DESIGN AND CONTROL OF A LOWERKNEE PROSTHESIS

by

Özer TAĞA

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ABSTRACT

In this thesis, transfemoral amputations and prosthetic knees evolved for transfemoral amputations are investigated and the electronic control unit of prosthetic knees is designed. The first stages of this work contain information about human walking in medical meaning and bipedal walking. Then, definition of transfemoral amputations, leg biomechanics when walking and phases of walking is discussed. After that, prosthetic knee design for transfemoral amputations is mentioned and prosthetic knees developed by worldwide companies are investigated and discussed in details. At the last stage, electronic control unit is designed and produced for prosthesis used by above knee amputees.

Keywords: Transfemoral amputation, prosthetic knee, bipedal walking, electronic control of prosthetic knee.

DİZ ALTı PROTEZ AYAK TASARIMI VE KONTROLÜ

ÖZ

Bu tezde diz üstü ampütaşyon durumu ve bu durum için geliştirilen protez bacaklar incelenmiş ve diz üstü protez bacaklar için elektronik kontrol devresi tasarlanmıştır. Tezin ilk aşamasında insanın tibbi anlamda yürümesi ve bipedal yürüme hakkında bilgi verilmiştir. Ardından da diz altı ampütaşyon durumundan, yürümede bacak biomekaniğinden ve yürümenin fazlarından bahsedilmiştir. Bundan sonraki aşamada, bahsedilen diz üstü amputeler için protez bacak tasarımına üzerine düşünülmüş ve bu konuda dünyaca ünlü firmalar tarafından geliştirilen protez bacaklar incelenerek tasarımı detaylı olarak ele alınmıştır. En son aşamada ise ayağın dizinin
The reason why lower knee prosthesis is investigated in this study is that walking is one of the most important and composite process of human body. The knee is the significant role at human walking especially stability of walking, and so worth of knee prosthesis for the above knee amputation is understandable.

For this purpose, firstly, walking will be discussed in terms of anatomical meaning and also in terms of its technical meaning.

2. Limb Amputation

There are several levels at which the surgeon can amputate a limb that is shown Figure 2.1. The most common are:

- Through the foot
- Ankle (Syme)
- Below the knee (transtibial)
- Through the knee (knee disarticulation)
- Above the knee (transfemoral)
2.1 Transfemoral Amputation

Transfemoral amputation is most commonly known as an above-knee amputation, or AK. It's referred to as a transfemoral amputation because the amputation occurs in the thigh, through the femoral bone (femur). Most of these amputations occurred as a result of severe vascular and diabetic disease, with a poor potential to heal a lower level amputation. However, other etiologies included severe soft tissue, vascular, neurological and bone injury resulting from trauma. Additionally, some amputations occurred as a result of severe infection or tumor. Upon amputation, the amputee begins a large rehabilitation process that will involve his surgeon, prosthetist and therapist. But the surgeon has the first and most immediate responsibility, to perform a good amputation. That involves leaving as much residual limb as possible, preserving the adductor, and effective suturing of the remaining soft tissue. It has been shown that the length of the residual limb is inversely related to the energy consumption in walking with prosthesis. Because abduction of the femur is a common problem amongst transfemoral amputees affecting both their gait and energy consumption, preservation of the adductor (to balance the abductor) is important.

While the transfemoral amputation level is fairly common, there's nothing simple about adjusting to life after surgery. The person living with transfemoral limb loss faces distinct challenges, such as increased energy requirements, balance and stability problems, the need for a more complicated prosthetic device, difficulty rising from a seated position, and, unlike with amputation levels in the tibia and the foot, prosthetic comfort while sitting.

3. Designing Prosthetic Knee

In general, prosthetic limb has regenerative and electronically controlled prosthetic joints. More specifically, it is converting electrical energy to mechanical
energy. The electrical energy can be used for assisting with an amputee’s gait cycle or providing power to various other electrical energy consuming devices associated with the amputee.

Lower limb amputations can be divided commonly in two types;

- Below knee (BK)
- Above knee (AK)

A below knee amputation is related to a line through the tibia and fibula of lower leg; with knee joint remaining intact. An above knee amputation, however, is a transfemoral amputation we know; meaning that the knee joint is also removed.

