ARTIFICIAL MECHANICAL SYSTEMS for the UPPER EXTREMITY

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Technische Universiteit Delft

2007-03-07 STATE OF THE ART IN UE PROSTHETICS

2007-03-14 CONTROL

2007-03-21 ACTUATION

TU Delft

ACTUATION
OF
UPPER EXTREMITY
PROSTHETICS

Technische Universiteit Delft

PROSTHESES

CONTROL

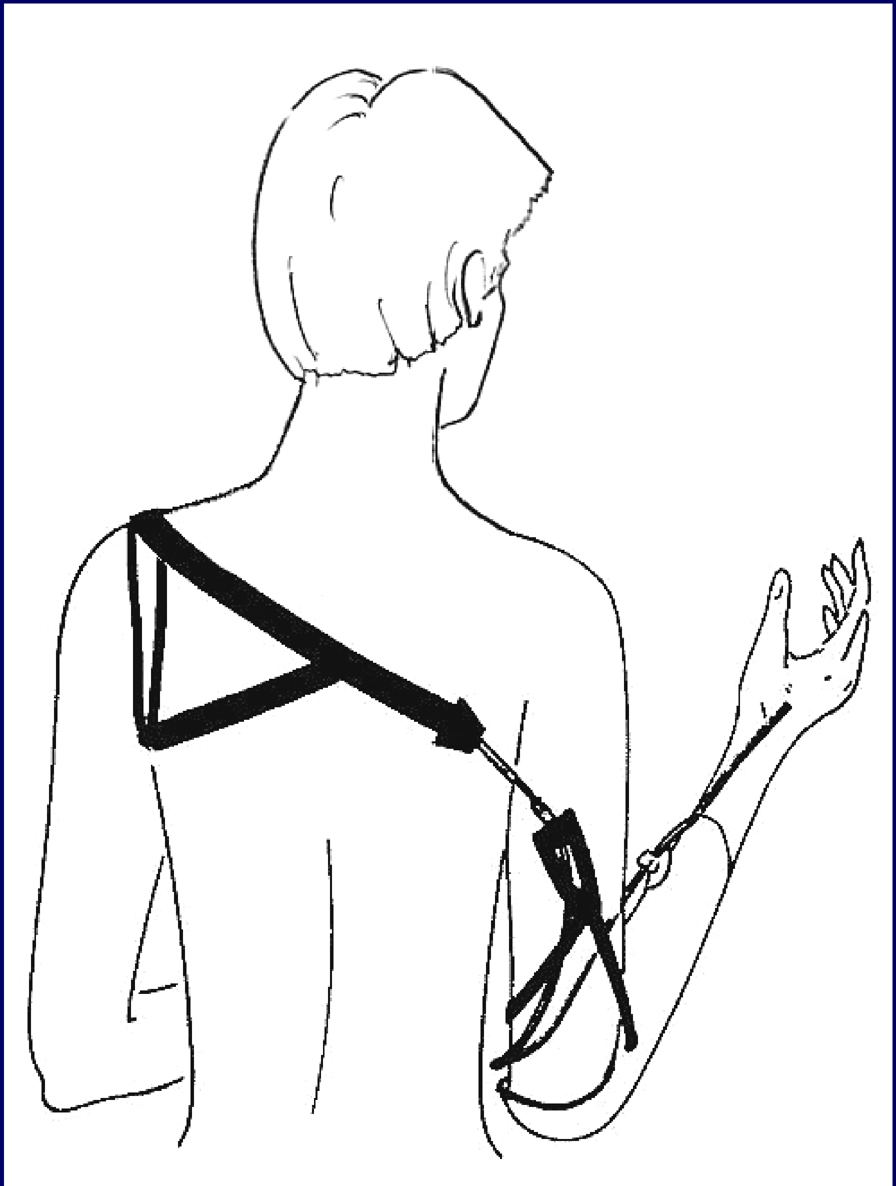
- ALWAYS BY THE BODY
  - MECHANICAL
  - ELECTRICAL

POWER

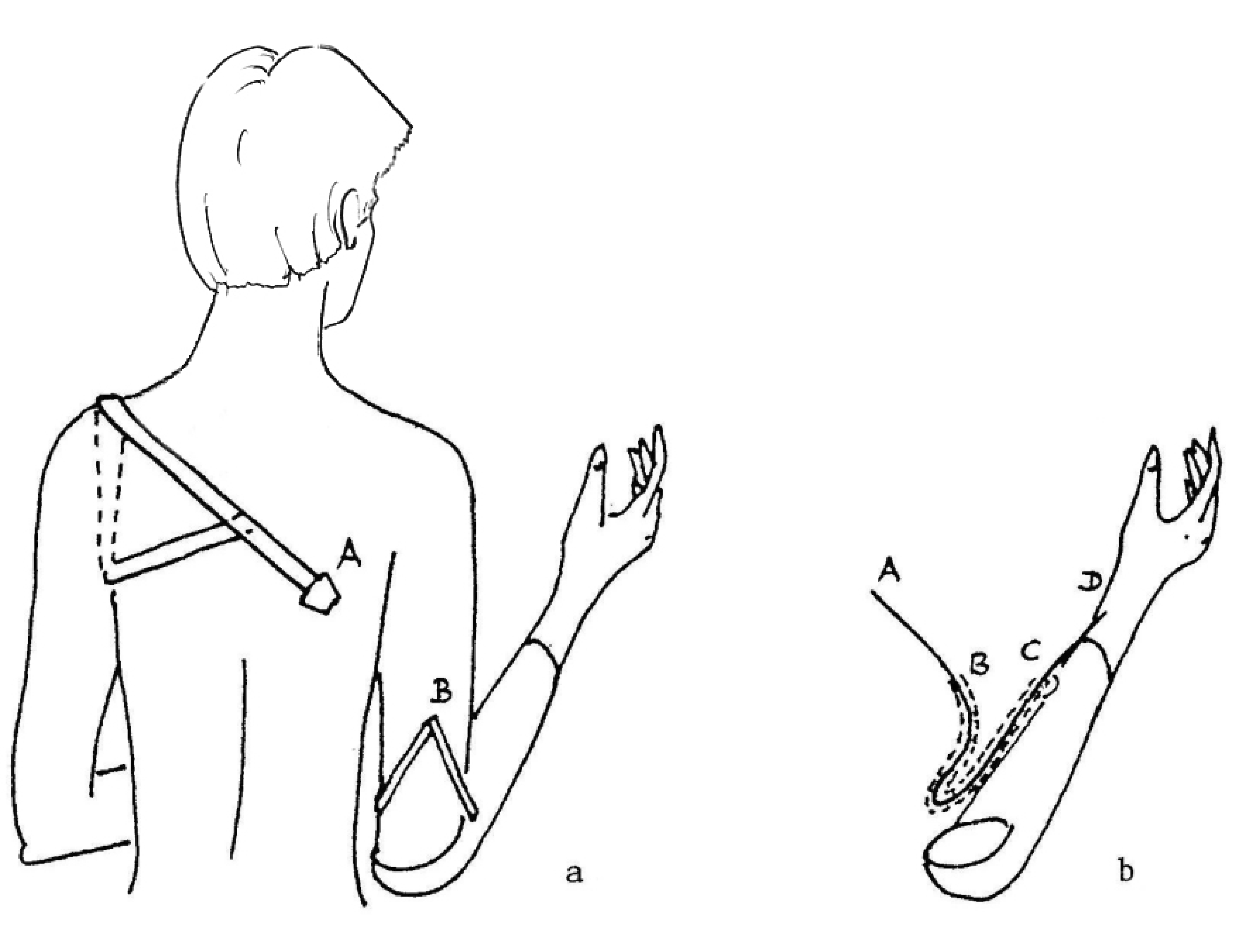
- FROM THE BODY
- EXTERNALLY

BODY POWER

STRAPS



STRAPS



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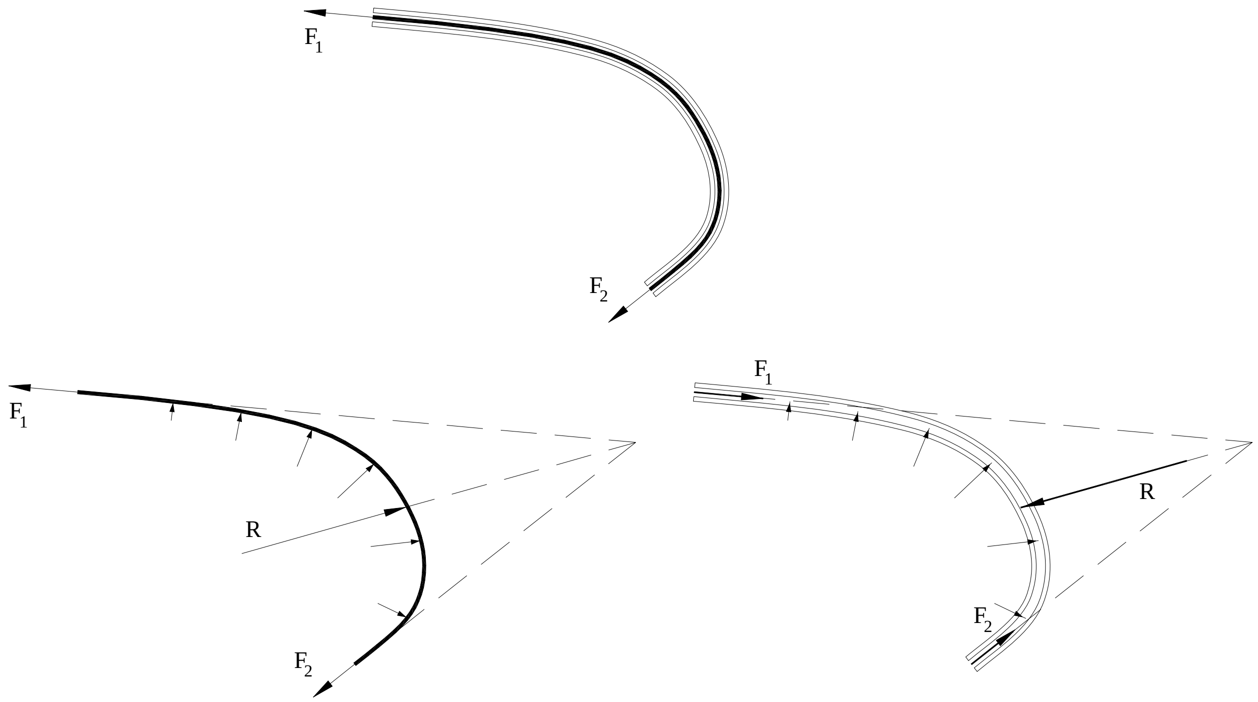

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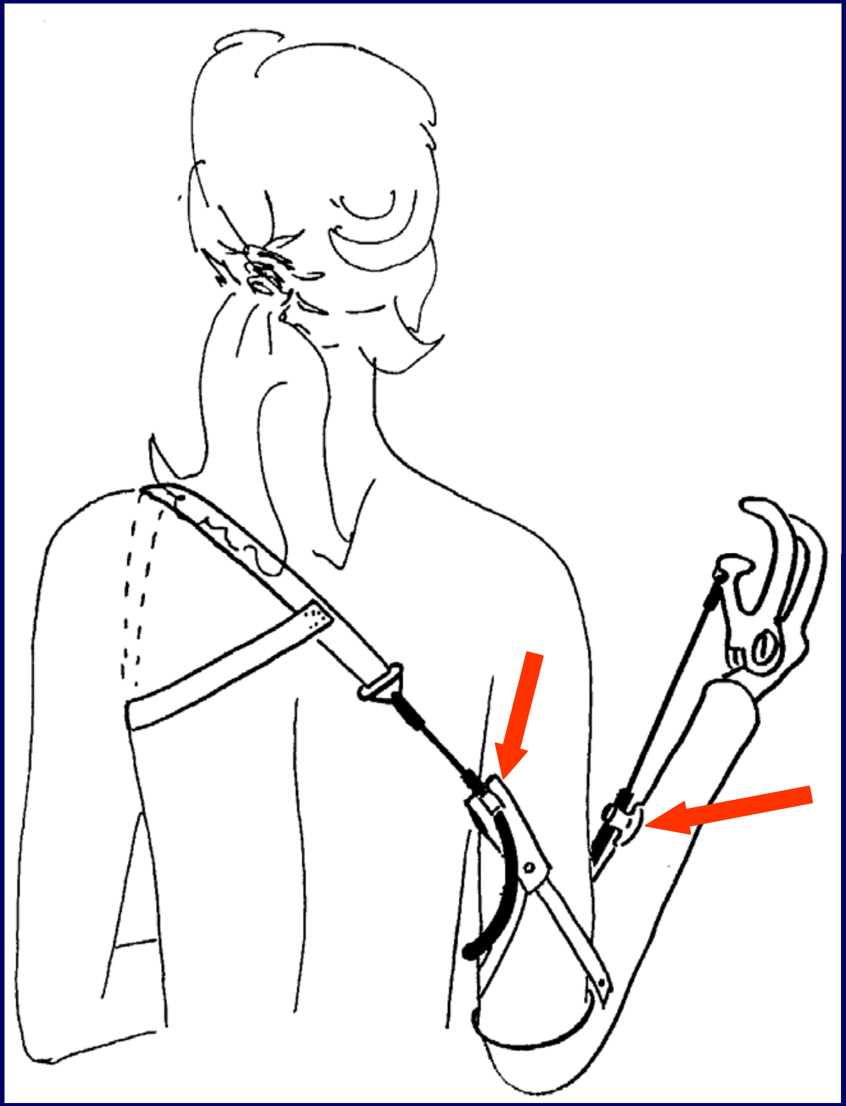
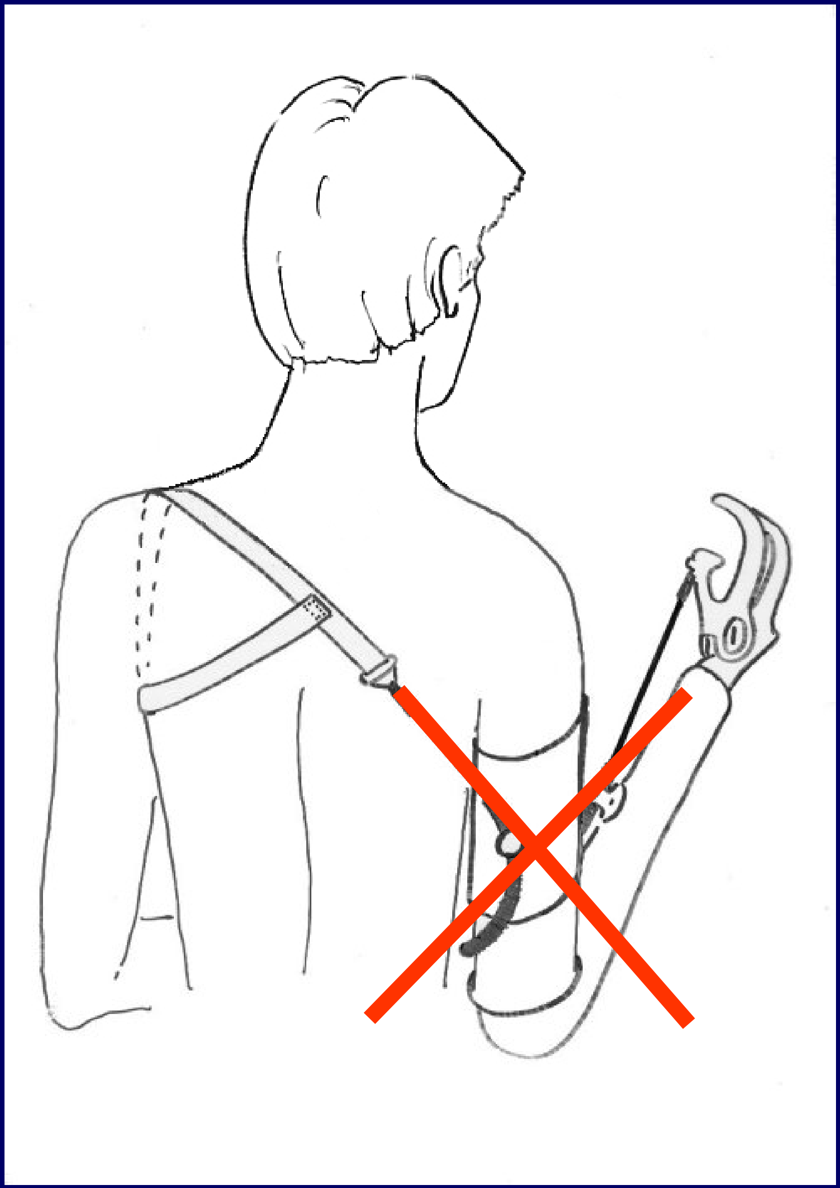
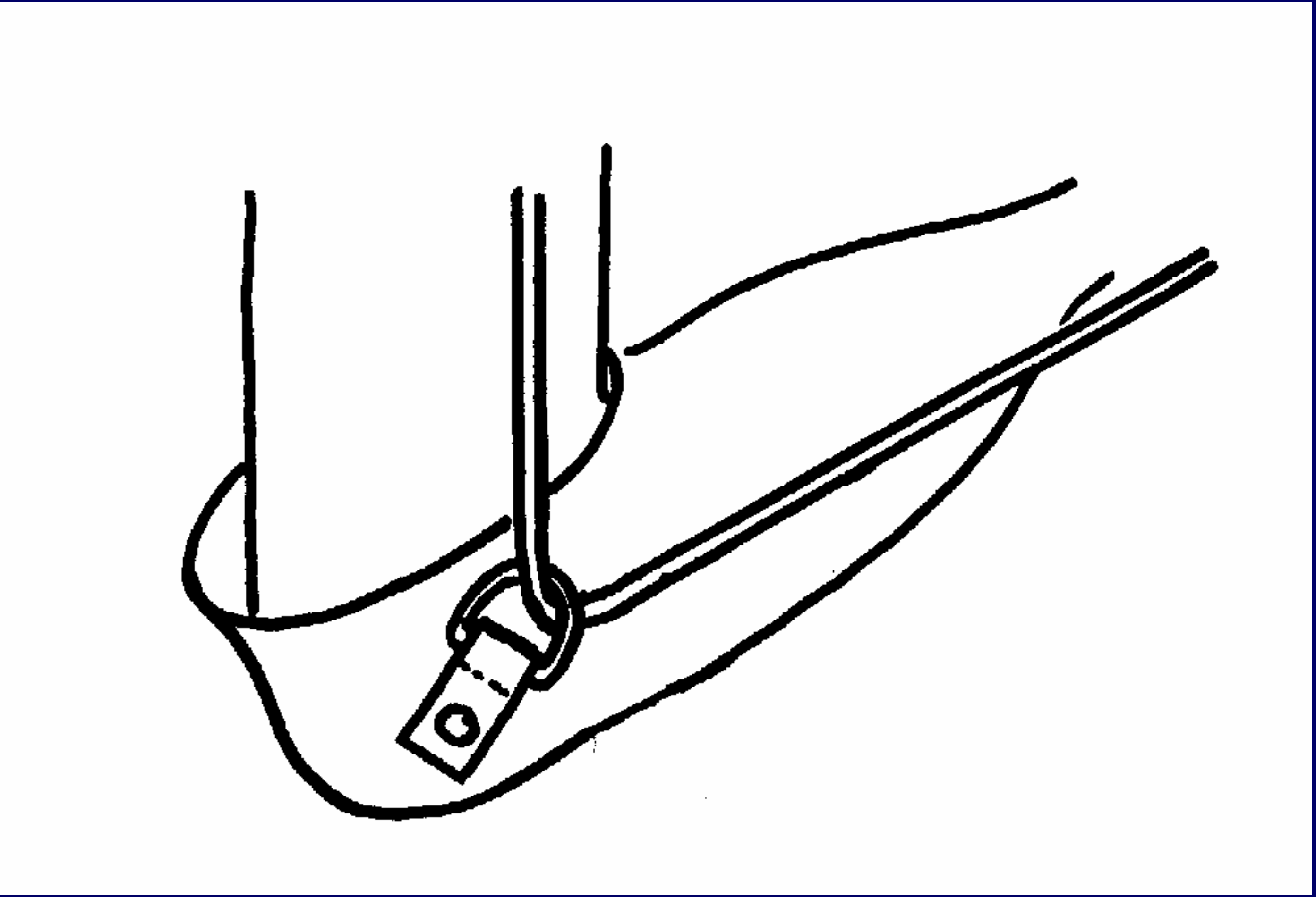
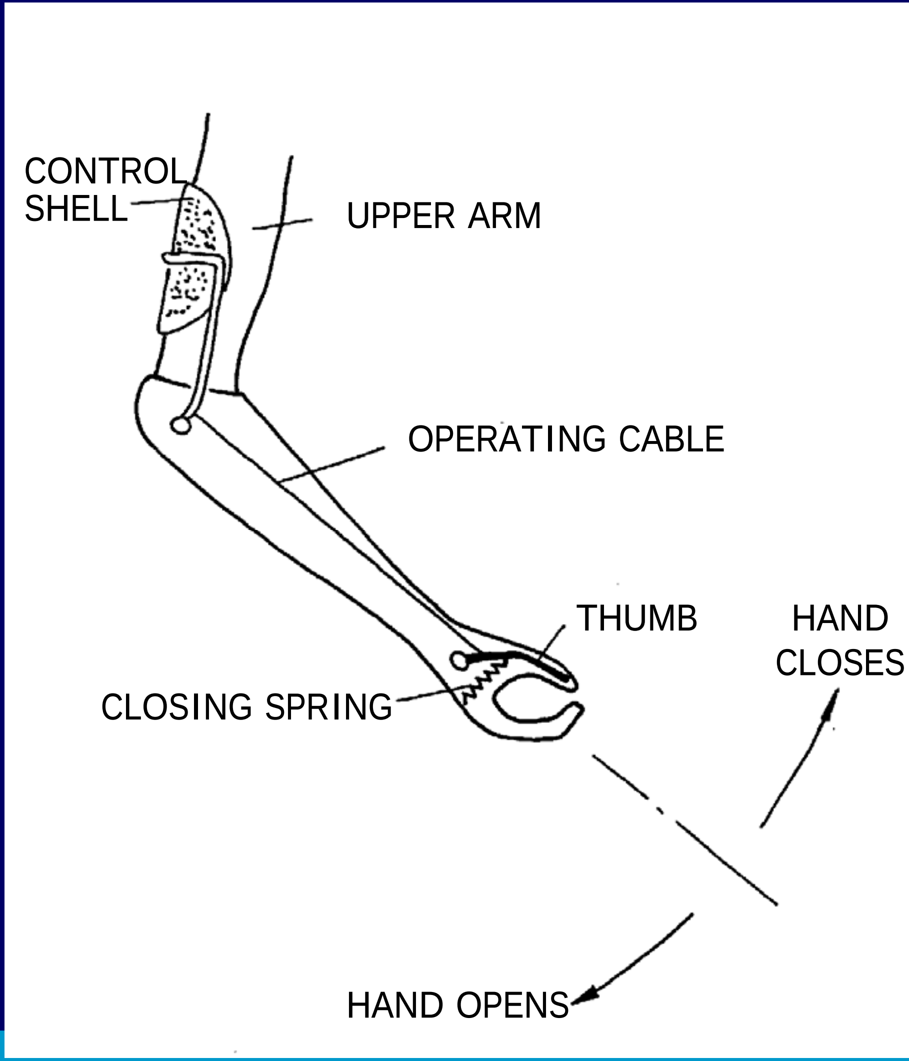




