Study on Mechanical Adaptive Design, Construction and Control of Knee Continuous Passive Motion Machine

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***Abstract*—In this study, the authors' afford is to solve three basic problems remaining in current Knee Continuous Passive Motion (CPM) machine, that is designing to reduce production costs in accordance with the conditions of Vietnam, structural adaptive design to help minimize relative sliding between leg, thigh and device's linkages and design the controller with the purpose of having diversity operation modes, user-friendly interface and easy operation. Furthermore, many attempts were made to ensure the device appearance, stability and safety. In order to minimize relative sliding, parallelogram joint mechanism was proposed, designed, verified and implemented. Both simulation results and experimental result reflect very good results and fulfill the design objective. Furthermore, controller was design to help diversify the operation mode and increase the interaction between user and device.**

***Index Terms*—knee physical training, CPM machine, parallelogram mechanism**

I. Introduction

The knee joint is a complex and important part of the human body. Part of its complexity lies in the fact that knee movement involves a set of coupled translations and rotations [1]. The knee can move in one of two ways. Active motion of the knee joint occurs when the muscles surrounding the knee contract and induce motion. Passive motion involves the movement of the knee joint by an outs ide force, such as that applied by a doctor or physical therapist.

The knee plays an important role in many everyday activities, incl uding walking, running and kneeling, making it vulnerable to a variety of injuries and disorders. Injury to the anterior cruciate ligament (ACL), for example, causes the tibia to slide too far anterior relative to the femur and also affects side-to-side ro tation of the lower leg. Knee kinematics may also be affected when the joint is diseased, such as by osteoarthritis, which is caused by the breakdown and eventual loss of joint cartilage. Surgical procedures, such as ACL reconstruction and total knee arthroplasty, commonly are required to alleviate pain and rest ore more normal joint function.

In recent years, research has been aimed at discovering how surgical procedures like these affect knee kinematics and what can be done to better restore normal knee motion and function after surgery [2-6]. A device that can be safe and comfortable must be able to reproduce the natural human joint kinematics accurately. Such design must have two functions: It must be able to estimate the kinematics of a natural joint which has an inter-individual variability and which can change in time, and then self-adjust its geometry to match the kinematics of the natural joint as closely as possible.

In this study, mechanical structure design is focused on solving the problem of relatively sliding between thigh, leg and device's linkages when getting training. There are two solutions considered in this study, firstly, slide joint is added to main revolve joint and expected to automatically adjust the mismatch between thigh, leg and device's linkages. Second, parallelogram joint and length adjustable linkage was proposed as a solution for minimize sliding effect.

A controller with friendly user interface utilizing graphic LCD and multimode operation with 8 modes motion from 0 to 120 degrees and a range of angular velocities from 30 to 750 degrees/minute, in which one custom mode was design for patient to configure the operation parameters by themselves.

II. Adaptive Mechanical Design

Most of current designs utilize revolve joint as shown in Fig. 1, the main drawback of these designs is the relative sliding between patient's leg and thigh and device's linkages.

Fig. 2a and Fig. 2b show that, to maintain position, thigh and foot must relatively slide 126 mm and 65 mm respectively on device's linkages. For healthy person, it should not be a problem, however, for disease people

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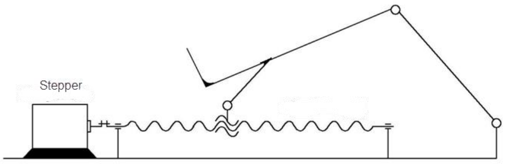
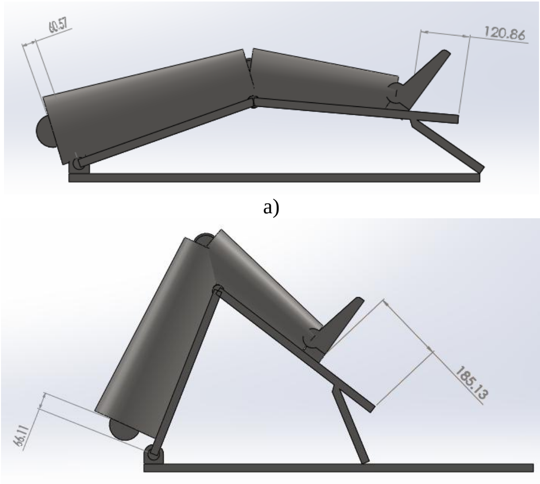


