3.2 'Novel Serial Elastic Actuator Elastic module without friction hysteresis' (MD-T-02)

Martin Mallwitz[(1)]*,Christian Oekermann*[(1)]

(1) Robotics Innovation Center, DFKI GmbH, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: martin.mallwitz@dfki.de

Abstract

A serial elastic actuator (SEA) includes a physical compliance. Thereby the actuator provides the following characteristics: sensible for external mechanical impacts, decoupling loads from the motor side, low-pass filter behavior for loads and it stores energy. This characteristics privilege the actuator for applications with a direct human-robot contact like industrial, rehabilitation or teleoperation scenarios and for walking robots. The talk gives an overview of common applications and designs. It gives a more detailed view on SEA-development at the DFKI project 'Capio'. Generally the implementation of a compliance cause hysteresis problems by friction or material characteristics. Depending of the positioning of elasticity it complicates the design development and increases the actuator size. To solve these problems a customized torsional disc spring is implemented in a serial elastic actuator module. The iterative spring design workflow from the CAD model to the large displacement FEM simulation is described. The DFKI design of a serial elastic module for a 5 Nm actuator is shown beside other research designs.

Novel Serial Elastic Actuator

Elastic module without friction hysteresis

Martin Mallwitz, Christian Oekermann

25.06.2015

DFKI Bremen & Universität Bremen
Robotics Innovation Center
Director: Prof. Dr. Frank Kirchner
www.dfki.de/robotics
robotics@dfki.de

Universität Bremen

Outline

- SEA Motivation
- SEA Applications
- Design of SEAs
- Capio SEA, Design and Usage
- Novel SEA Module, Design and Dimensioning
- Next Steps and Future Work
- References

Universität Bremen

2

SEA Motivation

- Robot safety principles
  - Supervision, force control, lightweight
  - ISO 13482, ISO 10218
  - Inherent safe design → SEA
- Robot industrial application
  - Usually robot human interaction with safety distance
  - Dangerous situation by robot motion
  - New: robot as cooperative partner in direct contact
- Robot rehabilitation application
  - Direct human robots contact
  - Unhealthy operator/patient

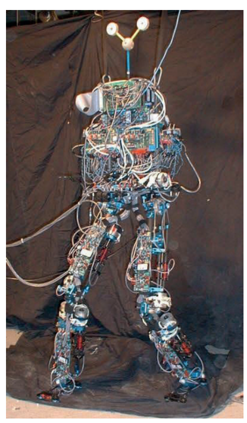
Universität Bremen

3

SEA Applications

- Mostly used for legged robots
- No commercial actuators available
- Few industrial application