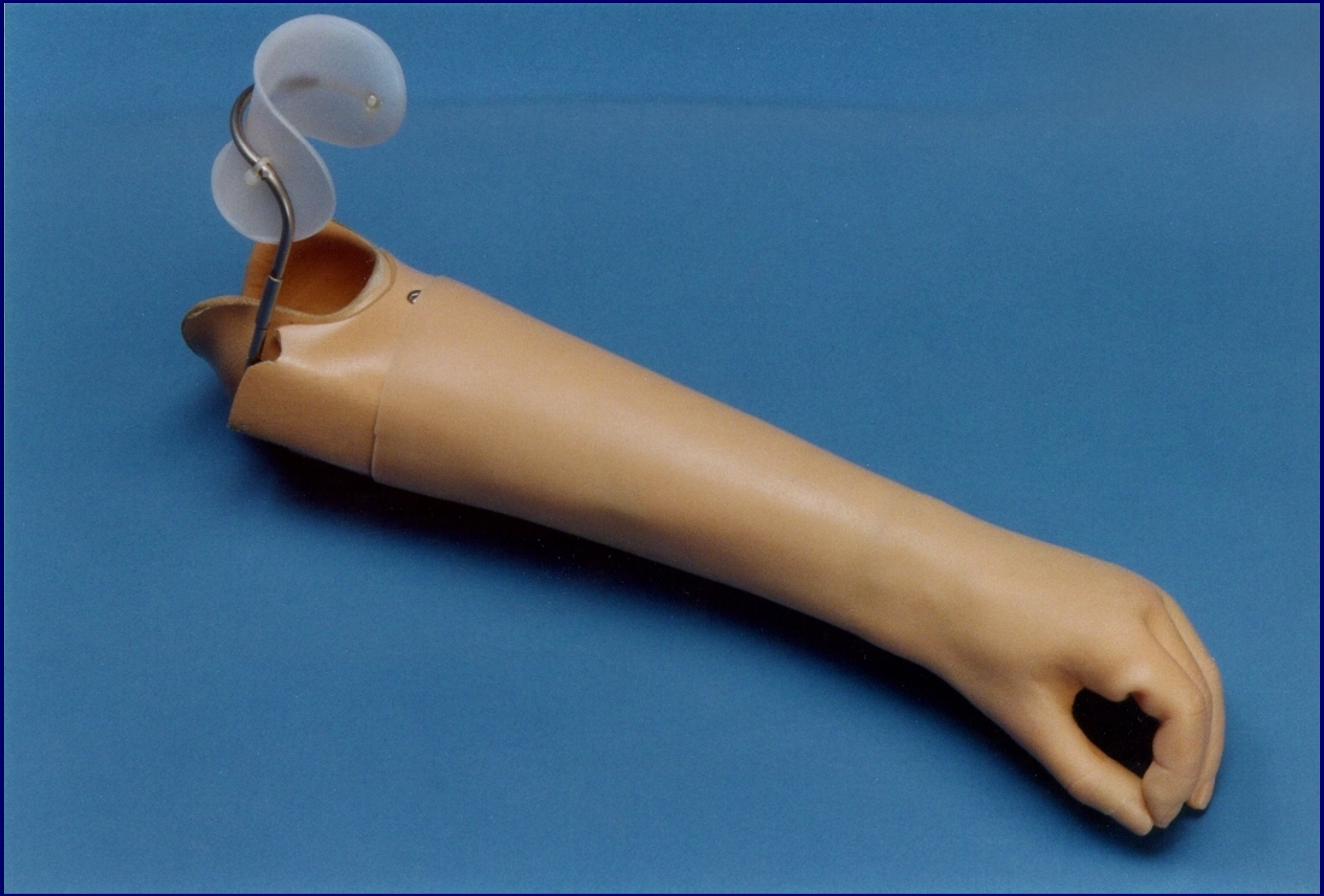
STRAPS



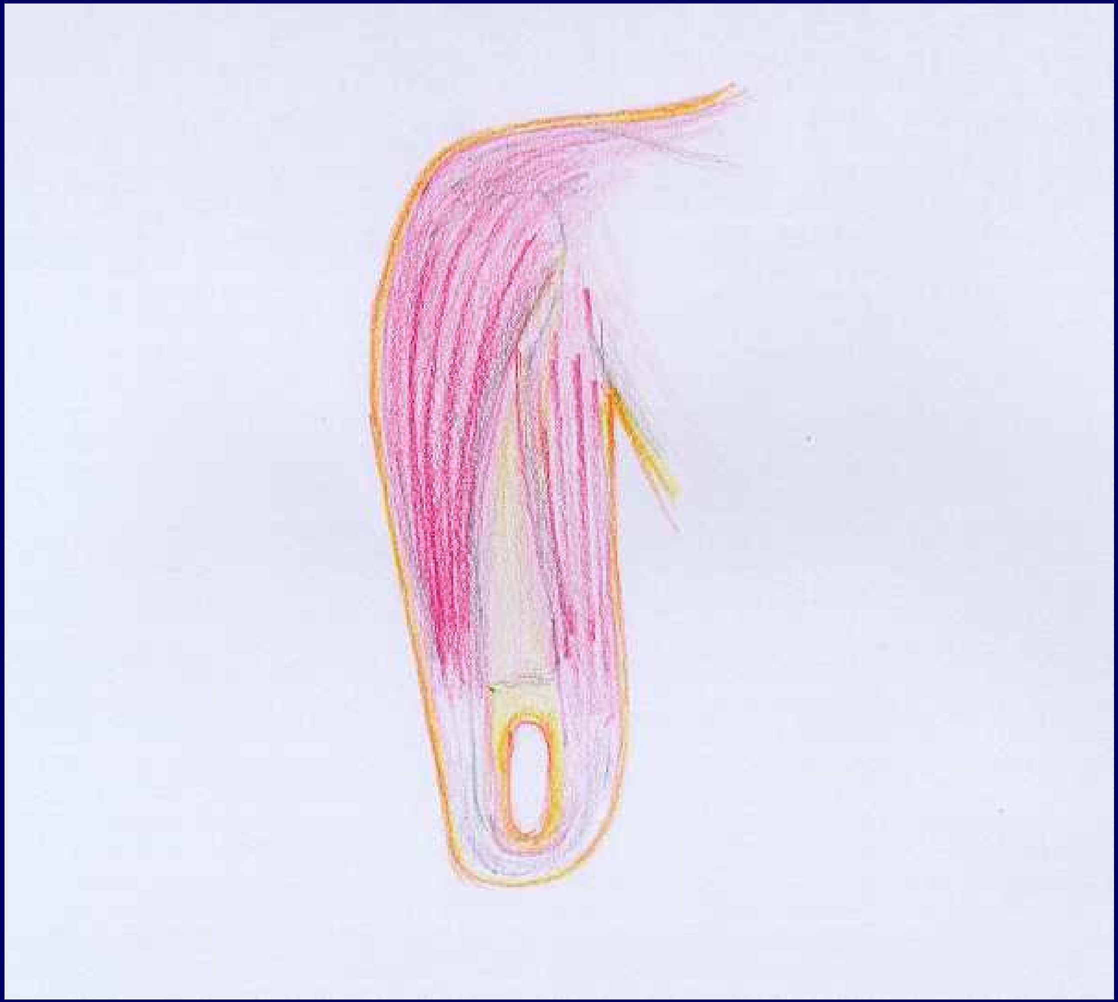
ELBOW CONTROL



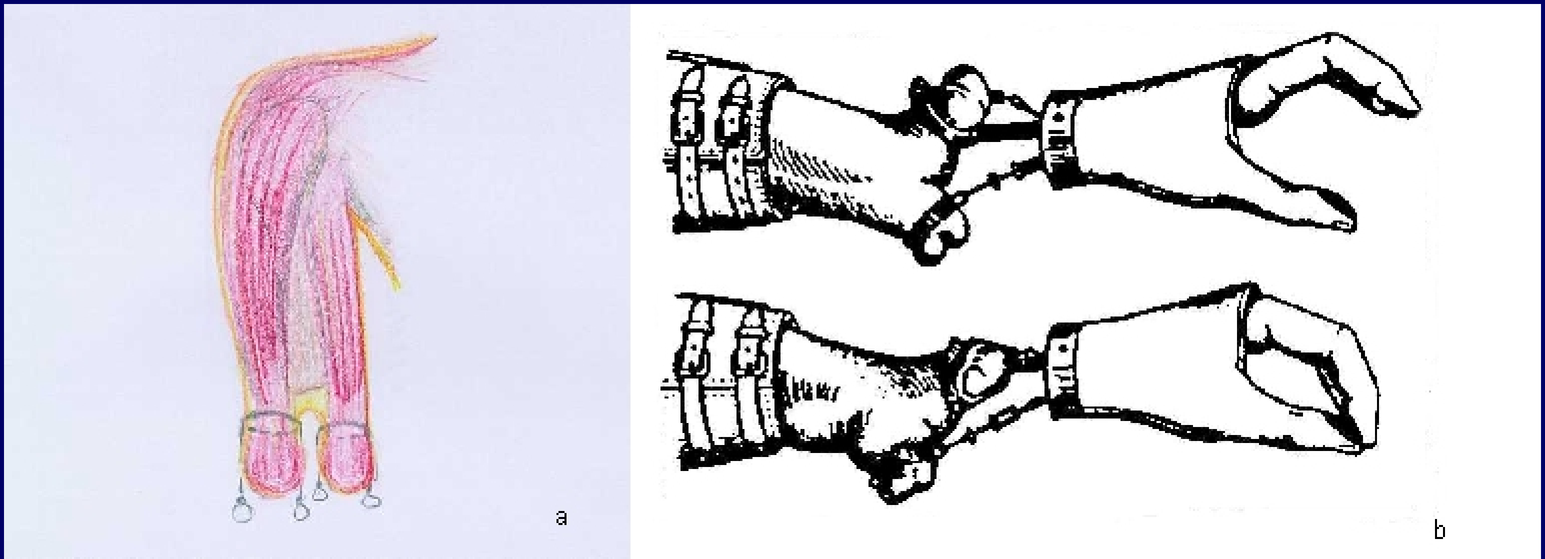
ELBOW CONTROL



CINEPLASTY: GIULIANO VANGHETTI 1898

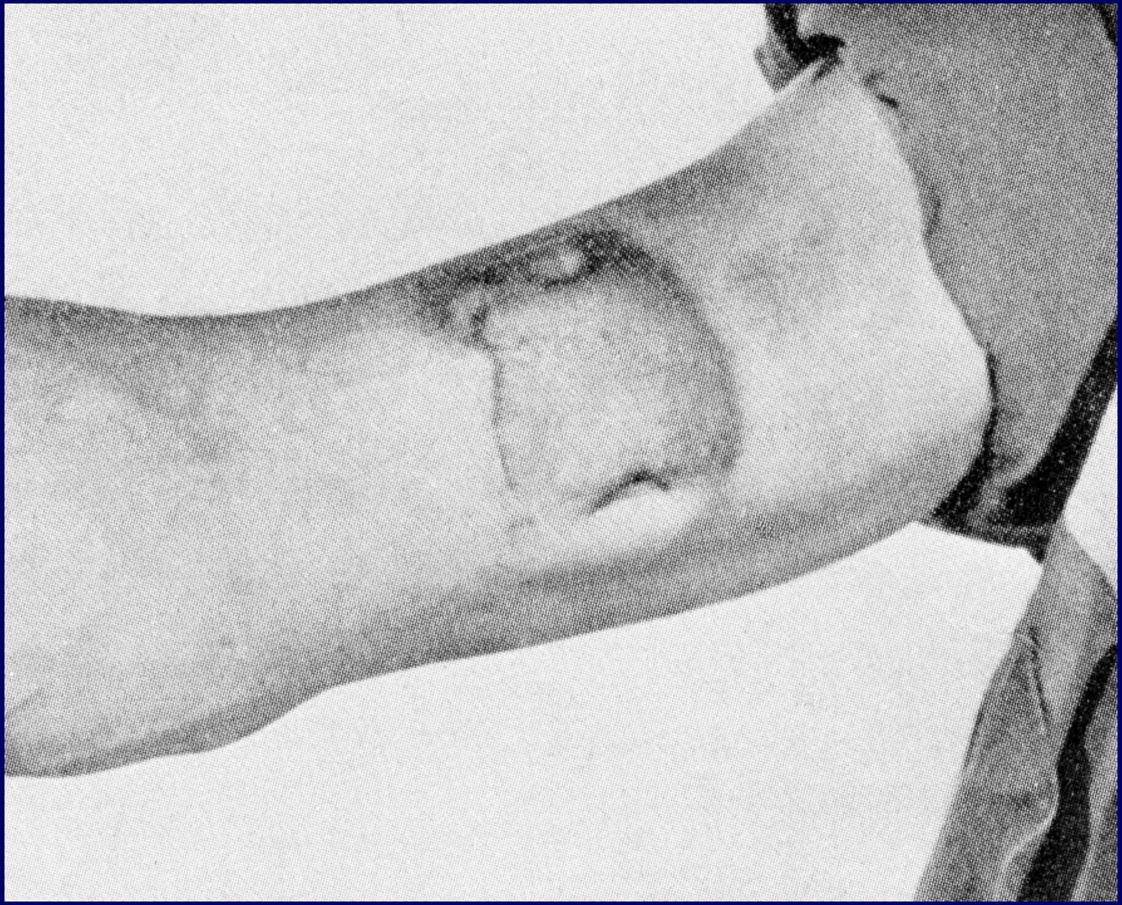


CINEPLASTY: GIULIANO VANGHETTI



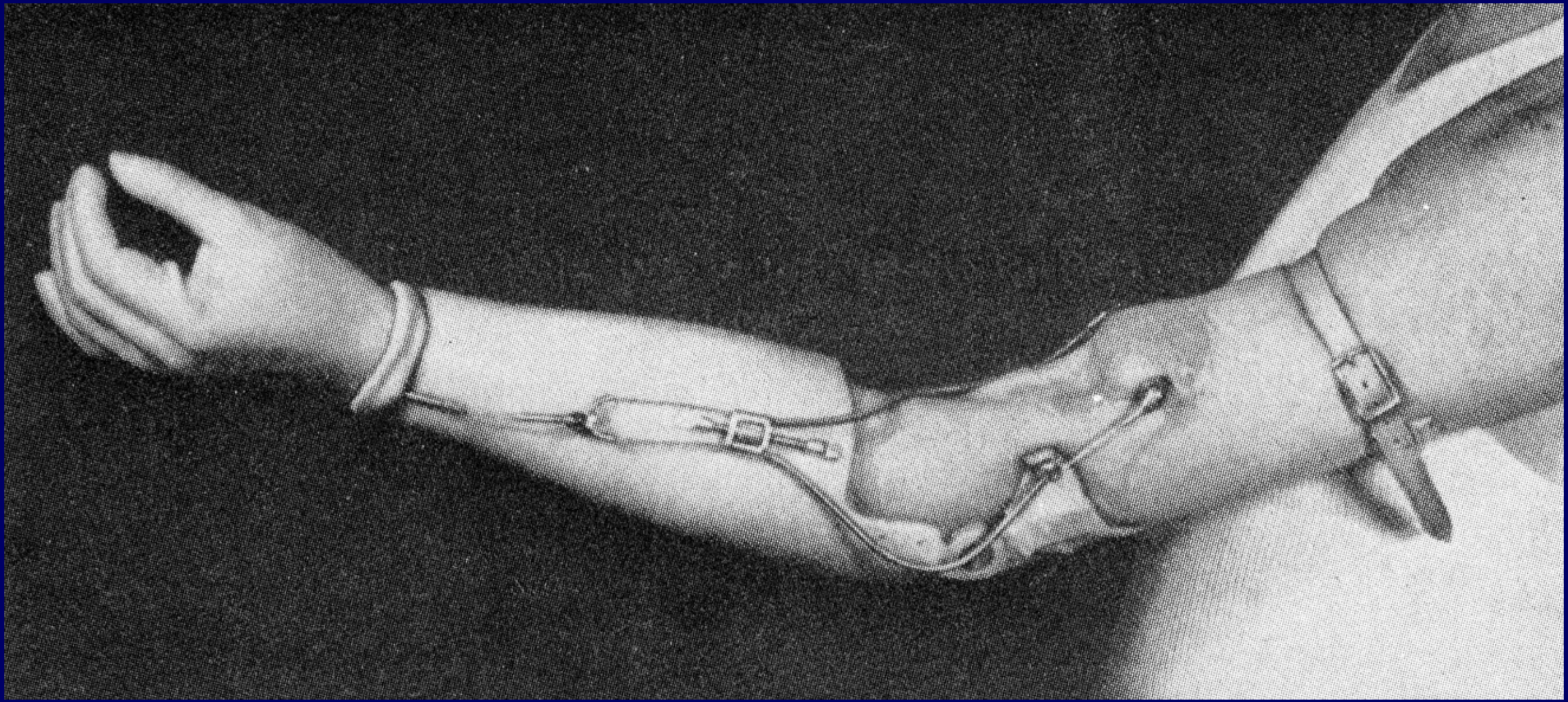
Weir, 1998

CINEPLASTY: FERDINAND SAUERBRUCH 1915



Klopsteg & Wilson, 1954

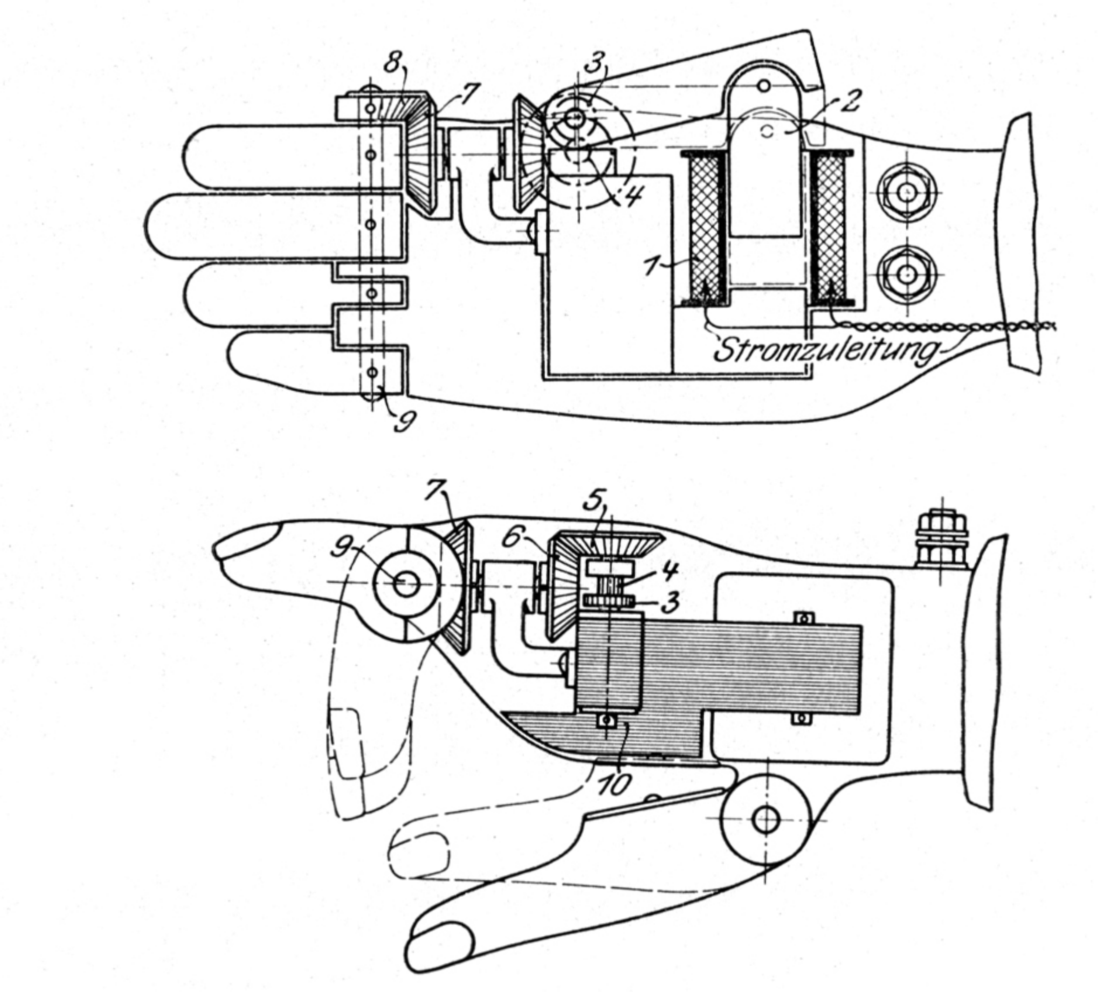
CINEPLASTY: FERDINAND SAUERBRUCH



Klopsteg & Wilson, 1954

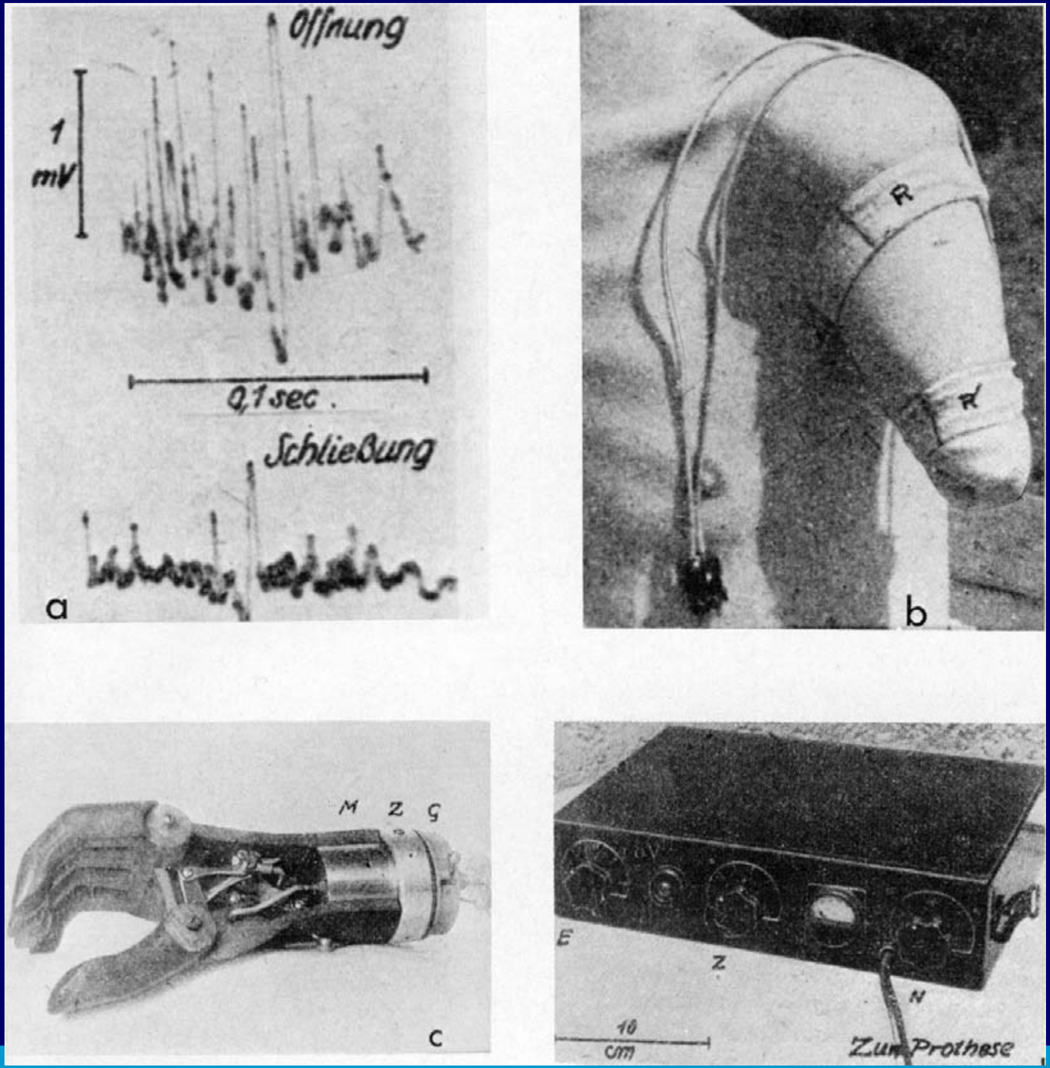
EXTERNAL POWER

ELECTRICAL



Borchardt et.al., 1919

ELECTRICAL: REITER 1948



Childress & Billock, 1970

