Digital vs. Analogue Control Systems

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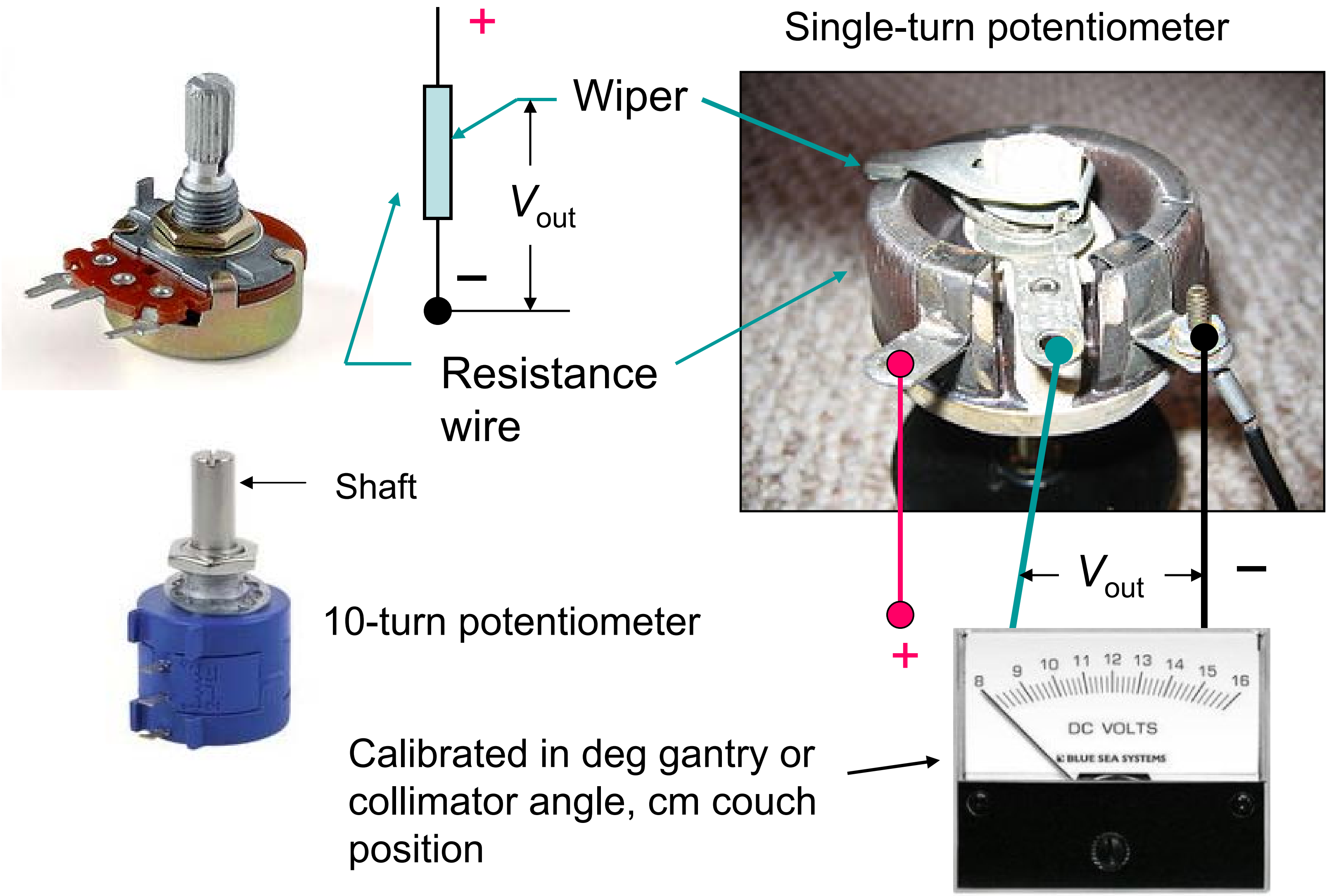
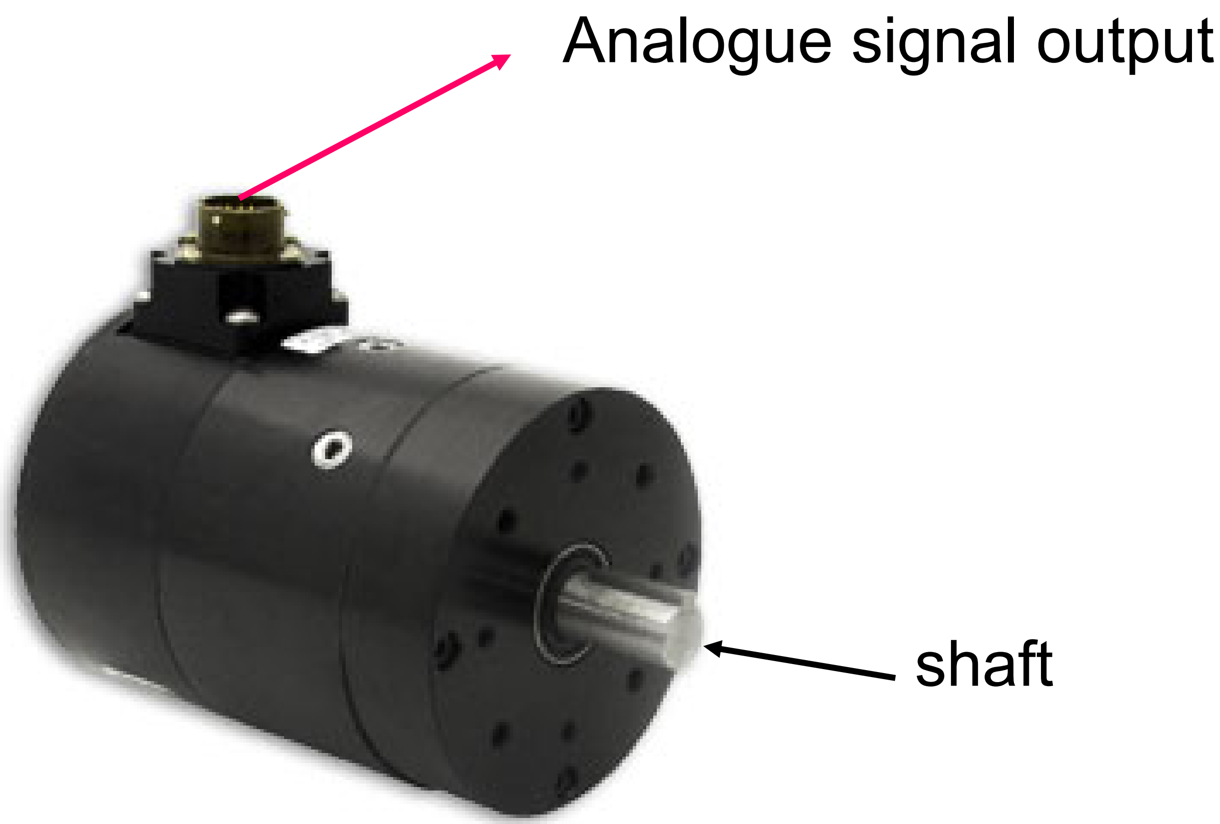
Accelerator control systems

- **Mechanical** – Analogue or digital
  - Gantry angle
  - Collimator angle
  - Jaw position
  - MLC leaf position
  - Couch positions (angle, vertical, long, lat)
  - Internal devices (target, flattening filter, light field projector)
- **Electronic** – Analogue or digital
  - Beam production
    - Electron gun
    - Rf power
    - Steering coil current
    - Bend magnet current
  - Dosimetry system
  - Ancillary systems (vacuum, temperature control, etc.)