Figure 1. Mechanism of revolve based k nee CPM machine



a)

b)

Figure 2. Sliding phenomenon between leg, thigh and device's linkages

Figure 3. Leg injured patient under training

such as leg surgery patient (see Fig. 3), it could be a big issue.

Consequently, mechanical structure design in this study focus on solving the above problem.

There are two solutions considered in this study, firstly, in Fig. 4, slide joint is added to main revolve joints and expected to automatically adjust the mismatch between thigh, leg and device's linkages.

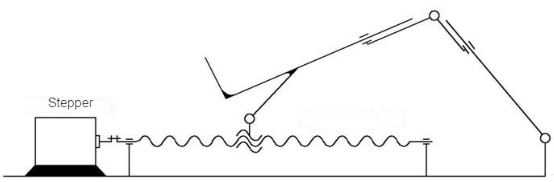


Figure 4. Mechanism of slider based knee CPM machine

Fig. 5 is perspective view of slider based knee CPM machine design.

Secondly, Fig. 6 presents an orthogonal joint and length adjustable linkages proposed as a solution for minimize sliding effect. Fig. 7 is perspective view of parallelogram based knee CPM machine design.

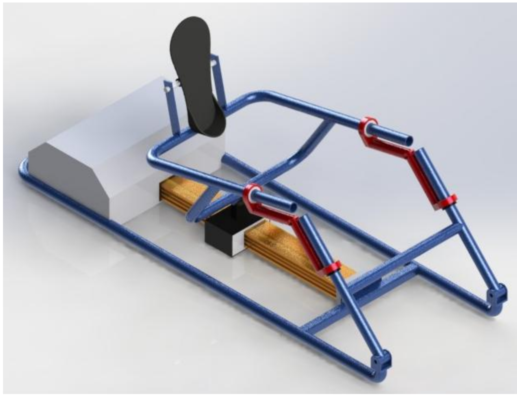


Figure 5. Slider based knee CPM machine design

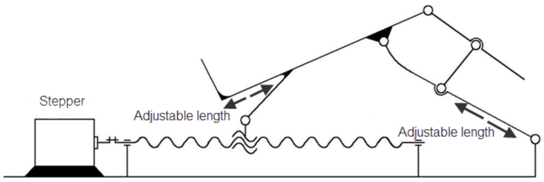


Figure 6. Mechanism of parallelogram based knee CPM machine

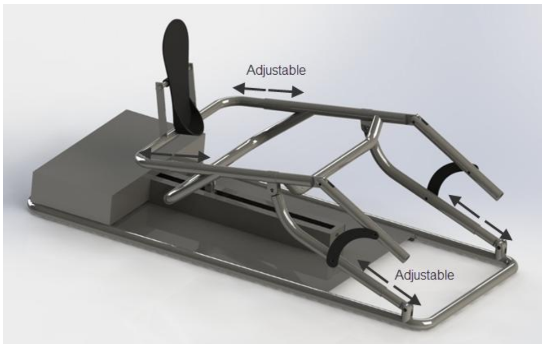


Figure 7. Parallelogram based knee CPM machine design

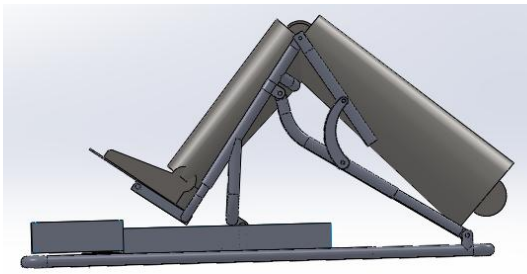


Figure 8. Relative position between leg, thigh and device's linkages

With parallelogram mechanism and adjustable length linkages, when observed training, patient leg is posisioned so that knee joint is exactly place concentric with upper revolve joint of parallelogram joint as shown in Fig. 8. In this way, when device is in operation, leg and foot are totally fixed in place to the linkage and therefore no sliding occurs. Simulation result also showed that, no sliding between thigh and its supporting linkage, however, relative rotating movement still exist. This movement is about 10 degree and considered to be relatively small, furthermore, rotating movement is supposed not to cause painful or bad feeling to patient.