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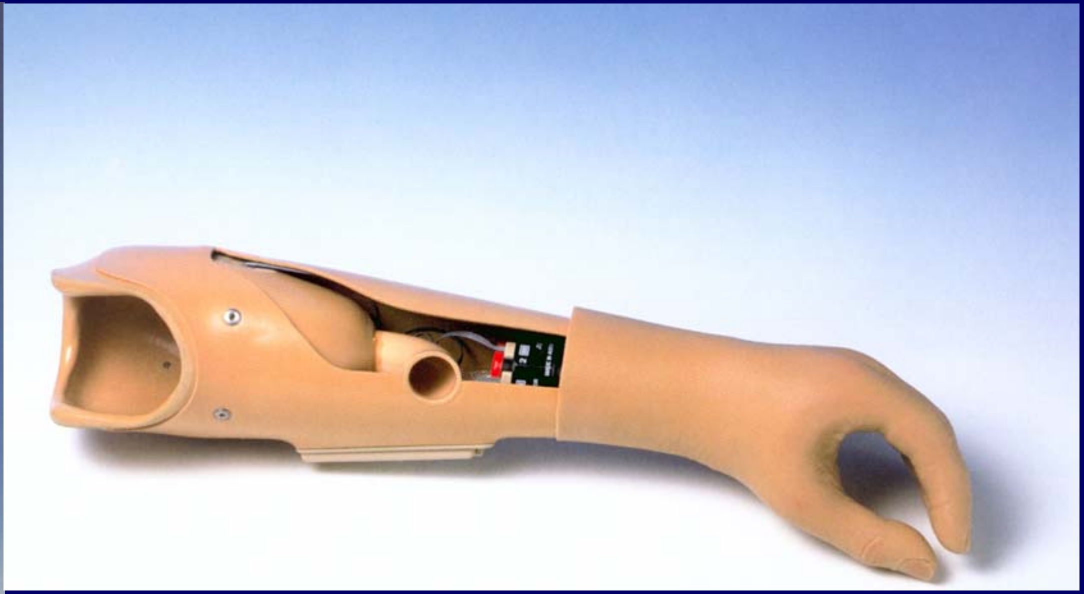
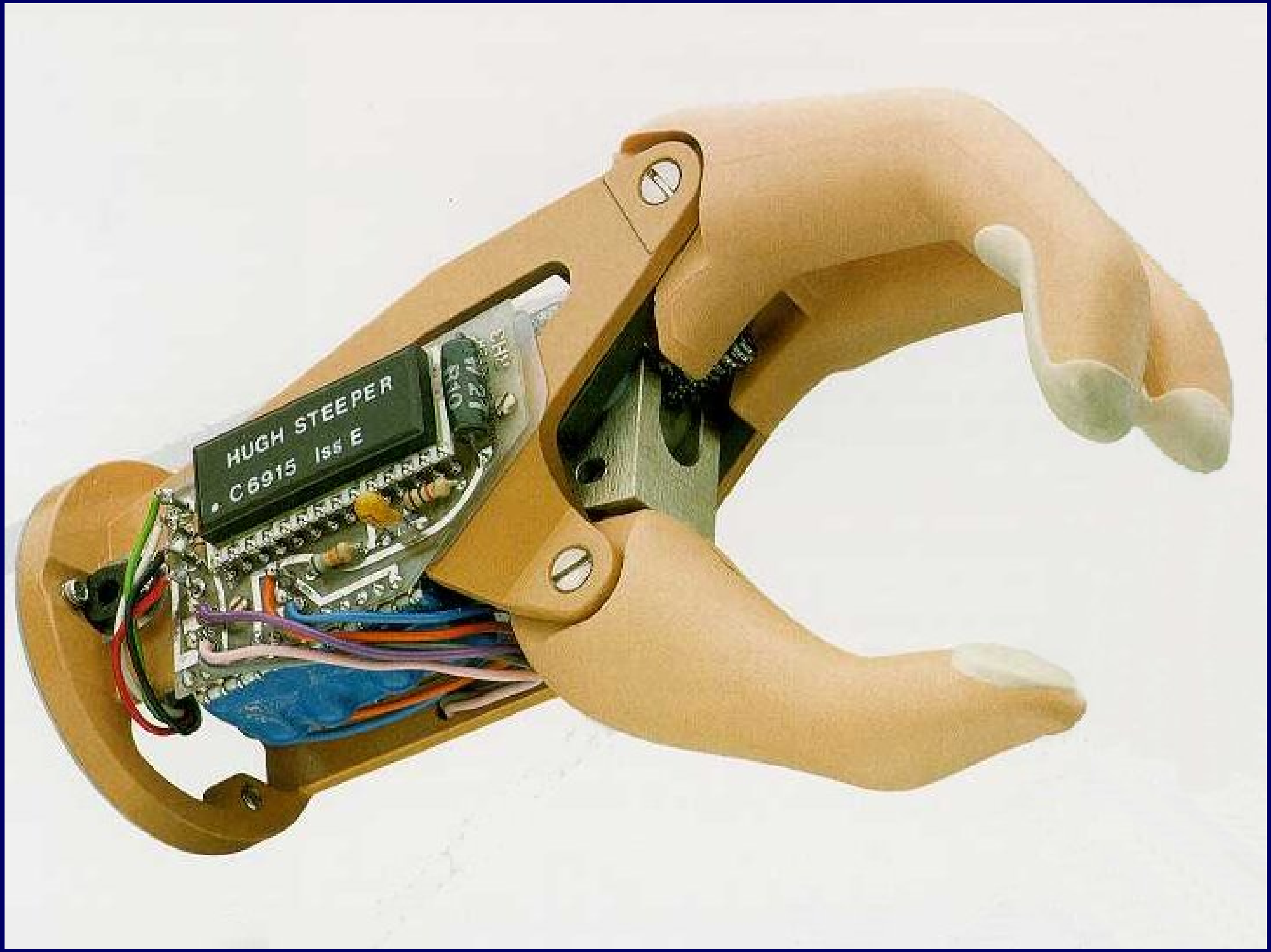
ELECTRICAL



Otto Bock

ELECTRICAL

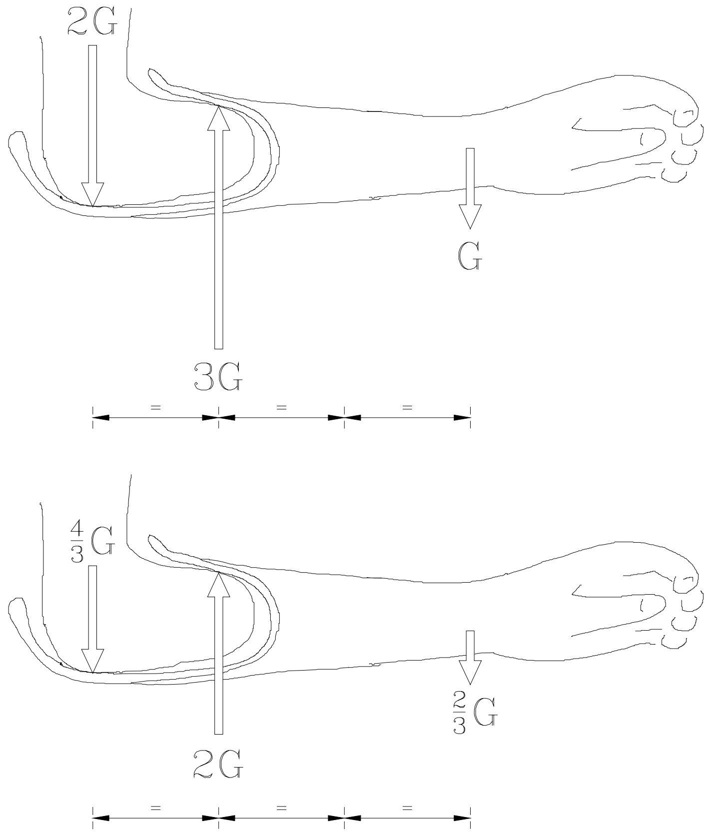


Steeper

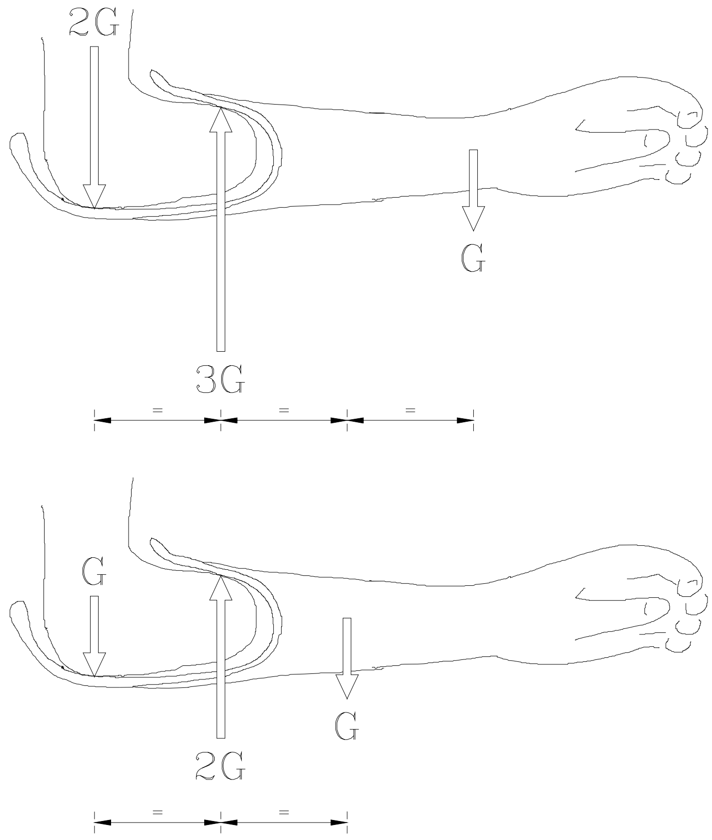
ELECTRICAL

DISADVANTAGES:

- HIGH MASS



TU Delft


2G
G
3G
=
=
=
G
G
2G
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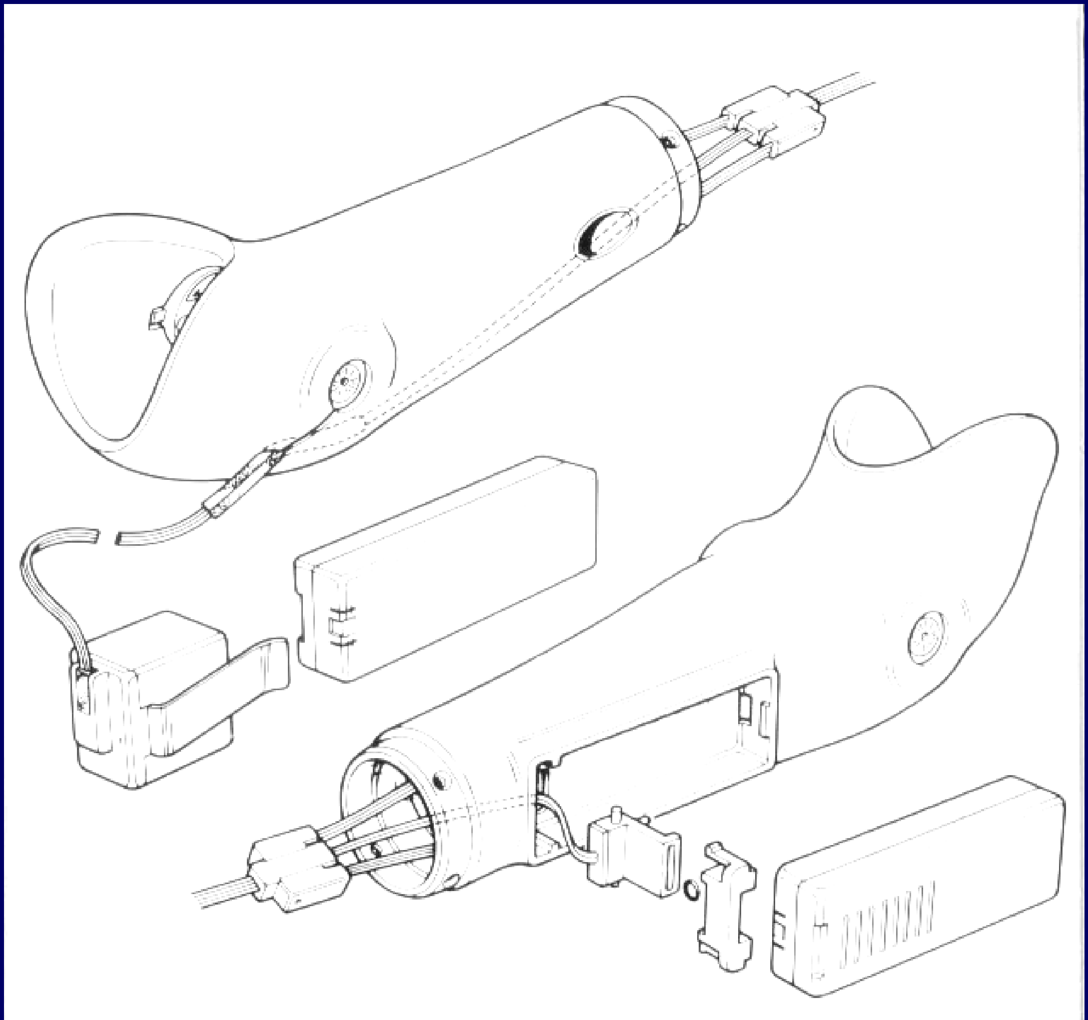
ELECTRICAL

DISADVANTAGES:

- HIGH MASS
- LOW SPEED
- VULNERABLE
- SIZE

ELECTRICAL



Steeper

HYDRAULICAL

ADVANTAGES:

- GOOD CONTROL
- FAST
- QUIET
- NO LOCKING DEVICES NEEDED

DISADVANTAGES:

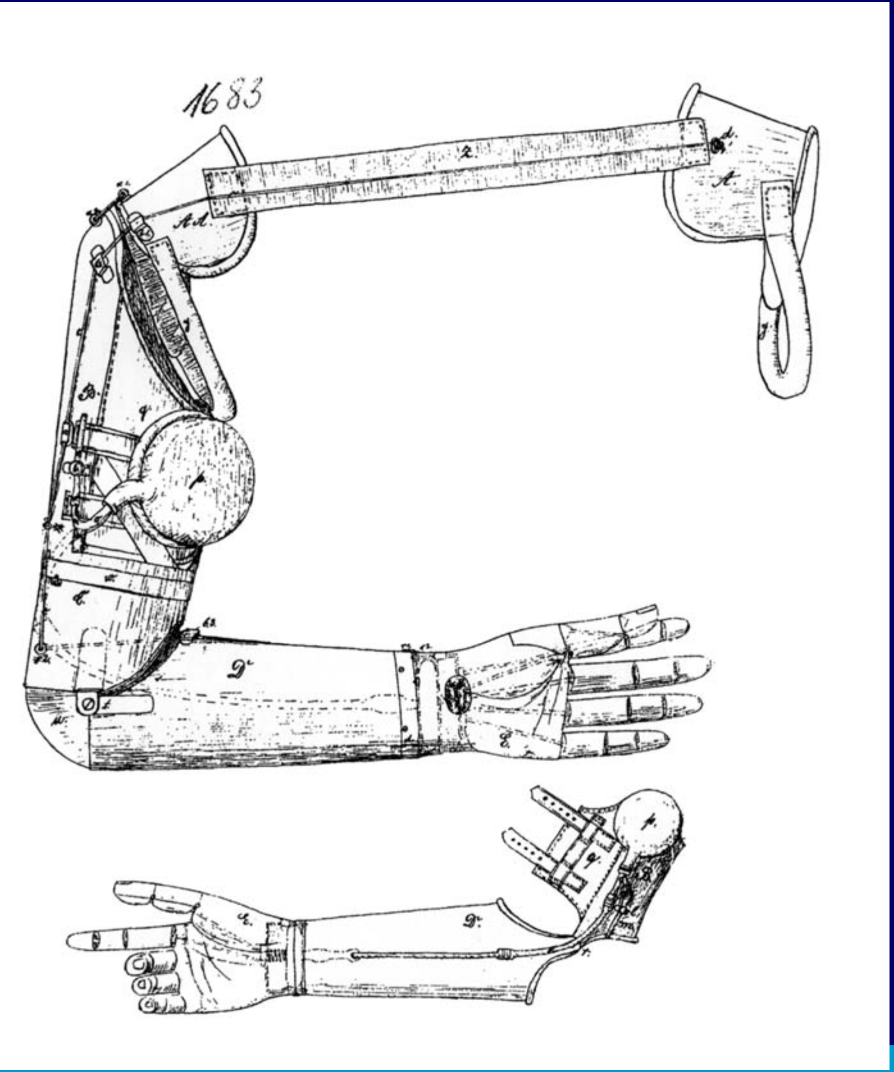
- HIGH TOTAL MASS
- LEAKAGE
- ENERGY STORAGE