Analogue transducer, analogue readout



Resolver: brushless analogue rotation transducer



Resolver - principle of operation

Armature

shaft

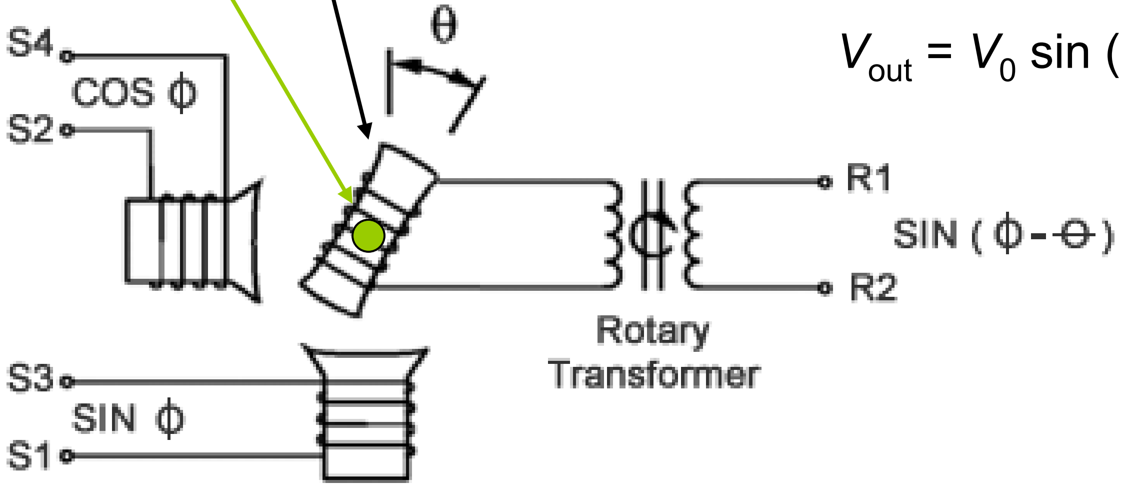
Input signals

Shaft angle

Output signal

$V_{in1} = V_0 \cos \Phi$

$V_{out} = V_0 \sin(\Phi - \theta)$

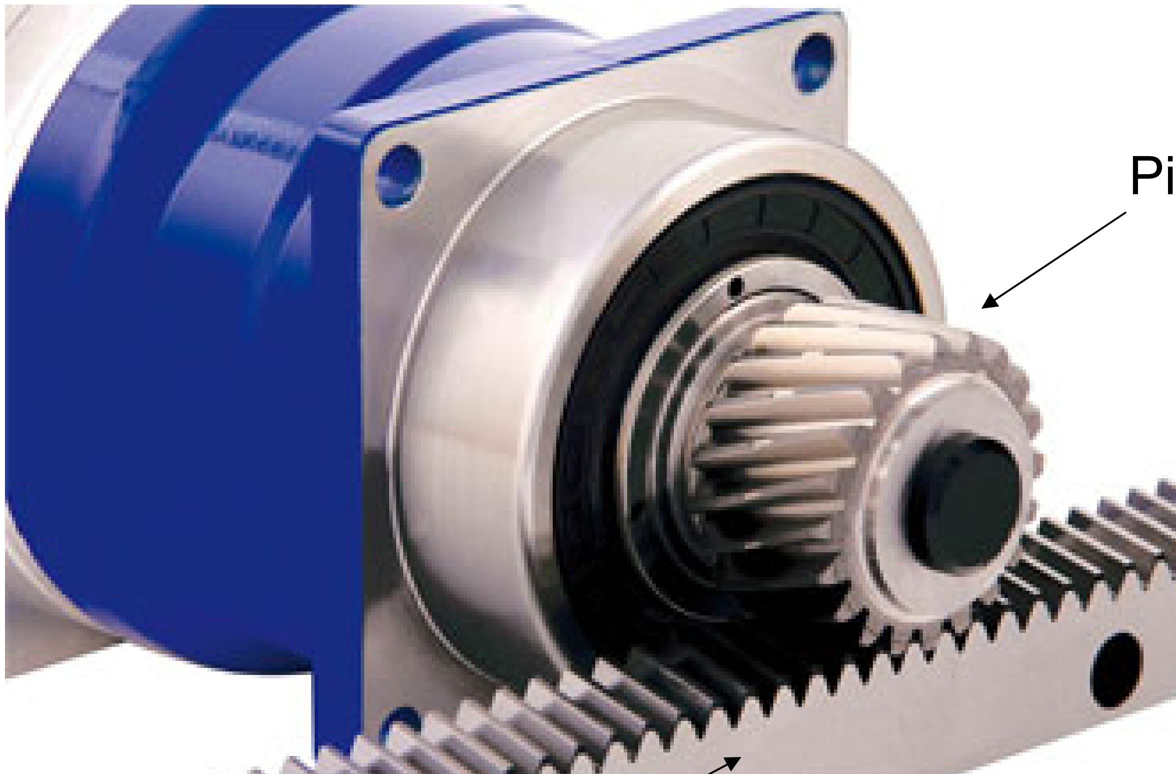


$V_{in2} = V_0 \sin\Phi$

Shaft angle θ found from phase angle of V_{out}

Rack and pinion drive for couch movements

Motor with gear drive with position indicator in back

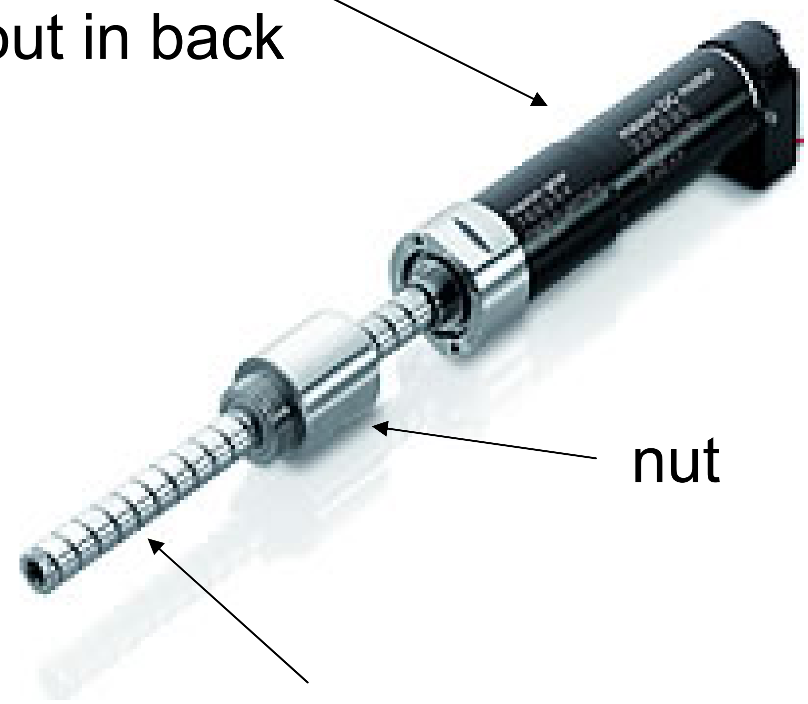


Pinion

Rack, attached to couch top

Spindle (screw) drive

Geared motor with position readout in back



nut

Rotating spindle

Limitations of analogue devices

- Precision of potentiometer ~ 0.1% linearity
  - 0.4 mm for 40x40cm^2 field
  - Sensitive to small changes in wire resistance
  - Degraded accuracy by use and age (brush)
  - Sensitive to power supply voltage
- Reading accuracy ~ 0.2%
  - Digital readout - used even in early linacs

Analogue transducer, analogue and digital readouts (potentiometer)

Single-hand clock: purely analogue display

Reading accuracy about 6 minutes ~ 1%

2-hand clock: Hybrid, one digit + analogue

Reading accuracy ½ min (0.1%)

King’s Cross railway station, London

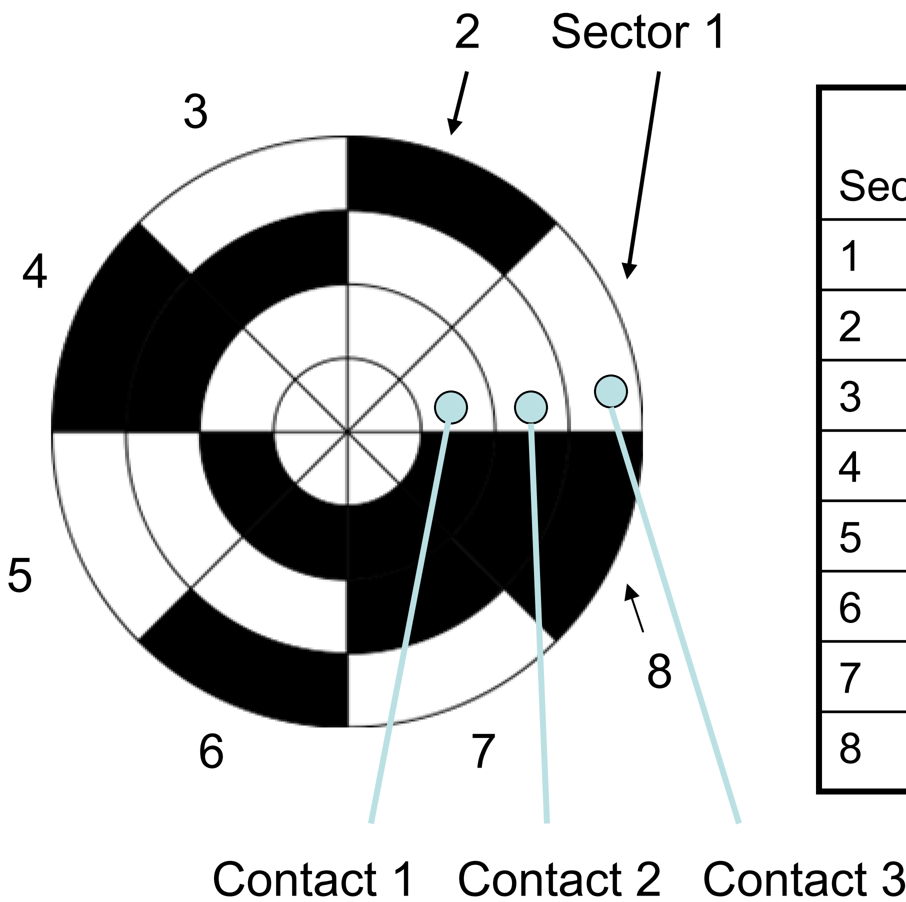
3-hand clock: Hybrid, two digits + analogue

