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AUTOMATION SYSTEMS – INDUSTRIAL ROBOTS

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2 - BASICS

Objectives of the lecture

- We want to find out:
  - How are robots constructed and which typical structures are used?
  - Which sensory and actuator components are installed in robots?
  - Basics of grasping objects
  - In addition:
  - Short review of:
  - Forces
  - Torques and moments of inertia
  - Steiner's theorem

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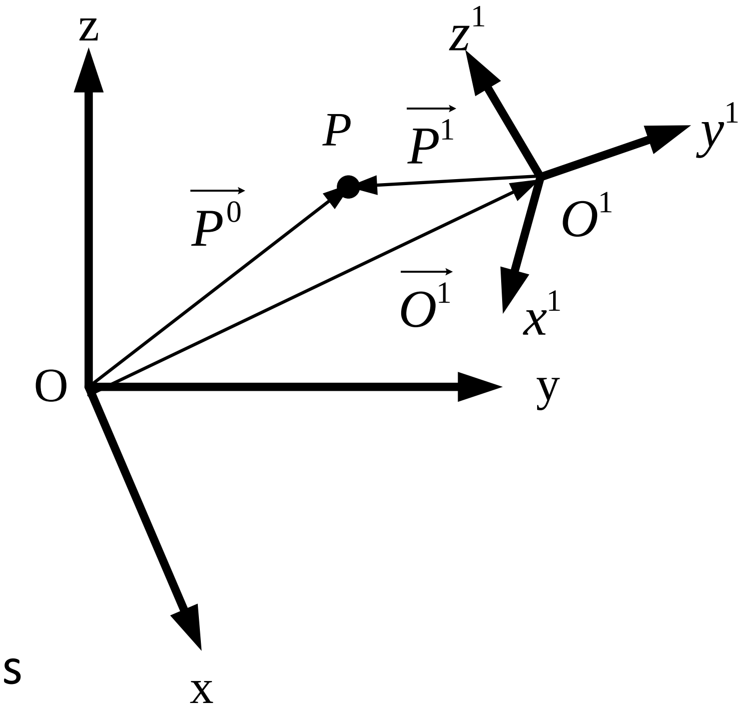
Contents of the lecture

- Basics:
  - Construction of robots
  - The kinematic chain
  - Forces and torques
  - Actuators and sensors
  - Handling and gripper
- Exercise: supplementary tasks to the chapter

Construction of robots

- Pose:
  - Objects have 6 degrees of freedom in space
    - 3 translational
    - 3 rotational
    - Position = translational coordinates
    - Orientation = rotational coordinates
  - The transformation of individual poses is called a coordinate transformation and includes:
    - Translation
    - Rotation
    -



$$\overrightarrow{P^o} = \overrightarrow{O^1} + \mathbf{R_1^0}\overrightarrow{P^1}$$

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Construction of robots

- Example: Articulated robot
  - Joints
    - Base
    - Shoulder
    - Elbow
    - Wrist
    - Wrist Rotation / Twist
  - Links
  - With gripper at the
    Tool Connector Point (TCP)
  - Through which movements does the robot reach the target position?
  - What does the workspace look like?

Bildquelle: concetti.com

Construction of robots

- Example: Scara robot
  - No tool at the Tool Connector Point
  - With control
  - Keypad

- What movements does the robot use to reach the target position?
- What does the workspace look like?

Bildquelle: kuka.com

Construction of robots

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- Example: Gantry Robot

-
- What movements does the robot use to reach the target position?
- What does the workspace look like?

Bildquelle: directindustry.com

Construction of robots

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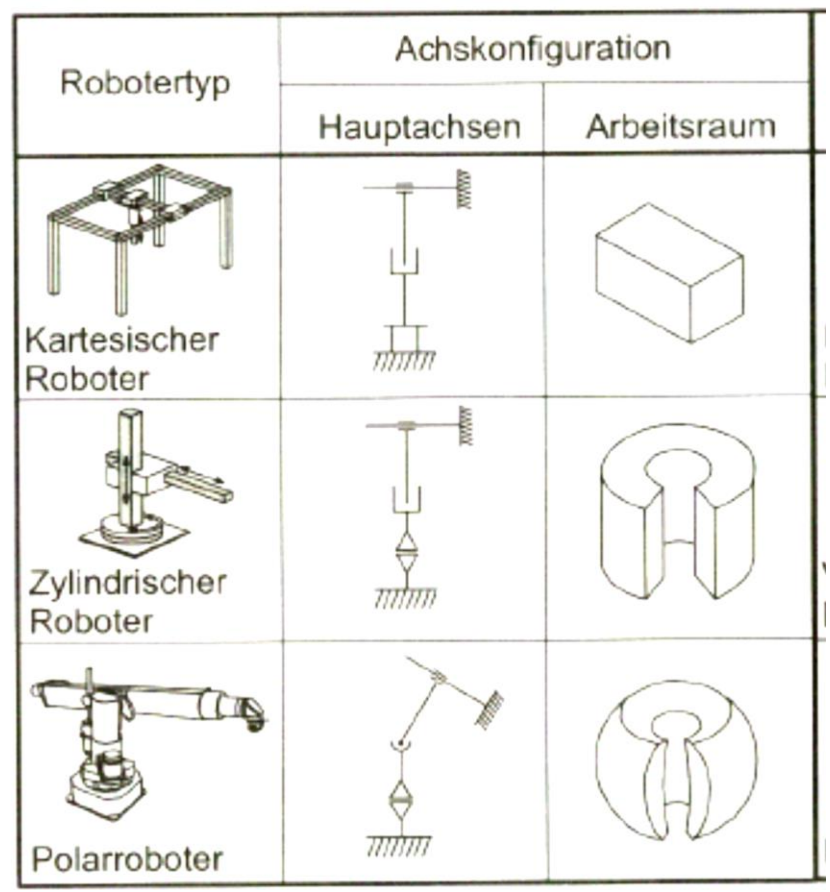
- General structure
  - T = translational drive
  - R = rotatory drive
  -