PNEUMATICAL

ADVANTAGES:

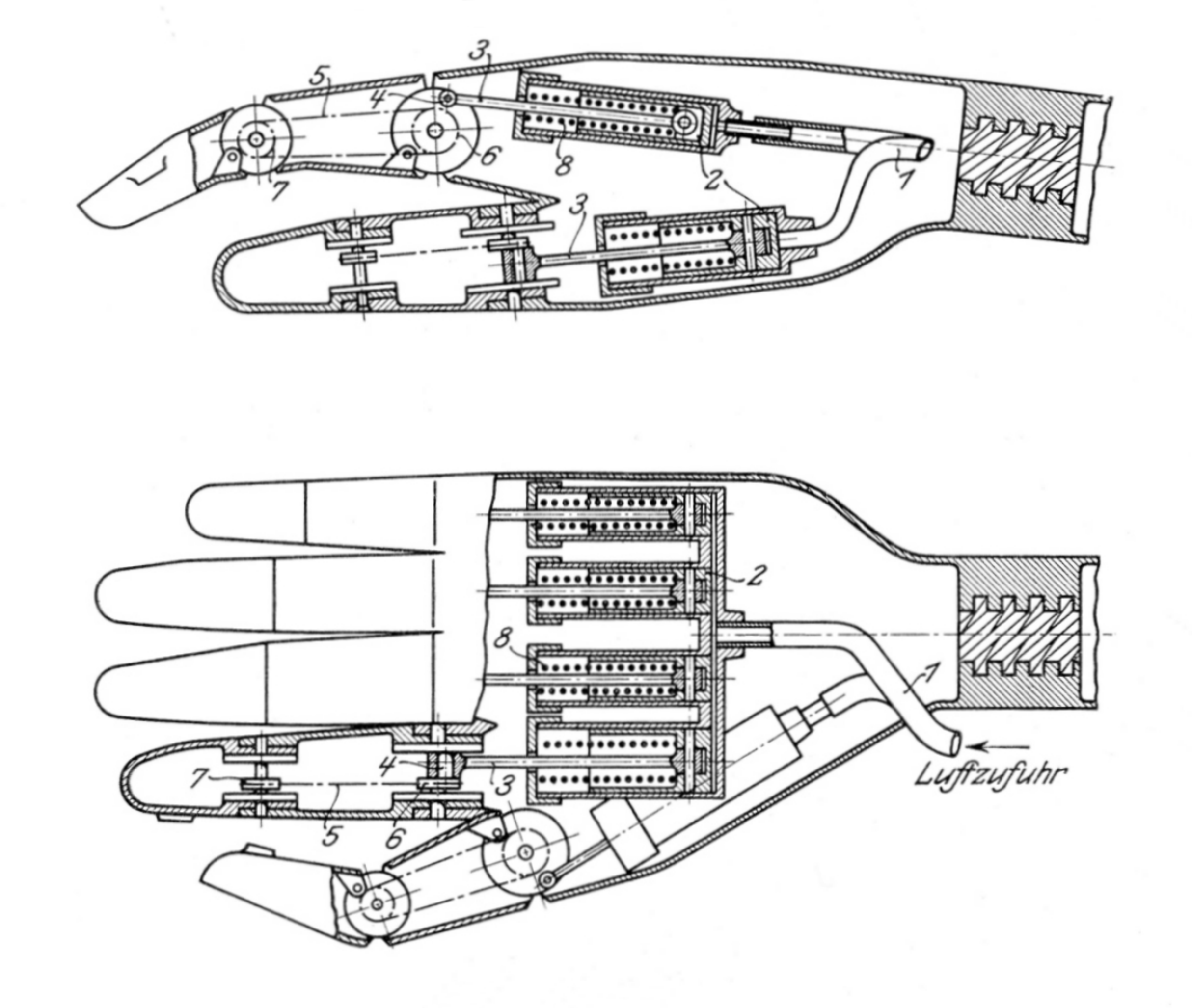
- LOW MASS
- HIGH SPEED
- RELIABLE
- SMALL

PNEUMATICAL: DALISH 1877



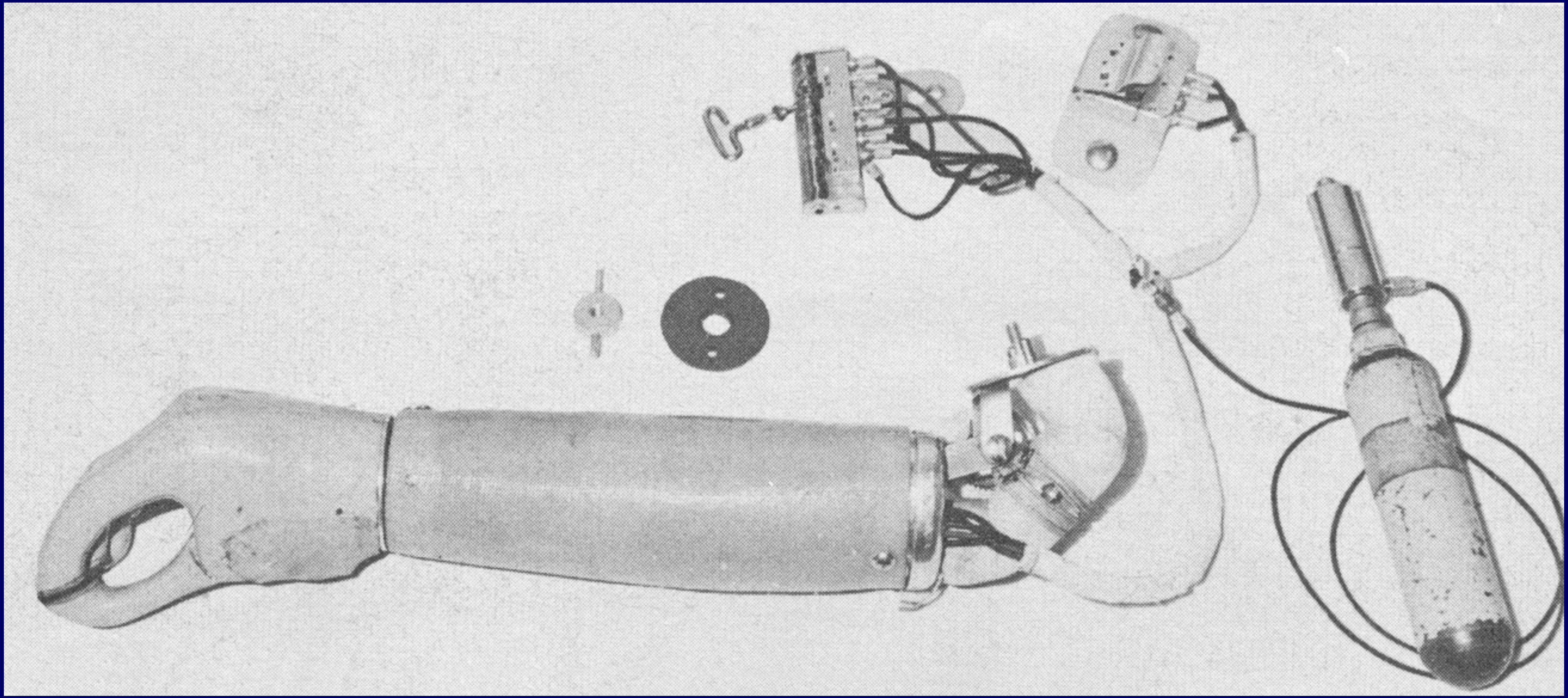
Dalish, 1877

PNEUMATICAL: ANONYMOUS



Borchardt et.al., 1919

PNEUMATICAL: HEIDELBERG 1949+

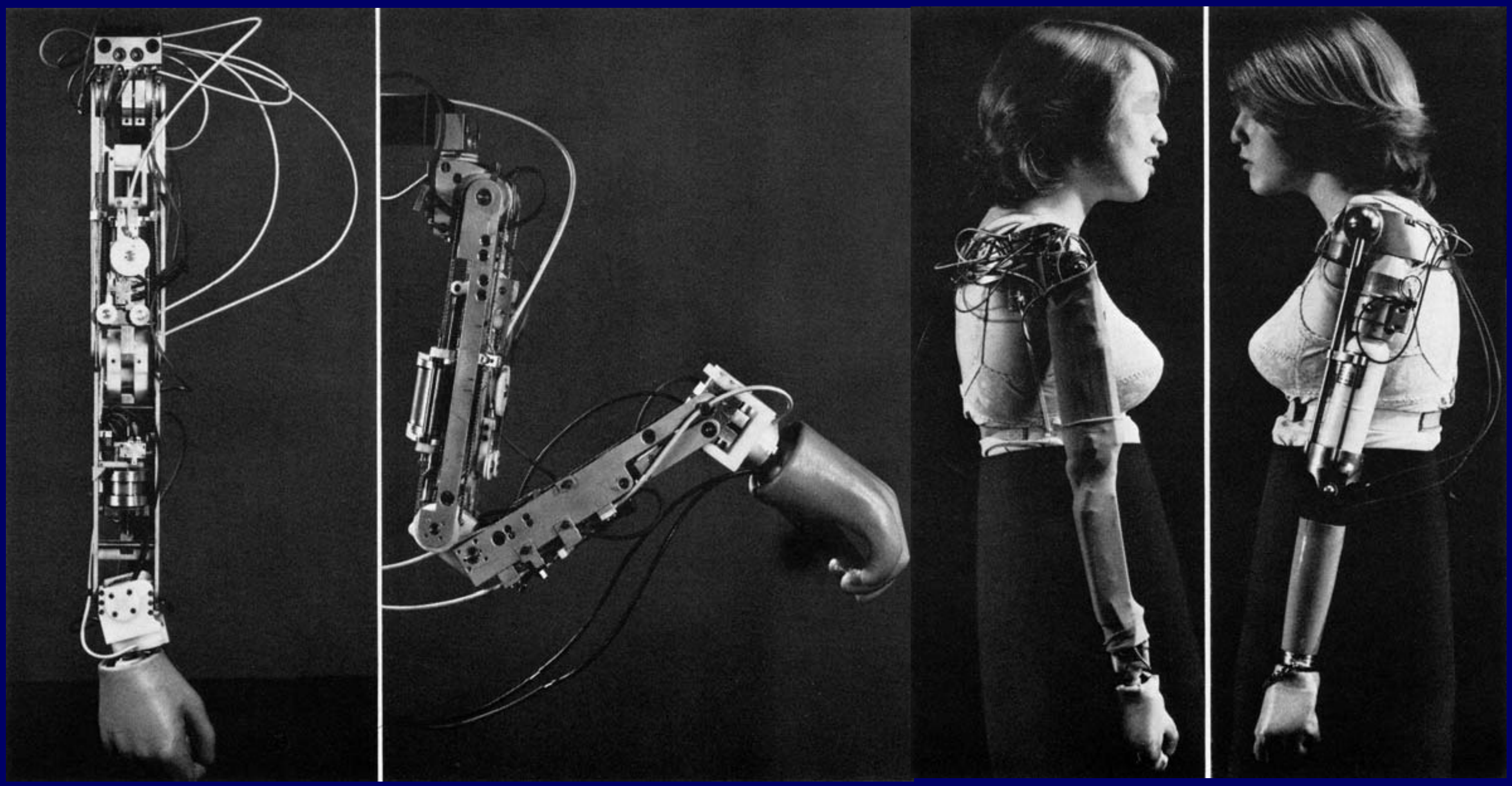


Lucaccini, 1967

THALIDOMIDE

Issued in 1956 by Chemie Grünenthal to fight nausea and sleeping problems in pregnant women.

PNEUMATICAL: EDINBURGH 1963+



Baumgartner, 1977

PNEUMATICAL: Limb Fitting Centre at Queen Mary's Hospital, Roehampton, London, 1964

Steeper, 1964

PNEUMATICAL

DISADVANTAGES:

- HIGH OVERALL MASS
- UNRELIABLE
- HIGH GAS CONSUMPTION
- CUMBERSOME REFILL PROCEDURE

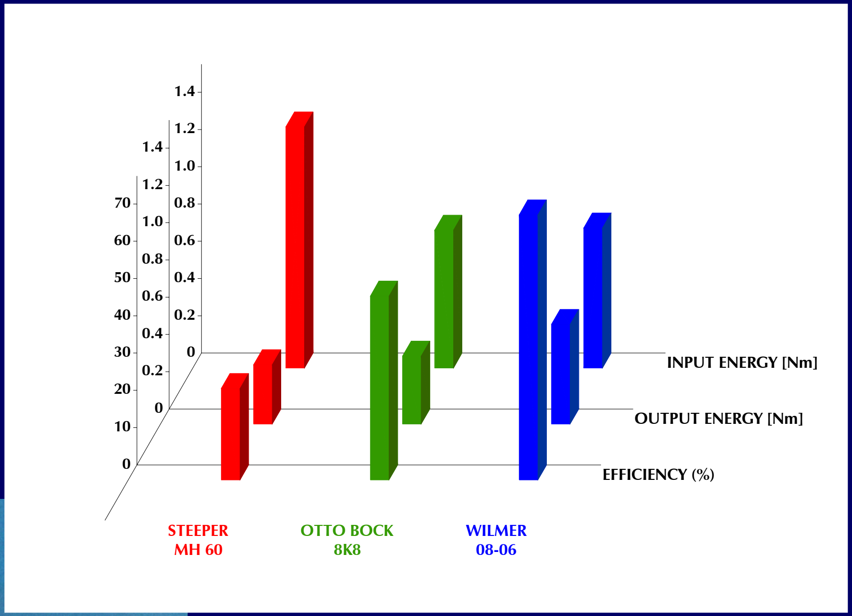
PNEUMATICAL

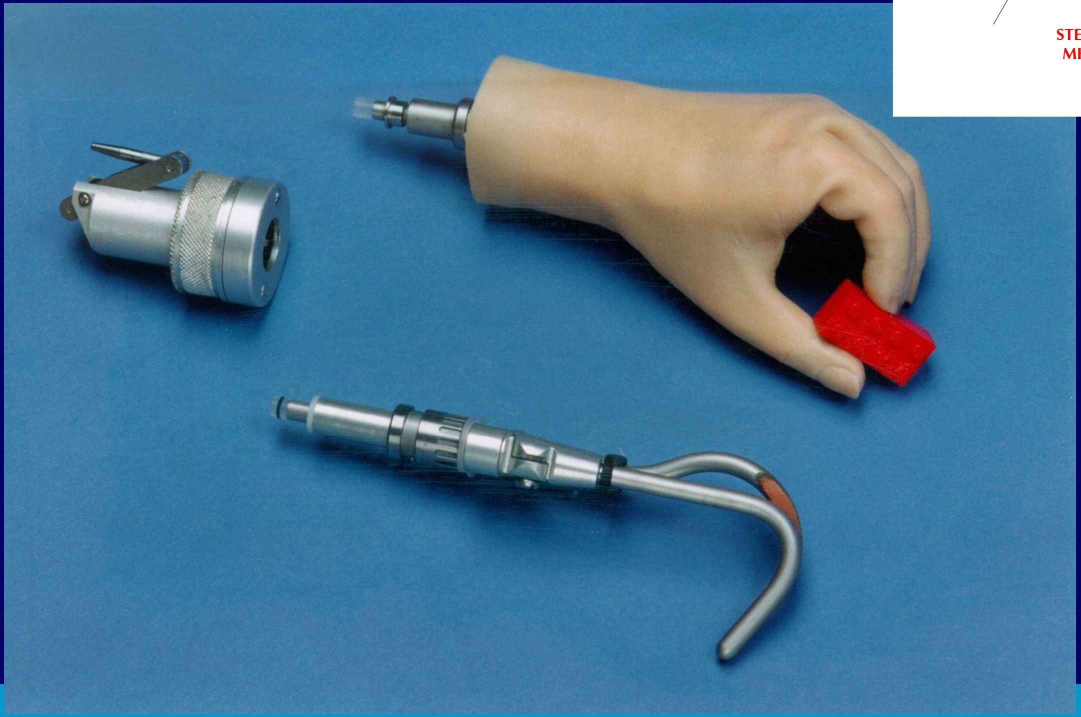
PNEUMATICAL

RE-ASSESSMENT PNEUMATIC ACTUATION:

- LIGHT?
- FAST?
- RELIABLE?
- SMALL?

