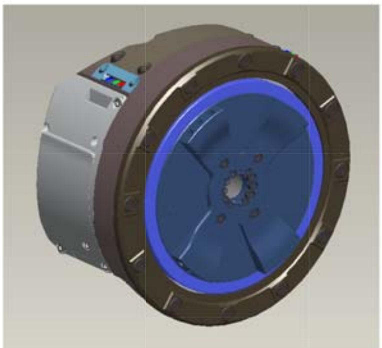
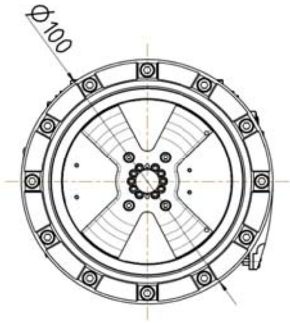
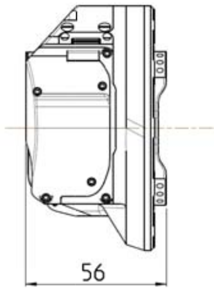
DLR Bidirectional Antagonism with variable Stiffness (BAVS)

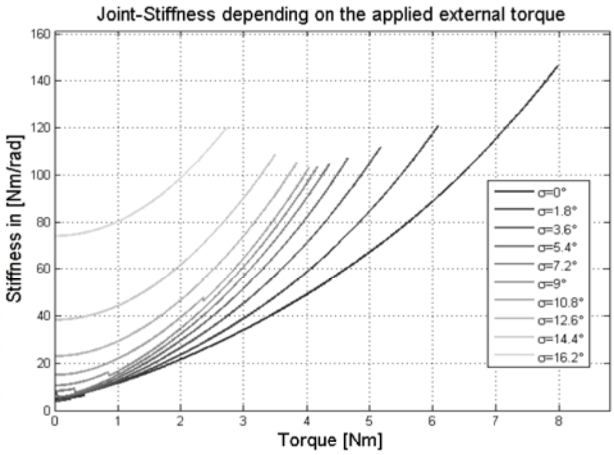
Helping Antagonistic Joint

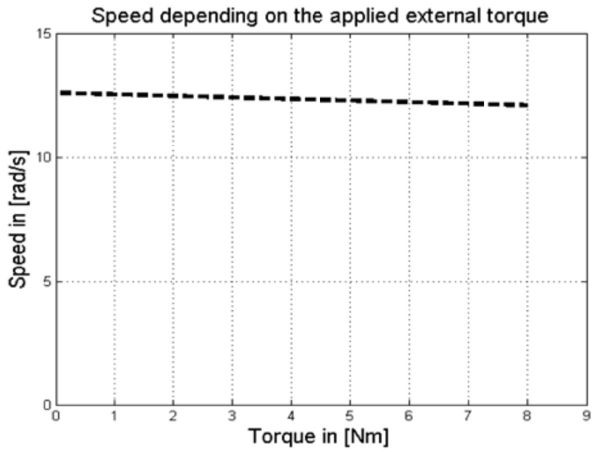


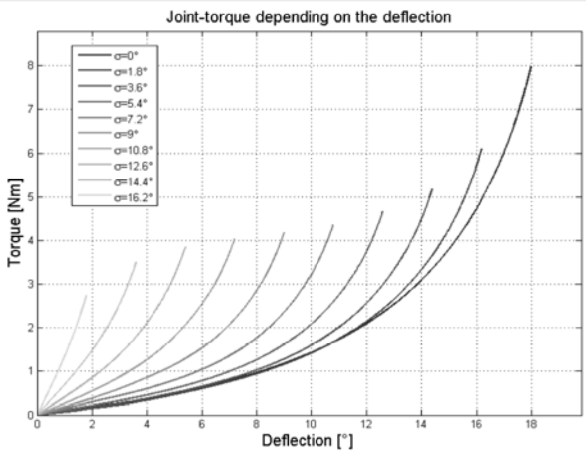


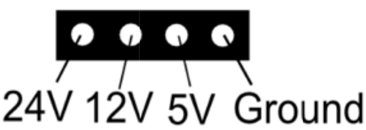


Operating Data				
#	(quantity)		(unit)	(value)
Mechanical				
1	Continuous Output Power		[W]	134.4
2	Nominal Torque		[Nm]	4.8
3	Nominal Speed		[rad/s]	12.6
4	Nominal Stiffness Variation Time	with no load	[s]	0.014
5		with nominal torque	[s]	0.014
6	Peak (Maximum) Torque		[Nm]	8
7	Maximum Speed		[rad/s]	12.6
8	Maximum Stiffness		[Nm/rad]	146.6
9	Minimum Stiffness		[Nm/rad]	3.9
