

MOBILE ANKLE PERTURBATOR WITH RIGID CONTROL

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Abstract - A perturbator by which it is possible to measure the mechanics of the ankle joint during walking has been developed.

It consists of a two link functional joint with a clutch. The joint is connected by means of 4 bowden wires to a powerful motor and a double pneumatic cylinder. The actuators are placed next to the treadmill where the subject is walking.

The system has been reduced in weight by finite element analysis. The material is aluminum 7075 and the total weight of the system is 0.9 kg.

Preliminary results shows that the clutch is able to engage the mechanical joint in a rigid connection and the system is able to perform a perturbation of the ankle joint of up to 10° with a velocity of 350°/s during any time of the gaitcycle.

It is meant as a tool to investigate the ankle control in healthy humans and neurological patients i.e. using FES assistive devices.

Keywords: Ankle joint, perturbator, treadmill walking

1. Introduction

Different techniques have been described in the literature for investigating muscle afferent feedback in the control of muscle activity, during human walking.

Yang et al. 1988 developed a pneumatic system, which was able to apply a muscle stretch to the ankle extensors in early stance phase [1]. Llewellyn et al. 1987 investigated the transmission of the Ia mediated human tendon jerk reflexes during gait by a spring-loaded hammer [2].

A mobile ankle perturbator presented in [3] was able to perturb the human ankle joint during the complete step cycle of treadmill walking [4,5]. The device was constructed as two joints; the first joint was acting on the ankle joint; the second joint was connected to a powerful actuator placed next to the treadmill where the subject was walking, this joint was also acting on the ankle joint but with a slip of +/- 3.5 deg.

When a perturbation of the ankle joint was intended the slip of the two joints was bridged and the actuator could force the ankle joint in a plantar or dorsal direction with a well-defined velocity. The construction of a two-link system with a slip between the links was beneficial when the subject was walking without any perturbation, since the ankle joint was uncoupled and thereby not affected by the actuator. It was however a disadvantage not to have a rigid connection when a perturbation was wanted. When holding a dorsal perturbation of the ankle joint in the early stance phase, the ankle was free to perform a dorsal flexion, within the slip range of the mechanical joint. This prevented force measurements during the perturbation. No

system can today measure the torque of the human ankle joint during walking.

The aim of this work has been to develop a mechanical system, which is able to deliver a well-defined perturbation to the ankle joint throughout the entire gait cycle with rigid control of the joint and without affecting the normal unperturbed gait pattern. The system should not weight more that 1 kg and it should according to Andersen and Sinkjær 1995 be able to operate with an acceleration of up to 15.000°/s and a velocity of up to 310 deg/s in the unperturbed gait pattern if the system has operate at a cadence of up to 6 km/h [3]. The system should be able to deliver a perturbation with a net stretch velocity of at least 100 °/s and a perturbation amplitude of at least 5 deg. The system is intended to be used to investigate electrophysiological and biomechanical features of the human ankle joint during gait in healthy humans and neurological patients i.e. using FES assistive devices.

2. Method

A solution to the rigid control problem would be to construct a two link system as described in [3] and incorporate a clutch in the mechanical joint that would give a rigid connection whenever engaged. Choosing traditional principles of clutches would increase the weight of the attached system with a weight of approximately 5 kg, which would affect the natural pattern of gait.

A solution to the problem is shown in figure 1 (See figure 2 for experimental set-up). The system is based on a two link mechanical device aligned on an axis with 6 independent slide bearings [3] with a clutch mechanism integrated into the functional joint. The first link of the system is acting on the ankle joint; the second link is connected to a powerful actuator placed next to the treadmill where the subject is walking, this link is also acting on the ankle joint but with a slip of +/- 3.5 deg.

The system is constructed in Aluminium 7075 (AlZnMgCu 1,5,th) and it has been reduced in weight by finite element analysis [6] to compensate for the weight of the clutch. The total weight of the system is only 921 gr. including the clutch and fittings.

The clutch is a two-armed construction, with 10 slide bearings, connected to a double pneumatic cylinder by means of two bowden wires. When the clutch is disengaged, the arms of the clutch are flexed by two torsion springs, to allow the mechanical joint to move within the slip of the two joints.

When a perturbation is wanted the clutch is engaged in the following way; (numbers refer to figure 1). The actuator pulls the power bowden wire (1) causing the slip to be bridged (2). This act allows space for the clutch to extend its leg, by a pull in the bowden wire of the clutch (3). When the leg of the clutch is extended to 180 deg. the clutch is engaged (4). The actuator is by means of the power bowden wire now able to control any rotational movement of the ankle joint. The clutch is released by pulling the second bowden wire of the clutch.

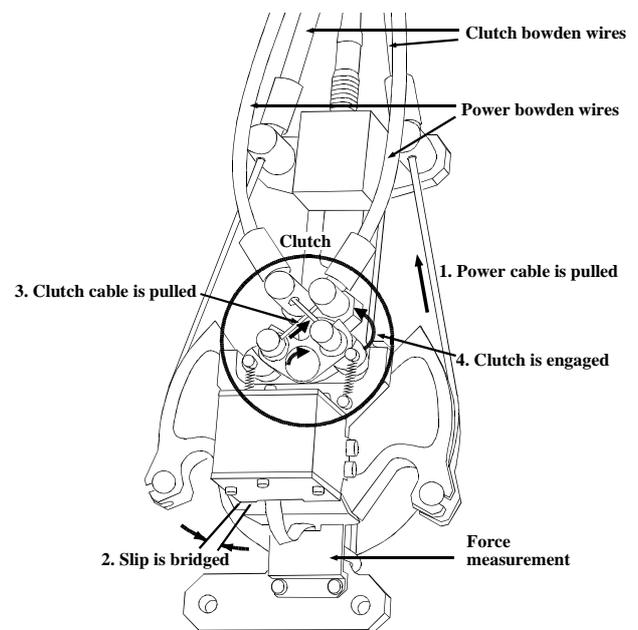


Figure 1 Functional joint

The two bowden mechanism connects the functional joint to the motor and the pneumatic actuators. The bowden

cable is a bendable power transmission element, which is only able to transmit tensile forces. It consists of two cables; an inner wire and an outer cable constructed as a steel spiral which provides compressional strength. The bowden cable is a flexible, light, and powerful transmission. The Inner cable of the power bowden wire is a 2.6 mm wire and the inner cable of the clutch is 1.5 mm both 7x7 right-regular lay wires.