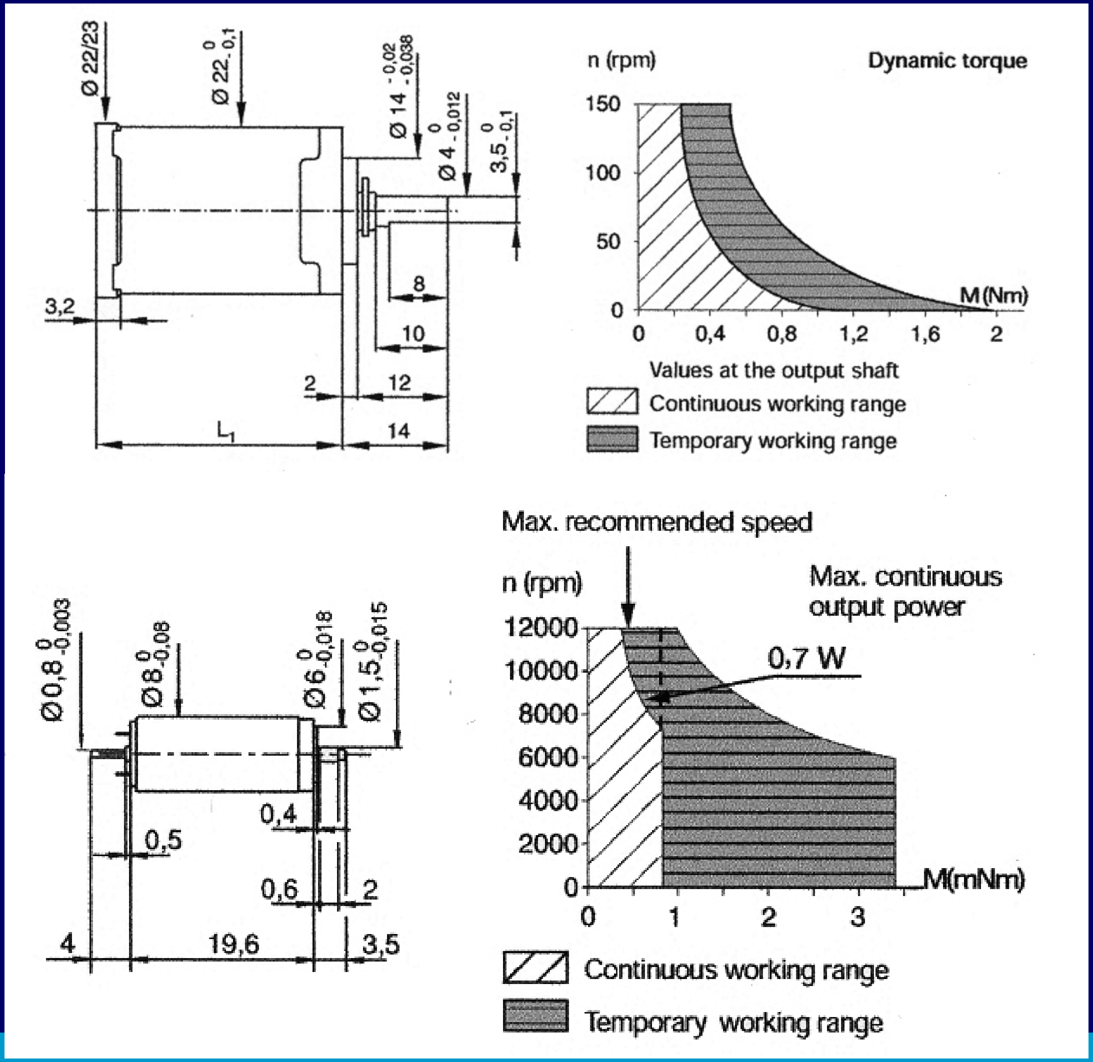
PNEUMATICAL





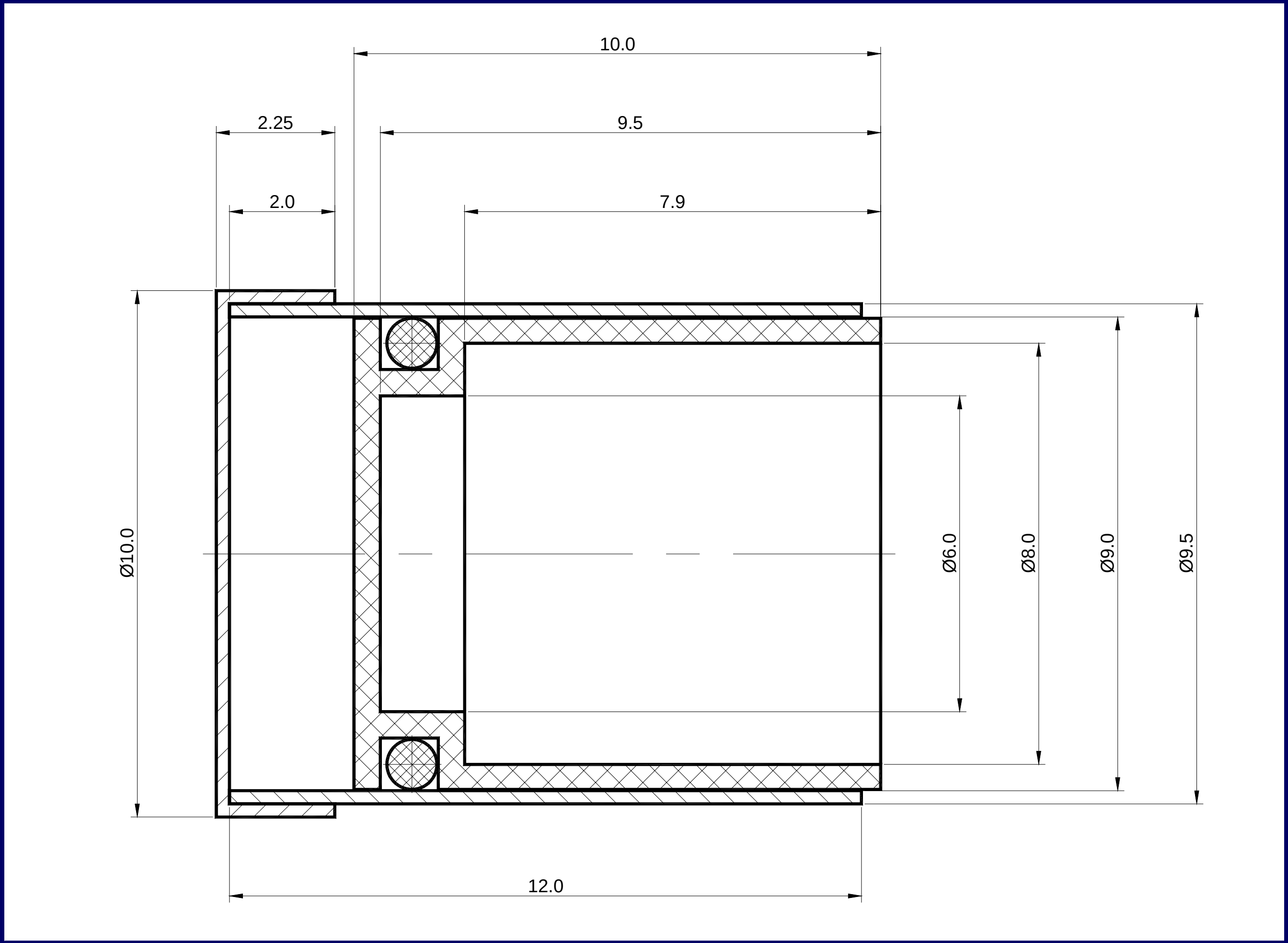
E_{req} = 750 Nmm

PNEUMATICAL



m = 37.5 g

PNEUMATICAL



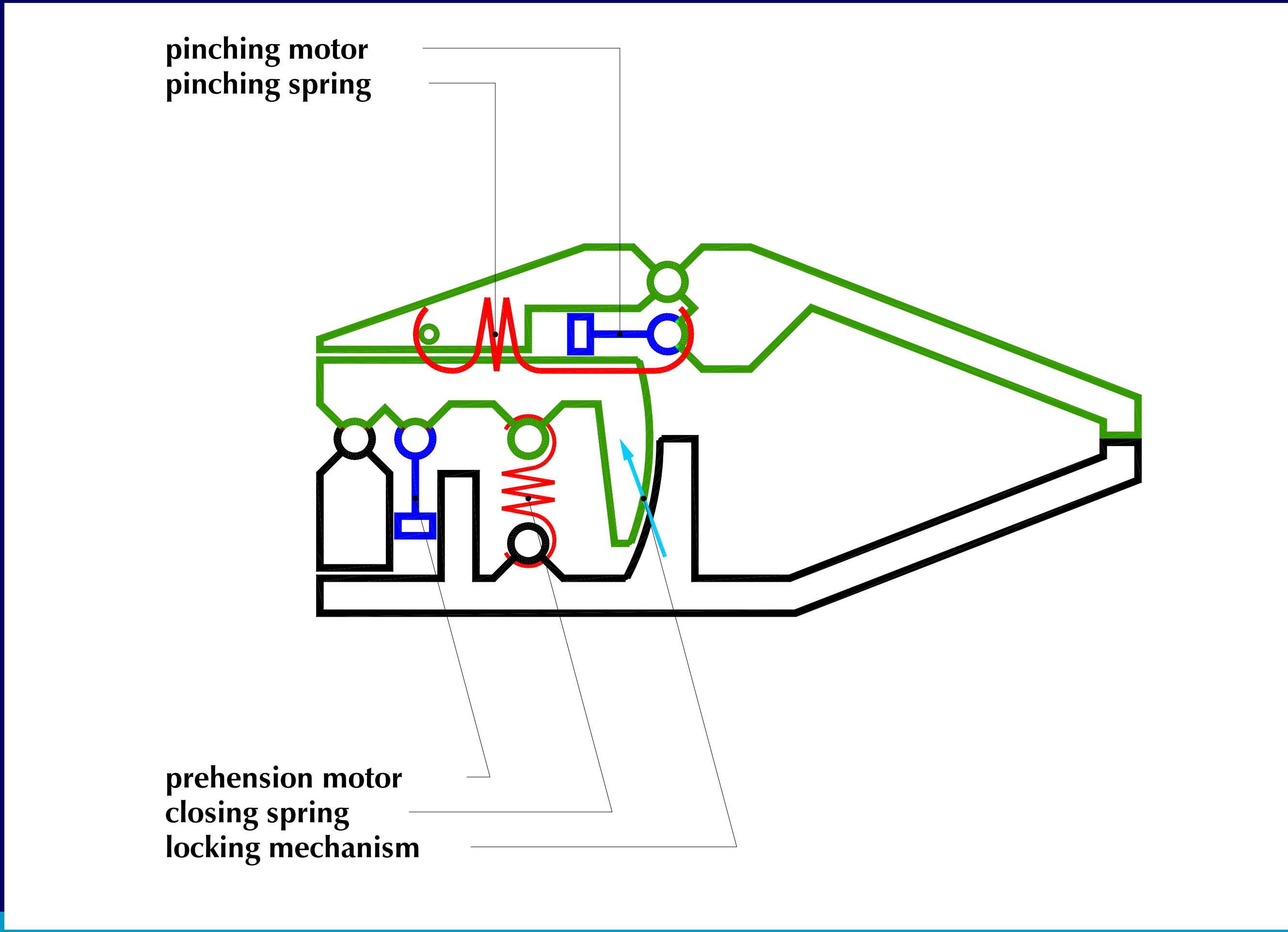
m = 1.2 g

PNEUMATICAL

- MINIMIZE GAS CONSUMPTION BY
  - SYSTEM CHOICE
  - REDUCTION OF FRICTION LOSSES
  - REDUCTION OF DEAD SPACE
  - SUPPLY PRESSURE
- PROTOTYPES

PNEUMATICAL

‘BI-PHASIC’ OPERATION



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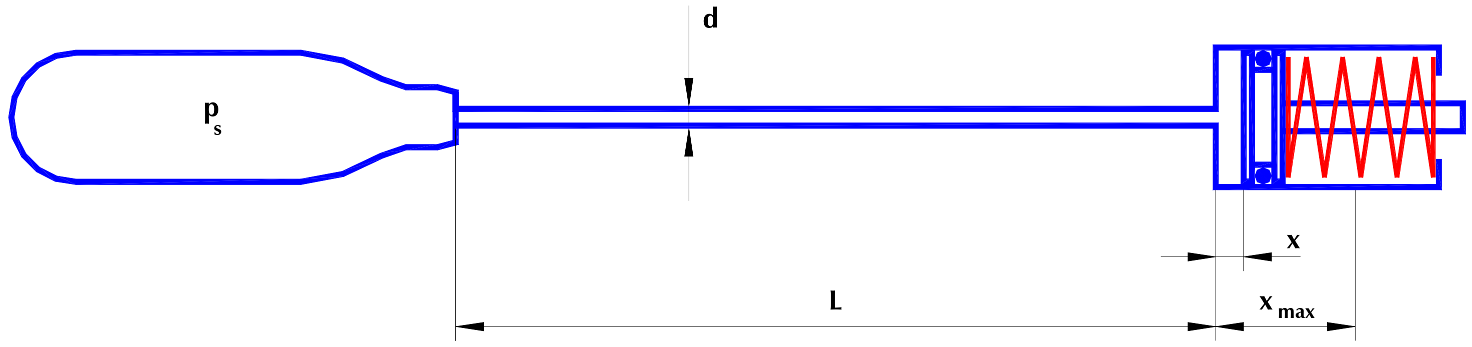
PNEUMATICAL

SUPPLY PRESSURE

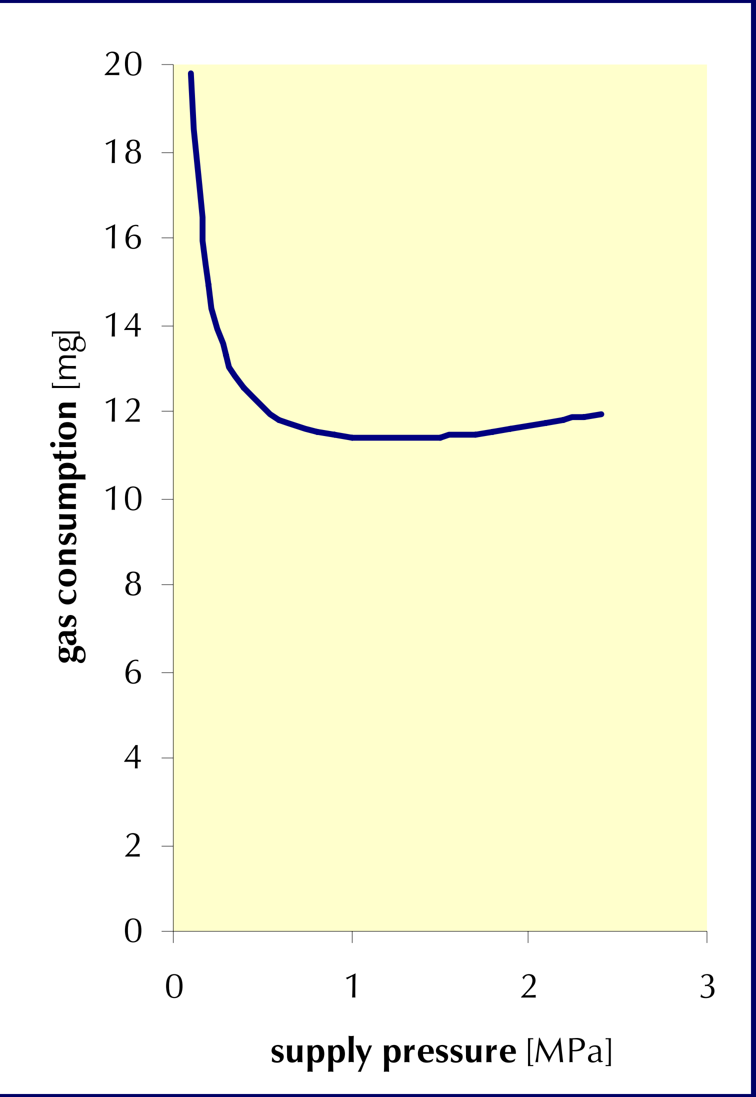


PNEUMATICAL

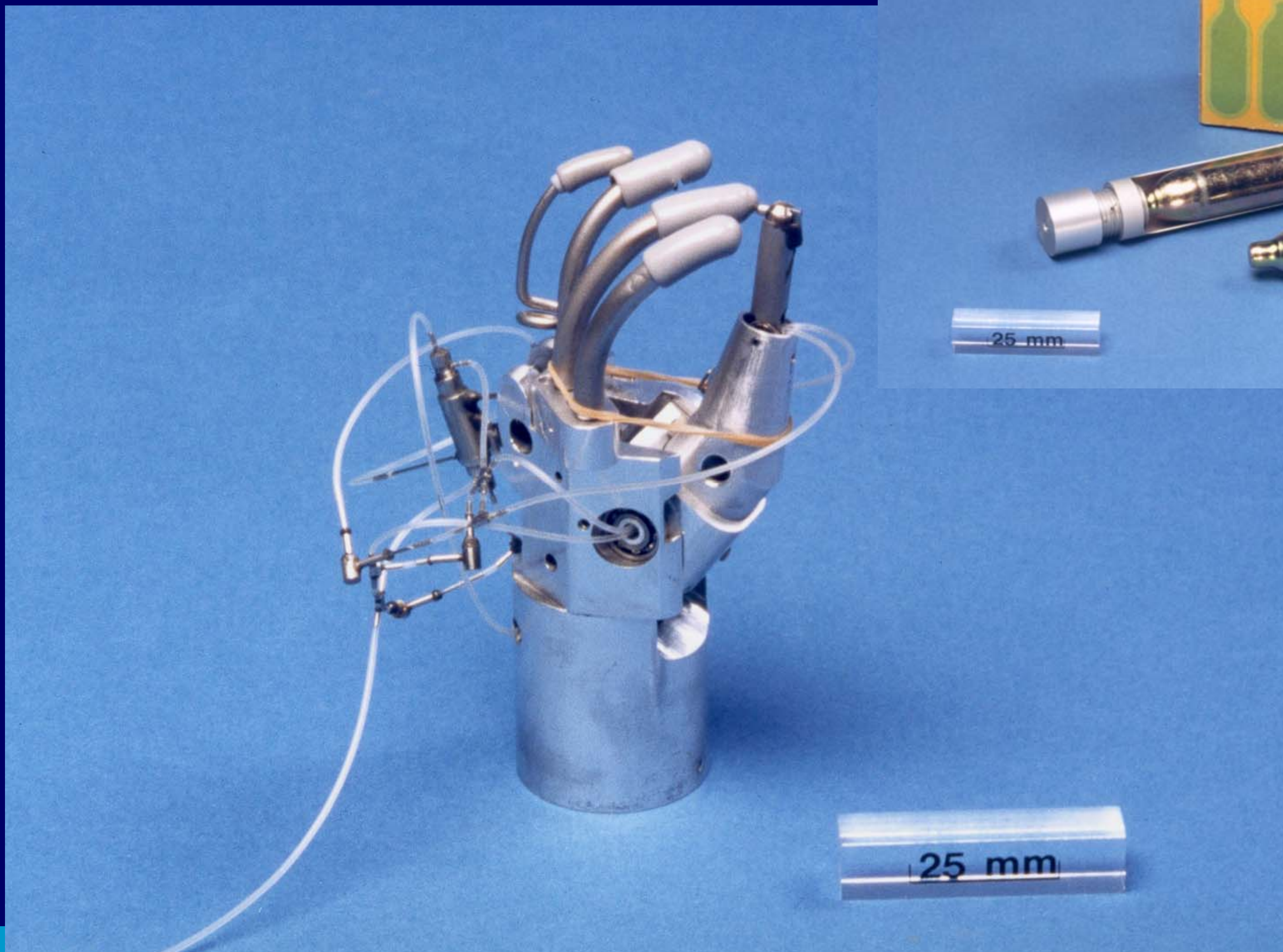
$P_{s,\,opt}$ = 1.2 MPa

Independent of:

Δt, L, F_s, and x



PNEUMATICAL



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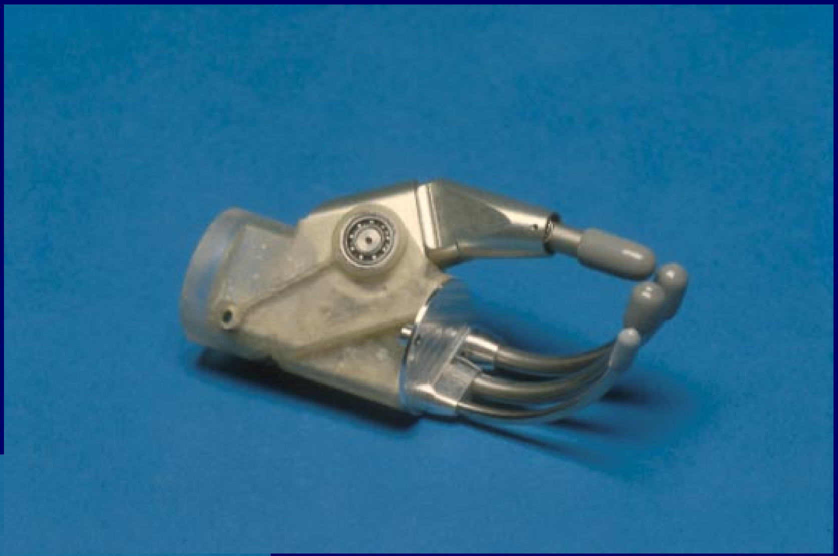
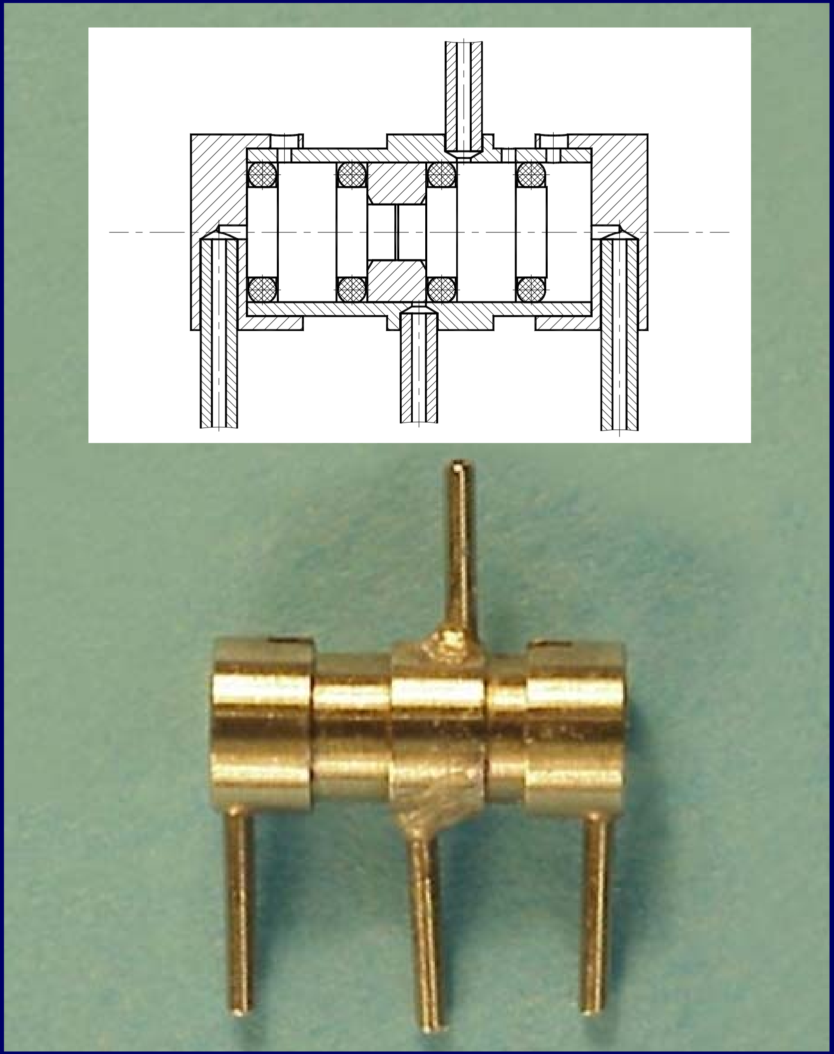
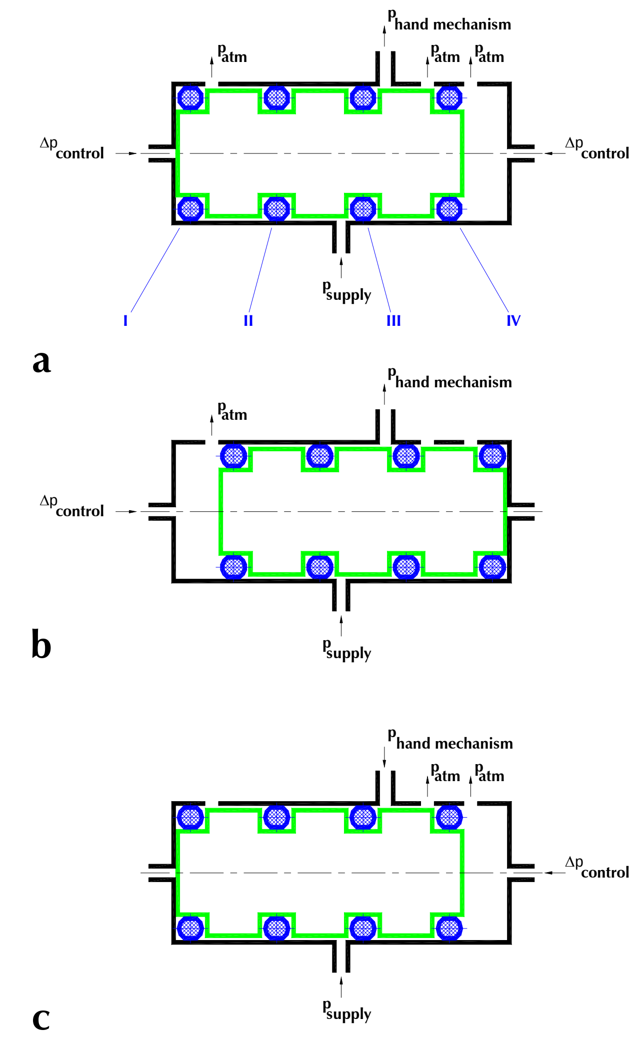
PNEUMATICAL