Baxter



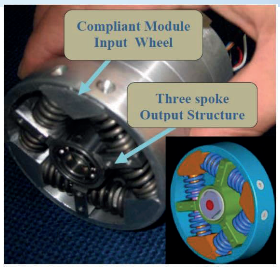
M2

Herbert

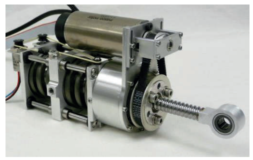
Universität Bremen

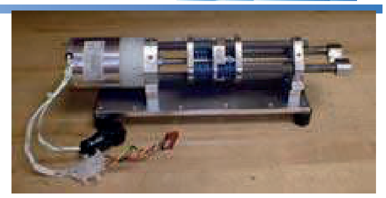
4

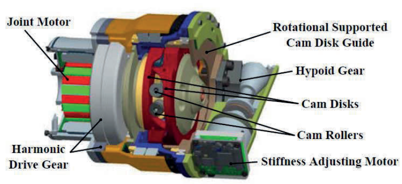
Designs of SEAs



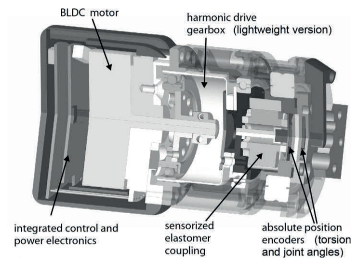
Tsagarakis 2009


Paine 2012


Pratt 1995



Wolf 2011



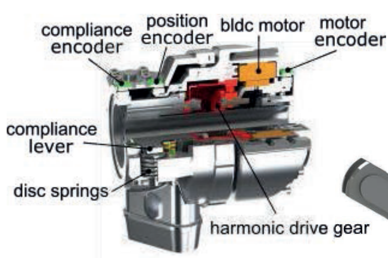
Paskarbeit 2013

Universität Bremen

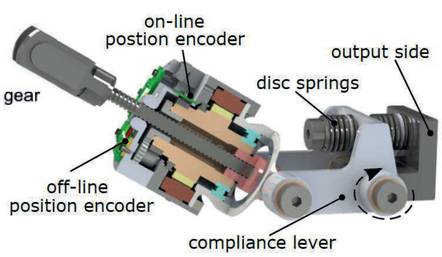
5

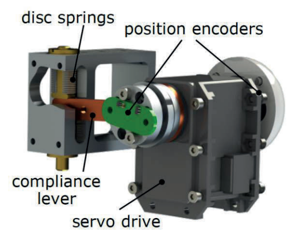
Capio SEAs at the RIC

- Nominal torque 60 Nm
- Overall weight 1kg
- Robodrive ILM 70 x 10, 370 W, 3500 rpm, 1.25 Nm
- Harmonic Drive CPL 20, ratio 1:80
- Variable set of disc springs



- Maximum force 790 N
- 166 mm/s max. travel velocity
- Overall weight 320 g
- Robodrive ILM 50x10, 140 W, 5000 rpm, 0.28 Nm
- Driven nut, Spindle 2 mm lead
- Offline tooth wheel nonius with iC-Haus MH 12 bit sensors
- Online iC-Haus MU 19 bit sensor for BLDC commutation and travel
- Compliance via structure
- Variable set of disc springs





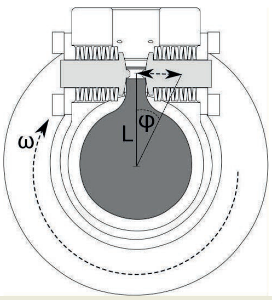
- Dynamixel 24F, 2.6 Nm toque at 12 V, 126 rpm
- Compliance via structure
- Variable set of disc springs
- Compliance measured with two iC-Haus MH sensors

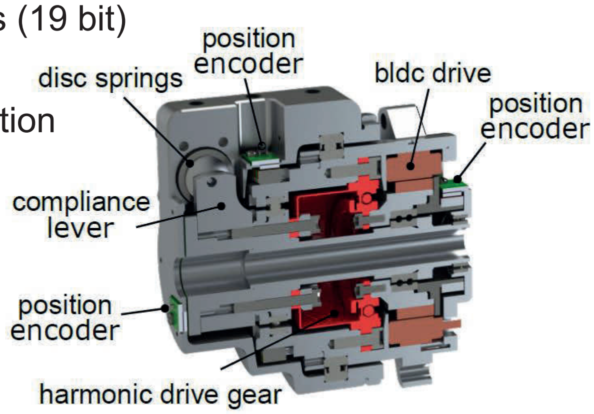
Universität Bremen

6

Capio Design 14 / 28 Nm

- ILM 50x8 robodrive and CPL 14 - 50/100 harmonic drive
- 28 Nm, 140 W, 600g
- 3 x iC-Haus MU sensors (19 bit)
- Variable disc springs
- Hysteresis by spring friction

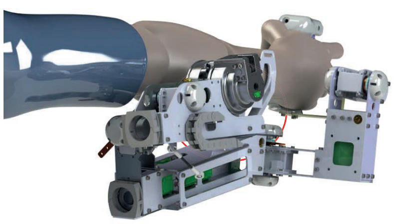




Universität Bremen

7

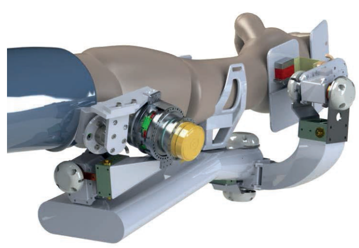
Usage at the Capio Exoskeleton



Current forearm setup

- Current setting for internal/external rotation of upper arm and ellbow extension/flexion: Capio SEA 14 Nm
- Weight 4 x 600 g =2400 g
- Experimental evaluation showed a max required torque of 4 Nm