TTT

RTT

RRT

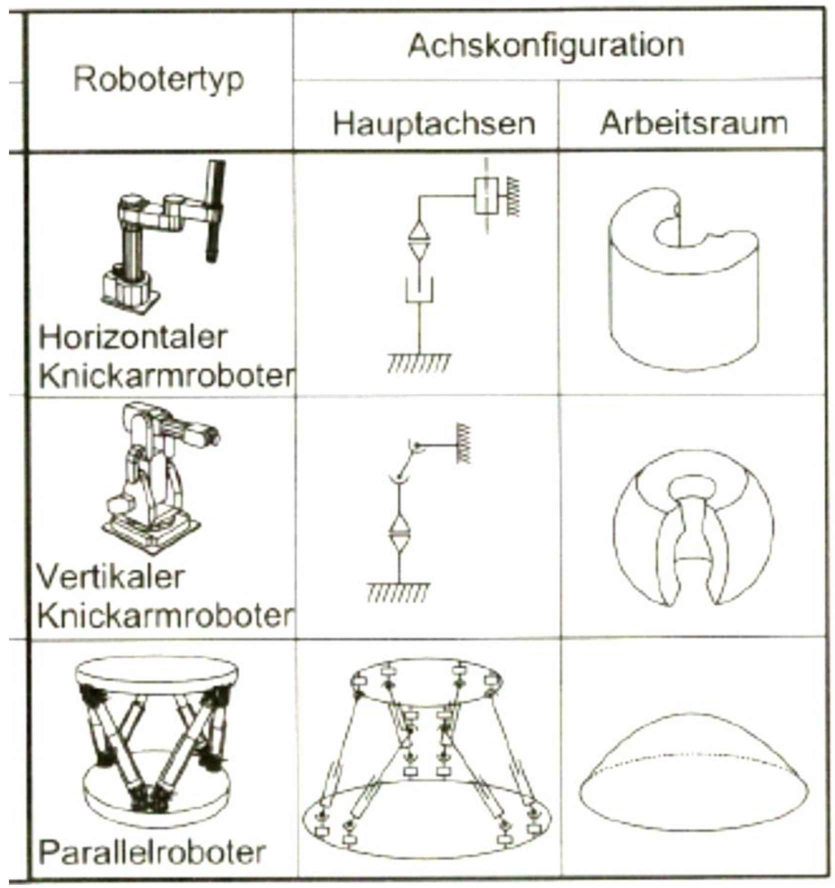


Construction of robots

- General structure
  - T = translational drive
  - R = rotary drive

RRT

RRR



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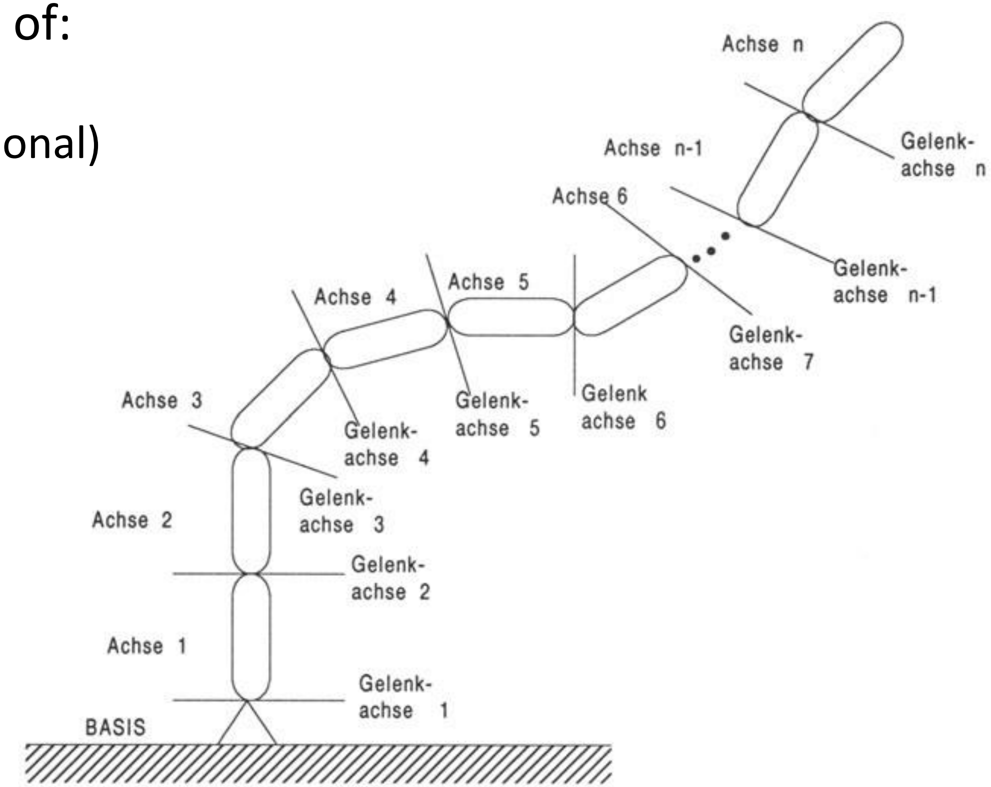
Kinematic chain

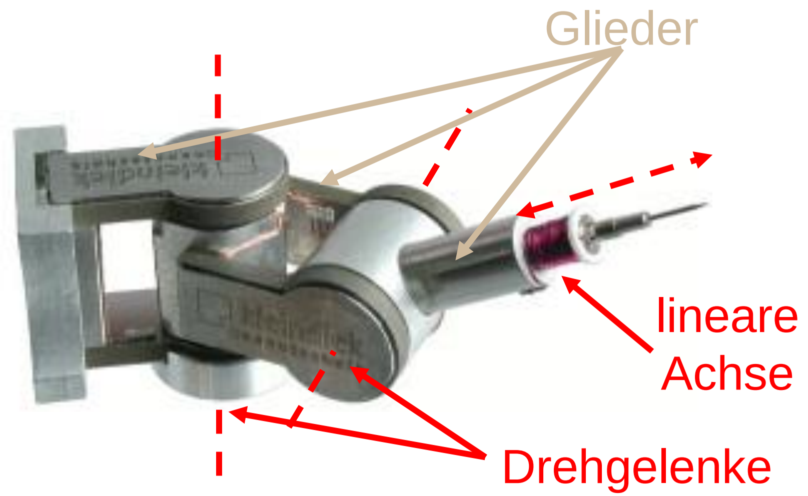
- Kinematic chain:
  - Structure of the robot consists of:
    - Joints
      (both rotational and translational)
    - And links
      (are assumed to be rigid)
  - Open chain:
    - Serial kinematics
    - No reciprocal Dependences
  - Closed chain:
    - Parallel kinematics
    - Reciprocal Dependences
    -