Reading accuracy ½ sec ~ 0.001%

“Analogue” precision transducers

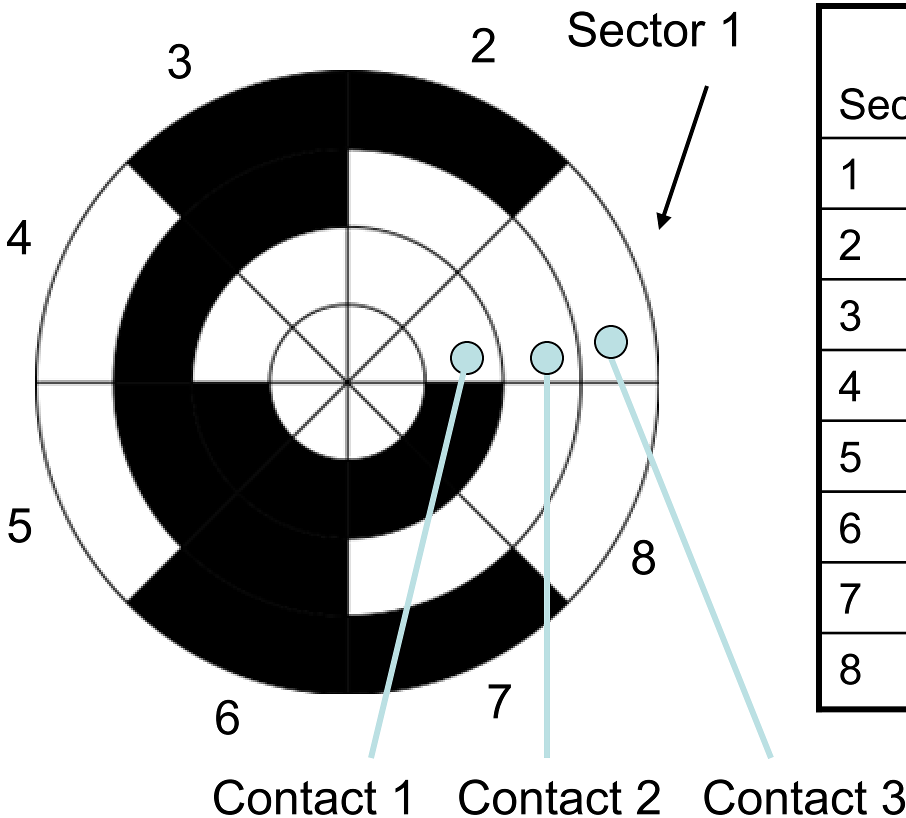
- Geared potentiometers
  - “Hour hand” pot goes around once
  - “Minute hand” pot goes around many times
  - 0.01% rotational precision readily obtained with 0.2% accuracy pots
- Geared (dual) resolvers – same principle

Digital transducer: 3-bit shaft encoder
Standard binary encoding



Sector	Con-tact 1	Con-tact 2	Con-tact 3	Angle
1	off	off	off	0° - 45°
2	off	off	ON	45° - 90°
3	off	ON	off	90° - 135°
4	off	ON	ON	135° - 180°
5	ON	off	off	180° - 225°
6	ON	off	ON	225° - 270°
7	ON	ON	off	270° - 315°
8	ON	ON	ON	315° - 360°

3-bit shaft encoder
Gray encoding



Sector	Con-tact 1	Con-tact 2	Con-tact 3	Angle
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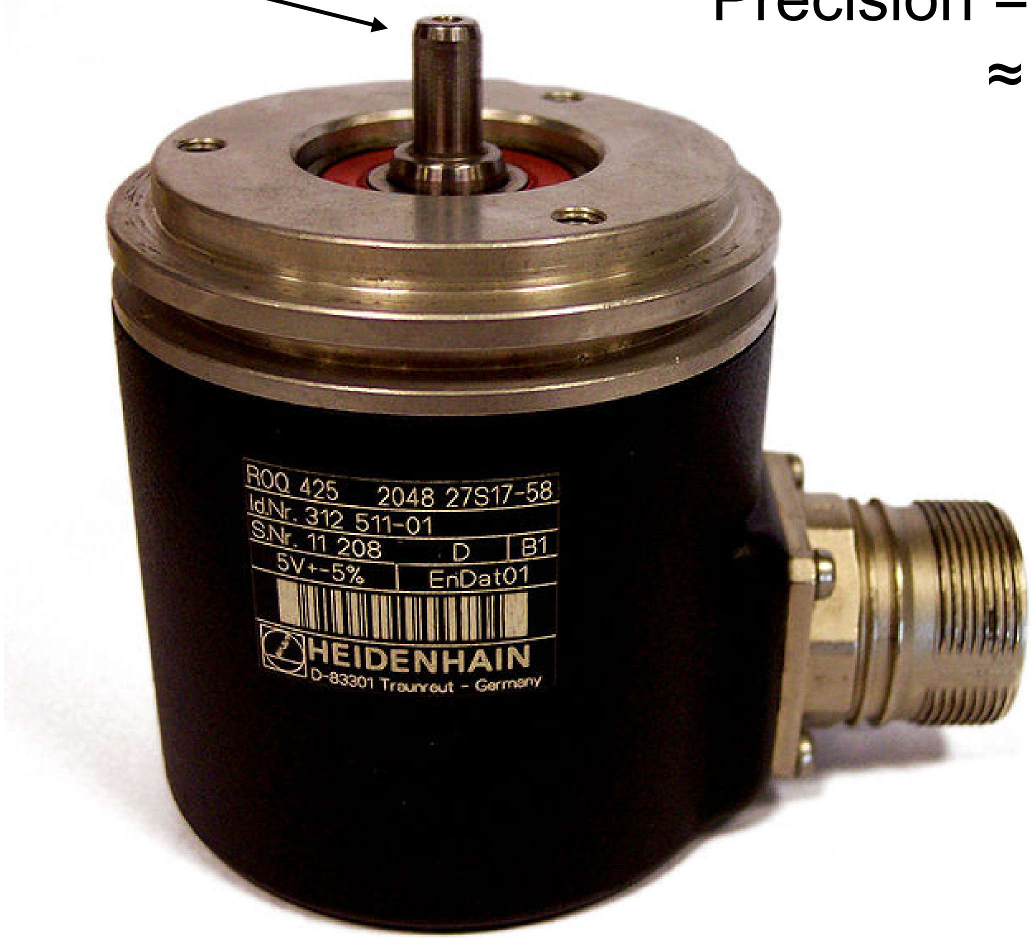
4	off	ON	off	135° - 180°
5	ON	ON	off	180° - 225°
6	ON	ON	ON	225° - 270°
7	ON	off	ON	270° - 315°
8	ON	off	off	315° - 360°