- Development of adapted torque SEA for weight reduction and safety aspects
- Expected weight reduction about 1000 g



Sketch of new forearm setup

Universität Bremen

8

Known SEA Problems

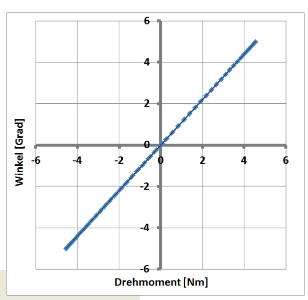
- Hysteresis by spring contact friction
- Hysteresis by elastomer compliant element (nonlinear material characteristics)
- Hysteresis by friction in a sealed bearing
- Short lever arm design if inside housing
- Expensive milled parts necessary
- Clunking and moving of unloaded springs
- Not all torques possible with commercial springs

Universität Bremen

9

Serial Elastic Modul

- Goals: 5 Nm, +-5 ° deflection
- Given Diameter by bearing
- Friction free spring application
- Spring package possible
- 300 ° limited working range

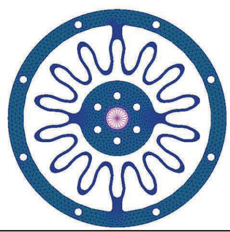
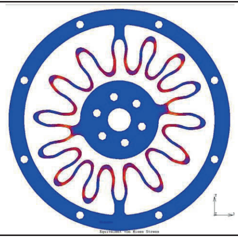
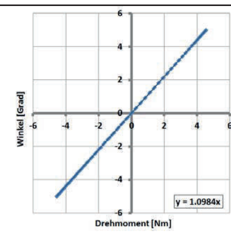


Universität Bremen

10

Spring Dimensioning Workflow

- Goals: 5 Nm and +-5 ° deflection
- Iterative process, morphological adaption for stress reduction

CAD-Design Solidworks	**Mesh-Design Patran/Nastran**	**FEM-Simulation Marc/Mentat**	**Evaluation**
			
Parametric Design	2D- simplification TRIA-Elements	Large-Displacement Simulation	Spring-Stiffness Calculation

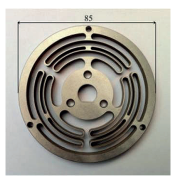
Universität Bremen

11

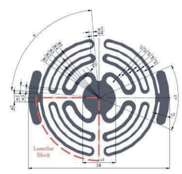
Custom Rotative Spring Designs

Stienen 2008

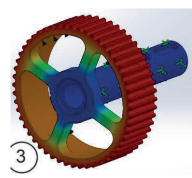
Lagoda 2010



Carpino 2012



Accoto 2013



Pierce 2014

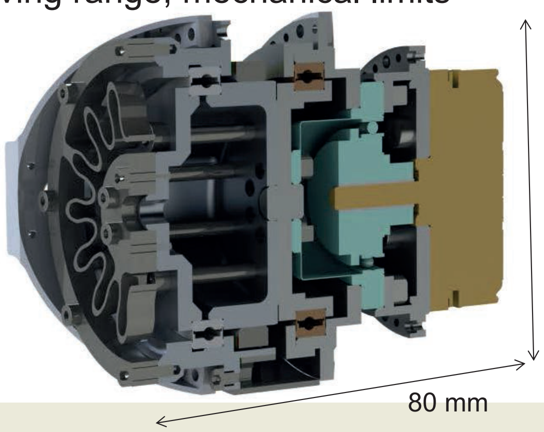
Year	Name	Stiffness [Nm/rad]	Max Torque [Nm]	Max Deflection [rad]	Outer Diameter [mm]	Thickness [mm]	Weight [g]
2008	Stienen	88,00	22,00	0,25	50,00	10,00	-
2010	Lagoda	219,00	90,00	0,50	~90	-	-
2012	Carpino	98,00	7,68	0,08	85,00	3,00	61,50
2013	Accoto	272,25	30,00	0,11	90,00	23,50	370,00