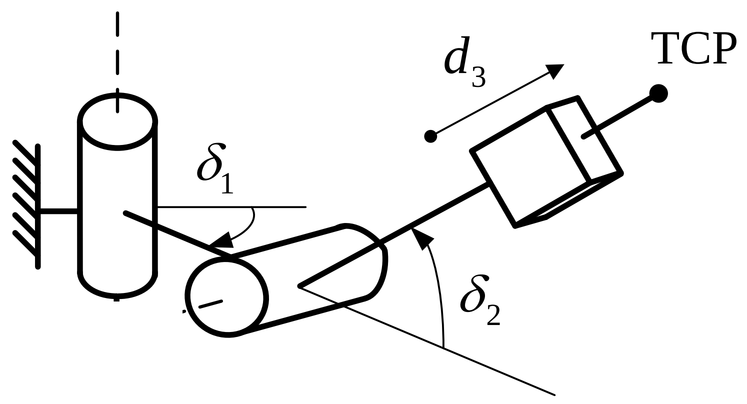


Bildquelle: Bartenschlager et al, „Handhabungstechnik mit Robotertechnik“, Springer 1998

Kinematic chain

- Description of the kinematic chain:
  - Swivel joints (R) as cylinder
  - Push joints (T) as cuboids
  -





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Forces and torques

- Mechanical basics:
  - Force F
    - 2. Newton's Law:
      with mass m and acceleration a
    - Unit: kg*m/s²
    - Examples:
      - Stroke (g:Gravitational acceleration):
      - Mech. Spring (c: Spring stiffness):
  - mechanical power P:
    - Work W per time t
    - Unit: Watt [W]

$$F = m \cdot a = m \cdot \ddot{x}$$

$$F = m \cdot g$$

$$F = c \cdot x$$

$$P = \frac{\Delta W}{\Delta t}$$

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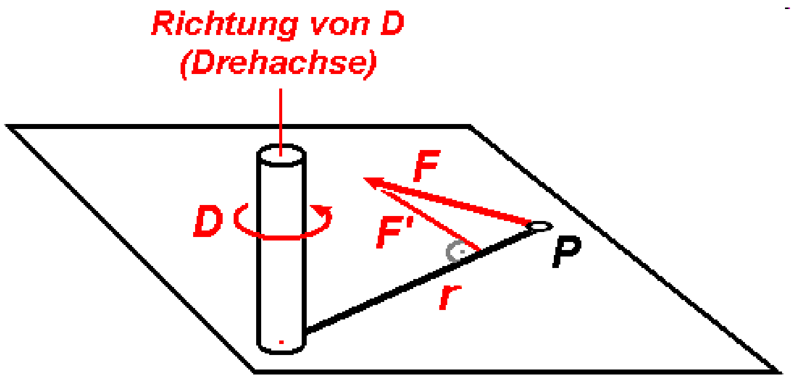
Forces and torques

- Mechanical basics
  - Torque
    - Definition:
      Force F acting orthogonally
      on the lever r
    - Unit: Nm
    -

$$\vec{M} = \vec{F} \times \vec{r}$$



    - important for drive technology:
      Torque is the product of moment
      of inertia J and angular acceleration
    -

$$M = J \cdot \dot{\omega} = J \cdot \ddot{\varphi}$$

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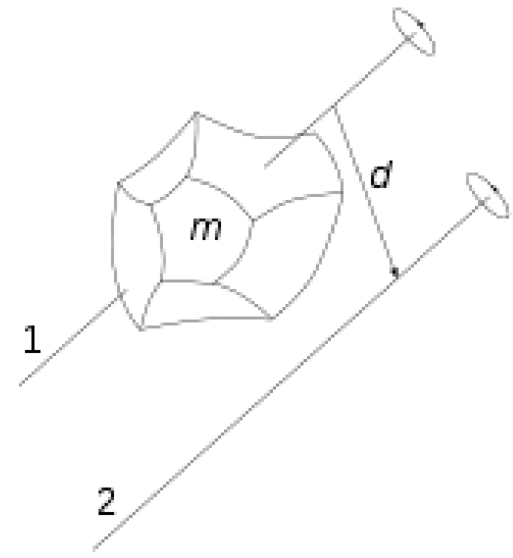
Forces and torques

$$J = \int_V r^2 \cdot \rho(\vec{r})dV$$

- Mechanical basics
  - Moment of inertia J:
    - Inertia of a body to rotational movement
    - Unit: kg m²
  - Steiner's theorem:
    If the moment of inertia for a body is known with respect to a defined axis, the moment of inertia of a parallel axis can be determined by:

$$J_P = J_S + md^2$$

  - Sudden changes in the speed are not possible due to the moment of inertia (cf. Newton's laws)!
  -