13-bit shaft encoder

shaft

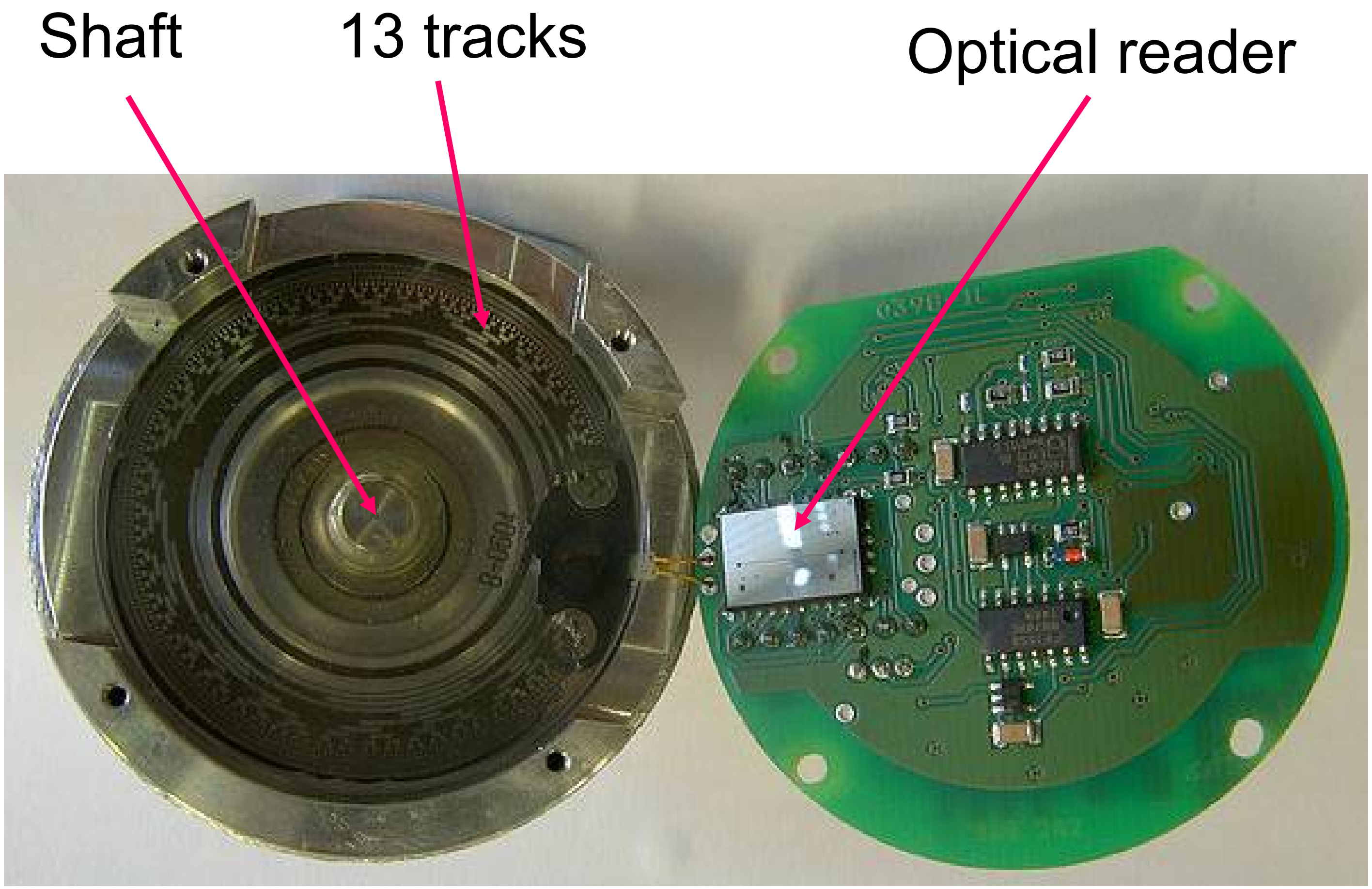
Precision = 1rev/2^{13}

≈ 0.01% of 1rev

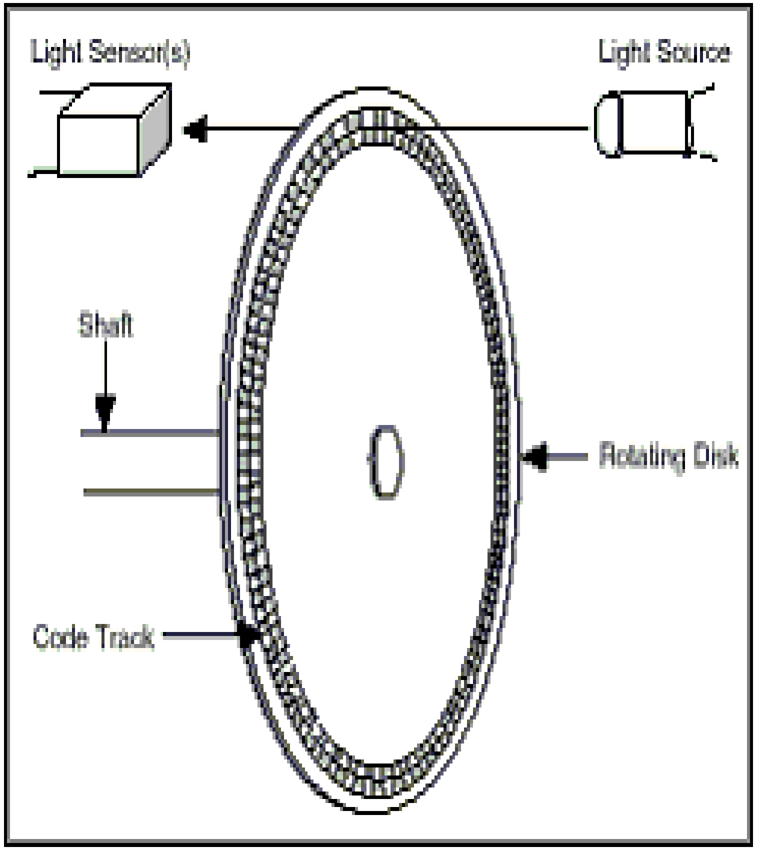


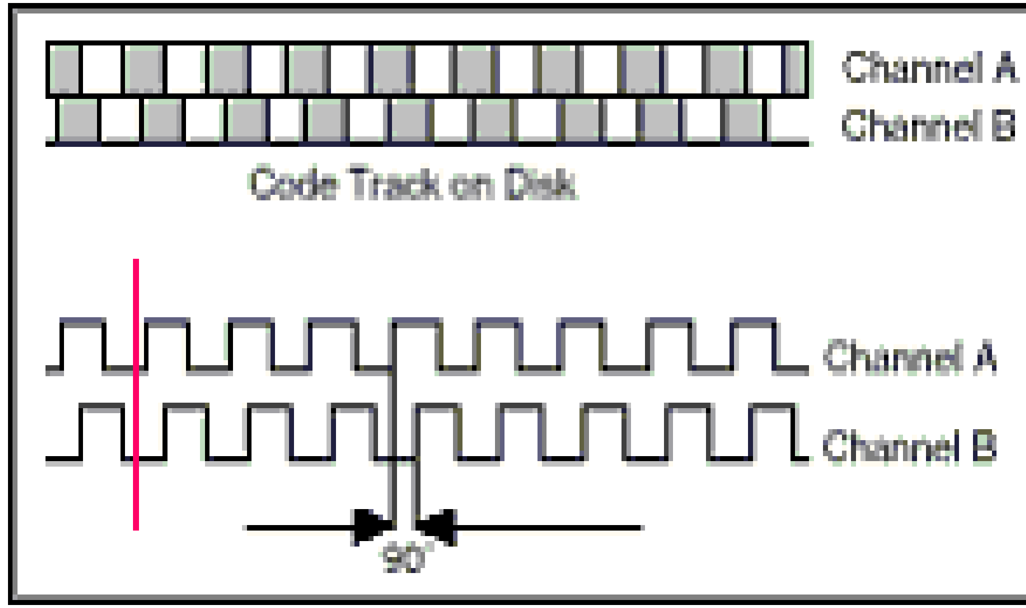
Digital output

13-bit shaft encoder



Incremental encoders count pulses