10	Maximum Elastic Energy		[J]	0.9
11	Maximum Torque Hysteresis		[%]	tbm
12	Maximum deflection	with max. stiffness	[°]	0
13		with min. stiffness	[°]	±18.2
14	Active Rotation Angle		[°]	203
15	Angular Resolution		[°]	0.0031
16	Weight		[Kg]	0.75
Electrical				
17	Nominal Voltage		[V]	24
18	Nominal Current		[A]	6
19	Maximum Current		[A]	18
Control				
20	Voltage Supply		[V]	12
21	Nominal Current		[A]	1
22	I/O protocol			Spacewire









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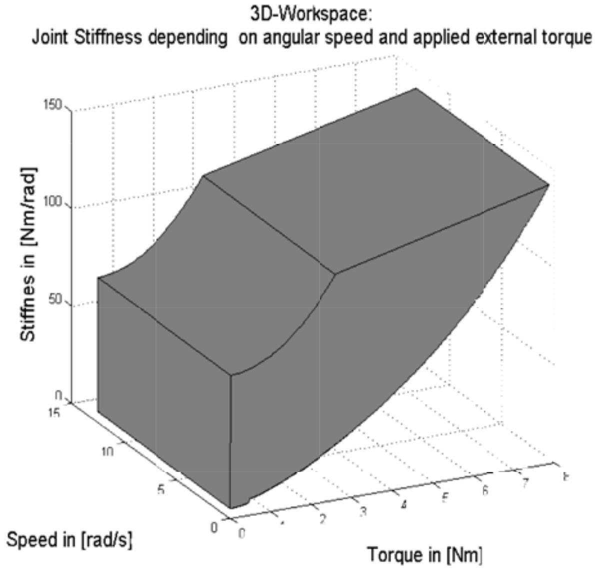
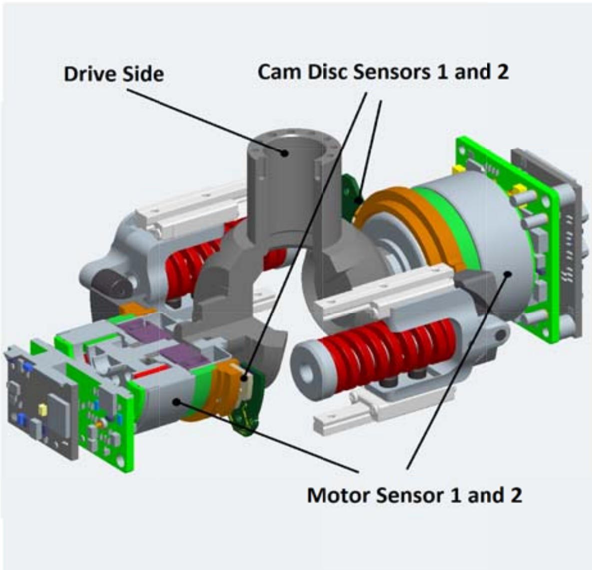
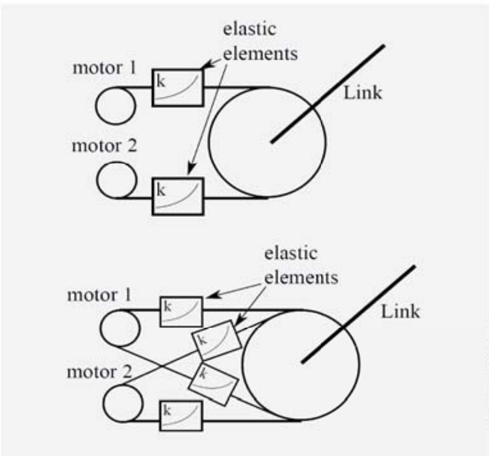
Helping Antagonistic Joint

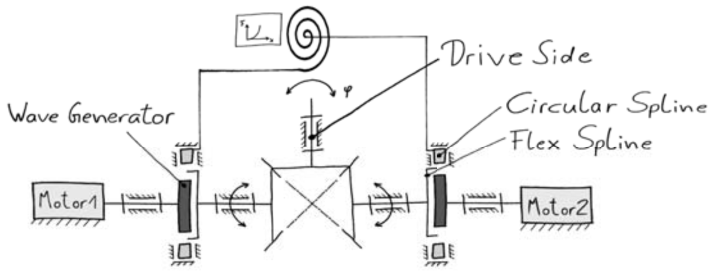
Fig.7
Measured
Torque
vs
Deflection
to be measured