Forces and torques

- Mechanical basics
  - For continuous mass Distributions applies:

$$J = \sum_{i=1}^{n} m_i {r_i}^2 \quad \rightarrow \quad J = \int r^2 \, dm$$

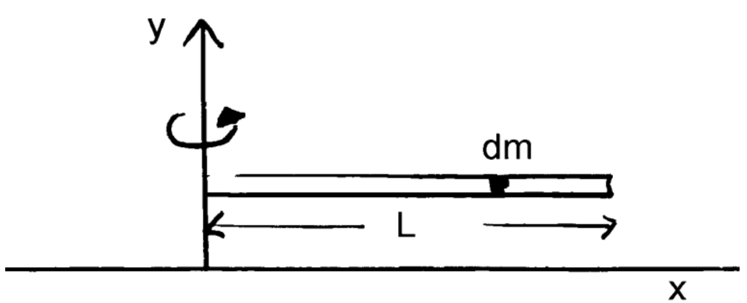
  - Calculation of moments of inertia

$$\rho = \frac{m}{V} \quad \rightarrow \quad m = \rho V \quad \rightarrow \quad dm = \rho dV$$

$$J = \rho \int r^2 \, dV \quad \text{für } \rho = konst.$$

  - Example: Rod with constant Density ρ (assumption: L>>Lz and L>>Ly and "line density" ρ=m/L)

$$\mathrm{J} = \frac{m}{L} \int_0^L x^2 dx = \frac{1}{3} m L^2$$



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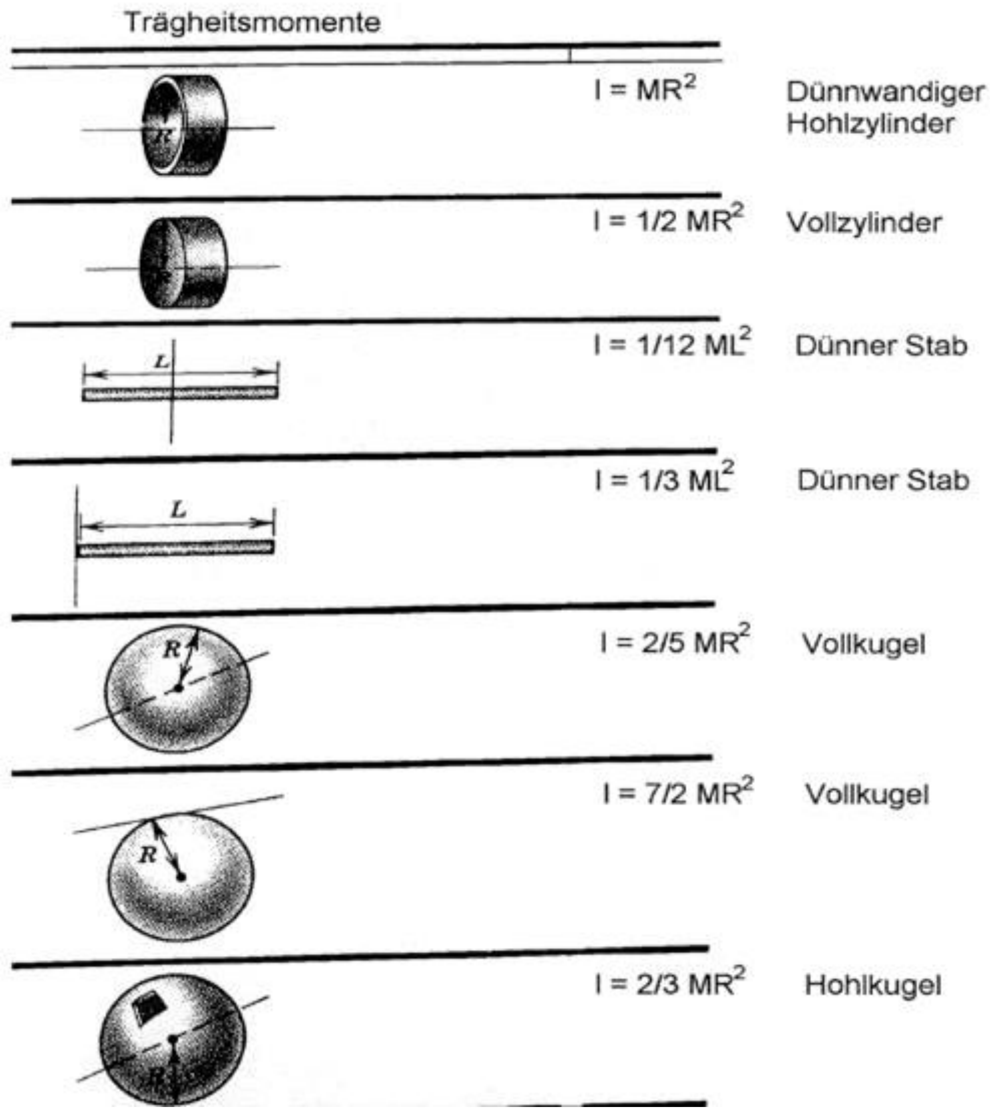
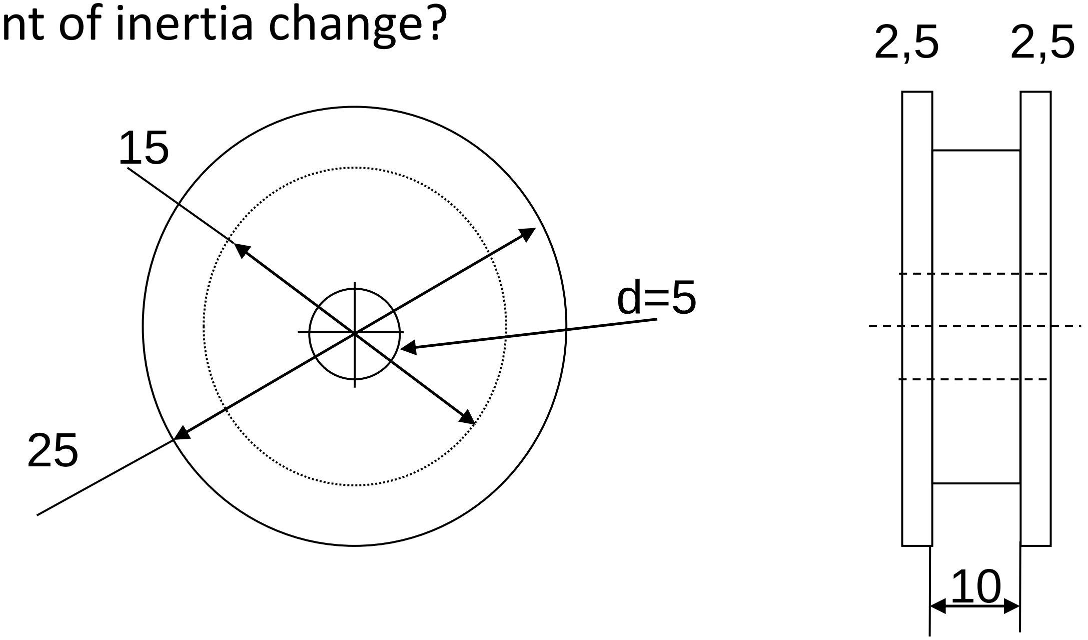
Forces and torques