Nevertheless, to maintain relatively fix position between leg, thigh and their supporting linkages, one more degree of freedom need to be solved, that is linear movement between device's base and patient's body. Of course patent body should not be moved due to high weight and inconvenient, device base was design to have the ability of moving back and ford as indicated in Fig. 9 .

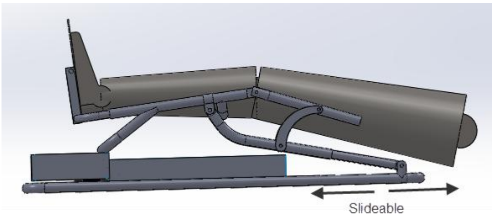


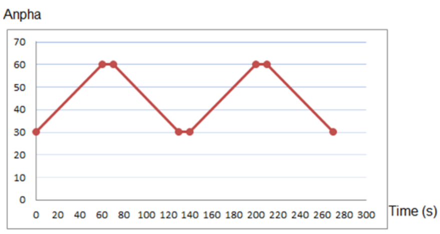
Figure 9. Slide degree of freedom

III. Operation Modes and Controller Design

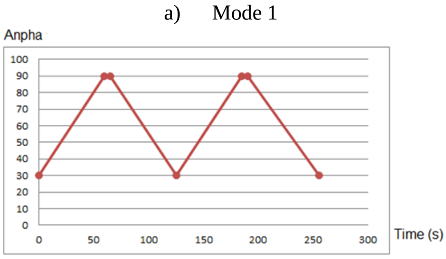
It is evident that operation modes are very crucial. Base on expert suggestion, the operation parameters tabulated in Table I were used for building operation modes.

TABLE I. Operation Parameters

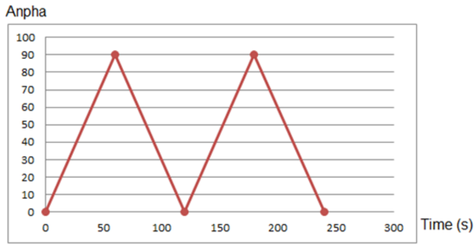
				
Lower limit	0	5^0	45^0/min	0s
Upper limit	115^0	120^0	155^0 /min	900s
Speed	1-9(150^0-440^0)/min			
Extension pause	15 min			