The actuator system is based on the same system as described in Andersen and Sinkjær 1995 [3]. (95DSE92300 Dutymax AC-servo motor 2.6 kW and DB420 Digitax AC-servo amplifier 3x380 V IP20 8.5 A/17A) and a planetary transmission (Harmonic Drive HPGP36 I=12:1). This combination gives a rated torque of 100 Nm and a peak torque of 331 Nm of the output shaft of the gear. Up to 33% of the power is lost in the bowden cable, leaving a rated torque of 66 Nm and a peak torque of 222 at the joint.

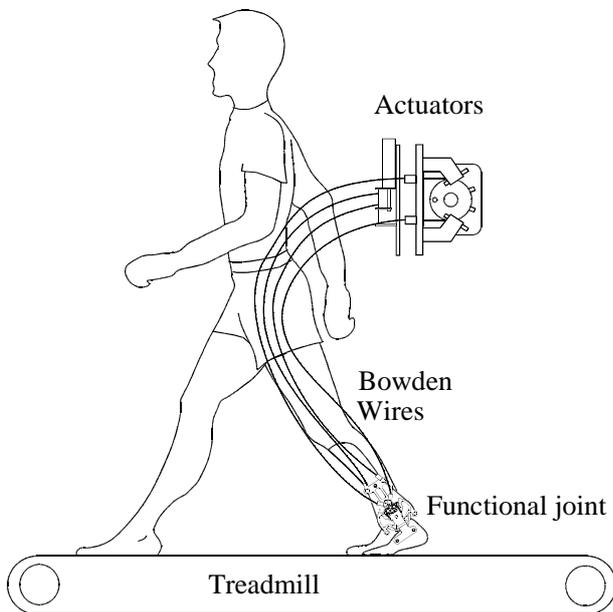


Figure 2 Experimental set-up

The actuator for engaging the clutch is a 32 mm² low friction double pneumatic cylinder, with a stroke of 40mm (Festo 163366DNC-32-40PPV-A-S11) operating on an 8 bar pressure system. The speed is increased by quick exhaust valves and oversize tubing. The clutch is connected to the pneumatic cylinder by two bowden

wires. The motor controller module controls the timing of the pneumatic valves [3].

The strain gauge based force measurement (Whetstone strain gauge bridge 2 x HBM1.5/120XY21) is placed, as proximately as possible, on a single based beam in the part attached to the foot/lower leg.

Position of the slip and the joint is based on one Codewheel (HP HEDS-6100) with two optical incremental encoder modules (HP HEDS-9000) giving a resolution of 4096 CPR (11.37 counts/Deg.) on both slip and joint angle.

3.Results

Figure 3 shows an example of a dorsal perturbation of the ankle joint.

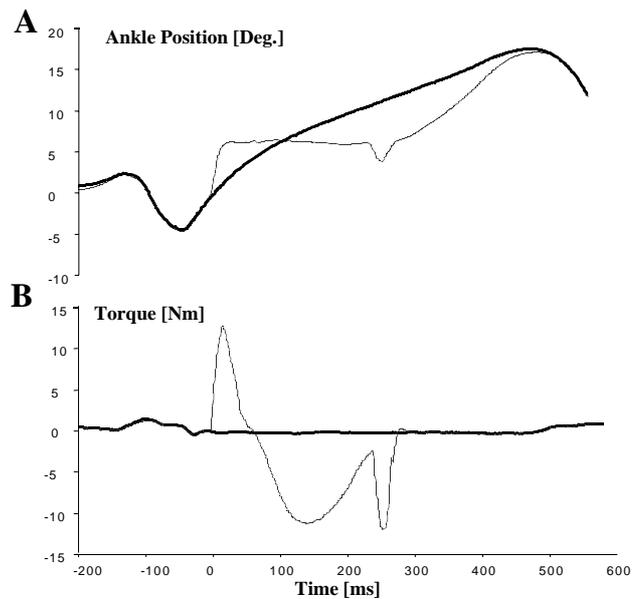


Figure 3 Perturbation of the ankle joint in mid stance phase

The perturbation of the ankle joint is 50 ms after heel contact. The perturbation is 7.6 deg., the velocity of the perturbation is 322 deg/s and the perturbation is held for 200 ms. The peak torque value of the perturbation is 12.8 Nm and it is reversed after 72 ms since the position of the control step is passing the position of the perturbation. The release of the clutch at end of perturbation can be seen as a peak in the torque measurement.

The system was tested successfully throughout the entire gait cycle, and it was capable of performing a 7-8 deg stretch with a constant velocity of 310-330 deg/s

Conclusion:

With the system presented in this paper, it is now possible to measure the mechanics of a perturbation of the human ankle joint during gait. The system is capable of following the unperturbed gait pattern and performing a perturbation throughout the complete gait cycle. The system is meant as a tool to investigate the ankle control in healthy humans and neurological patients i.e. using FES assistive devices.

References:

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