- Mechanical basics
  - Moments of inertia Selected Primitivs
  -



Forces and torques

- Mechanical basics
  - Example moment of inertia:
  - Determine the moment of inertia of the displayed pulley. The pulley is made of unalloyed steel with a density of 7.9 g/cm³.
  - The bore for the shaft is moved eccentrically by 5mm. How does the moment of inertia change?
  -



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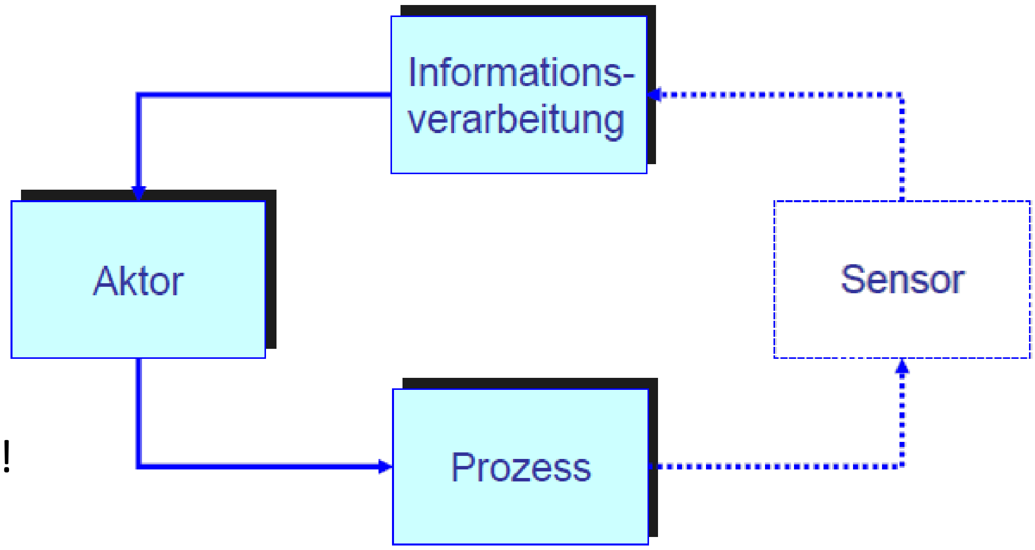
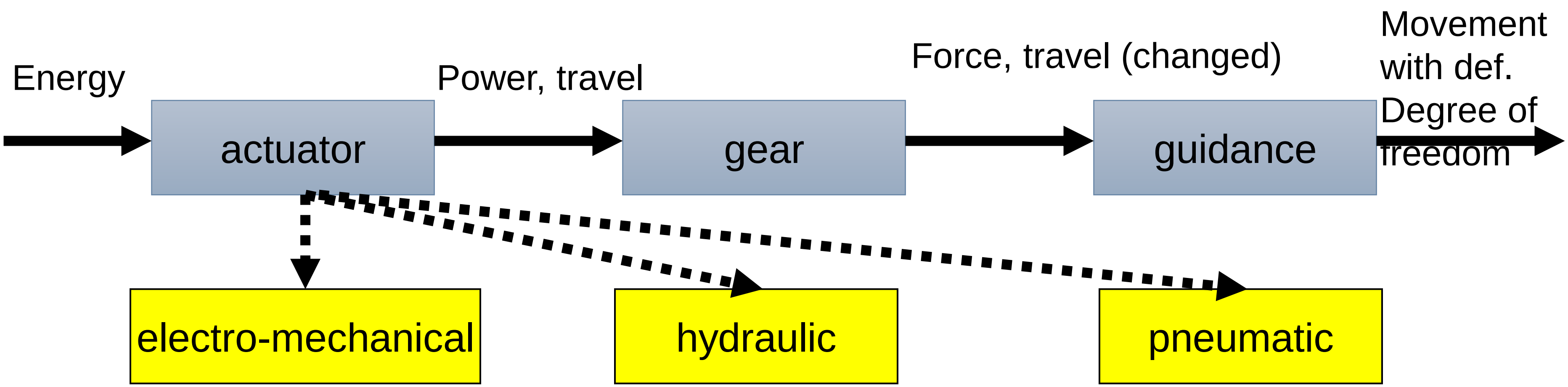
Actuators & Sensors

- Drive system
  - open loop:
    - open timing chain
    - Stability in the open timing chain required!
  - closed loop:
    - Sensor feedback necessary!
    - control values:
    - Position, angle of rotation
    - Power, torque
    - Speed, angular velocity
  - Essential in robotics!
  -



Actuators & Sensors

- Drives



Stepper motor

Dc motor

Synchronous motor

Asynchronous motor

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linear piston

…

linear piston

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Actuators & Sensors

- Drives / Actuators:

  - Pneumatic:
    - Compressed air is used for displacement/force generation
    - Version as linear drive or rotary drive
    - Compressibility of the air makes the robot "soft" ("Cobot" vs. position control)
    - Loud (compressed air escapes)
    - Expensive (air resources)

