DESIGN OF A REACTION FORCE SERIES ELASTIC ACTUATOR FOR POWERED KNEE AND ANKLE PROSTHESES

Matthew E. Carney and Hugh M. Herr

MIT Media Lab Biomechatronics, Massachusetts Institute of Technology, Cambridge, MA

ABSTRACT

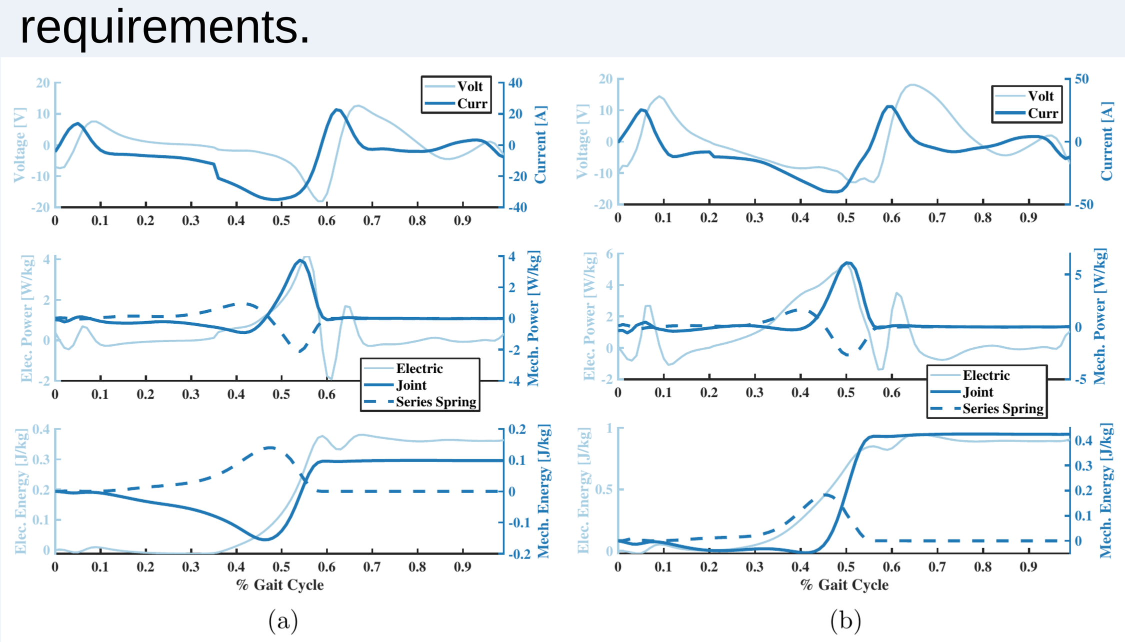
We present TF8 a reaction force series elastic actuator to be used as a research platform for knee and ankle powered prostheses. The hardware design is optimized for minimum electric energy consumption during a walking stride. Actuator dynamics were kinematically clamped to healthy-subject gait data and subject to constraints on motor and power-electronics saturations limits, and geometry, resulting in optimal: motor, reduction ratio, spring stiffness and linkage geometry. Identical hardware can be configured as a knee, or an ankle by attaching standard prosthetic component adapters. The series stiffness can also be adjusted to match task performance requirements such as user mass or knee or ankle configurations. The actuator achieves biologically relevant kinetics and kinematics with 115 degree total joint range of motion, 200Nm peak torques, and 650W mechanical power, within a 1.7kg mass. The actuator has been tested with 7 subjects and has been demonstrated on a 70kg user jogging at 2m/s.

OBJECTIVES

1) To build a power dense actuator capable of - approaching biological performance of human knee and ankles.
2) To build an actuator tuned for individual users and applications.