PNEUMATICAL





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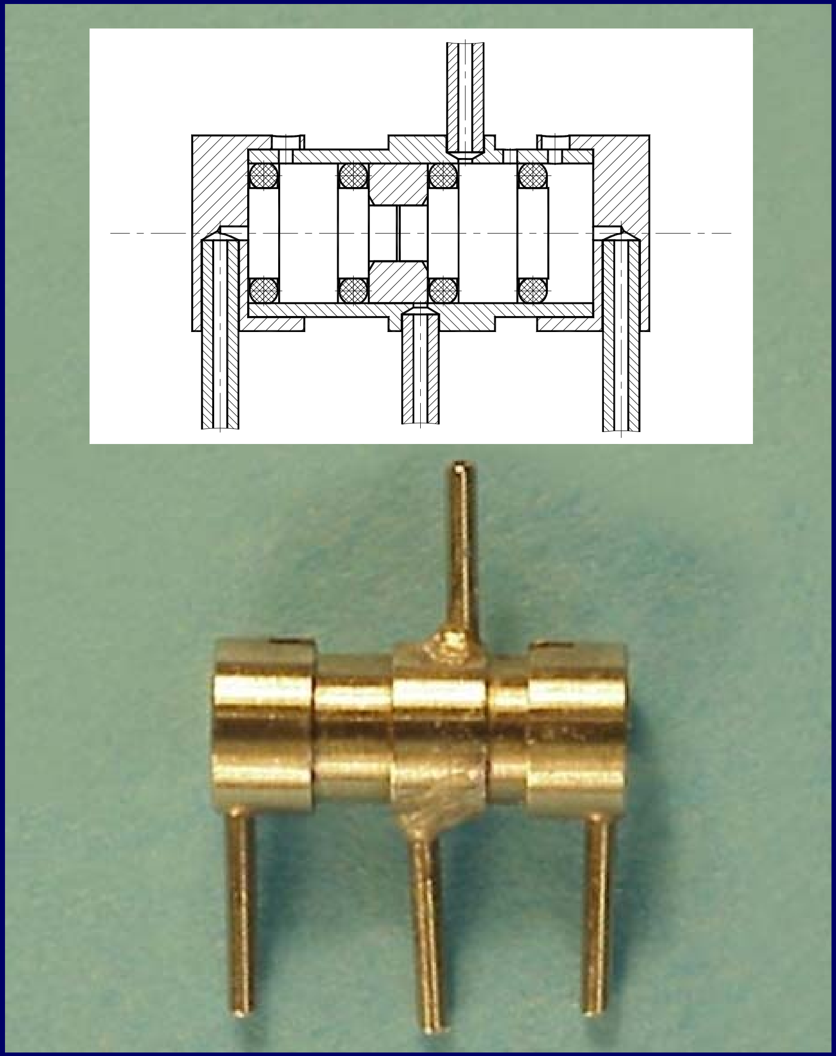
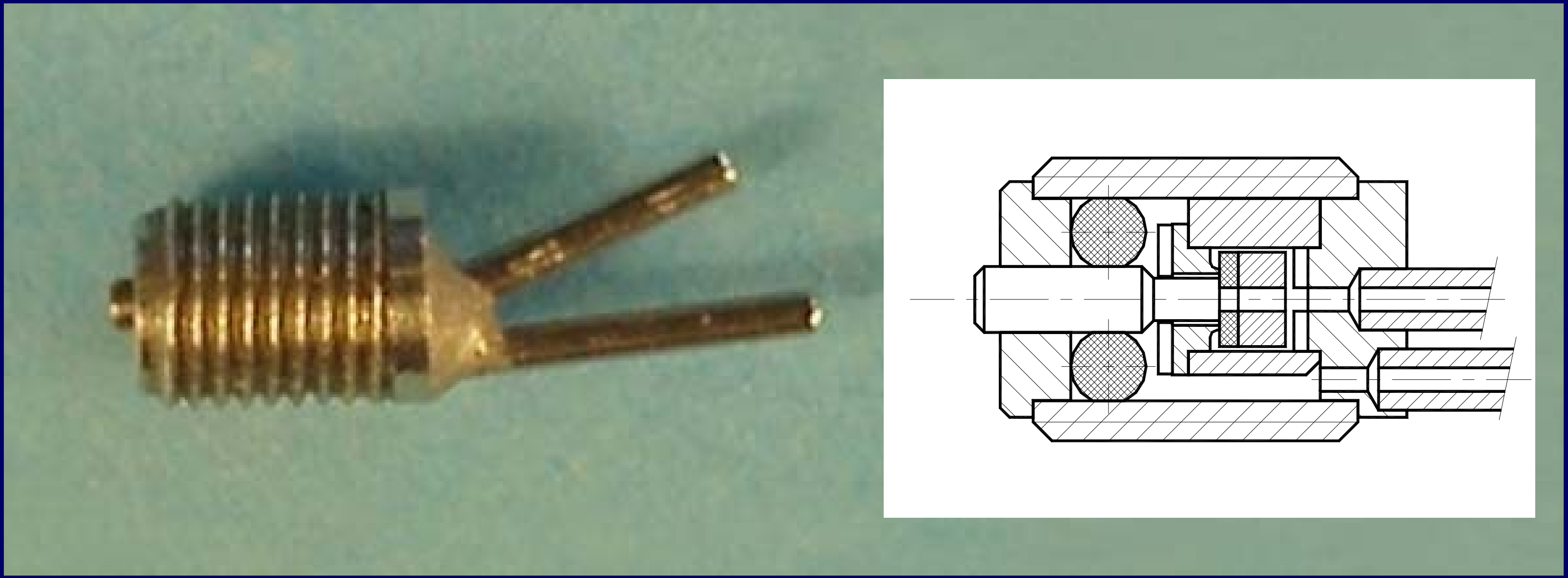


Pneumatic relay:

- Ø 3.5 x 8.15 mm
- ΔP = 0.4 MPa
- Q = 74.2 ltr/hr
- m = 0.66 g

PNEUMATICAL

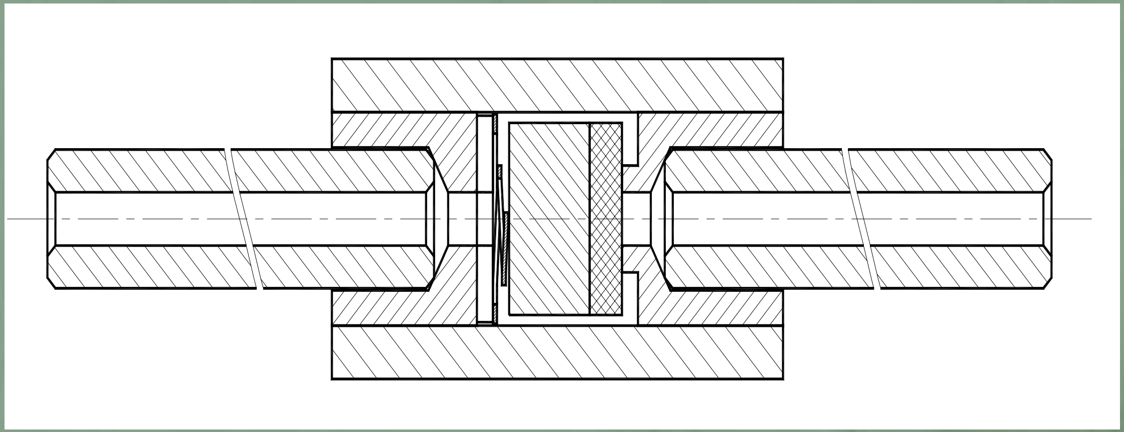


PNEUMATICAL

Pneumatic switch:

- Ø 3.0 x 4.3 mm
- F = 0.6 N
- Q = 97.0 ltr/hr
- m = 0.19 g

PNEUMATICAL

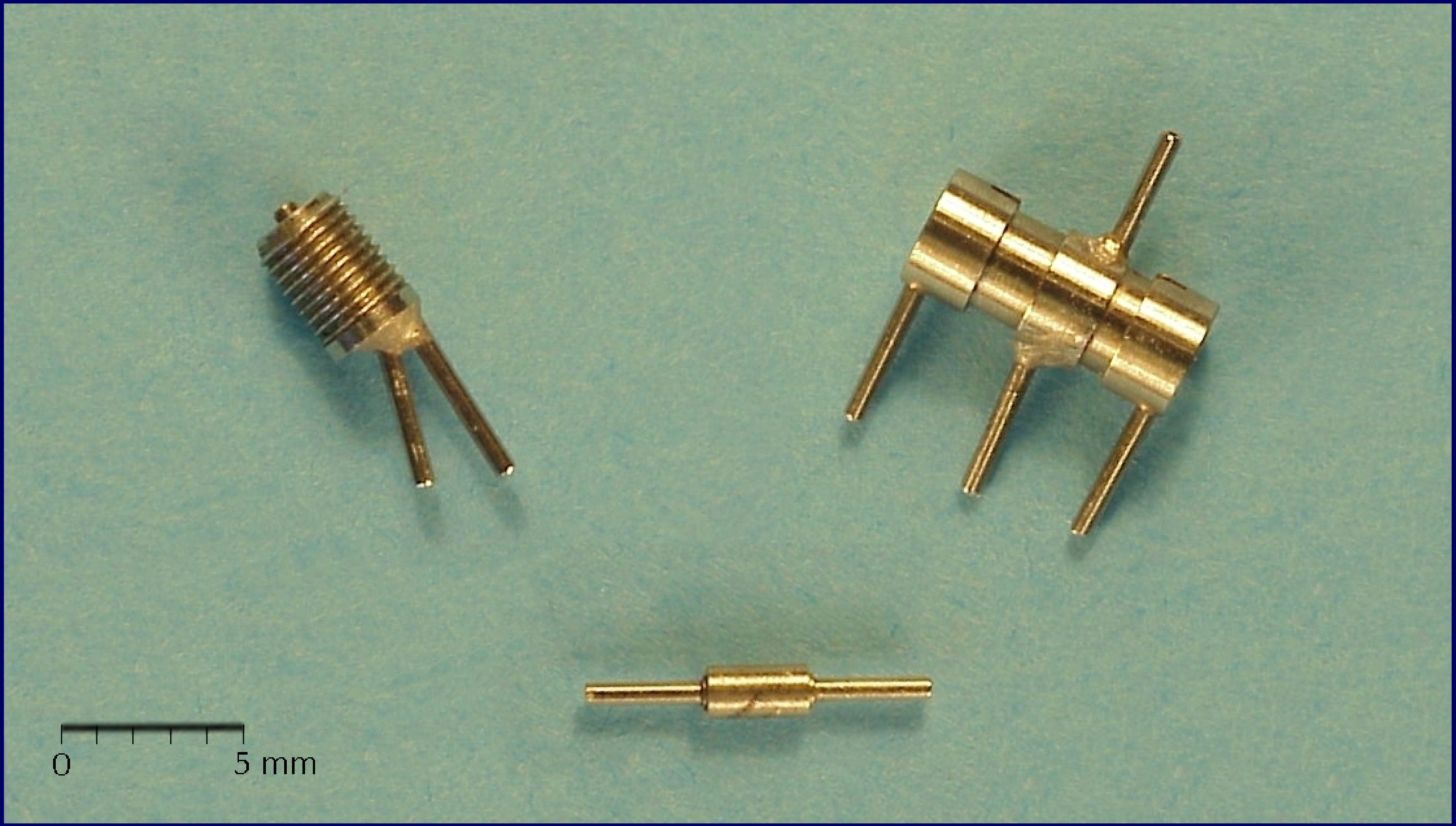


PNEUMATICAL

Check valve:

- Ø 1.5 x 2.8 mm
- ΔP = 0.48 kPa
- Q $\geq$ 120.0 ltr/hr
- m = 0.05 g

PNEUMATICAL



PNEUMATICAL

	MYOELECTRIC STEEPER	MYOELECTRIC OTTO BOCK	PNEUMATIC TECHNICAL PROTOTYPE WILMER	PNEUMATIC CLINICAL PROTOTYPE WILMER
MASS OF THE HAND [grams]	230	130	128	60
MASS OF THE ENERGY STORAGE SYSTEM [grams]	75	60	60	36**
MASS OF THE COMPLETE PROSTHESIS [grams]	550	340	300*	250*
ELBOW TORQUE [Nmm]	760	470	400*	290*
ENERGY CONSUMPTION [per day]	1 BATTERY	1 BATTERY	0.5 GAS CONTAINER	< 0.5 GAS CONTAINER
OPERATING CYCLE [seconds]	2.5	>2.5	<1	<1

* estimated figure

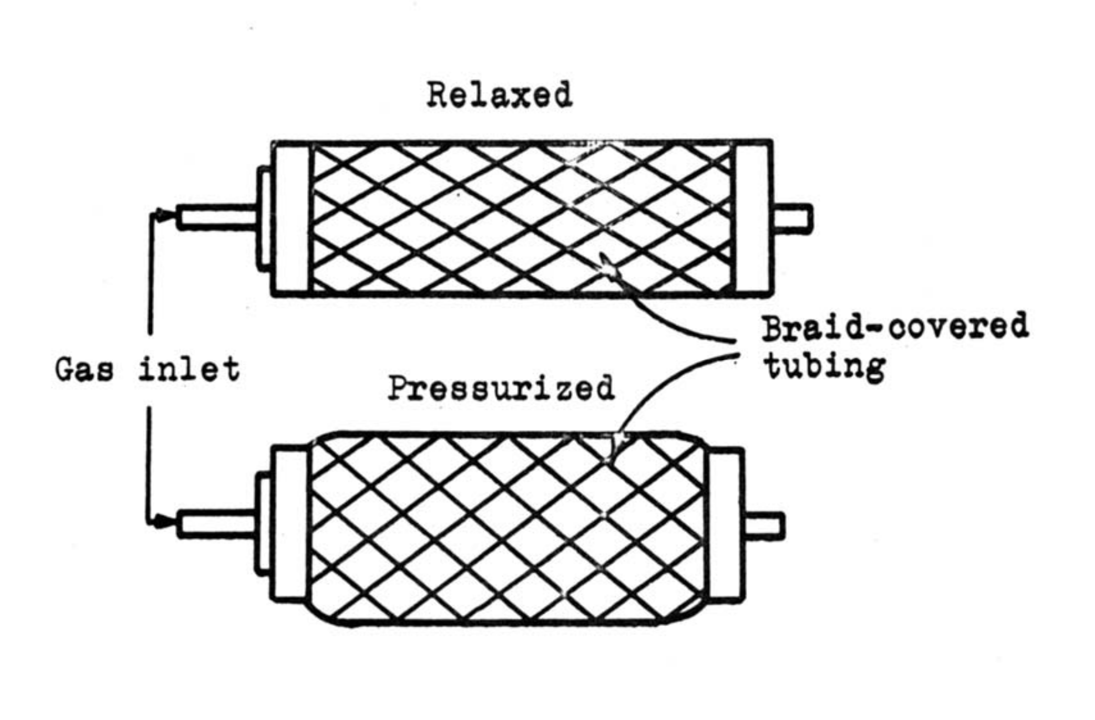
** estimated figure, based upon a mass for the pressure reducing valve of 4 grams after a redesign

PNEUMATICAL

PNEUMATIC ACTUATION EXCELS ELECTRICAL ACTUATION:

