3.2 ‘Novel Serial Elastic Actuator Elastic module without friction hysteresis’ – Martin Mallwitz, Christian Oekermann

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

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
SEA Motivation

- Robot safety principles
  - Supervision, force control, lightweight
  - ISO 13482, ISO 10218
  - Inherent safe design \(\rightarrow\) 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

SEA Applications

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

Baxter

M2

Herbert
Designs of SEAs

Tsagarakis 2009

Paine 2012

Wolf 2011

Paskarbeit 2013

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 torque at 12 V, 126 rpm
- Compliance via structure
- Variable set of disc springs
- Compliance measured with two iC-Haus MH sensors
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

Usage at the Capio Exoskeleton

- Current setting for internal/external rotation of upper arm and elbow 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
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

Serial Elastic Modul

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

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

<table>
<thead>
<tr>
<th>CAD-Design</th>
<th>Mesh-Design</th>
<th>FEM-Simulation</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solidworks</td>
<td>Patran/Nastran</td>
<td>Marc/Mentat</td>
<td>Spring-Stiffness</td>
</tr>
<tr>
<td>Parametric Design</td>
<td>2D- simplification</td>
<td>Large-Displacement</td>
<td></td>
</tr>
<tr>
<td>TRIA-Elements</td>
<td></td>
<td>Simulation</td>
<td></td>
</tr>
</tbody>
</table>

Custom Rotative Spring Designs

<table>
<thead>
<tr>
<th>Year</th>
<th>Name</th>
<th>Stiffness [Nm/rad]</th>
<th>Max Torque [Nm]</th>
<th>Max Deflection [rad]</th>
<th>Outer Diameter [mm]</th>
<th>Thickness [mm]</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Stienen</td>
<td>88.00</td>
<td>22.00</td>
<td>0.25</td>
<td>50.00</td>
<td>10.00</td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>Lagoda</td>
<td>219.00</td>
<td>90.00</td>
<td>0.50</td>
<td>~90</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>Carpino</td>
<td>98.00</td>
<td>7.68</td>
<td>0.08</td>
<td>85.00</td>
<td>10.00</td>
<td>61.50</td>
</tr>
<tr>
<td>2013</td>
<td>Accoto</td>
<td>272.25</td>
<td>30.00</td>
<td>0.11</td>
<td>90.00</td>
<td>23.50</td>
<td>370.00</td>
</tr>
</tbody>
</table>
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

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
References


Thank you!

Question?