METHODS

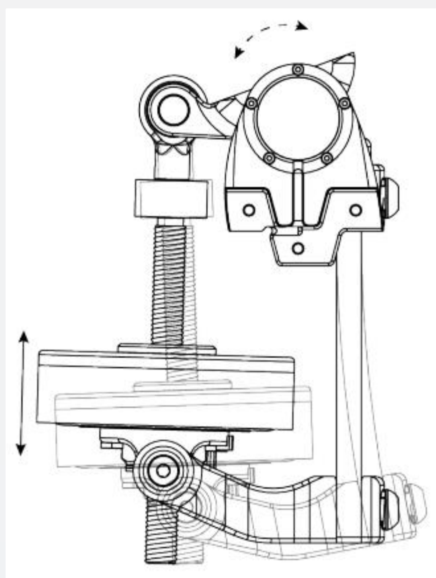
Kinematically clamped optimization searches for minimum electric energy configuration of motor, drive-train and spring component specifications [1,2]. Secondary optimizations used to find minimum mass spring and linkage geometry to align power-stroke of actuator with kinetic requirements.



(a) (b)

MECHANICAL DESIGN

The design is a reaction force series elastic actuator: the motor mass is grounded to a cantilever beam spring by way of a moment arm. This configuration maximizes strain energy storage in the spring and packages well with the linear actuator [3]. The minimum mass configuration of the actuator is 1.4kg.

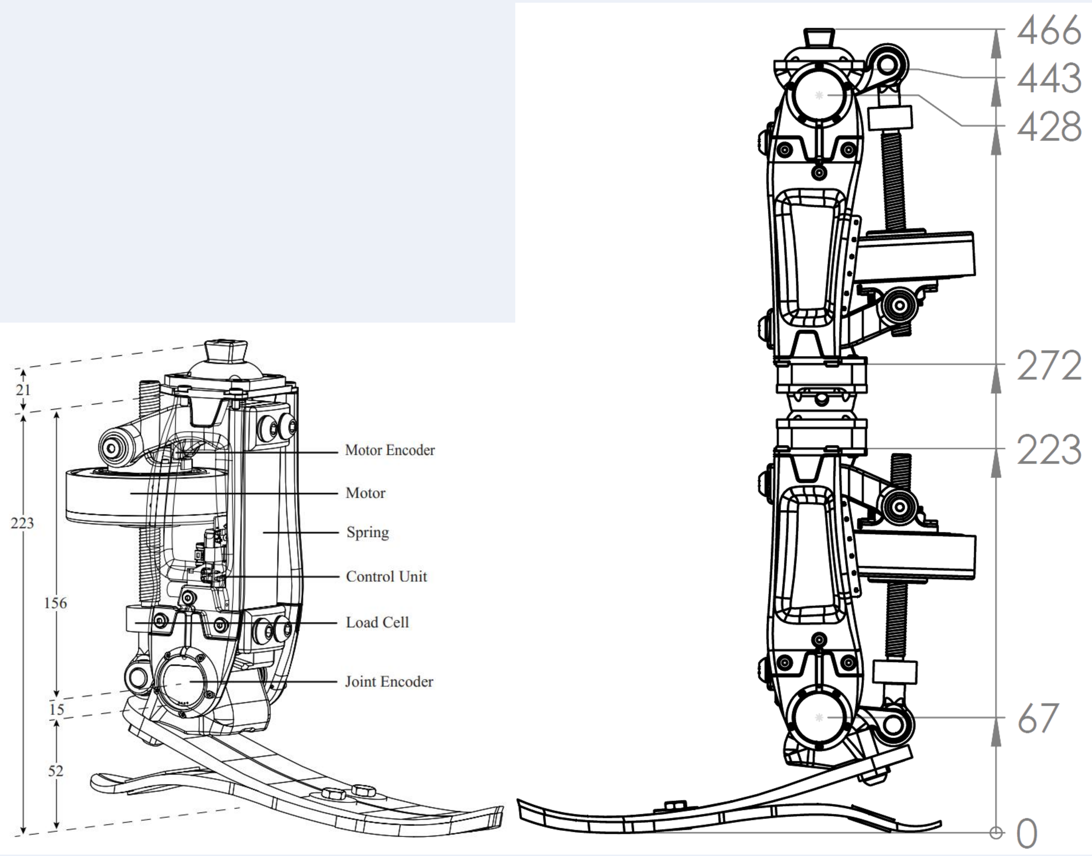


: Minimum Configuration Mass Distribution of the TF8

Component	Mass (g)	(%)
Motor	549	40
Structural Components	374	27
Spring	116	9
Ballscrew	100	7
Spring Clamping Hardware	95	7
Load Cell	54	4
Fasteners	48	4
Encoder Hardware	25	2
Total	1362	100

In the knee configuration the system has a mass of 1.7kg and the ankle with foot and battery, as shown below, has a mass of 2.0kg. Total mass of an ankle and knee is 3.9kg when including additional connectors..