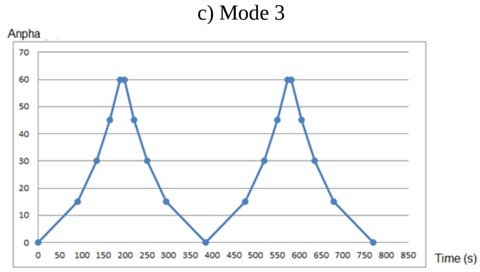
a) Mode 1



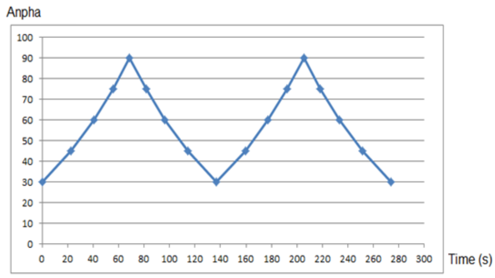
b) Mode 2



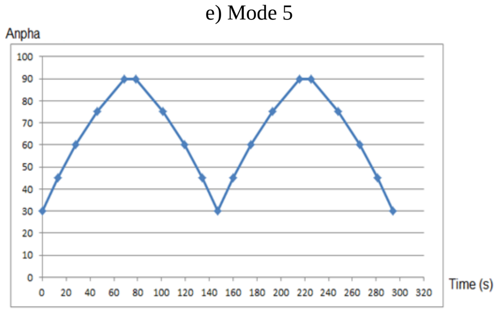
c) Mode 3



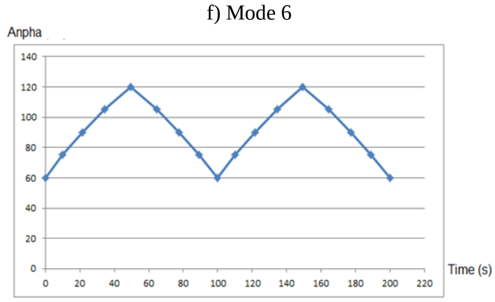
d) Mode 4



e) Mode 5



f) Mode 6



g) Mode 7

Figure 10. Operation modes

Fig. 10 presents seven operation modes proposed and applied in this study. These seven modes are varied from extension pause duration and speed when lower limit angle and upper limit angle are keep the same and referenced from Table I. Finally, eighth mode is a custom mode and patients can configure the operation parameters by themselves. Configured parameters including lower limit angle, upper limit angle and extension pause duration. However, custom mode should only be used under doctor suggestion.

IV. Result and Discussion

A. Structure Verification Results

Fig. 11 shows simulation result of structure deformation under loading. The result indicates that maximum deformation is about 1.027 mm and this result is supposed to be acceptable.

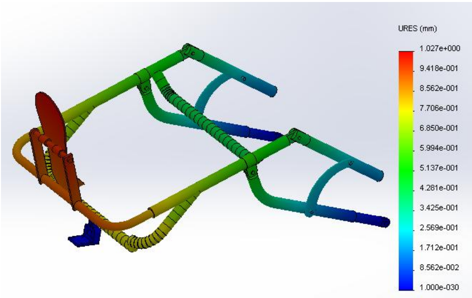


Figure 11. simulation result of structure deformation under loading.

Fig. 12 is simulation result of structure stress under loading. It is evident that the maximum von Mises stress is 34.7 MPa and much smaller than material yield strength of 172.339 Mpa.

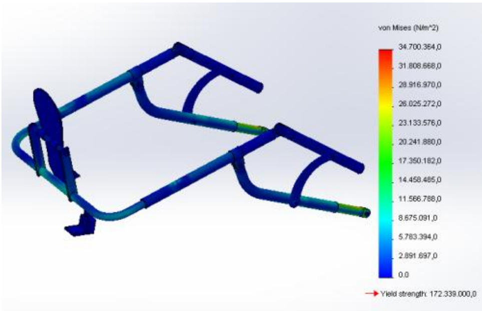
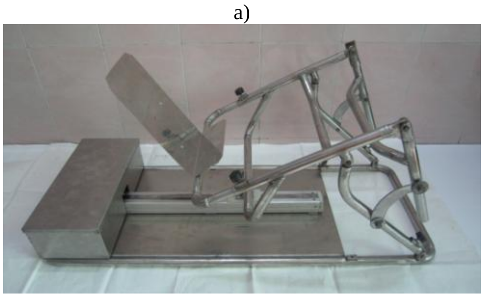


Figure 12. simulation result of structure stress under loading.

B. Experimental Results

A real model was built to validate the design concept and controller as shown in Fig. 13.

a)



b)

Figure 13. Knee CPM real machine

Testing operations were conducted and the results showed that the structure is stable and no sliding occurs during training process. Eight modes worked properly as expected. Furthermore, the device work well for both adult and child owing to adjustable linkage length.

V. Summary

This study has successfully solved the problem of relatively sliding between thigh, leg and knee CPM device's linkages. Parallelogram joint and length adjustable linkage was proposed as a solution for minimize sliding effect.

A controller with friendly user interface utilizing graphic LCD and multimode operation with 8 modes motion from 0 to 120 degrees and a range of angular velocities from 30 to 750 degrees/minute, in which one custom mode was design for patient to configure the operation parameters by themselves.

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