Additional sensors data			
#	(quantity)	(unit)	(value)
a0	**Sensor Cam Disc 1 and 2**		
a1	Resolution	[bit]	16
a2	Range	[°]	55
a3	I/O protocol		Biss
b0	**Sensor Motor 1 and 2**		
b1	Resolution	[bit]	12
b2	Range	[°]	Inf.
b3	I/O protocol		Biss
c0	**Sensor Drive Side**		
c1	Resolution	[bit]	16
c2	Range	[°]	203
c3	I/O protocol		Biss



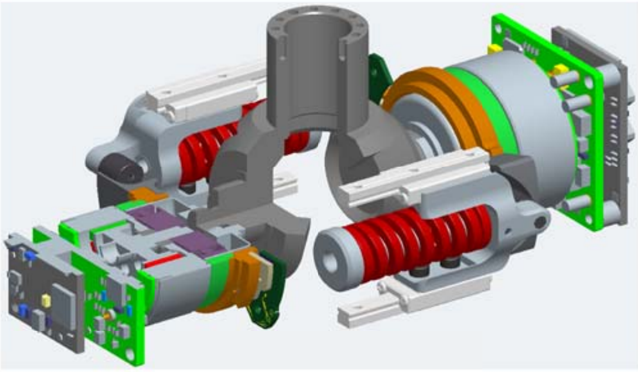


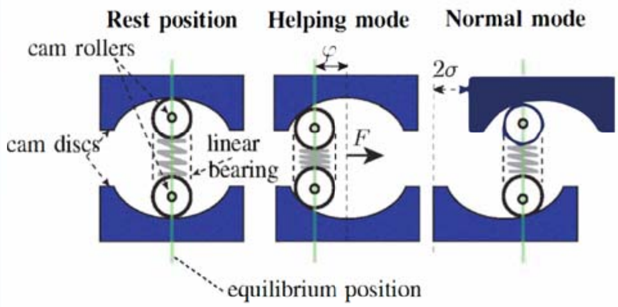


The difference between normal (picture left,above) and helping (picture left,below) antagonism is that the two motors of the helping antagonism can assist each other in both directions. Thus the maximum torque of the robotic joint is limited by the double motor stall torque and not by the single stall torque. The principle BAVS is realized with Harmonic Drives and without using a tendon driven system (picture above).

DLR Bidirectional Antagonism with variable Stiffness (BAVS)

Model





Mathematical model

101	Recoil Point Function	$x_e(q_{m1}, q_{m2}) = \frac{q_{m1} + q_{m2}}{2}$
102	Energy Function	$H(q_{Joint}, q_{m1}, q_{m2}) = \int \tau(q_{Joint}, q_{m1}, q_{m2})\, d\phi$
103	Output Torque Function	$\tau(q_{Joint}, q_{m1}, q_{m2}) = k_{LS} \cdot (x(\phi+\sigma) \cdot x'(\phi+\sigma) + x(\phi-\sigma) \cdot x'(\phi-\sigma))$ $x(\phi) = \begin{cases} R_1 - \sqrt{R_1^2 - r_{Disc}^2 \cdot (\phi-\beta)^2} & \phi < \beta \\ R_2 - \sqrt{R_2^2 - r_{Disc}^2 \cdot (\phi-\beta)^2} & \phi > \beta \end{cases}$ $k_{LS} = 22.1\, N/mm;\ R_1 = 10.9\, mm;\ R_2 = 5.7\, mm;\ \beta = 5°;\ r_{Disc} = 21.65\, mm$
104	Output Stiffness Function	$\sigma(q_{Joint}, q_{m1}, q_{m2}) = \frac{d\,\tau(q_{Joint}, q_{m1}, q_{m2})}{d\phi}$

Legend

Mechanical Operating Data

1 Continuous Output Power: product of Nominal Torque (3) and Nominal Speed (4).

2 Nominal Torque: torque the actuator can deliver for an unlimited amount of time without suffering performance losses.

3 Nominal Speed: speed reached by the actuator when powered at Nominal Voltage and applying a Nominal Torque.

4 Nominal Stiffness Variation Time with no load: time needed to achieve the maximum change of stiffness without load applied to the output shaft, using the peak torque of the motors, in the worst case (worst case between max. to min. stiffness and min. to max. stiffness)

5 Nominal Stiffness Variation Time with nominal torque: time needed to achieve the maximum change of stiffness with nominal torque applied to the output shaft, using the peak torque of the motors, in the worst case (worst case between max. to min. stiffness and min. to max. stiffness)

6 Peak (Maximum) Torque: maximum torque that the actuator can apply to the output shaft for a short period of time without suffering performance losses.