Bildquelle: festo.com

Actuators & Sensors

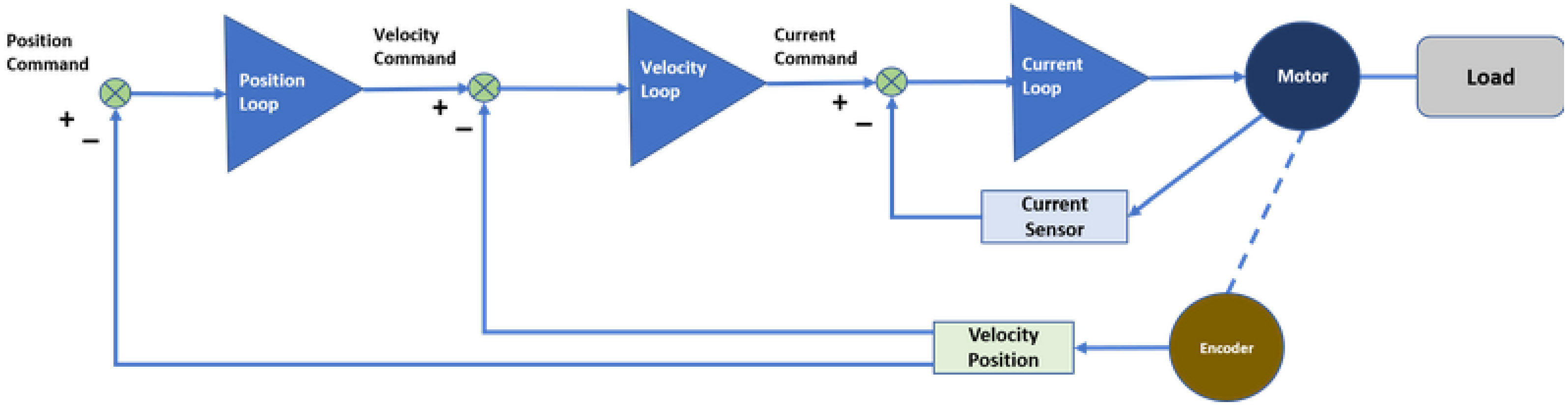
- Drives / Actuators:

  - Hydraulic drive:
    - Controllable valves control the oil flow
    - Very high forces / torques achievable
    - Contamination due to oil loss
    - Compressibility of the oil leads to positioning inaccuracies

Bildquelle: wikipedia.de

Actuators & Sensors

- Drives / Actuators:
  - Electric drives
    - preferably used in the field of robotics
    - Power 10W to 10 kW
    - Typical:
    - PMDC Servo Motor
    - Brushless DC servo motor
    - Servomotor:



Bildquellen: kollmorgen.com, requtec.de

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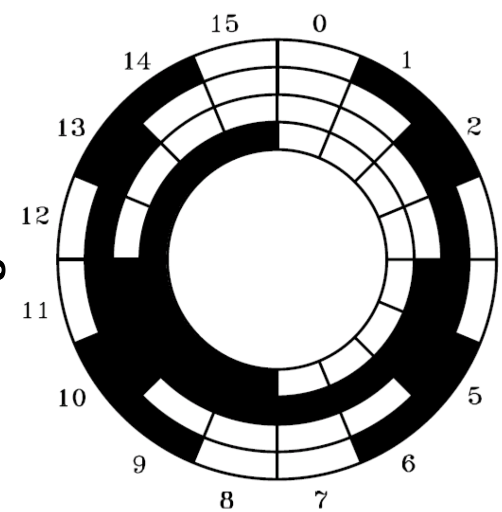
Actuators & Sensors

- Sensors for speed and position:
  - Measurement with on-board sensors:
  - Displacement measurement can often be based on an angle measurement be returned to the rotary drive
  - Important angle measuring systems: incremental and absolute encoders
  - Scanning of light signals with one photodiode per track
  - Resolution: 360°/ 2n with n: Number of tracks e.g. 4 tracks: 360°/ 24 = 22.5°
  - still in use: resolvers, potentiometers