The minimum build height of an ankle and knee is 466mm, with a knee joint height of 428mm.



RESULTS

Closed-loop torque control bandwidth is 6.2Hz at a magnitude of 82Nm.

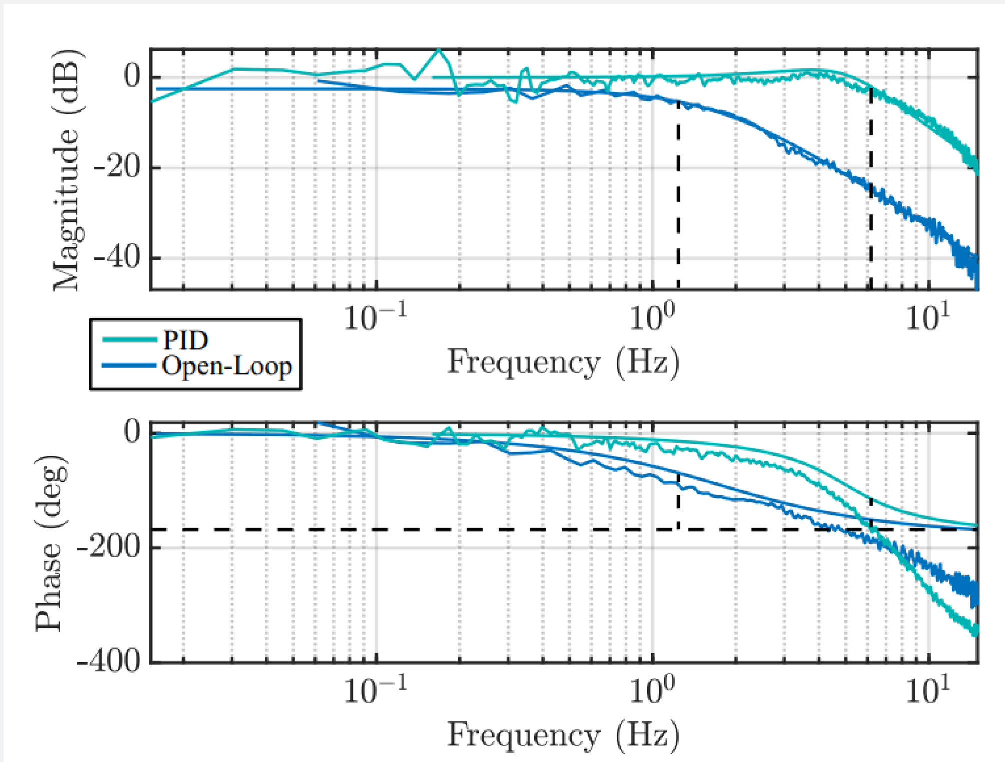
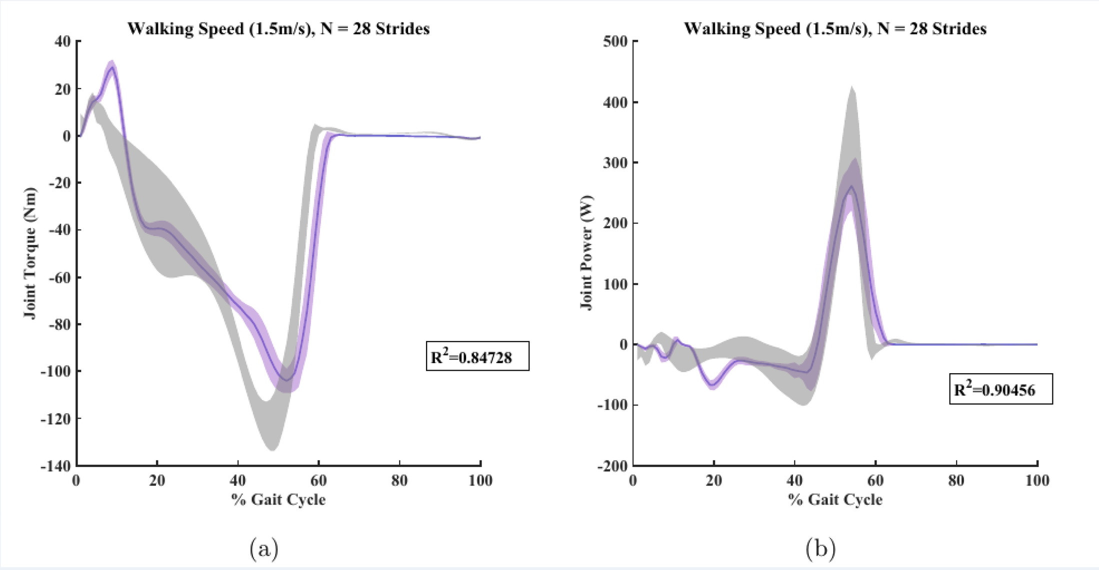