7 Maximum Speed: maximum speed at which the output shaft of the actuator can rotate for a short period of time without suffering performance losses.

8 Maximum Stiffness: maximum stiffness achievable by the actuator as derived from figure 8.

9 Minimum Stiffness: minimum stiffness achievable by the actuator as derived from figure 8.

10 Maximum Elastic Energy: maximum amount of energy the actuator can store in the springs.

11 Maximum Torque Hysteresis: maximum value of hysteresis on the experimental torque-deflection characteristic.

12 Maximum deflection with maximum stiffness: maximum physical deflection of the output shaft from an equilibrium point characterized by maximum stiffness.

13 Maximum deflection with minimum stiffness: maximum physical deflection of the output shaft from an equilibrium point characterized by minimum stiffness.

14 Active Rotation Angle: allowable actuated rotation amount, without considering passive deflection (#13 and #14)

15 Angular Resolution: resolution of the senor on the output shaft.

16 Weight: overall weight of the actuator unit.

Electrical Operating Data

18 - Nominal Voltage: continuous voltage at continuous nominal values of all other parameters.

19 - Nominal Current: current absorbed in the worst nominal working condition.

20 - Maximum Current: current absorbed in the worst working conditions.

Control Operating Data

21 - Voltage Supply: nominal voltage required by control electronics to work properly.

22 - Nominal Current: current absorbed required by control electronics to work properly.

23 - I/O protocol: communication protocol to interface with control electronics.

Additional sensors data

a0 - Sensor a: identifier and type of particular sensor a.

a1 - Resolution: ...

a2 - Range: ...

a3 - I/O protocol: ...

ax - (property x specific to sensor a): …

b0 - Sensor b: ...

bx - (property x specific to sensor b): ...

n0 - Sensor n: ...

nx - (property x specific to sensor n): …

to be defined depending on the particular sensor and typology.

Mathematical model

101 - Equilibrium Point Function: function relying the position of the unloaded output shaft given the positions of the motors.

102 - Energy Function: function relying the elastic energy stored in the elastic transmission given the position of the motors and the output shaft.

103 - Output Torque Function: function relying the output torque given the position of the motors and the output shaft.

104 - Output Stiffness Function: function relying the output stiffness given the position of the motors and the output shaft.

105 - Spring Torque Function: function relying the torque exerted on the springs given the position of the motors and the output shaft.

106 - Springs to Motors Transmission Ratio: derivative of the kinematic relation between deformations of the springs and position of the motors and output shaft with respect to the position of the motors.

107 - Springs to Output Transmission Ratio: derivative of the kinematic relation between deformations of the springs and position of the motors and output shaft with respect to the position of output shaft.

Figures

A short description is reported for every figure along with an example.

Fig. 1 – Picture: An overall picture of the actuator as similar as possible to an isometric view. (Example should be photographic).

Fig. 2 – Mechanical interface drawings: Minimum number of views of the actuator with dimensions defining its size and physical interfaces. Views should comply to European drawing conventions.

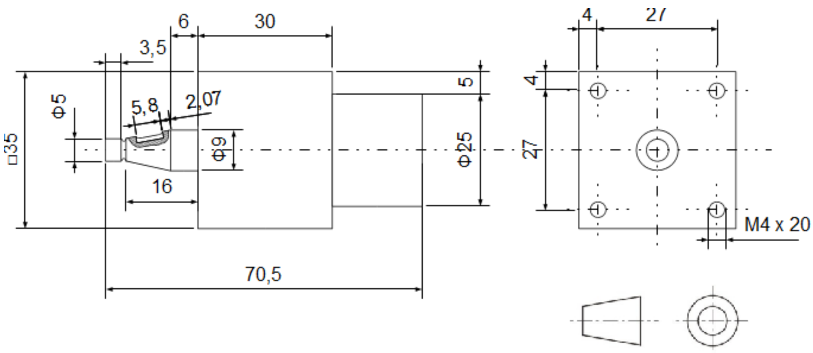


Fig. 3 – Stiffness Vs Torque: A two dimensional chart reporting the output stiffness (y axis) – output torque (x axis) curve.**