Inkrementaler Drehgeber

Scheibe eines Absolut-wertgebers



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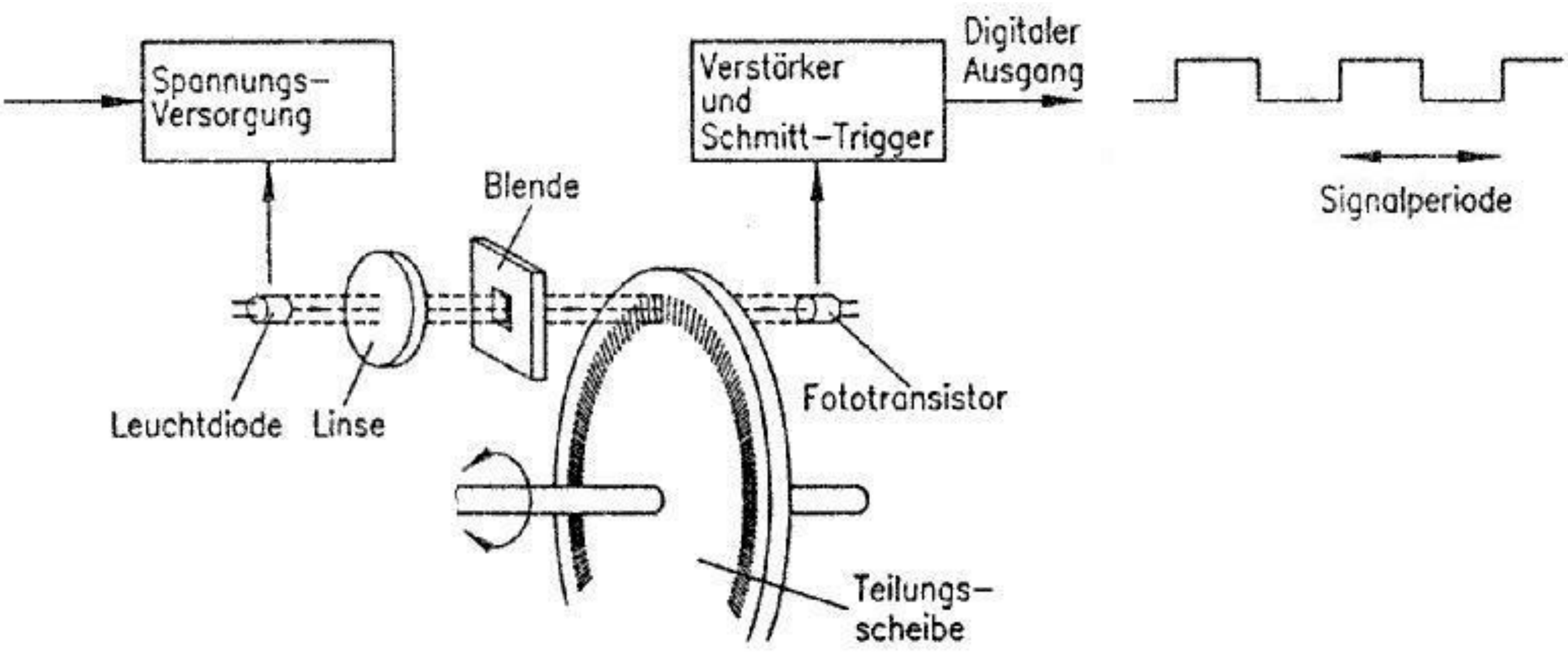
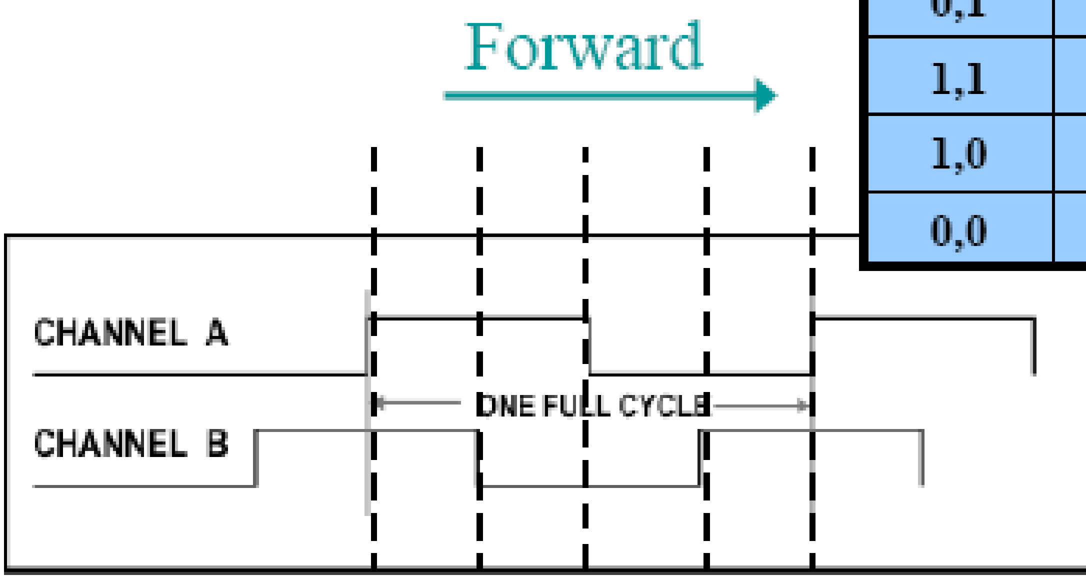
Actuators & Sensors

- Optical Encoders
  - Schmitt trigger: Converts sine wave signal to rectangular signal



Actuators & Sensors

- Optical Encoders
  - Direction detection
  -



FROM	TO	FROM	TO
0,1	1,1	0,1	0,0
1,1	1,0	1,0	1,1
1,0	0,0	1,0	1,1
0,0	0,1	0,0	1,0

Handling techniques and grippers

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- Principles of action:
  - Form fit
  - force bonded
  - adhesive bond
- Typical characteristics:
  - Jaw gripper (mechanical)
  - Jaw gripper (pneumatic)
  - Vacuum grippers / suction pads
  -