Table 3.1: Actuator Design Specification

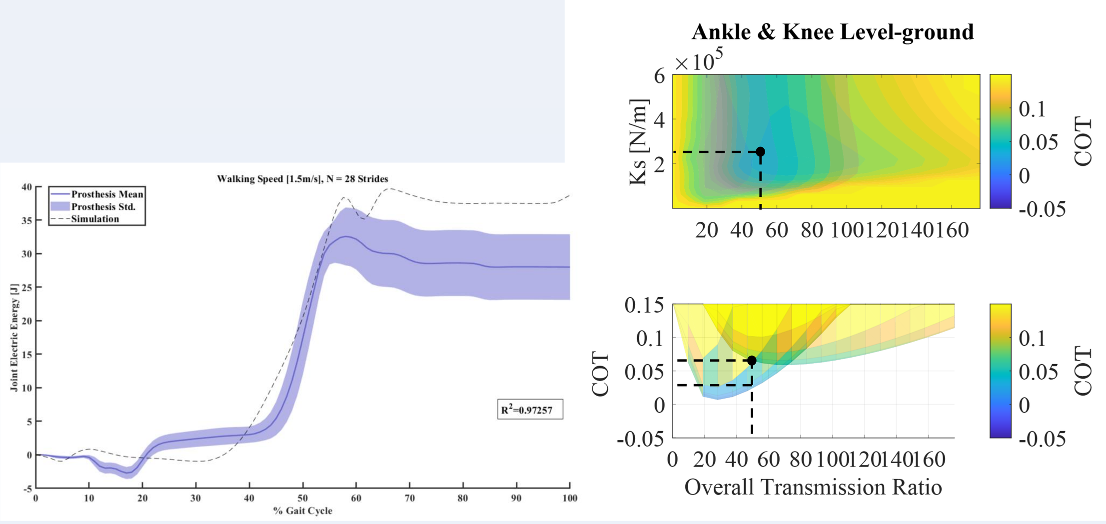
2m/s	Ankle	Knee	Target⁺	Result	Units
Range of Motion[1]	19-0-19	70	45-0-65	35-0-75	*Deg*
Velocity	6.0	8.6	7	6.8*	*rad/s*
Max Torque	160	118	175	175	*Nm*
Max Power	552	313	550	350	*W*
Bandwidth Magnitude	82	73	82	82	*Nm*
Bandwidth Frequency	4.8	6.0	6.0	6.2	*Hz*
Segment Mass[2]	2.6	2.6	2.0	1.6	*kg*