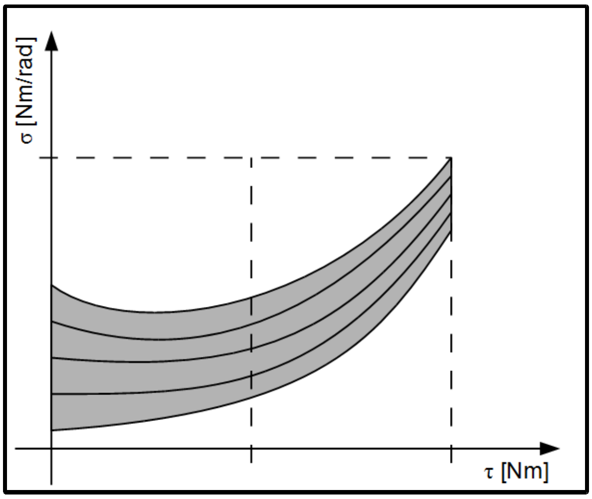


Fig. 4 – Speed Vs Torque: A two dimensional chart reporting the output speed (y axis) – output torque (x axis) curve.**

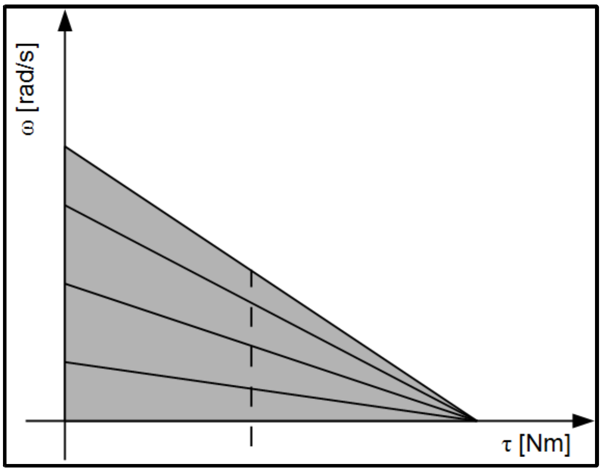


Fig. 5 – Deflection Vs Torque: A two dimensional chart reporting the output deflection (y axis) – output torque (x axis) curve.**

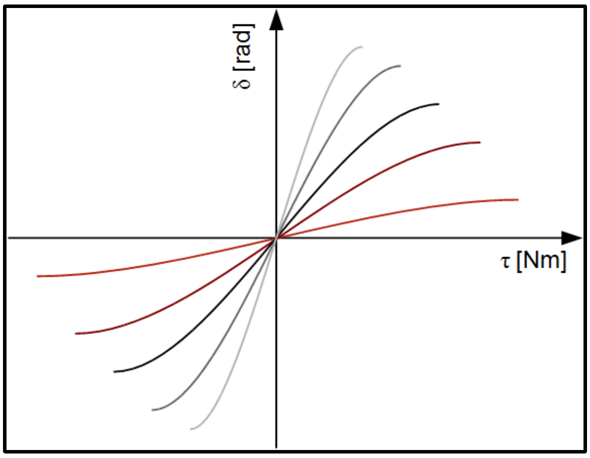


Fig. 6 – Connection diagram: The logical scheme showing electronic connections between actuator and external world.

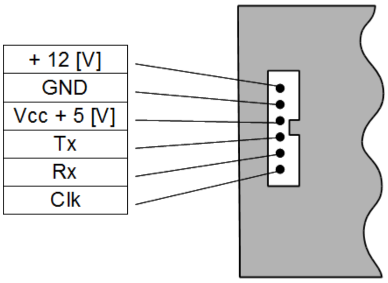


Fig. 7 – Measured deflection Vs Torque: A two dimensional chart reporting the measured output deflection (y axis) – output torque (x axis) curve.**

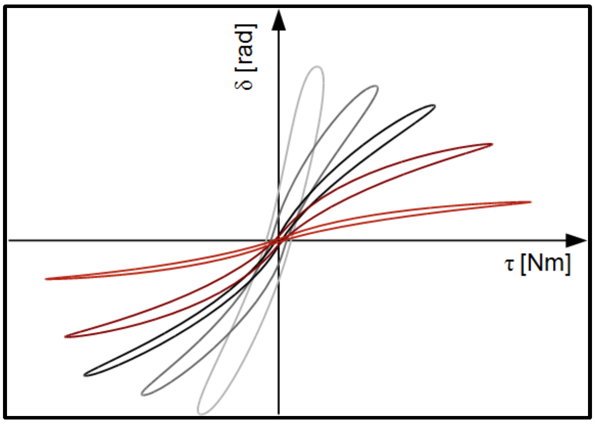


Fig. 8 – 3D Workspace: A three dimensional chart reporting the working volume of the actuator in the space defined by output torque (x axis) – output speed (y axis) – output stiffness (z axis).