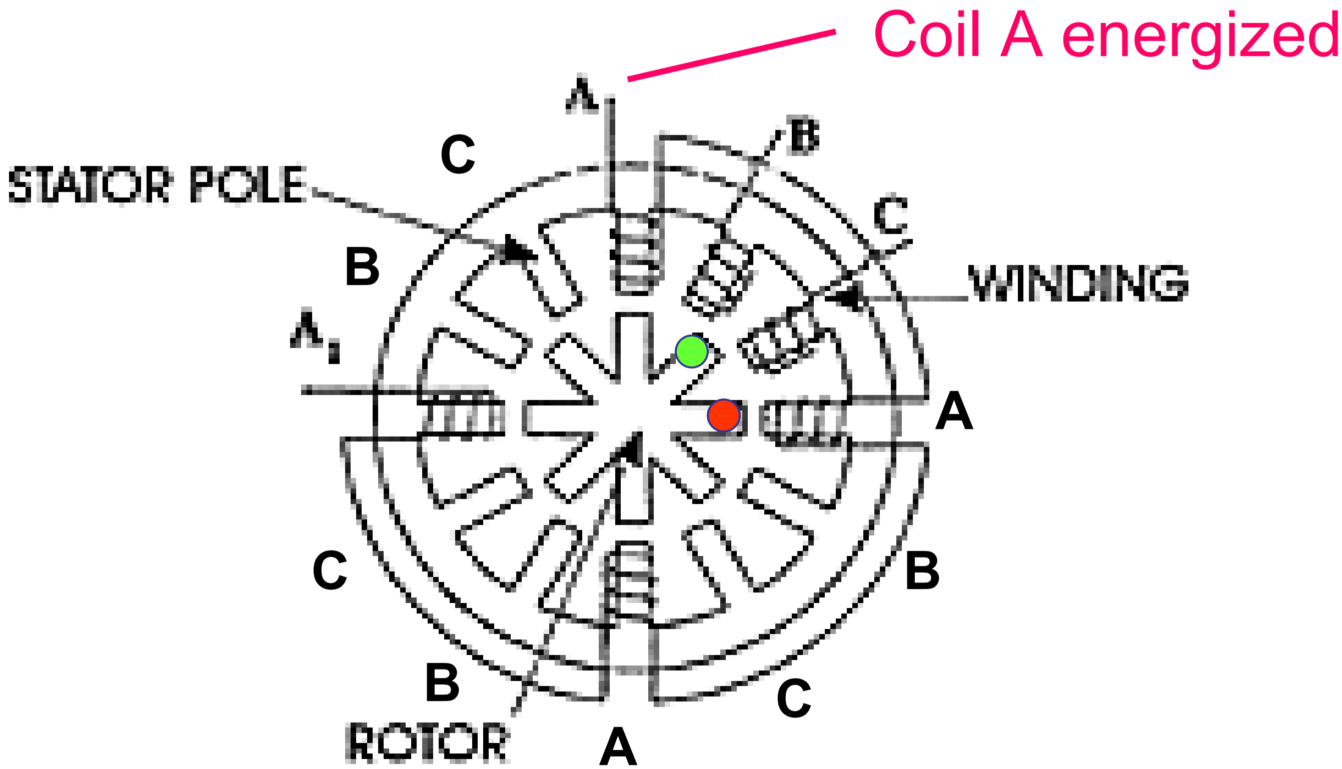




Cannel A leads … clockwise rotation

Cannel B leads … ccw rotation

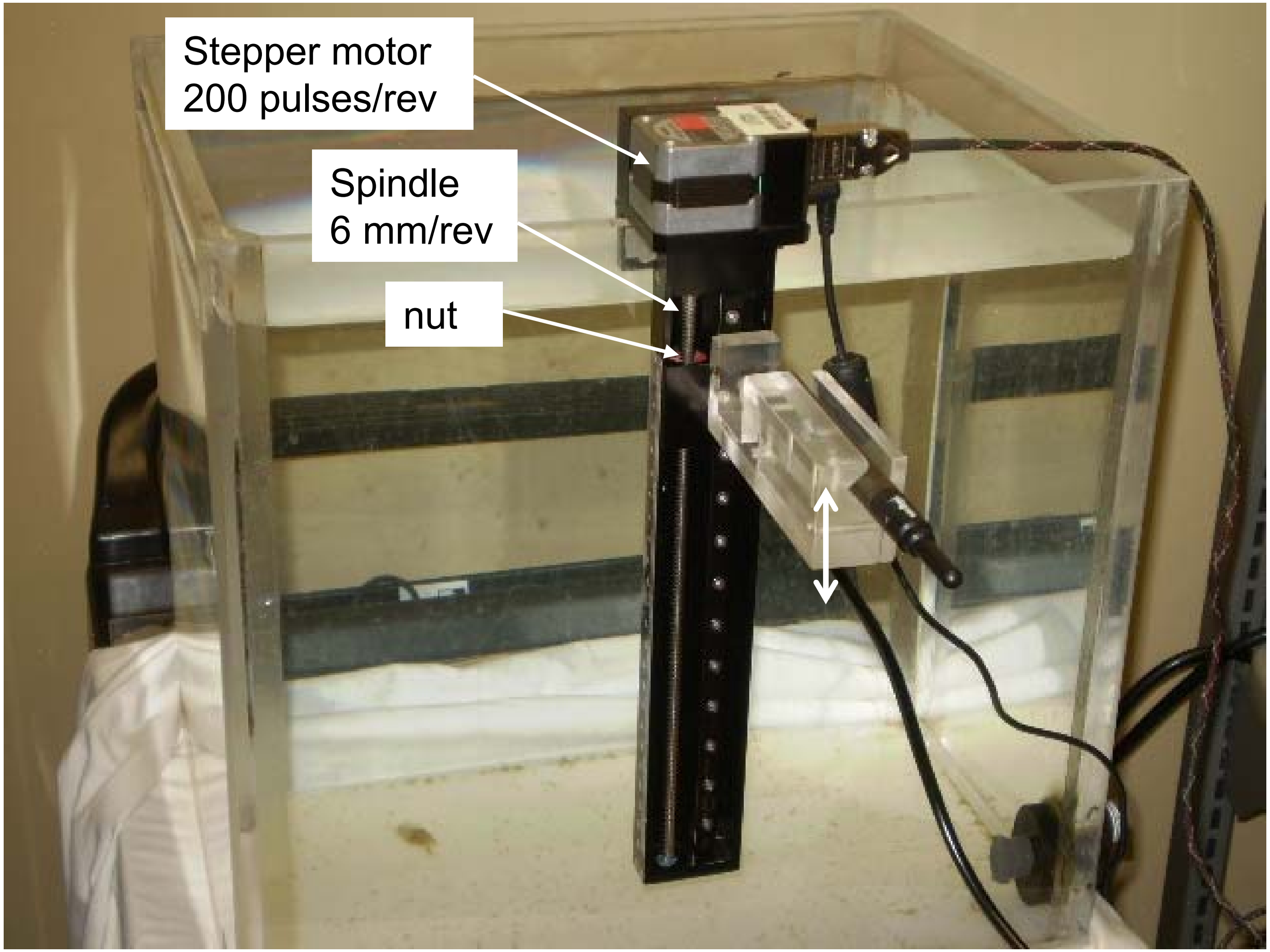
Stepper motor – driver and encoder



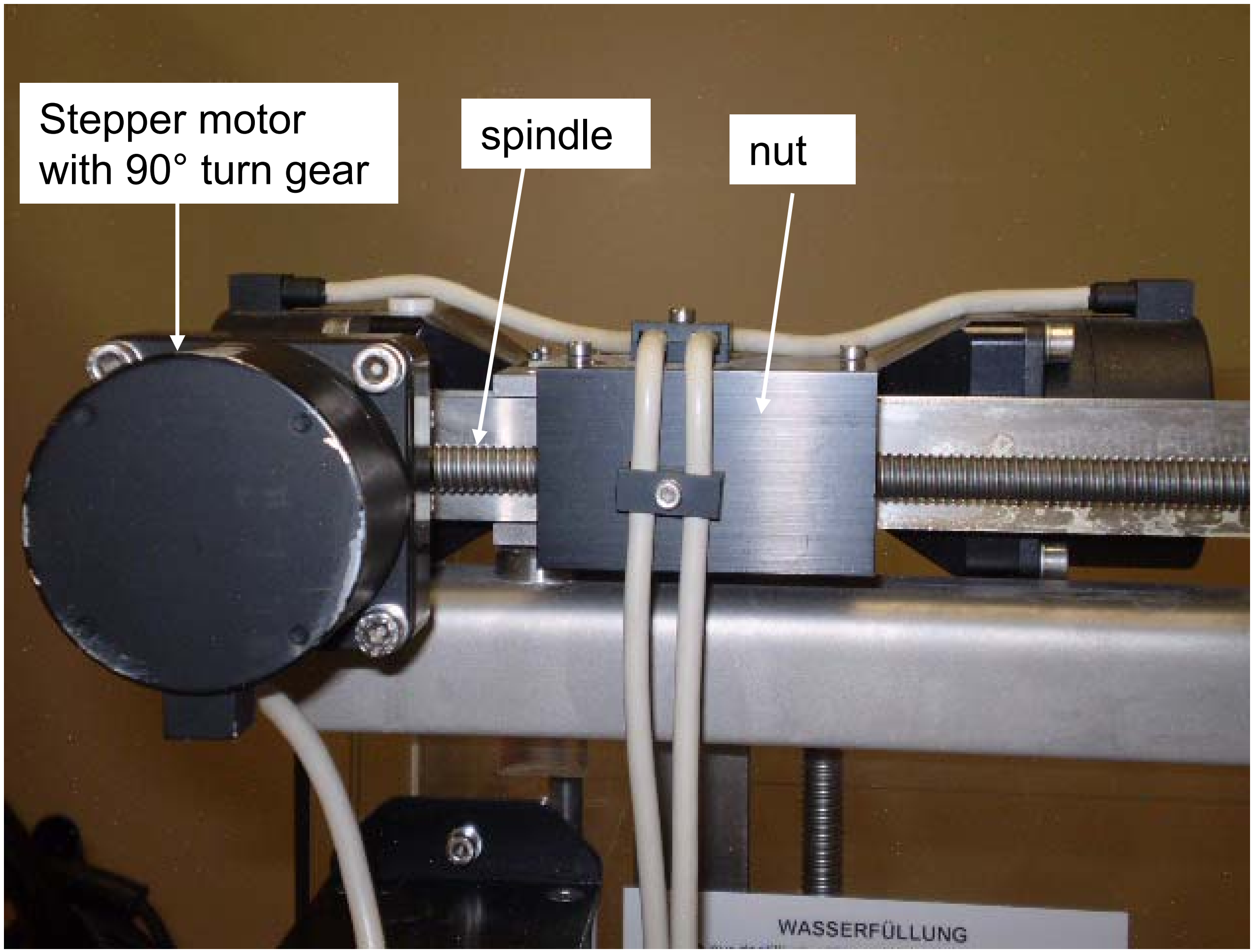
Energizing coils A, B, C …. ccw rotation

