ISB 2013
BRAZIL
24th CONGRESS OF THE INTERNATIONAL
SOCIETY OF BIOMECHANICS

ENERGY EXCHANGE BETWEEN KNEE AND ANKLE IN A TRANSFEMORAL PROSTHESIS

Bart Koopman, Sebastiaan Behrens, Edsko Hekman and Ramazan Unal
Biomechanical Engineering Group, MIRA Institute for Biomedical Engineering, University of Twente,
Enschede, The Netherlands. email: h.f.j.m.koopman@utwente.nl

SUMMARY

In order to make an energy efficient transfemoral prosthesis, there should be energy exchange between knee and ankle of the prosthesis. A concept containing various spring elements is designed and tested for a single subject. It is shown that the concept of energy exchange can be realized; in this specific situation up to 76 % of the mechanical energy is restored to support ankle plantar flexion during push-off.

INTRODUCTION

Transfemoral amputation and the use of prostheses have drastic consequences in human life. The lack of a smooth coordination of (biarticular) muscles leads to limited energy exchange between the leg joints and to a large increase of metabolic energy consumption when compared to normal gait. One of the open challenges in the design of a prosthesis is that it should provide efficient mobility in terms of both metabolic and mechanical energy consumption. The objective of this paper is to design a prosthesis that allows for energy exchange between prosthetic knee and ankle, thus minimizing the energy requirements during gait. The prosthesis is tested in one subject.

METHODS

During gait, the knee is often considered an energy dissipater, while the ankle generates most of the energy during push-off. Figure 1 shows the power flow in knee and ankle, based on data from Winter [1]. In the swing phase, energy at the knee is absorbed in two instances *A1* and *A2*, while at the ankle, energy is absorbed at early stance (*A3*). The total amount of absorbed energy (*A1+A2+A3*) sums up to about the required energy needed for ankle push-off (*G*).

The new prosthesis should store the energies *A1*, *A2* and *A3*, transfer it to the ankle and release it with the correct timing. This is achieved with the conceptual design of Figure 2.

A special feature of spring element *C2* is that it has a sliding distal attachment point. During swing, the spring remains in front of the ankle (thus allowing to store energy *A2*), while during stance it moves to the heel to generate a plantar flexion torque.

The dimensions and stiffness properties of the mechanism were optimized in a series of numerical simulations, resulting in expected power flows shown in Figure 1 (thick lines). A prototype of this mechanism is tested in one subject.

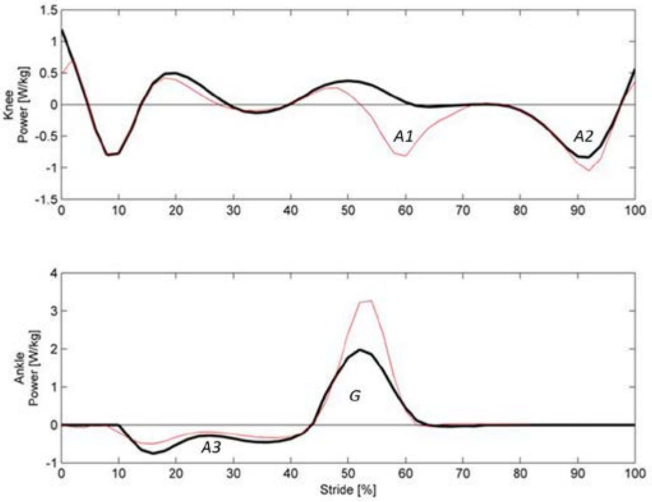

Figure 1. *The power flow of normal gait for knee (top) and ankle (bottom) joints during one stride (Winter, 1991). The areas A1,2,3 indicate the energy absorption, whereas G indicates the energy generation. The thick line represents simulation results for an optimized leg prosthesis with required behavior.*

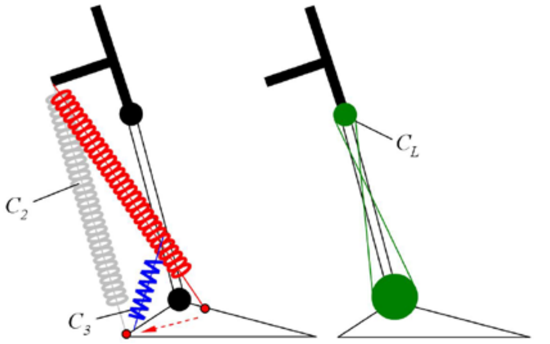

Figure 2. *Conceptual design of the proposed mechanism with three storage elements: C2 between the foot and upper leg; C3between foot and lower leg; CL links knee and ankle joint.*