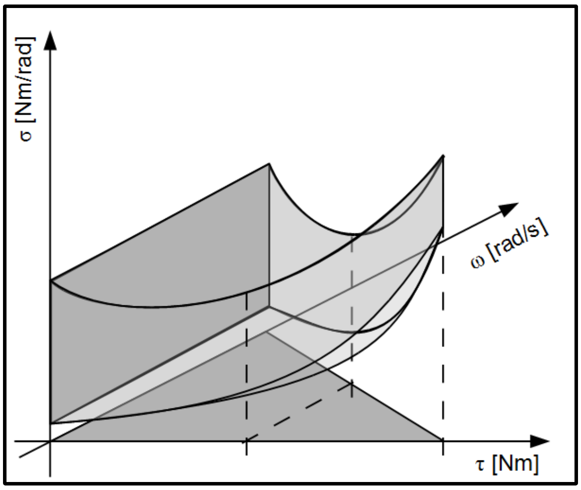


Fig. 9 – Sensor map: A logical scheme, with a sufficient detail level, showing the position and purpose of additional sensors inside the actuator.

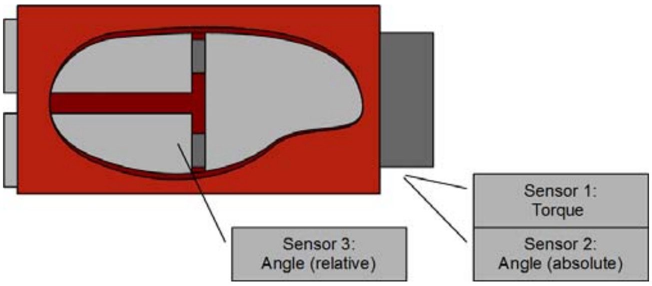


Fig. 10a – Actuator internals – Layout: Schematic drawing explaining internal layout of the actuator, representing interconnections among the components (motors, elastic transmission, output shaft).

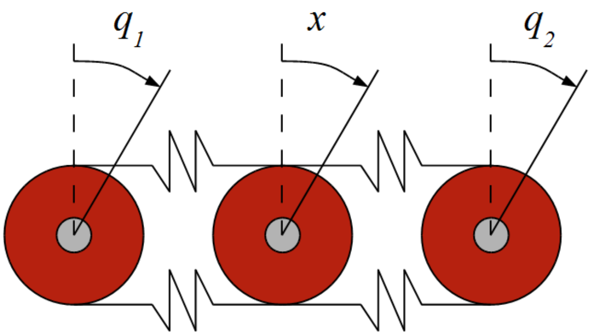
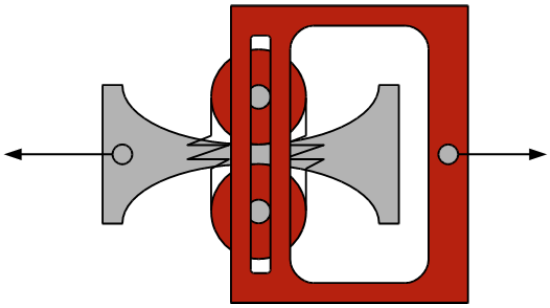


Fig. 10b – Actuator internals – Working principle: Schematic drawing explaining the working principle of the elastic transmission.



Notes

Symbols.

Symbols used in the mathematical model should be reported in the drawings of Figs. 10a and b, and in charts 3,4,5,7 and 8.

** **Drawing conventions.**

Figures 3,4 and 5 report 5 curves each. The 5 lines describe the extremal limits of the Working Volume and three intermediate levels. The three intermediate lines represent the behavior of the system when applying three intermediate levels of preset stiffness, the 25, 50 and 75% of the no-load stiffness range. One more dashed line is present representing the nominal torque of the actuator.