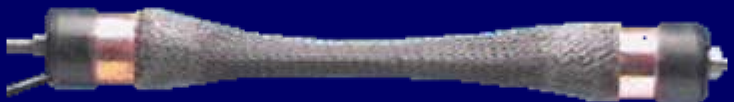
- LOW IN MASS
- FAST
- RELIABLE
- SMALL

McKIBBEN-MUSCLE



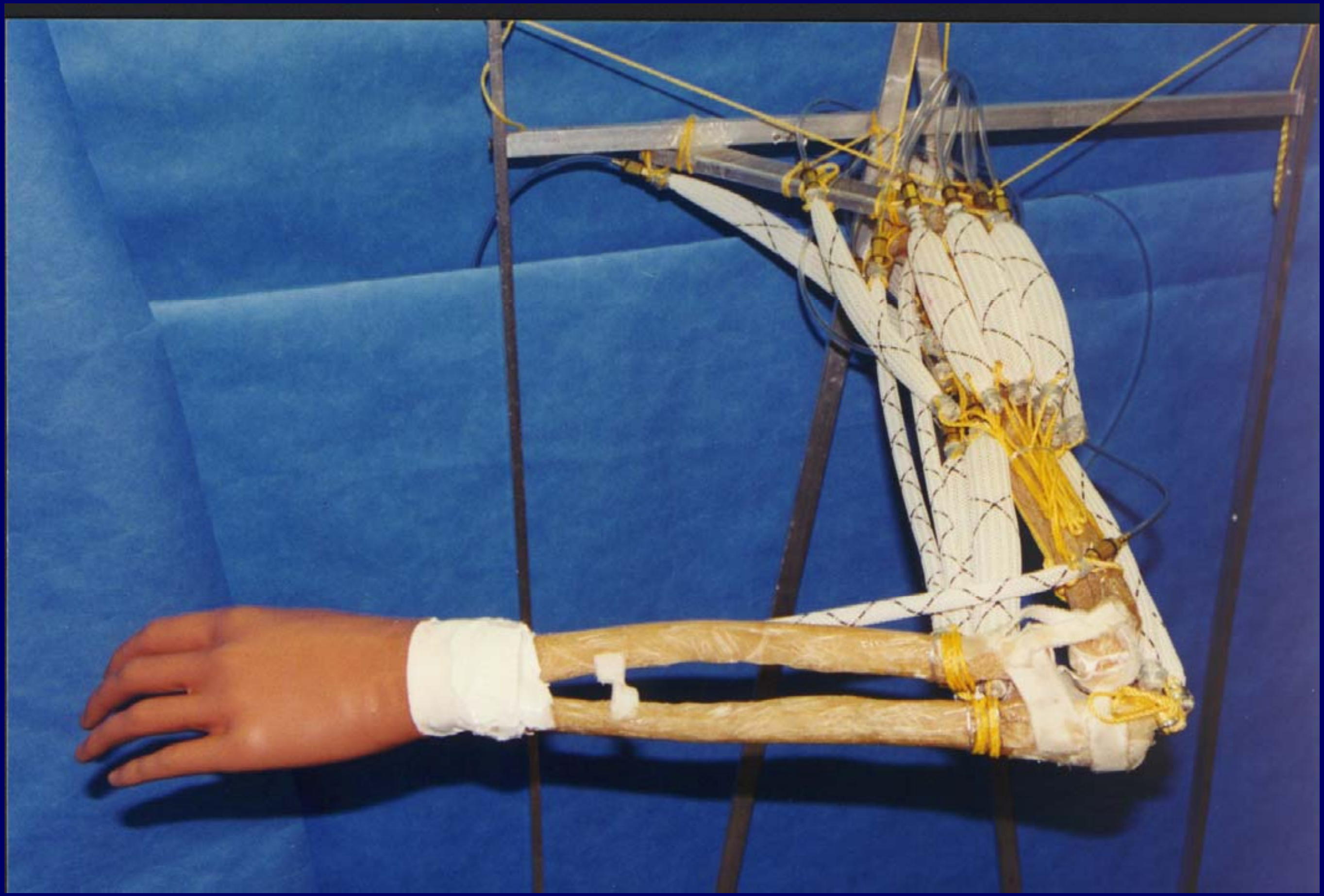
Carlson, 1971

McKIBBEN-MUSCLE



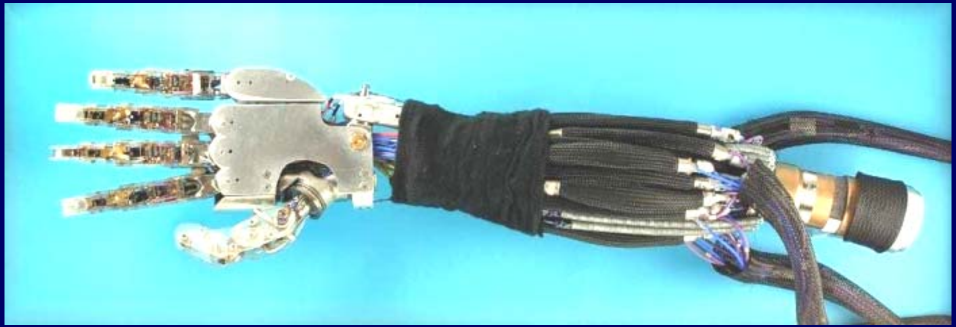
Shadow, UK

McKIBBEN-MUSCLE

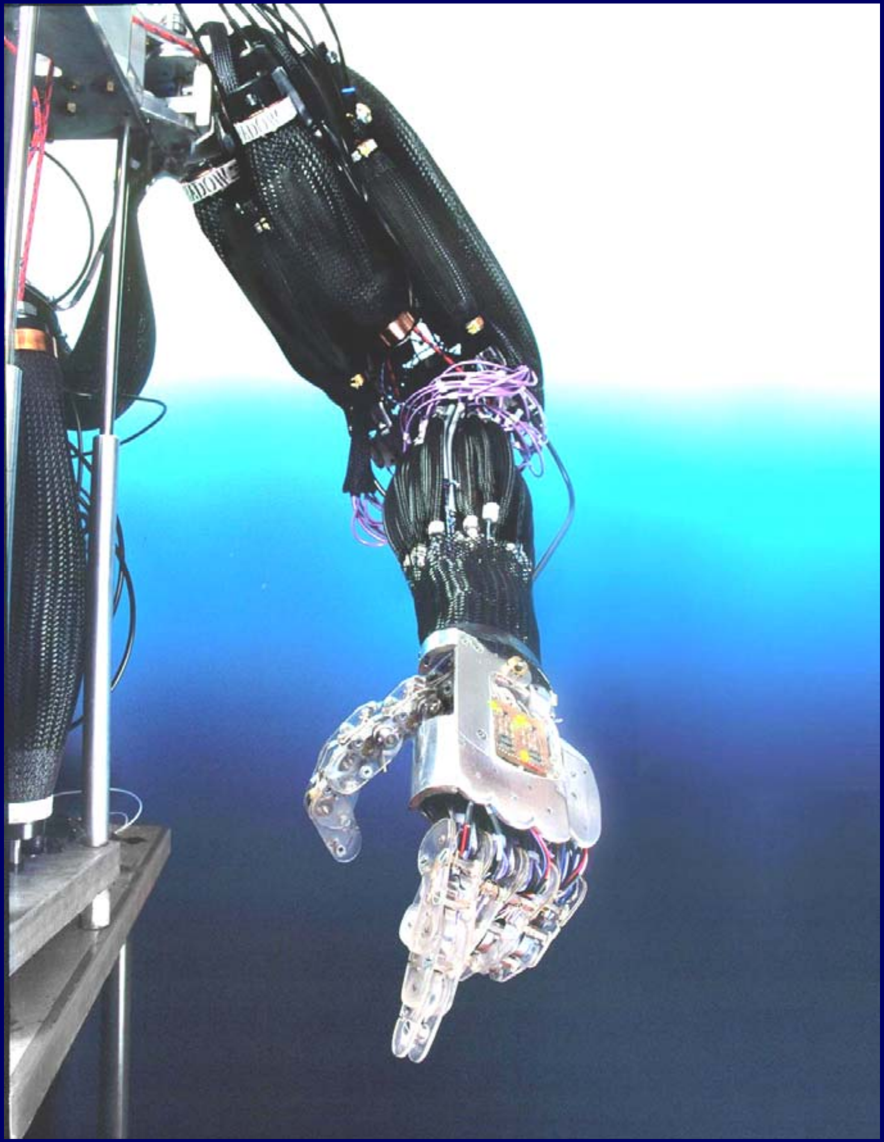


Univ. of Washington, USA

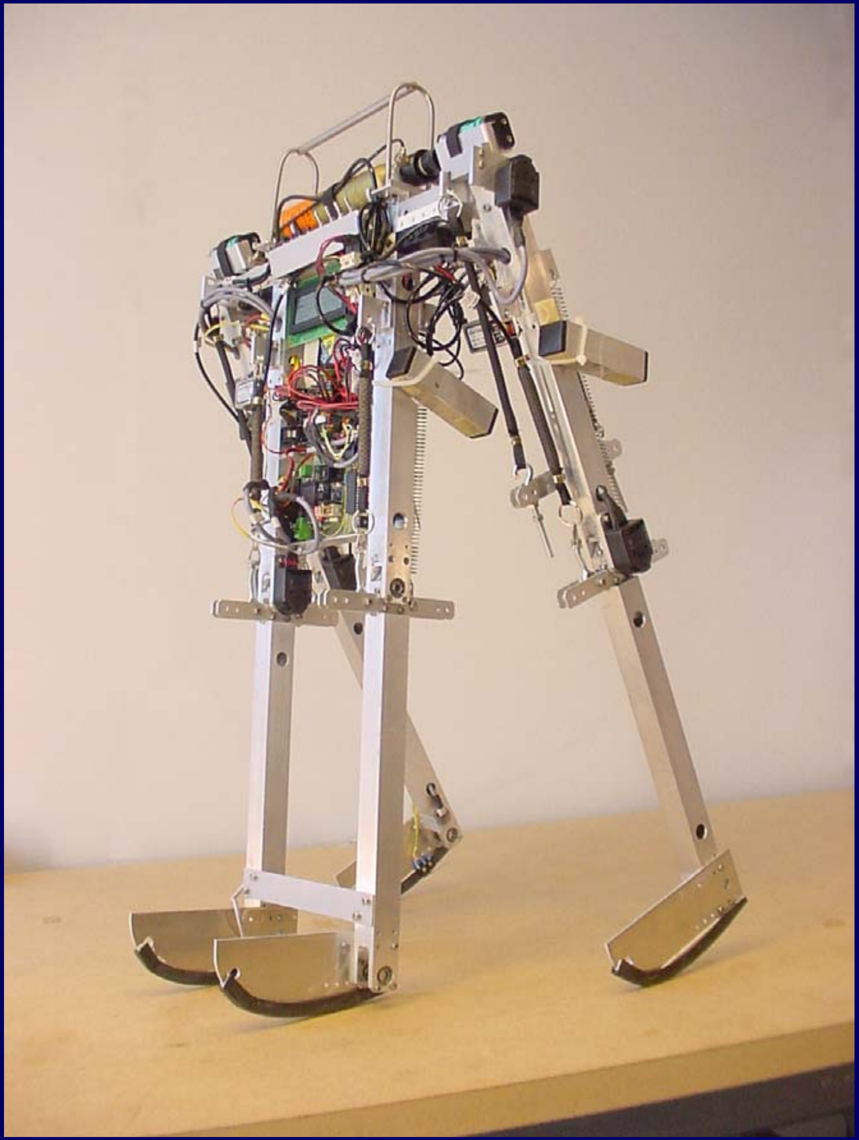
McKIBBEN-MUSCLE



Shadow, UK



McKIBBEN-MUSCLE



McKIBBEN-MUSCLE

McKIBBEN MUSCLE / PNEUMATIC ARTIFICIAL MUSCLE

KEY ADVANTAGE:

- LOW MASS COMPARED TO MUSCLE STRENGTH
- HIGH FORCE TO WEIGHT RATIO
- HIGH POWER TO WEIGHT RATIO
- ETC.

McKIBBEN-MUSCLE / PNEUMATIC ARTIFICIAL MUSCLE

CLAIMED ADVANTAGES:

- LOW MASS
- HIGH POWER-TO-WEIGHT RATIO

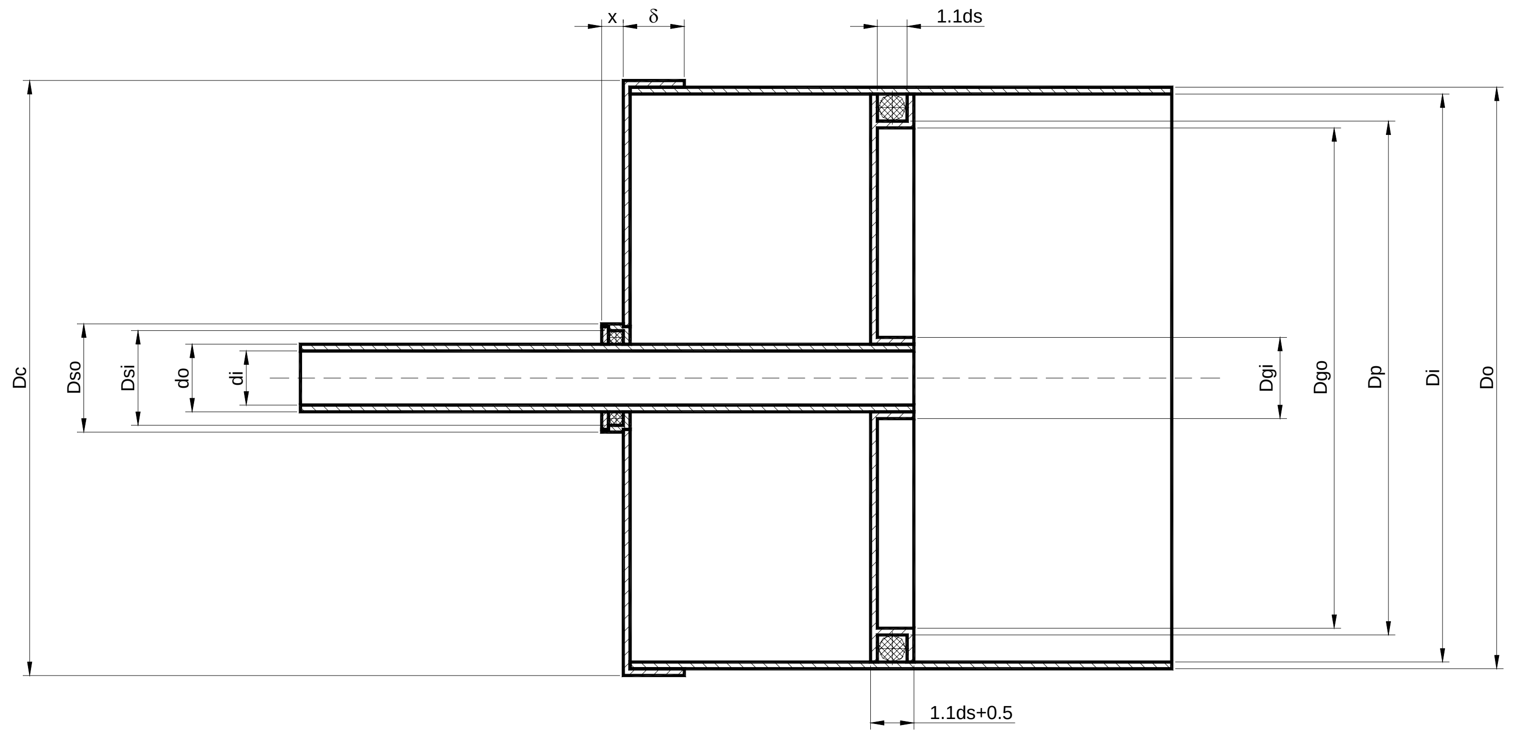
?

DISADVANTAGES:

- LOW PRESSURE
- UV-SENSITIVE

Festo AG

FESTO MAS-10 FESTO ADVC-25 FESTO DSN-25



WILMER 21xS

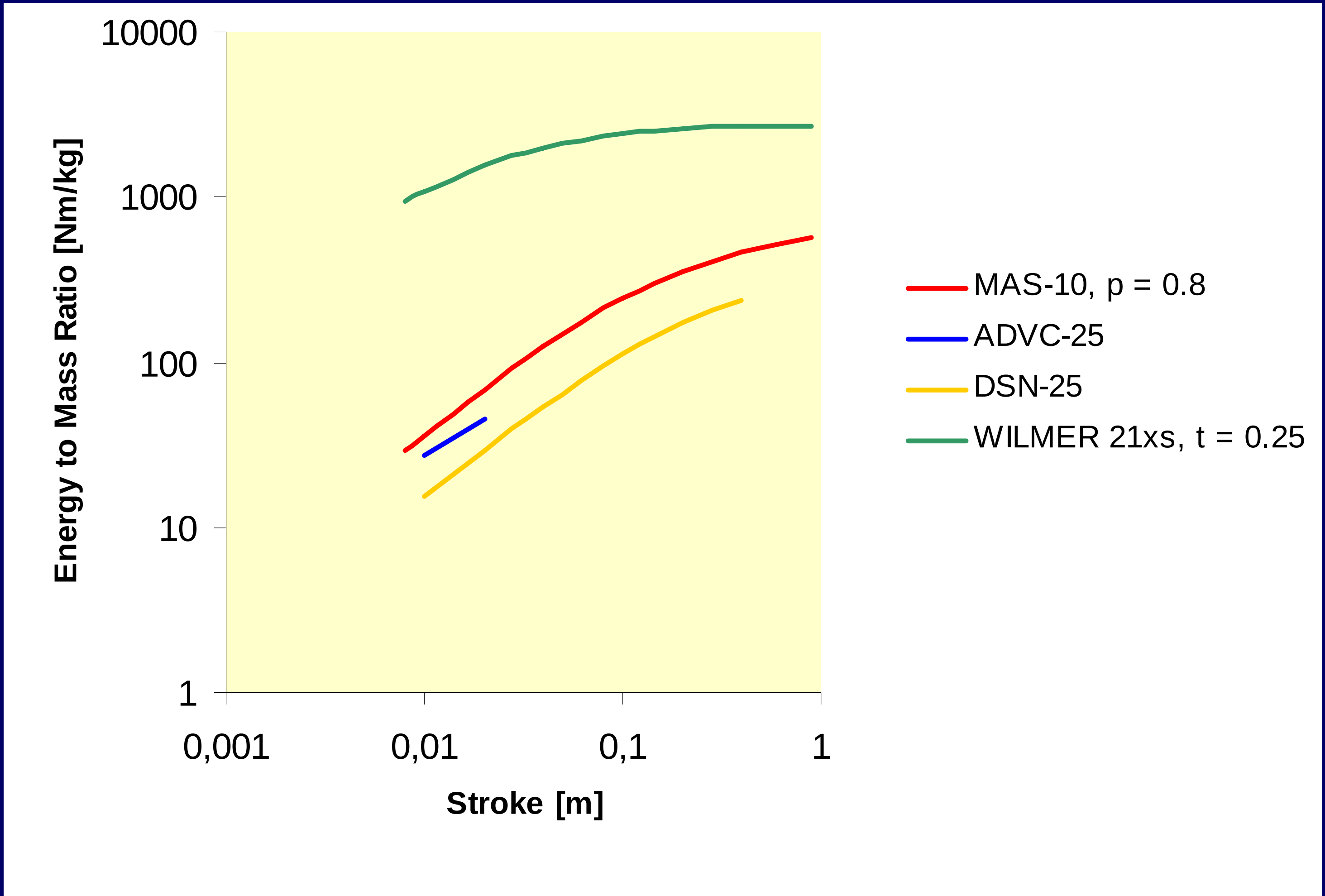
PNEUMATIC ARTIFICIAL MUSCLES

Output energy to mass ratio:

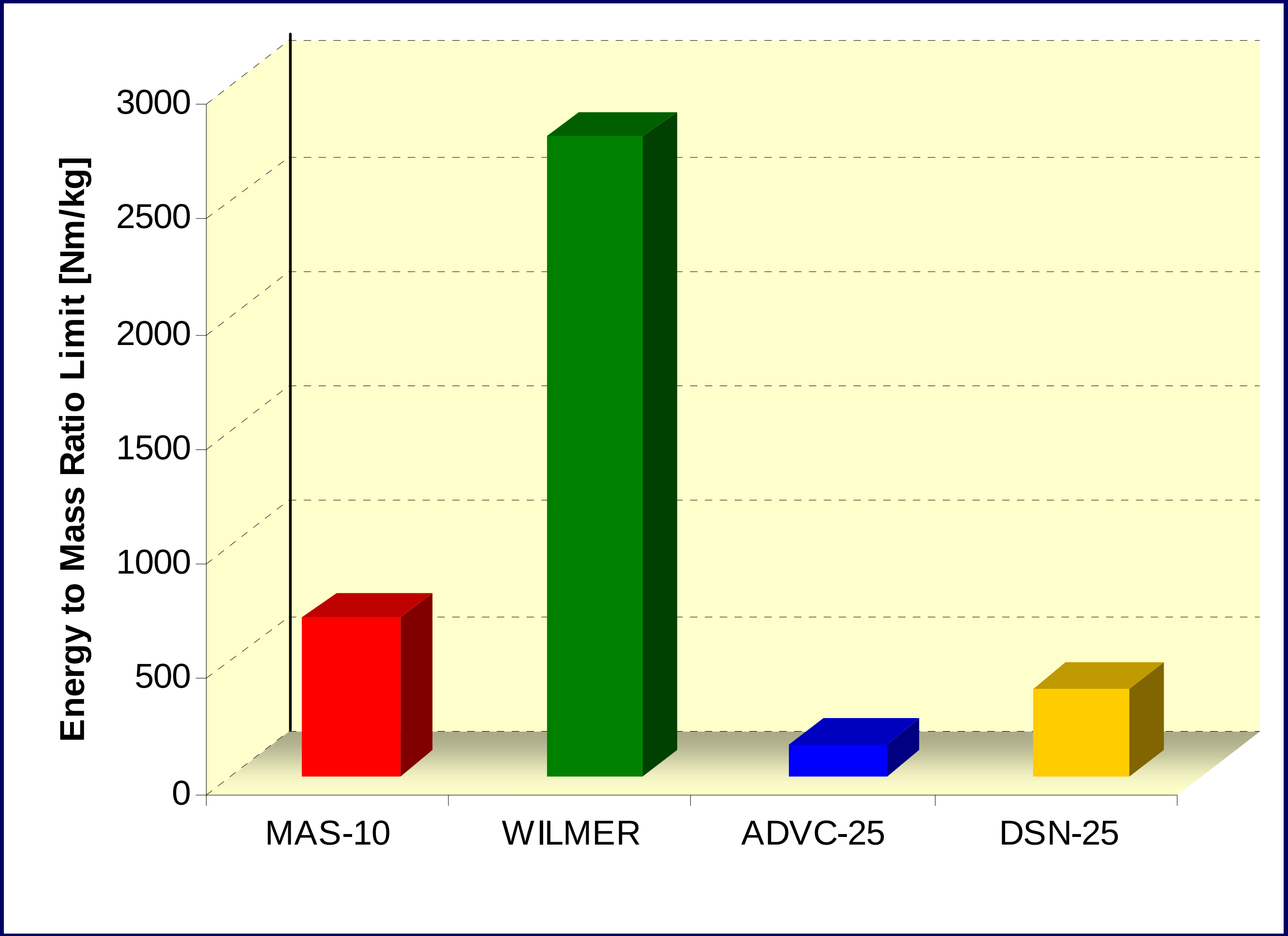
$$EtM = \frac{\int F(s) \cdot ds}{m}$$

EtM	= energy to mass ratio [Nm/kg]
F(s)	= ouput force as a function of the stroke [N]
s	= stroke [m]
m	= muscle mass [kg]

PNEUMATIC ARTIFICIAL MUSCLES



PNEUMATIC ARTIFICIAL MUSCLES



TUDelft

PNEUMATIC ARTIFICIAL MUSCLES

Output energy to volume ratio:

$$EtV = \frac{\int F(s) \cdot ds}{V}$$

EtV = energy to mass ratio [Nm/kg]
F(s) = ouput force as a function of the stroke [N]
s = stroke [m]
V = muscle volume [m^3]