Energizing coils A, C, B …. clockwise rotation

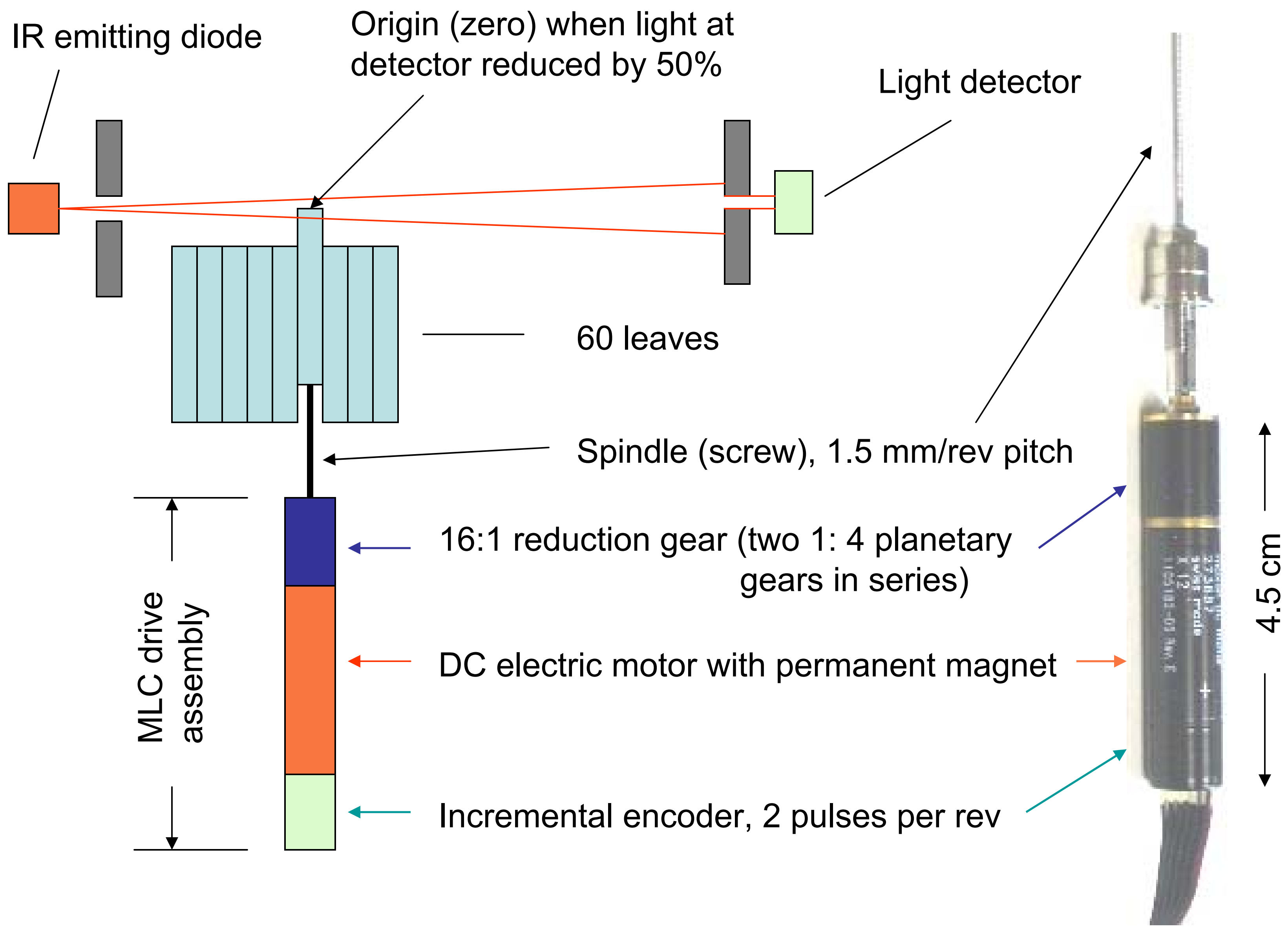
Stepper motor in 1-D water tank



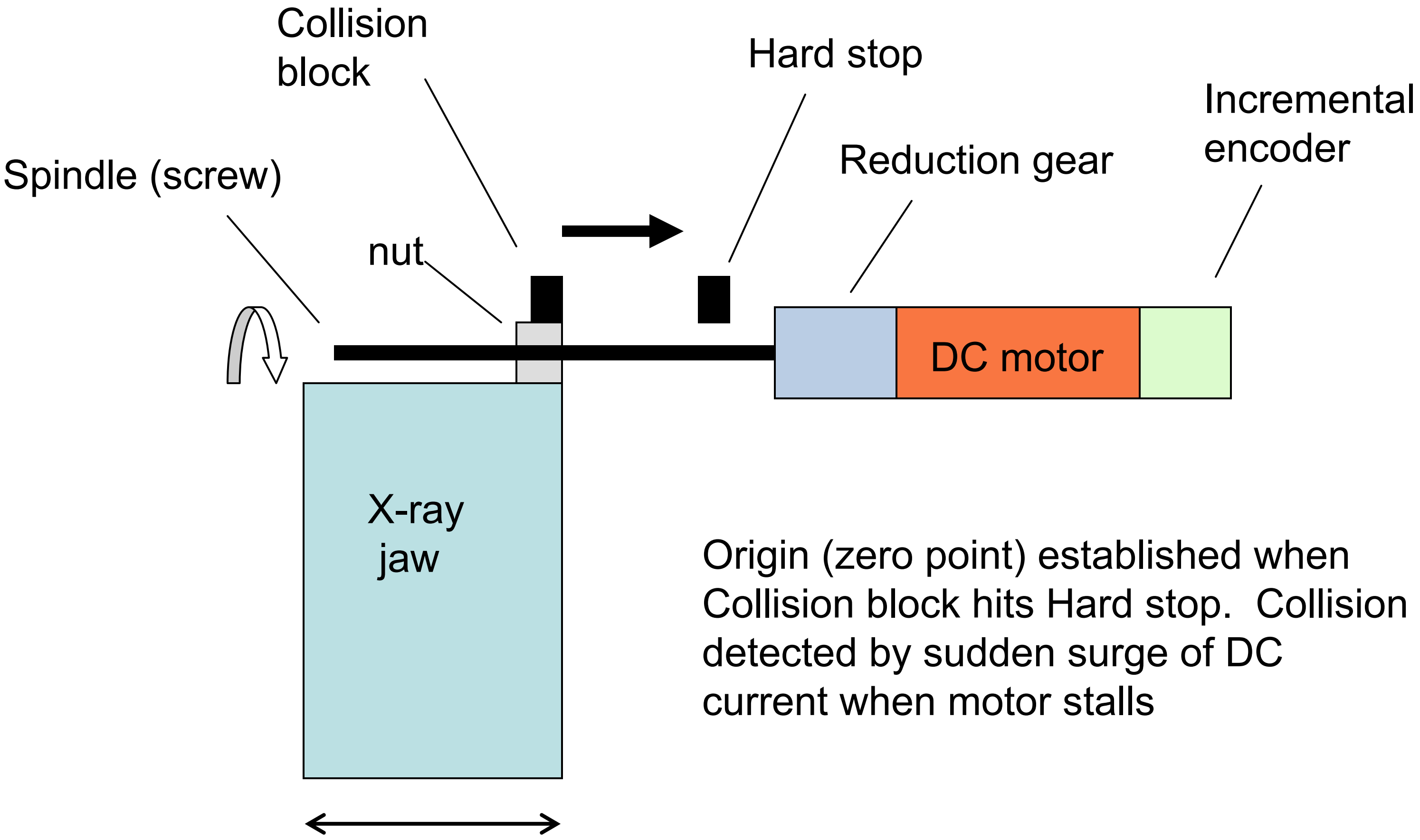
Stepper motor in 3-D water tank



Initialization of Varian MLC



Initialization of Varian x-ray jaws

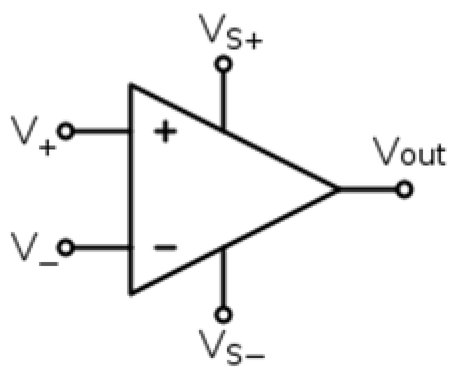


Origin (zero point) established when Collision block hits Hard stop. Collision detected by sudden surge of DC current when motor stalls

Control systems: Operational amplifier

input pos

input inv



V_s+ , V_s− pos and neg power supply voltages

$Z_{in} = \infty \quad I_{in} = 0$ small input current

$Z_{out} = 0 \quad I_{out} = \infty$ high output current

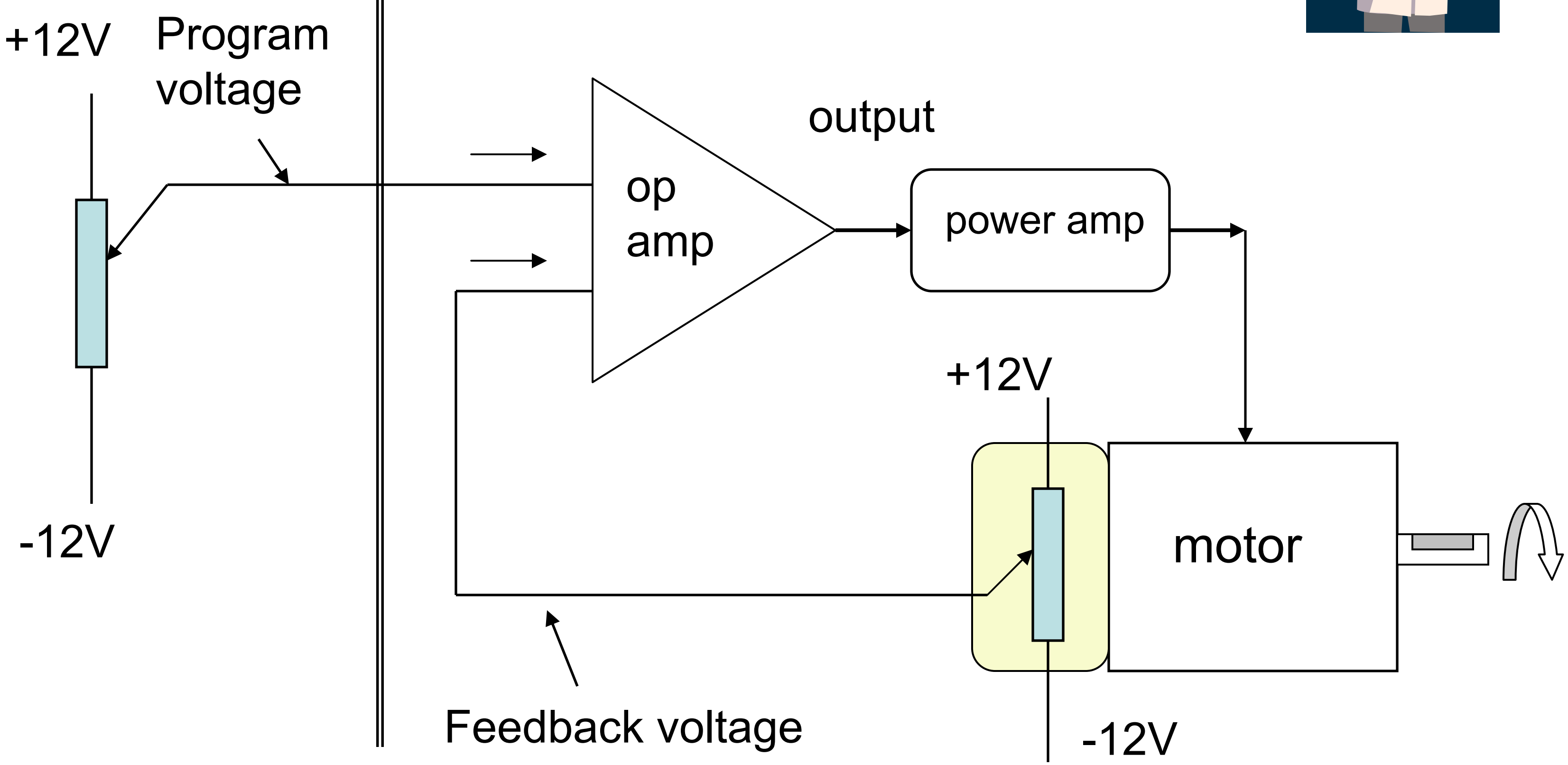
$\mathbf{V_{out} = (V_+ - V_-) \times A}$ high amplification $A \to \infty$