Universität Bremen

12

Serial elastic actuator

- Base: Limes Actuator 5 Nm, Maxon EC flat 45, HFUC11–50
- Module weight 160 g, Overall weight 380 g
- One iC-Haus MU target (19 bit) for deflection and position
- 300 ° moving range, mechanical limits



Universität Bremen

13

Next Steps and Future Work

- Assemble joint, integrate in testbed and Capio forearm
- Spring design
  - Evaluation spring characteristics
  - Optimize design concerning stress, size, weight of spring
  - Safety limits for deflection angle
- Module design
  - Implement strain gauge at spring for redundant torque signal or removing iC-Haus MU sensor
  - Compact design and weight reduction
  - Implement brakes on motor side

Universität Bremen

14

References

- Tsagarakis, N. G., Laffranchi, M., Vanderborght, B., & Caldwell, D. G. (2009, May). A compact soft actuator unit for small scale human friendly robots. In *Robotics and Automation, 2009. ICRA'09. IEEE International Conference on* (pp. 4356-4362). IEEE.
- Pratt, G., & Williamson, M. M. (1995, August). Series elastic actuators. In *Intelligent Robots and Systems 95.'Human Robot Interaction and Cooperative Robots', Proceedings. 1995 IEEE/RSJ International Conference on* (Vol. 1, pp. 399-406). IEEE.
- Pierce, B., & Cheng, G. (2014, November). Realising Herbert: An affordable design approach of an anthropometrically correct compliant humanoid robot. In *Humanoid Robots (Humanoids), 2014 14th IEEE-RAS International Conference on* (pp. 7-12). IEEE.
- Wolf, S., Eiberger, O., & Hirzinger, G. (2011, May). The DLR FSJ: Energy based design of a variable stiffness joint. In *Robotics and Automation (ICRA), 2011 IEEE International Conference on* (pp. 5082-5089). IEEE.
- Paskarbeit, J., Annunziata, S., Basa, D., & Schneider, A. (2013). A self-contained, elastic joint drive for robotics applications based on a sensorized elastomer coupling—Design and identification. *Sensors and Actuators A: Physical*, *199*, 56-66.
- Paine, N., & Sentis, L. (2012, December). A new prismatic series elastic actuator with compact size and high performance. In *Robotics and Biomimetics (ROBIO), 2012 IEEE International Conference on* (pp. 1759-1766). IEEE.
- Lagoda, C., Schou, A. C., Stienen, A. H., Hekman, E. E., & van der Kooij, H. (2010, September). Design of an electric series elastic actuated joint for robotic gait rehabilitation training. In *Biomedical Robotics and Biomechatronics (BioRob), 2010 3rd IEEE RAS and EMBS International Conference on* (pp. 21-26). IEEE.
- Accoto, D., Carpino, G., Sergi, F., Tagliamonte, N. L., Zollo, L., & Guglielmelli, E. (2013). Design and characterization of a novel high-power series elastic actuator for a lower limb robotic orthosis. *Int J Adv Robot Syst*, *10*, 359.
- Stienen, A. H., Hekman, E. E., Braak, H. T., Aalsma, A. M., van der Helm, F. C., & van der Kooij, H. (2008, October). Design of a rotational hydro-elastic actuator for an active upper-extremity rehabilitation exoskeleton. In *Biomedical Robotics and Biomechatronics, 2008. BioRob 2008. 2nd IEEE RAS & EMBS International Conference on* (pp. 881-888). IEEE.

Universität Bremen

15

Thank you!

Question?

DFKI Bremen & Universität Bremen
Robotics Innovation Center
Director: Prof. Dr. Frank Kirchner
www.dfki.de/robotics
robotics@dfki.de

Universität Bremen