Designing a prosthetic limb for an above knee amputee is a more complicated process than constructing for a below knee amputee. Below knee prosthesis is fitted to the amputee’s residual leg, with amputee’s knee joint. However, there is no natural knee joint for above knee amputee, an above knee prosthesis should be constructed to simulate knee flexion and extension for amputee’s satisfaction to use the prosthesis for normal walking. For this purpose, the flexible joint connection must be constructed and connected to lower leg portion to an upper socket portion which fits to the amputee’s residual leg. A prosthetic knee allows the amputee to freely swing during the extension part of the gait cycle and also during the flexion part of the cycle. Some artificial knee joints cause problems for amputees such as instability at flexion and extension parts, for instance.

Controlling gait cycle of an above knee prosthetic leg, both basic and electronically controlled passive knee joints must be developed. These knees employ devices such as pneumatic and hydraulic cylinders, magnetic particle brakes, and other similar damping mechanisms, to damp energy generated during the gait cycle.
to control motion of a prosthetic knee. These damping devices also make resistance to bend knee joint for additional stability. These devices must be designed based on amputee’s weight, gait pattern and motion type, among other factors. In case of an electronically controlled passive prosthetic knee, a software enabled microprocessor adjusts the best. Electronic control systems associated with passive prosthetic knee also needs energy source as a battery for their operation.

The need for a highly active prosthetic knee to limit heel rise and terminal impact requires significant energy consumption by the amputee. The faster an amputee walks, the faster the prosthetic knee must move and the more energy is required for prosthetic leg, but unfortunately, most of energy is lost at the end of heel rise, or at terminal impact. If the amputee tries to walk faster, the energy dissipation will increase rapidly with speed.

In an attempt to solve these and other problems associated with known passive knee joints, active prosthetic knee joints have been developed. However, up until these active knee joints have suffered from various deficiencies including, among other things, the lack of accurate control, the lack of an acceptable actuator for imparting energy to the amputee’s gait cycle, and the inability to produce a sufficient power supply for purposed actuators that can also be easily transported. For instance, Hydraulic or pneumatic active prosthetic joints are developed, and so hydraulic or pneumatic pump is designed.

3.1 Developing Prosthetic Knee

According to many researches and studies, the amount of energy consumption for amputee is higher than non-amputee. All prosthetic knees are designed to overcome deficiencies like these.

During normal gait cycle, the human knee has been shown to absorb more energy
than it expends. This is true both a normal and prosthetic knee joint.

3.2 Parts of Prosthetic Leg

The above knee prosthesis consists of five major parts of the system.

- The socket
- The knee
- The foot
- The components
- The alignment

Although, the knee part has been described in detail in the previous sections, it will be mentioned.

3.3 Prosthetic Knee Technologies in the World

There are over 100 different prosthetic knee designs available. Space and other limitations make it impossible to showcase every recently marketed prosthetic knee, but here's a representative samples are discussed.

3.4 Comparison of Marketed Prosthetic Knees

In this part of study, 7 different prosthetic knees from 4 well known companies compared below according to its weight, max flexion, classification, stance and swing phases.
Table 1 Comparison table of prosthetic knees

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>WEIGHT</th>
<th>MAX FLEXION</th>
<th>CLASSIFICATION</th>
<th>STANCE PHASE</th>
<th>SWING PHASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nabtesco Intelligent knee</td>
<td>1015 g</td>
<td>160°</td>
<td>Wt limit 100 kg</td>
<td>Four Bar linkage mechanism</td>
<td>Micr...</td>
</tr>
<tr>
<td>Nabtesco Hybrid knee</td>
<td>1290 g</td>
<td>140°</td>
<td>Wt limit 100 kg</td>
<td>Hydraulic and MRS</td>
<td>Micr...</td>
</tr>
<tr>
<td>Endolite IP+</td>
<td>1247 g</td>
<td>135°-140°</td>
<td>Wt limit 125 kg</td>
<td>Mechanical weight activated stance control</td>
<td>Micr...</td>
</tr>
<tr>
<td>Endolite Smart Adaptive</td>
<td>1361 g</td>
<td>140°</td>
<td>Wt limit 125 kg</td>
<td>Microprocessor control Hydraulic</td>
<td>Micr...</td>
</tr>
<tr>
<td>Otto Bock C-leg</td>
<td>~1300 g</td>
<td>125°</td>
<td>Wt limit 125 kg</td>
<td>Microprocessor control Hydraulic</td>
<td>Micr...</td>
</tr>
<tr>
<td>Ossur Rheo knee</td>
<td>1630 g</td>
<td>120°</td>
<td>Wt limit 100 kg</td>
<td>Microprocessor control Hydraulic</td>
<td>Micr...</td>
</tr>
<tr>
<td>Ossur Mauch knee</td>
<td>1140 g</td>
<td>115°</td>
<td>Wt limit 136 kg</td>
<td>Single axis stance control</td>
<td>Single axis Swing control</td>
</tr>
</tbody>
</table>