RESULTS AND DISCUSSION

Figure 3 shows the design of the prototype, spring element *C2* is clearly visible. The change of configuration of the distal attachment of *C2* is realized along a trajectory that keeps the length of the spring constant and, therefore, the energy stored in the spring remains constant during this change. The elements *C3* and *CL* are hidden inside the construction.

The subject could walk relatively easy with the prosthesis, requiring only little training time (Figure 4). Moreover, the subject could walk in a large range of velocities and was tested at 4.6 km/h, which is relatively large for transfemoral amputee gait. Careful observation of Figure 4 shows ankle plantar flexion during push-off, this is confirmed with gait analysis measurements.

Energy measurements revealed that about 76 % of the required push-off energy could be retrieved from the mechanism. Since the system is fully passive, the rest of the energy should be provided by the subject and requires additional metabolic energy. As already indicated by the simulations, energy *A1* (Figure 1) is not captured by this mechanism.

CONCLUSIONS AND FUTURE WORK

The concept of energy exchange between knee and ankle in a prosthesis does work, it allows for a more efficient push-off during gait. About 76 % of the otherwise dissipated energy is now re-used for this specific subject.

The concept will now be tested in larger groups of amputees. Further improvements of the mechanism are possible and will be developed to further increase efficiency.

ACKNOWLEDGEMENTS

The Reflexleg project is funded by the Dutch Science and Technology Foundation STW.

Figure 3. *CAD representation of the prosthetic prototype.*

REFERENCES

[1] Winter DA (1991), *The Biomechanics and Motor Control of Human Gait: Normal, Elderly, and Pathological*, University of Waterloo Press.

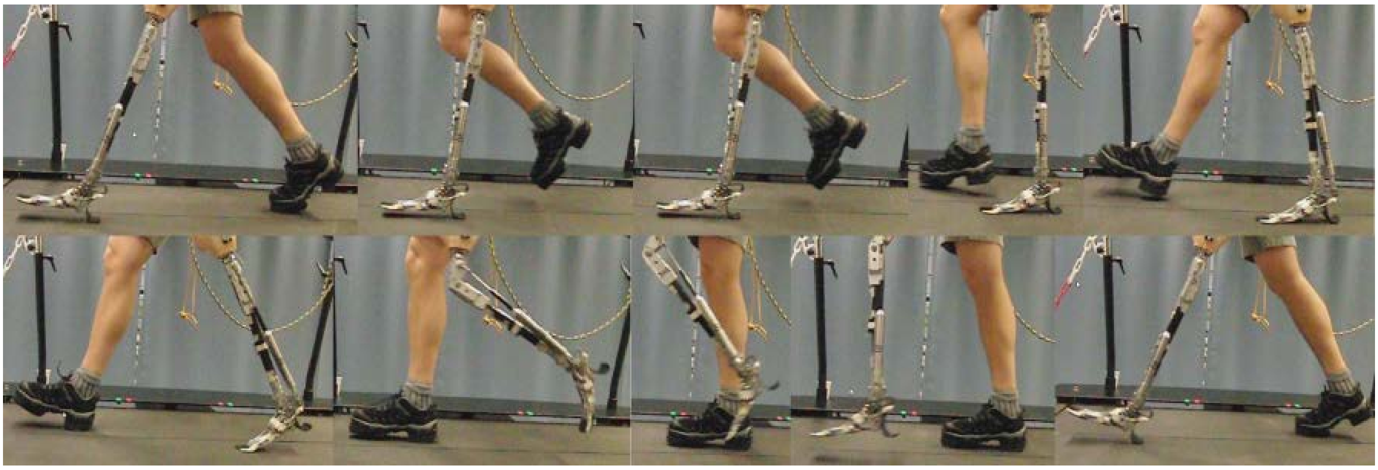

Figure 4. *Gait cycle of the amputee*