Analogue mechanical control system

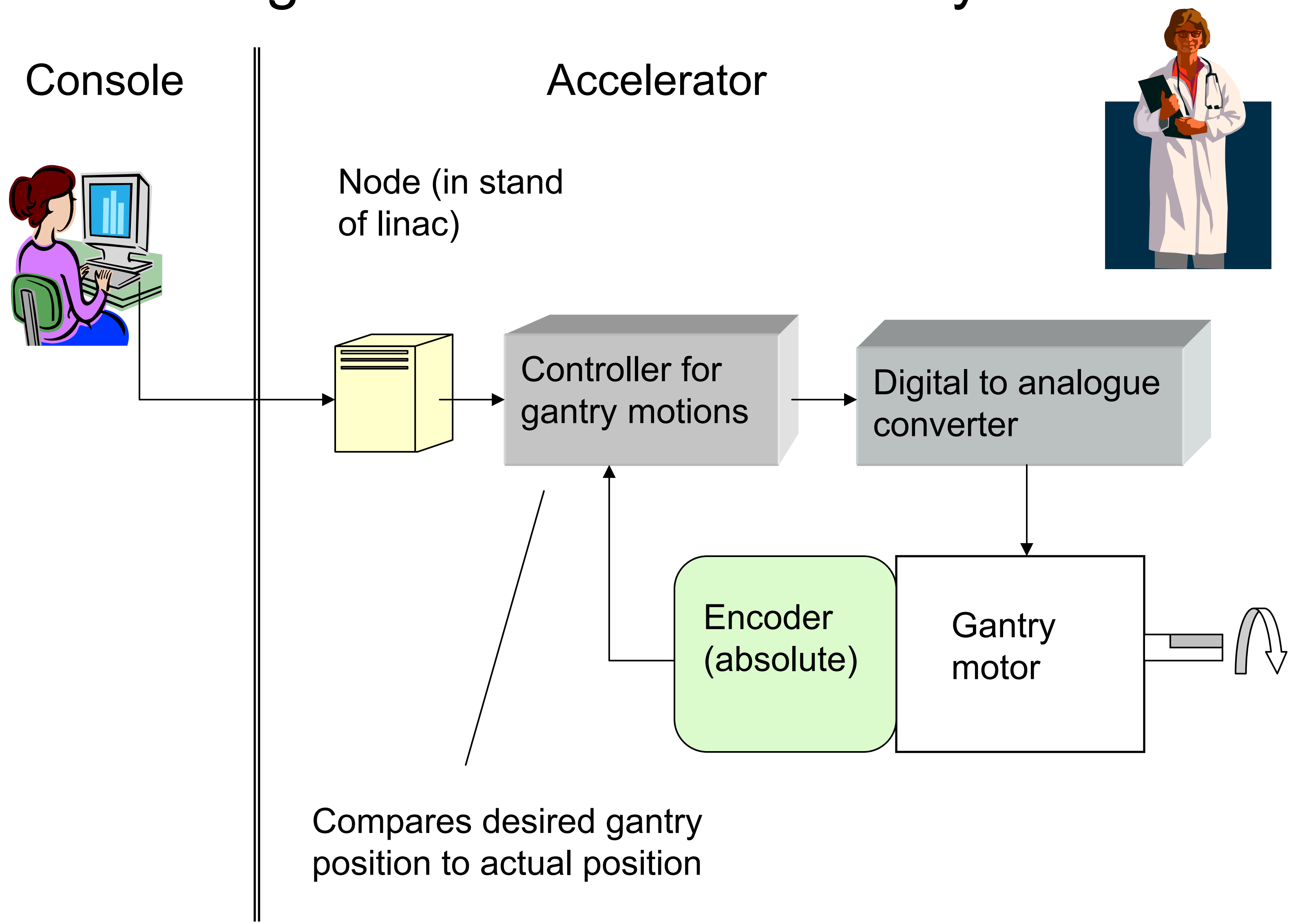
console

accelerator

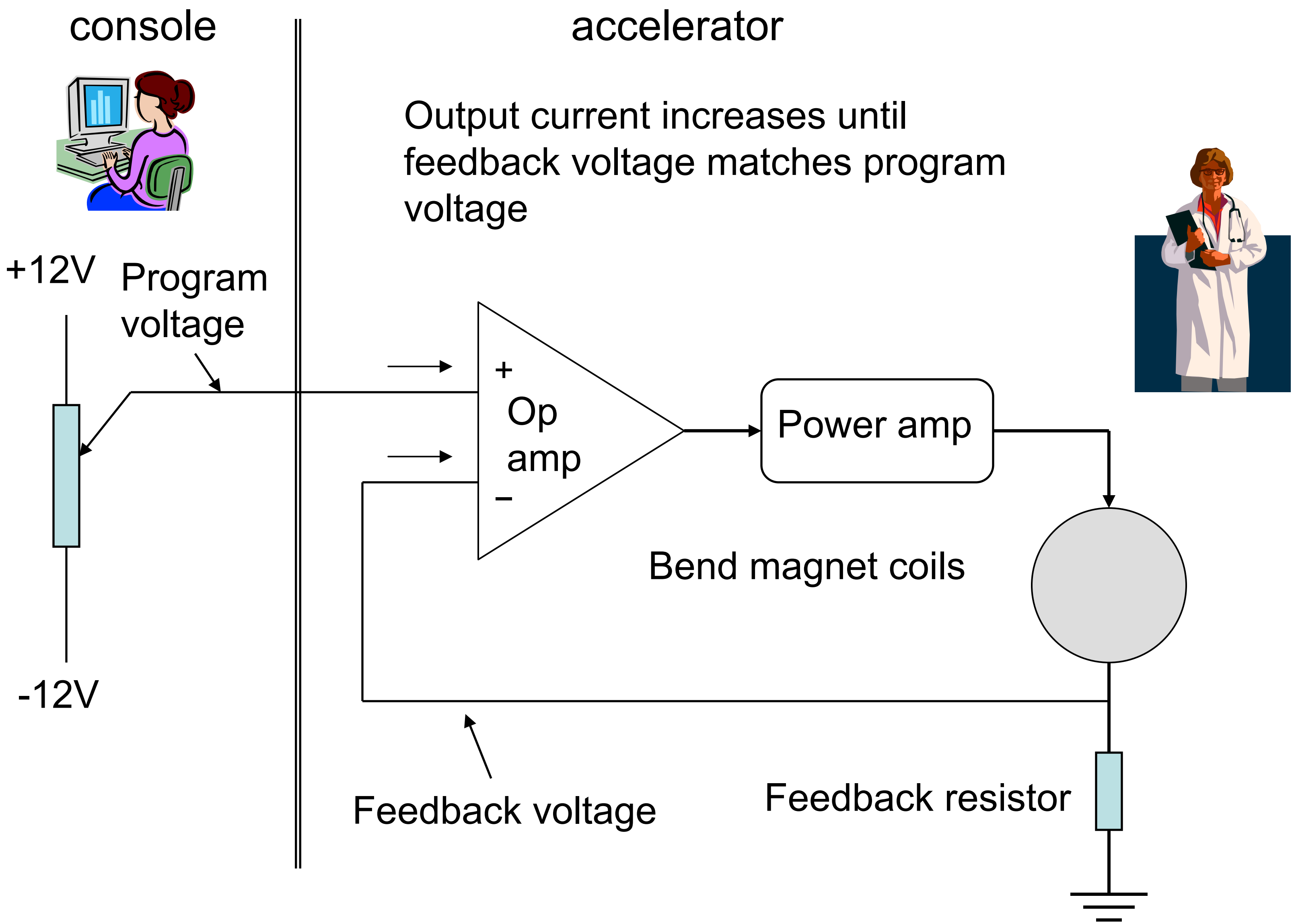
Motor spins until voltage of potentiometer at back of motor matches program voltage