4. Controlling the Knee

In order to control the throttle valve of pneumatic cylinder it’s used apparatus at the previous prosthetic knee. In recent years, with occurrence of intelligent knee we can use remote control easy to program for all types of motion.

The programming procedure is simply to select a speed of walking, and then adjust the valve position of the swing phase control by pressing an increase / decrease button. The settings are then saved at the required speed. Repeating this sequence at two other speeds, automatically leads to the generation of valve settings.
Firstly, an audible sound confirms receipt of signal and end of task at remote control. The flashing led’s switch to selection of speed, inviting the user to select one of speeds or reset. After selection of a speed, the amputee is asked to walk at that speed at right distance while the prostheteist can observe the gait. The increase (+) or decrease (-) of resistance to flexion controls how fast or slow the limb should be extending. An audible sound confirms each resistance change with the additional feature. Once satisfied with the swing phase performance on any step, the SAVE button is pressed. This stores the selected valve settings as well as the average speed at the time of pressing the key. The sequence is repeated for another two speed selections and this will complete the programming procedure.

It is useful to note that the system goes to automatic mode whenever the SAVE button is pressed. This means that the valve position automatically changed with speed. It is possible to go back to the program and simply adjust the valve setting at one speed or change the walking speed selection at a particular valve setting.

The values stored in permanent memory can only be over written by a new programming sequence.

4.1 Programming

The pic programming has been written using micro code studio program in basic language. Then hex file which is being programmed to processor was created by pic basic pro complier. The processor was programmed by using dm programmer with icprog.

Unnecessary components were avoided while the electronic circuit is designing. Screwed step motor is used to control the throttle valve from Copal Electronic Company.
16f628 has been selected to fulfill the tasks of microprocessor control unit from Microchip Company. These properties are:

- High programming and Eeprom memory
- Self contained internal oscillator
- Internal pull up resistances

Having self contained internal oscillator and pull up resistances provided the great simplicity at the control unit electronic circuit.

ULN2003 is integrated to drive unipolar step motors. It has provided simplicity to circuit. Lm7805 voltage regulator is used for conducting stable electric current to step motor and microprocessor. Buzzer is used to receive voice alerts.

5. Conclusion

The purpose of this thesis is to investigate prosthetic legs developed for transfemoral amputations to walk healthy again, and to give information about parts of prosthetic legs, and also to design control of phases of prosthetic knee with microprocessor.

From thesis results, designing and manufacturing prosthetic legs for above knee amputees are the following points should be taken into consideration:

- Prosthetic legs should be designed light as possible. Therefore, the material selection part is very important during the design of prosthetic leg. Composite material should be preferred as a material of knee frame because the greatest advantage of composite materials is strength and stiffness combined with
lightness. Titanium also should be preferred as a material of other components such as knee joints instead of steel or aluminum as possible as because of same reason like using composite material.

- Prosthetic legs should appeal to a wide range of amputee patients, so prosthetic legs’ size has large spectrums for long or short patients because leg length is direct proportional with human length. Moreover, the carrying capacity will be used in the prosthetic leg in a similar way to apply to the seriously heavy weight patient should be because today, most of prosthetic leg has 100 kg carrying limit.

- The stability of designed prosthetic leg is very important. For this purpose, the harmony of knee joint and the control unit should be synchronized.

- The longevity of the production of leg prostheses is very important that is to say Durability. This is explained in the first clause is related to material selection.

- The produced prosthesis leg should be energy saving. Easy rechargeable and designed long life batteries should be used.

If the prosthetic leg is used exclusive use of the special places, such as athletes amputees, it should be changed certain structures based on the conditions. This type of real patients by taking into account the above items that are most optimally designed legs.

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**References**