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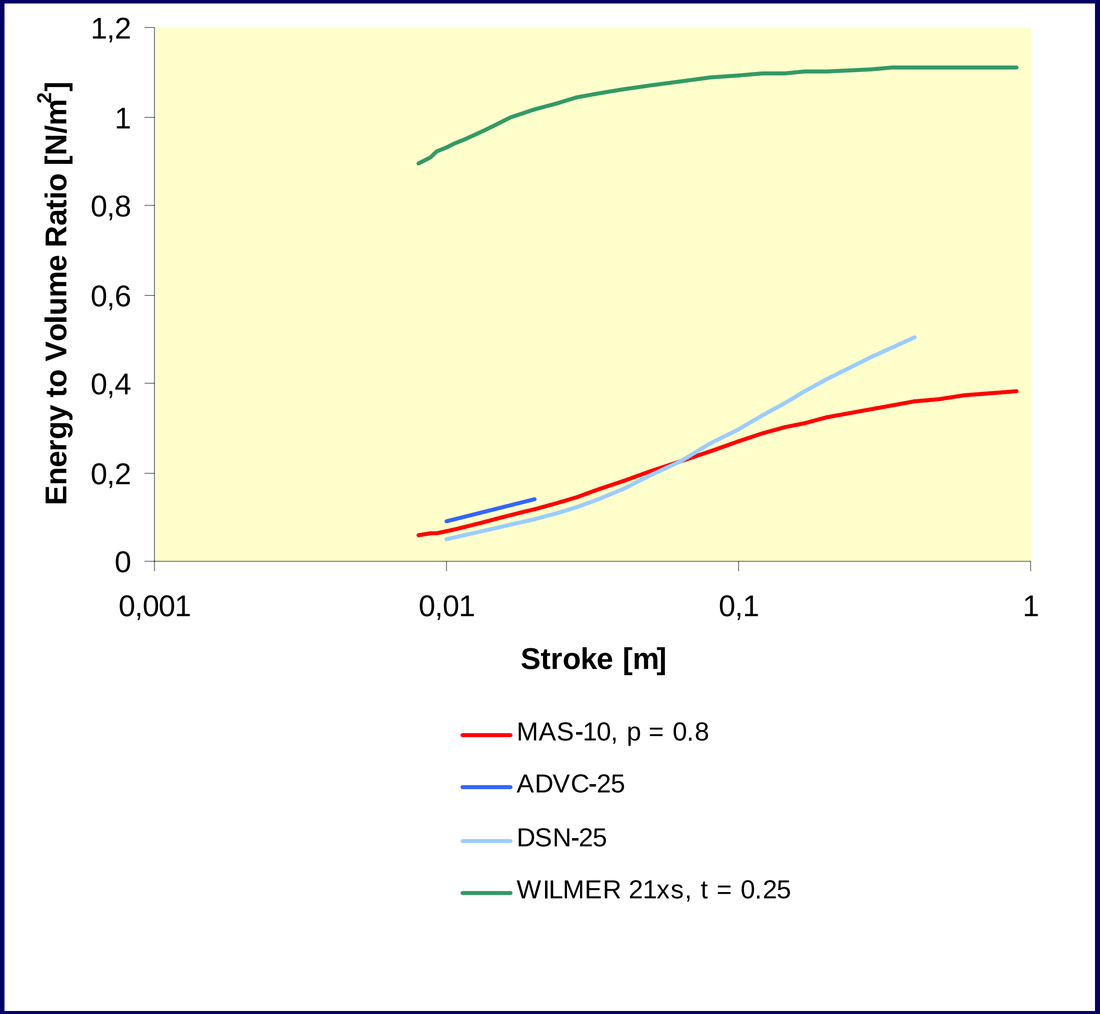
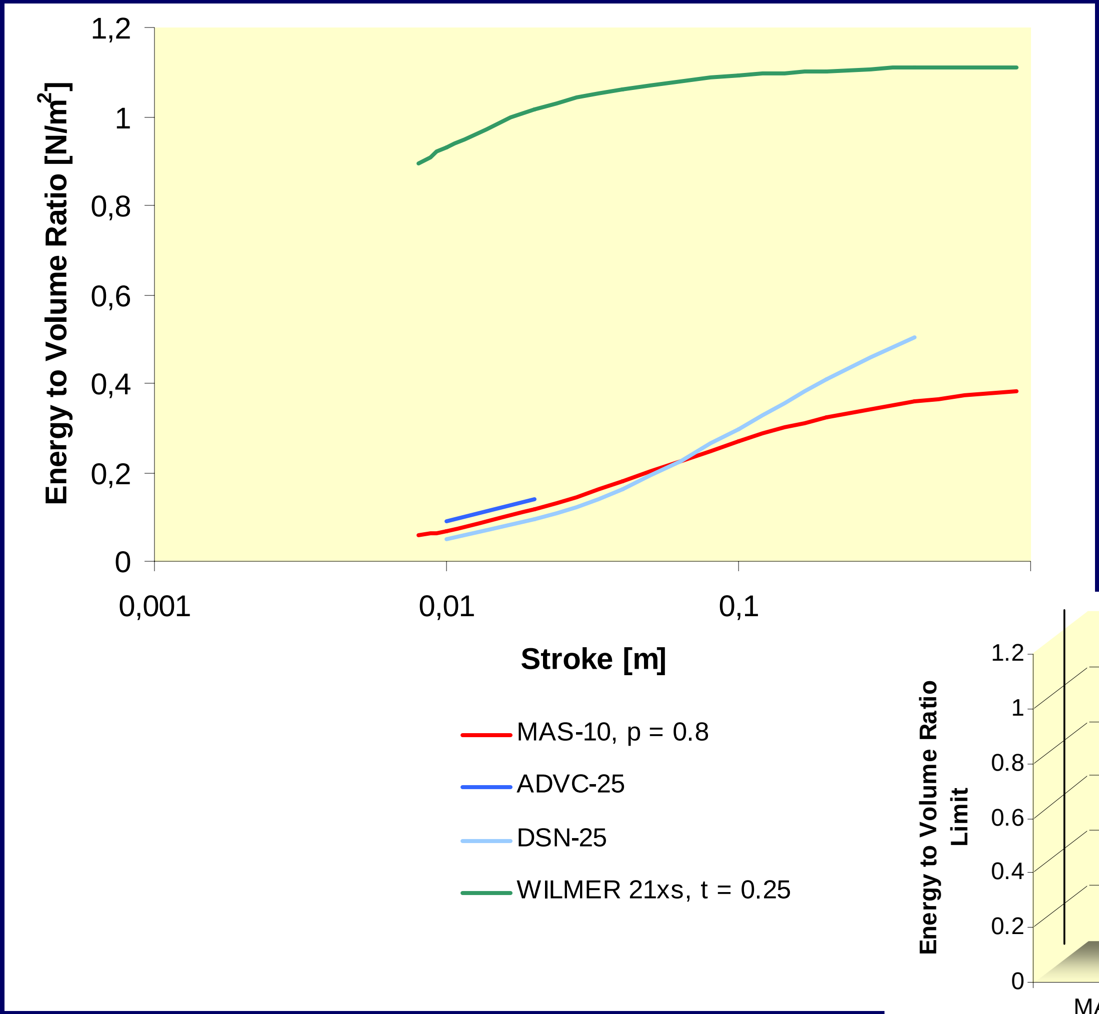
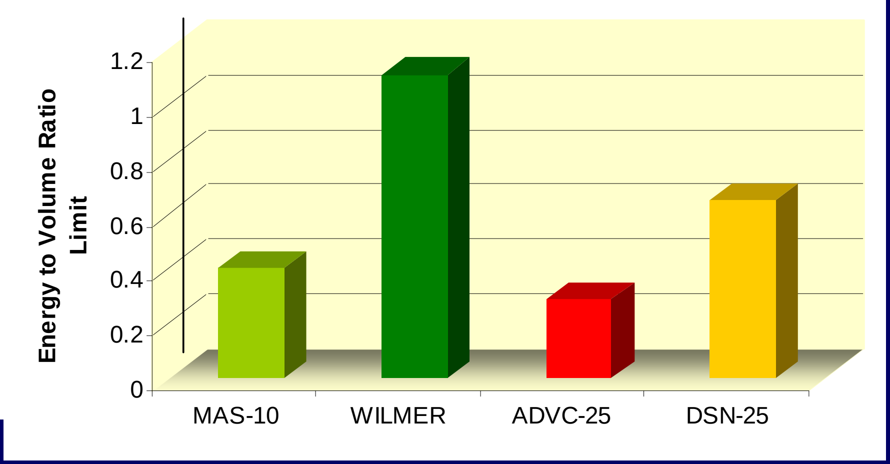
PNEUMATIC ARTIFICIAL MUSCLES

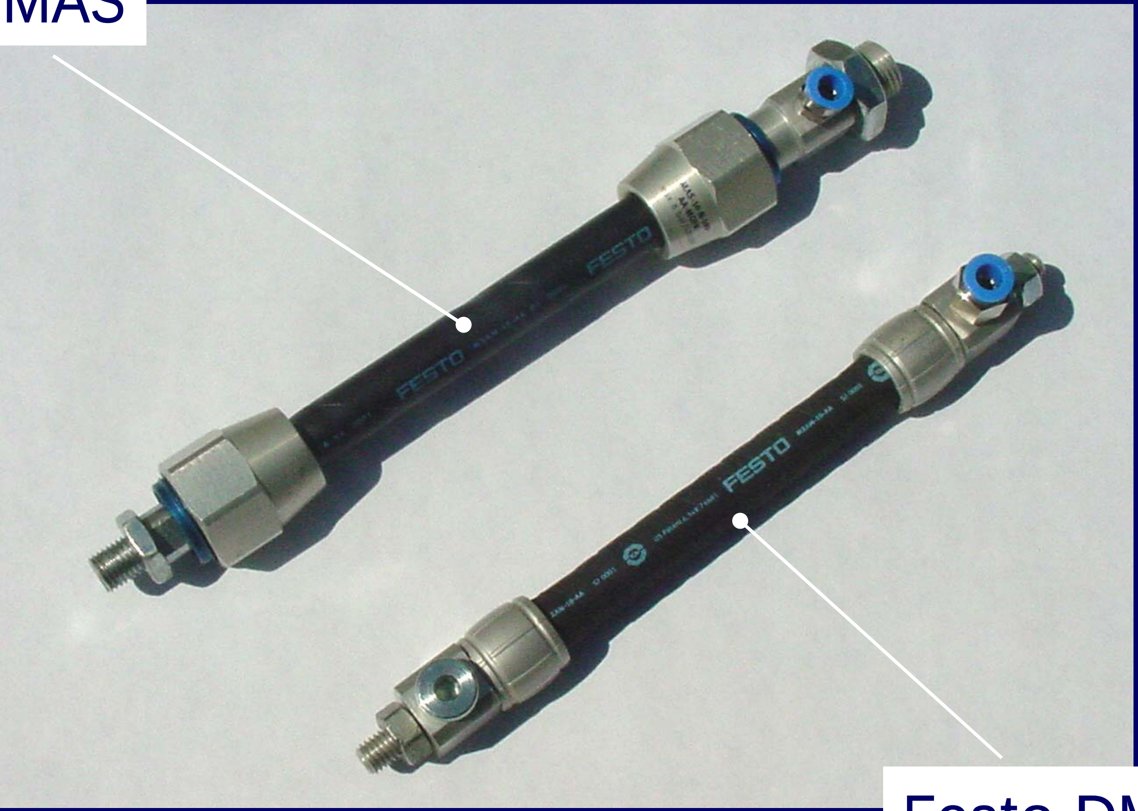


PNEUMATIC ARTIFICIAL MUSCLES



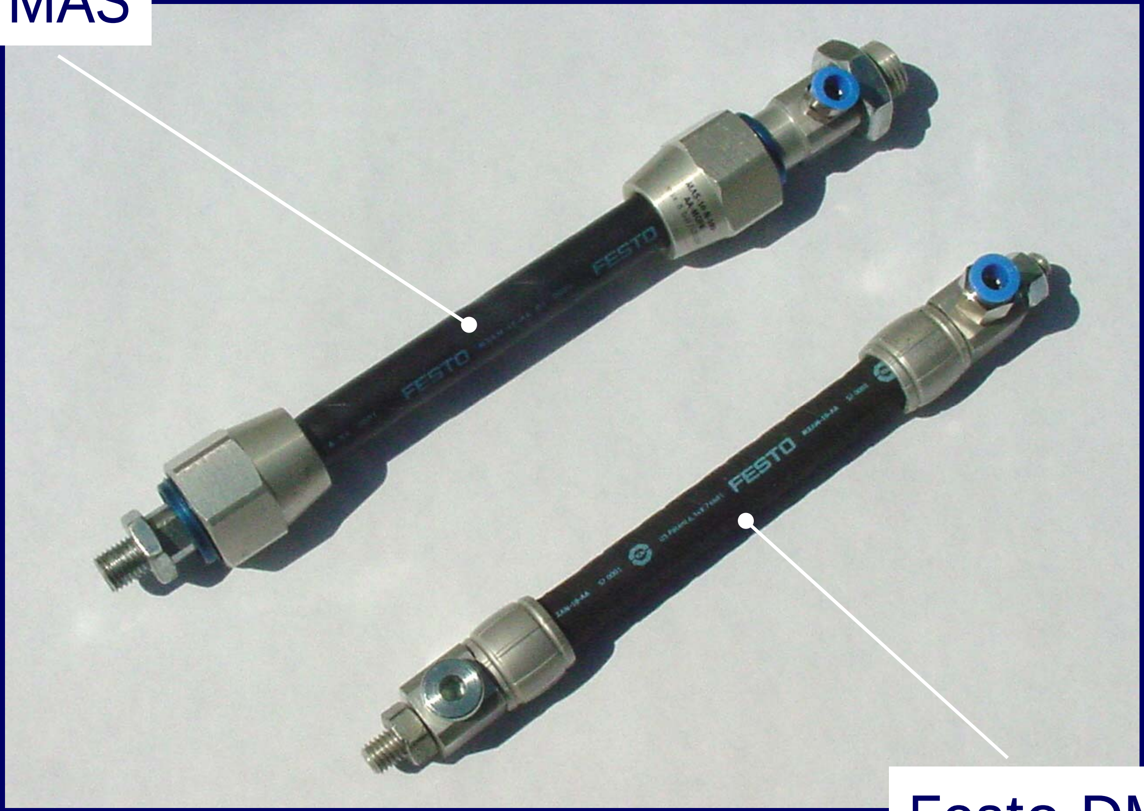


PNEUMATIC ARTIFICIAL MUSCLES



PNEUMATIC ARTIFICIAL MUSCLES

Festo MAS



Festo DMSP

Basic mass difference

$\Delta m = 20$ g

CONCLUSIONS:

$(EtM)_{PAM} > (EtM)_{\text{Standard Industrial Actuators}}$

$(EtV)_{PAM} < (EtV)_{\text{Standard Industrial Actuators}}$

REDESIGN OF CYLINDER ACTUATORS:

EtM: $5 – 30 \times (EtM)_{PAM}$

EtV $> 3 – 13.5 \times (EtV)_{PAM}$

DO NOT USE PAM WHERE EtM AND/OR EtV IS CRITICAL

SUMMARY

- CONTROL vs ACTUATION
- BODY POWER
  - SHOULDER HARNESS
  - ELBOW CONTROL
- EXTERNAL POWER
  - ELECTRICAL
  - HYDRAULICAL
  - PNEUMATICAL

SUMMARY [cont.]

- PNEUMATIC ACTUATION EXCELS ELECTRICAL ACTUATION:
  - LOW IN MASS
  - FAST
  - RELIABLE
  - SMALL
- DO NOT USE PAM WHERE EtM AND/OR EtV IS CRITICAL

CHALLENGES IN PNEUMATICS:

Miniature and energy efficient pneumatical systems

Research at the Delft Institute of Pneumatics:

- Miniature components
- [Energy efficient] pressure supply
- Miniature servo mechanisms

Pneumatics

- miniature components

ADVANCED MEDICAL TECHNOLOGY

TU Delft

Delft University of Technology

Mechanical Engineering
Man Machine Systems
WILMER prosthetics laboratory

Address
Mekelweg 2
2628 CD Delft
The Netherlands

http://mms.tudelft.nl/wilmer

2004

MASTER GRADUATION PROJECT

DESIGN OF A MINIATURE PRESSURE REGULATOR

Autonomous systems, like hand prostheses and walking bipeds, are to be powered by pneumatic actuators for reasons of overall mass, speed, reliability, and size. With the proper system choice made, a relatively small gas container holds sufficient energy to power the system during its duty cycle. In the container the gas is stored at saturation pressure. In general the saturation pressure level does not correspond with energy efficient operation of the system. Therefore, a pressure regulator is needed to reduce the saturation pressure to the desired supply pressure for the system. Pressure regulators are available from many different commercial firms. These regulators are all characterized by a relatively large size and mass. Although several prototypes of pressure regulators have been made at MMS that are small compared to the commercially available regulators, they are still large compared to other system components in hand prostheses and/or walking bipeds.

ASSIGNMENT

Design, construct, and build a miniature pressure regulator. Typical dimensions: Ø 5 x 25 mm. Pressure range: 0.35 – 1.5 MPa. Output flow > 20 ltr/hr. Demonstrate the proper working order of the new design in an experimental setup.

ADDITIONAL INFORMATION:

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Pneumatics

- miniature components

Pressure regulation in the human eye
[treatment of glaucoma]

Project in co-operation with

DORC
Dutch Ophthalmic Research Center

&

Rotterdam Eye Hospital

Pneumatics

- supply pressure level

WILMER
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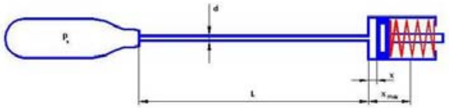

2004

MASTER GRADUATION PROJECT

OPTIMAL SUPPLY PRESSURE LEVEL

For autonomous and/or portable systems, like for instance hand prostheses or walking bipeds, pneumatic actuation is designated. For the energy supply pressurized carbon dioxide is used, and stored at its saturation pressure [5.7 MPa]. Previously performed theoretical analysis, based upon a isothermal approach, combined with limited experimental data, suggest the amount of gas used for an operating cycle of the system is at its minimum if the saturation pressure is reduced to a supply pressure level of 1.2 MPa. To further support this outcome additional theoretical analysis based upon an adiabatic and/or a polytropic approach is required, whereas additional experiments need to verify the theoretical results.

ASSIGNMENT

Examine the optimal supply pressure level by a theoretical analysis based upon an adiabatic and/or a polytropic approach.
Design, construct, and build an experimental setup for the verification of the theoretical analysis. Execute the experiments.

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Pneumatics

- exergy saving

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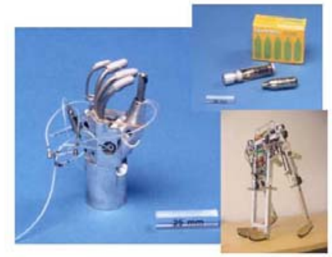

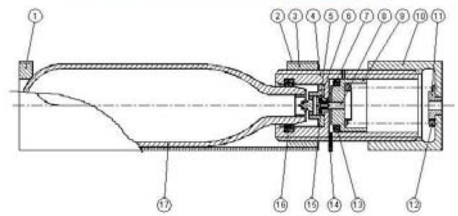

2004

MASTER GRADUATION PROJECT

EXERGY SAVING PNEUMATIC SYSTEMS

For autonomous and/or portable systems, like for instance hand prostheses or walking bipeds, pneumatic actuation is designated. For the energy supply pressurized carbon dioxide is used, and stored at its saturation pressure [5.7 MPa]. Previously performed theoretical analysis, based upon a isothermal approach, combined with limited experimental data, suggest the amount of gas used for an operating cycle of the system is at its minimum if the saturation pressure is reduced to a supply pressure level of 1.2 MPa. Yet, in reducing the gas pressure from 5.7 to 1.2 MPa a lot of potential energy [exergy] orginally stored in the gas at saturation pressure is wasted.

ASSIGNMENT

Investigate possible ways to utilize more of the potential energy of carbondioxide stored at saturation pressure. Design, construct, and build an experiment based upon one of these options and prove the energy savings.

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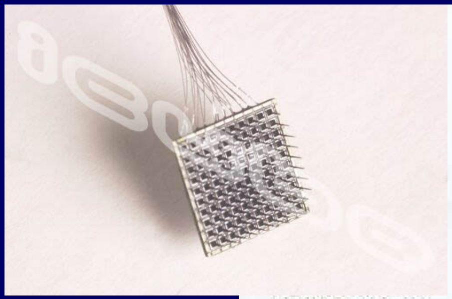
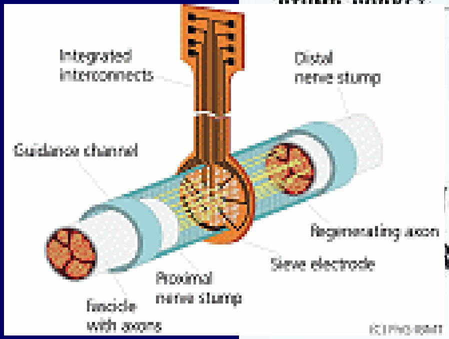
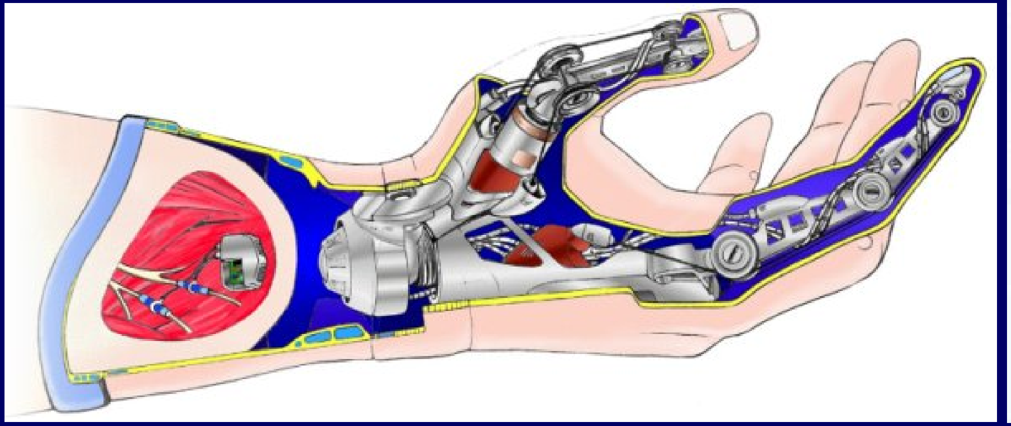


Pneumatics

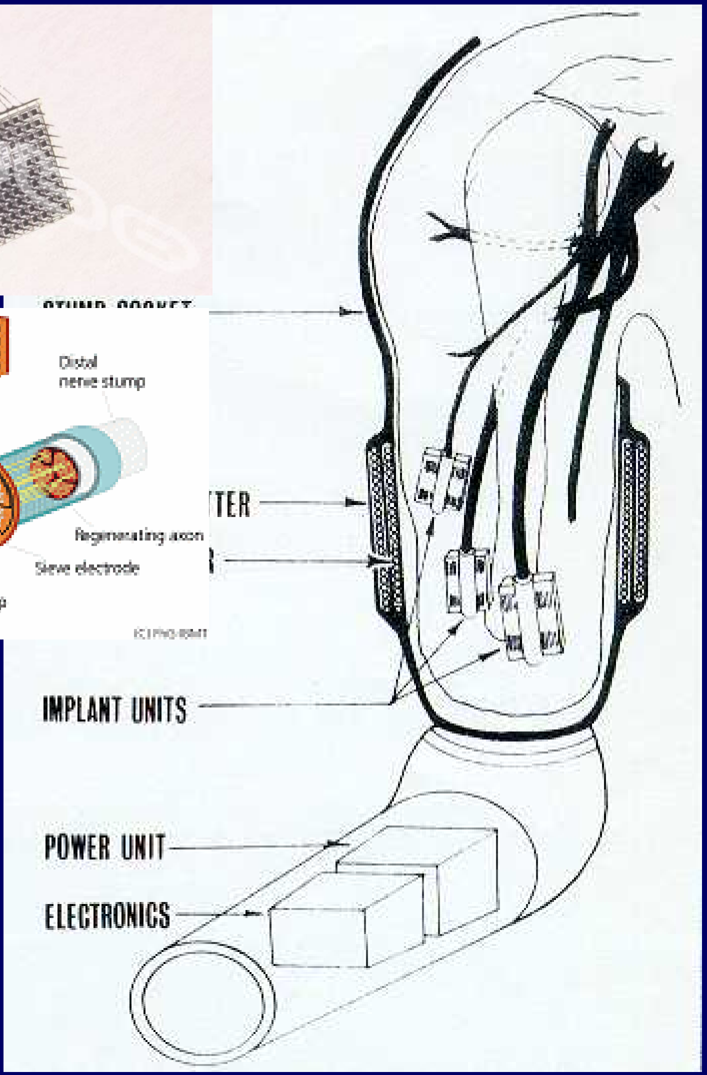
- servo mechanism



[Fraunhofer Institue für Biomedizinische Technik]



[Dario, 2004]



[DeLuca, 1978]