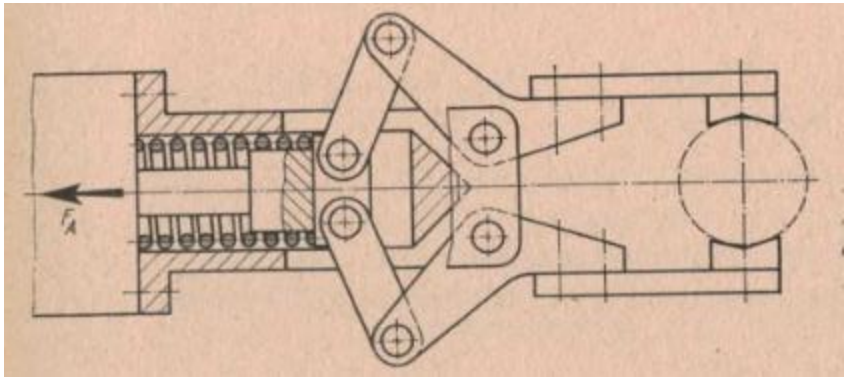
2-Backen-Greifer 3-Backen-Greifer

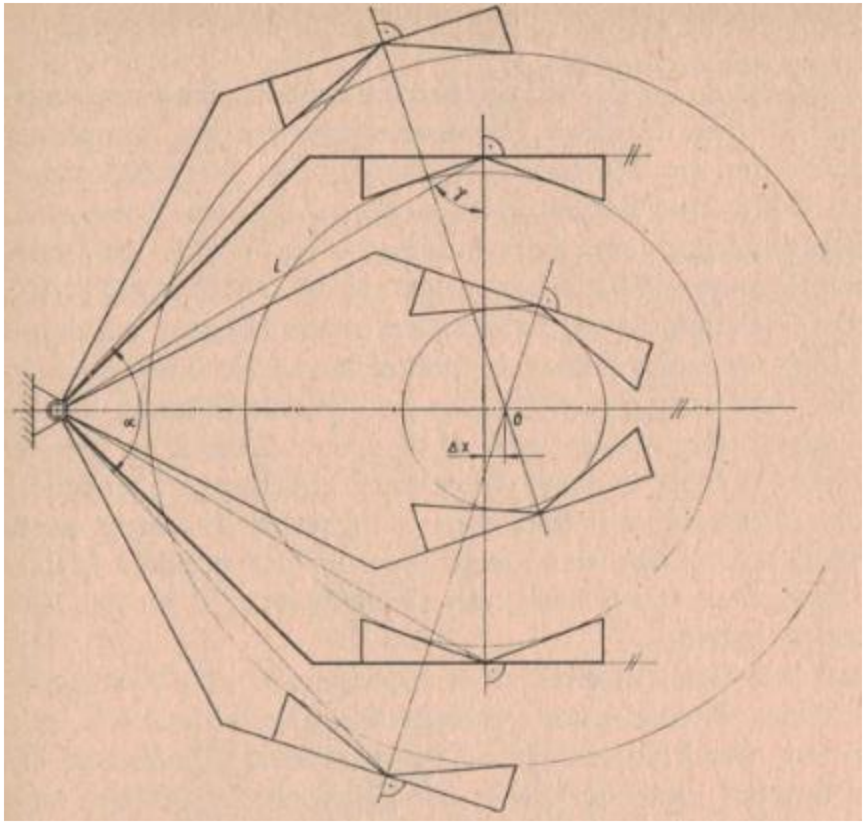
Handling techniques and grippers

- Requirements for grippers:
  - Optimal adaptation to handling surgery
  - Flexible adaptation to handling tasks
  - Great security against moving or slipping the object
  - Optimum gripping force-displacement characteristic curve
  - High gripping accuracy
  - Small installation space, low mass
  - Integration of sensors (camera, force sensors, etc.)
  -

Handling techniques and grippers

- Two-jaw gripper
  - Plier grippers:
    - Replaceable jaws
    - Gripping force is not constant!
    - Note size dependency
      of the recording location
    -





Bildquelle; Volmer, „Industrieroboter“ Verlag Technik Berlin, 1981

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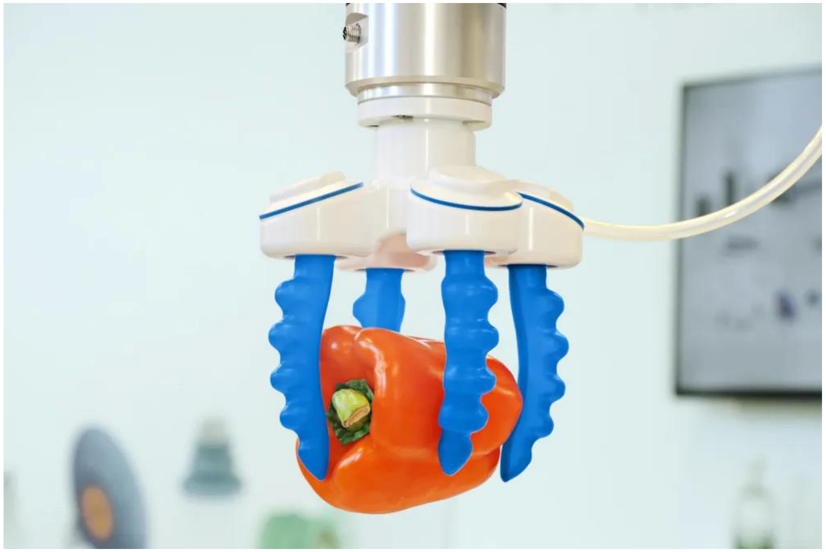
Handling techniques and grippers

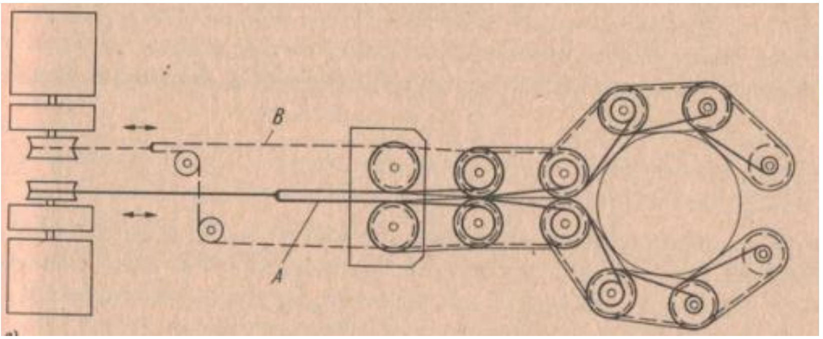
- Two-jaw gripper
  - Parallel
  - Gripper drive up and down in parallel
  - Pneumatic or electric
  - Gripper shape adaptable to the use case
  - It can also grip with the outer surface

Bildquelle: Schunk.com

Handling techniques and grippers

- Finger grippers
  - Enable easy implementation of the form-fitting gripping
  - Mechanical or pneumatic Execution possible
  - Finger design can be easily adapted to handling task
  - With pneumatic drive, the maximum gripping force can be easily adjusted





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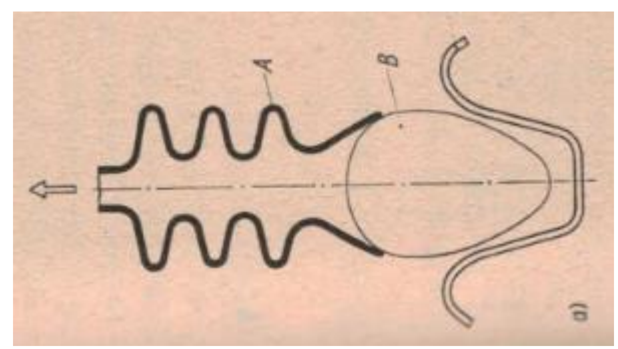
Handling techniques and grippers

- Vacuum grippers / suction pads
  - Objects are sucked in by vacuum
  - Vacuum generation via vacuum pump or compressed air
  - Surface must allow tight closure between suction cup and workpiece
  - No drives on the gripper necessary
  - Vacuum line across all joints



Bildquelle: schmalz.com Volmer, „Industrieroboter“ Verlag Technik Berlin, 1981