Digital mechanical control system

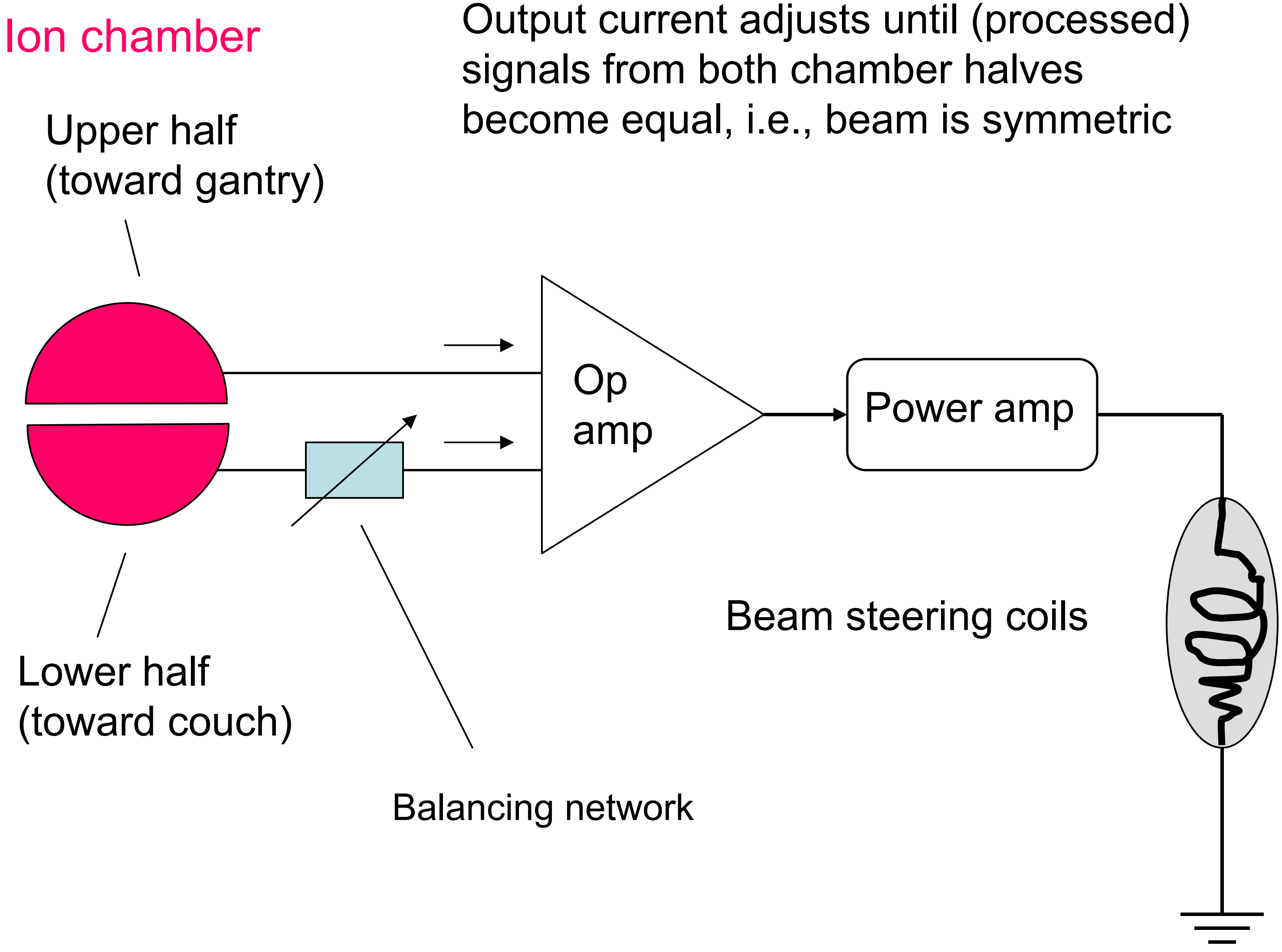


Analogue electronic control system for **energy**

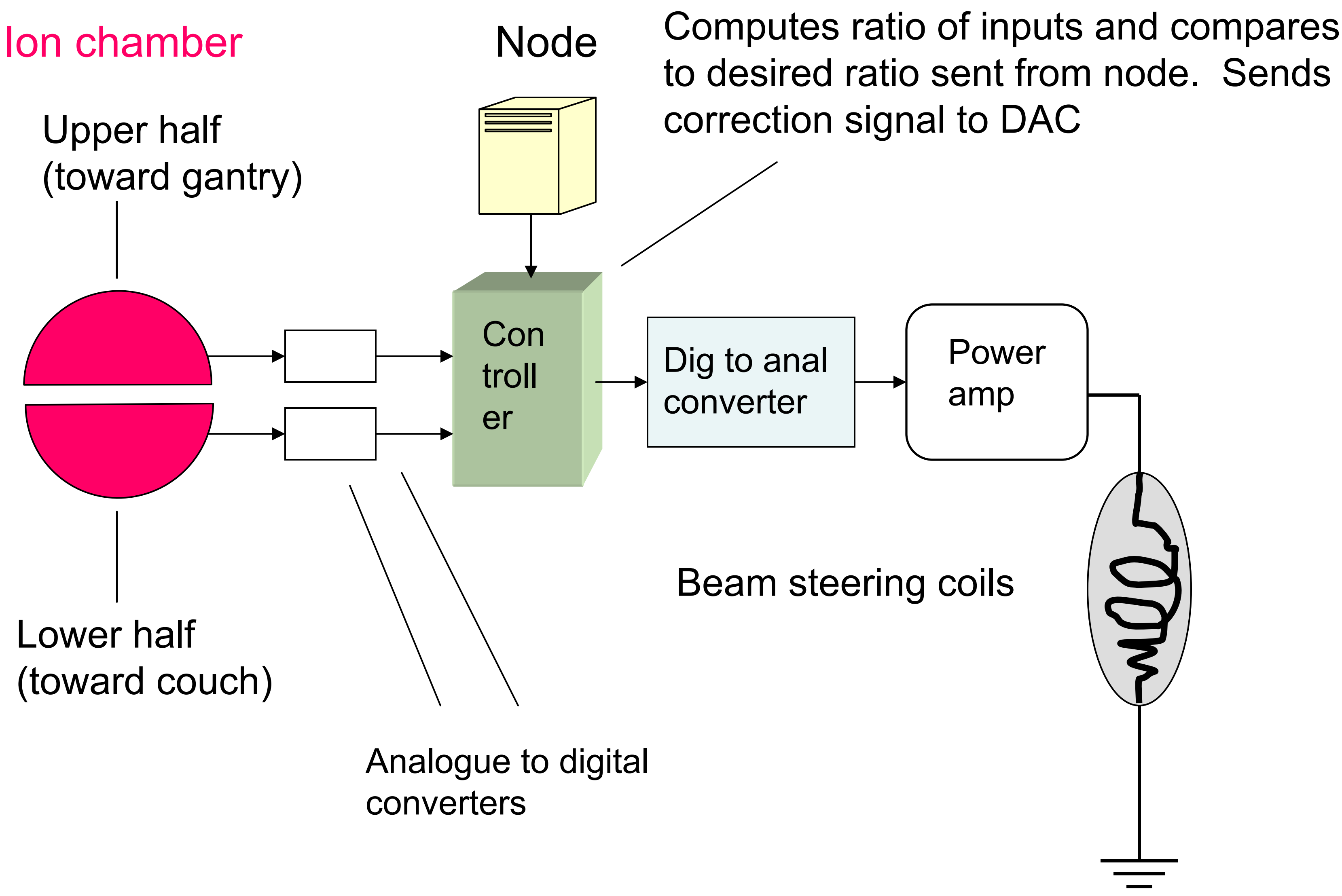


Analogue electronic control for beam **symmetry**

Output current adjusts until (processed) signals from both chamber halves become equal, i.e., beam is symmetric



Digital electronic control for beam **symmetry**



Dual systems for safety of modern digital accelerators

- Mechanical systems
  - Encoder on back of drive motor + encoder on driven object (gantry angle, couch position, etc.), agreement monitored by computer
- Electronic systems
  - Ion chamber has multiple segments, outputs monitored by computer
  - Resistance of bend magnet measured

Neutron protection – boron impregnated polyethylene plates protect against single-event upsets

Merits of digital systems

- Less sensitive to noise
- Less sensitive to component drift
- **Easy return to original settings**
- Easy replacement of broken components
- High precision of mechanical systems
  - Flattening filter and field light projector can be remotely adjusted
- Information readily available for processing
  - Monitor machine performance to predict problems
    - Cooling water flow rate monitored at many places
    - Vacuum system leaks
    - SF_6 leaks

Merits of digital systems

- Take into account “second order effects”
  - Flexing of image receiver arm
- Automatic tuning
  - Slow changes of components
    - Thyratron aging
    - Waveguide resonant frequency