 8.

The names of the various parts used are as follows:

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>NAME OF THE PART</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Timing pin disc</td>
</tr>
<tr>
<td>9, 19, 20, 21</td>
<td>Bearing</td>
</tr>
<tr>
<td>12, 24</td>
<td>Fasteners</td>
</tr>
<tr>
<td>14</td>
<td>Back Retainer</td>
</tr>
<tr>
<td>15</td>
<td>Pulley</td>
</tr>
<tr>
<td>16, 22</td>
<td>Countersink screws</td>
</tr>
<tr>
<td>17</td>
<td>Timing pin</td>
</tr>
</tbody>
</table>
Results and conclusion

The prototype was tested for various phases of a normal gait cycle. The ankle angles at various phases of walking are presented in a graphical and tabular form after our testing in this chapter. We also propose various tests to be carried out after building the actual model and for its commercial viability.

Different colour codes are used in the graph to specify the durations of energy storage and release with the help of the elastic member. The energy stored in the spring is released during the Push-off stage which is shown in purple in fig.

The graph is broken into steps and explained in the following section:

The various phases in walking are:

- **Heel strike**: Just prior to heel strike, clockwise movement of pin holder under force applied by linkage causes timing pin to engage pawl. With ratchet once engaged, motion of ratchet is only allowed in the counterclockwise direction, which occurs from heel strike to foot flat position under force of spring to retract linkage into clutch.

- **Foot flat**: In the foot flat position, as illustrated by image and the corresponding clutch position, the clutch is locked because linkage and elastic element apply clockwise force/torque on ratchet, and motion in the clockwise direction is prevented by the shapes of the teeth in ratchet and the corresponding shape of pawl.

- **Dorsiflexion**: During dorsiflexion, when the clutch is locked, elastic element (Spring) stretches from its resting position and stores mechanical energy produced by the user’s center of mass rotating over the ankle (during stance dorsiflexion).

- **Push-off**: During push off (stance plantar flexion), the energy stored in elastic element (spring) is released, aiding in locomotion of the subject. Timing pin contacts pawl and causes pawl to release from ratchet to allow free rotation of the ankle joint during the foot swing phase of walking prior to the next heel strike.
Scope for future work:

- We suggest using the 3D printing technique since it greatly reduces the weight of the component. The conventional manufacturing constraints can be overcome by this method.
- Testing the clutch on the bench top to verify robust behavior over many cycles
- Performing human walking tests (in both impaired and unimpaired subjects) to determine whether the device can reduce metabolic energy expenditure at different speeds and spring stiffnesses.
- Continuing to develop the next generation prototype with the capability to adjust the timing of engagement of the clutch automatically without any human intervention.

We also propose concept of development of knee joint

The mechanism for the knee exoskeleton is controlled such that the spring is in parallel with the knee joint from approximately heel-strike to toe-off, and is removed from this state during the swing phase. In this way, the spring is intended to store energy at heel strike which is then released when the heel leaves the ground, reducing the efforts required by the quadriceps to exert this energy, thereby reducing the metabolic cost of locomotion.

The purpose of this development is to compare knee joint stiffness in individuals with unilateral mild to moderate osteoarthritis of the knee between the affected knee and unaffected knee. The subject is seated on a table and the experimenter supports the weight of the lower leg with the knee extended. The stiffness and damping coefficient of the relaxed
knee is determined by measuring the time dependent response of the lower when the limb is allowed to freely oscillate after releasing the supported lower limb.