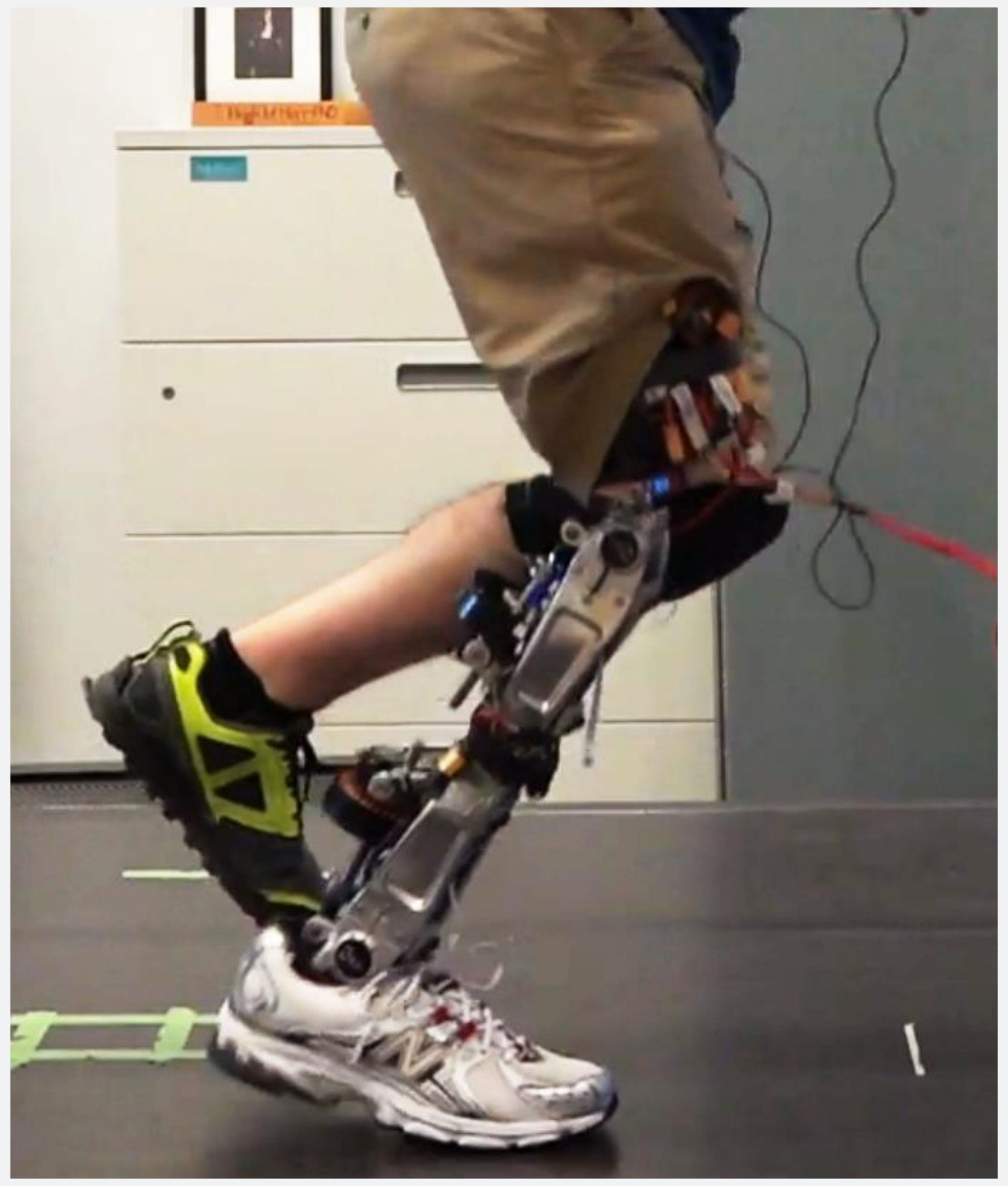
Ankle walking shows prosthesis tracking (purple) of biological data (grey).



(a) (b)

Electric cost of transport for level-ground walking of the ankle is 0.05 with measured consumption of 28J. This matches well with estimates for ankle.





CONCLUSIONS

Preliminary results show adequate performance to achieve walking kinetics and kinematics for both knee and ankle while remaining within biological segment mass. Limits in impedance matching between the power electronics and motor limited identifying ultimate system capacity. Future work includes updated electronics and knee clinical trials.

REFERENCES

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