Collimator Jaw Position Control

R. LOSITO
AB/ATB

LCWG, 28/2/2005

Collimation team wish

- ±10μm

- Resolution?
- Precision?
- Repeatability?
- Accuracy?

Stepping Motors

- Collimators will be moved by Stepper motors:
  - δL is defined by the geometry of the motor
  - That makes "easy" to implement a given ΔL
  - The movement can be implemented in Open loop → position sensors are not necessarily needed → the system is more robust.
  - After a power-cut, or single-event, we need to reset the step counter to a home position

Stepping Motors

- Ideal life solution
  - We use
    - 2-phase hybrid motors, 200 step/revolution
    - Angle resolution 1.8˚ ± 0.1˚
    - 2mm pitch leadscrew
    - Pull-out torque sufficiently higher than load torque (x 5)
  - And we have:
    - 2mm/200 step = (10 ± 0.5) µm !!!!
    - Static Error due to load negligible if
      - pull-out torque >> load torque
  - With Ministep Driver we can do 400, 800, 1600, 3200 steps/revolution (5, 2.5, 1.25, 0.75 µm)

BUT………

Stepping Motors

- Real Life:
  - Unprecedented Radiation levels: 3÷4 MGray/year
    - Will the leadscrew with dry lubrication work correctly on long term?
    - Will the motor keep its characteristics (pull-out Torque) on long term?
    - Mechanical play, heating...
  - Do we have a reliable reference point (ZERO)?
    - Motors only ensure ΔL (relative positioning is ok, what about absolute?)

Stepping Motors

- For all these reasons it is suitable to check the position with a sensor (or more...)

Position Sensors

- Analog:
  - Linear
    - Resistive
    - Capacitive
    - Inductive
    - Hall Effect
    - Magnetoresistive
    - Magnetostrictive
    - LVDT
  - Rotative
    - Resolver
    - RVDT

- Digital
  - Encoders, both linear and rotative.
    - Magnetic
    - Optical
    - Contact

Position Sensors

- Analog:
  - Signal is continuously changing with position → infinite resolution
  - Ouput Signal prone to significant reduction of SNR for transmission over long distances
  - Careful filtering and signal processing has to be performed (expensive electronics)
- Digital
  - Signal is in bit, resolution limited by quantization error (±½ bit)
  - Excellent performance with respect to long distance transmission.
  - In static condition, the electronics only need to detect "0" and "1", BER negligible.
  - No special effort on conditioning electronics, (cheaper)

Position Sensors

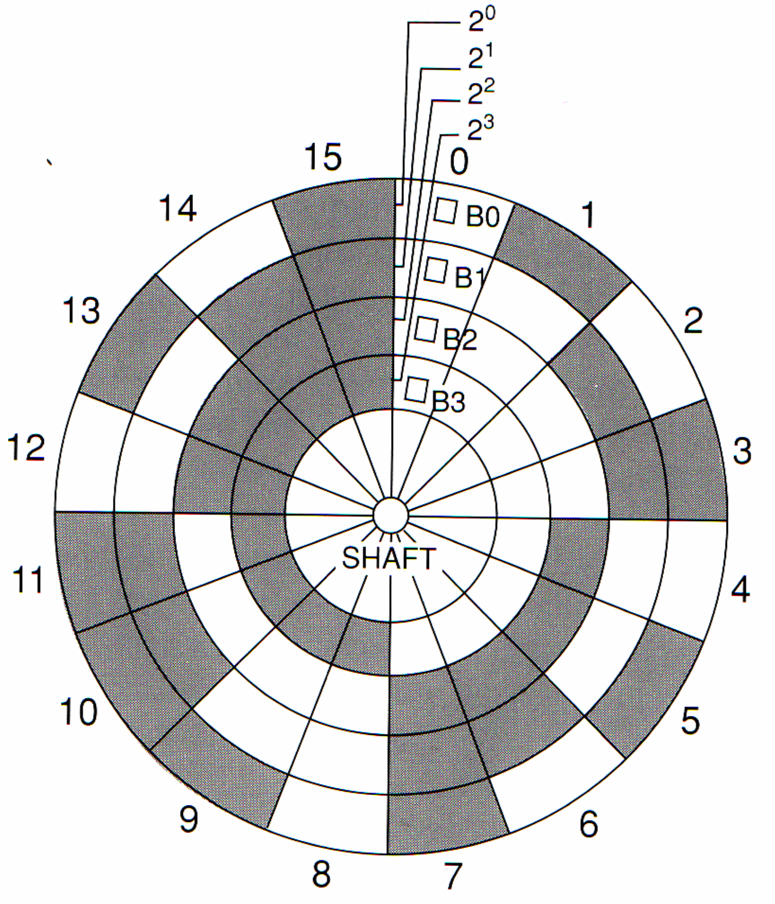
- Digital encoders:
  - Linear
    - Magnetic: Not Precise (for models available on the market) and not Rad Hard?
    - Contact: Not Precise and not on market anymore
    - Optical: Precise, good absolute measure rad hard? (2 Mgray ok?)
  - Rotative
    - Contact: Precise, good absolute measurement
    - Optical: Precise, rad hard? (2 Mgray ok?)

Position Sensors

- Digital:
  - Optical encoders:
    - Photodetectors tested up to 2 MGray gammas
    - Don’t know about behavior with respect to high energy neutron flux...
    - Resolution can go down to 1 nm (Heidenheim)
    - Precision well below 1 µm
    - Needs R&D for assessment of radiation hardness

Position Sensors

- Contact rotary encoders:



Position Sensors

- Contact rotary encoders:
  - Each bit is generated by contact of a wiper on a track, alternatively conductive or dielectric (epoxy).
  - 12 bit=12 wires (4 axes: NE48)
  - Good precision (tracks obtained by photolitography)
  - Good repeatability (±½ bit)
  - Lifetime might be limited by oxidation (100‘000 hours continuous operation guaranteed)

Position Sensors

- Contact rotary encoders:
  - A model is used at CERN in Linacs and PS 80MHz cavities. Qualified up to 1 MGray.
  - *IF* one can get them in time (usual delay 8 months for 1!!) and *IF* one can check for 10 MGray lifetime probably the best solution.
  - 12 bits on 1 turn → ±½ bit=±3 arc minute→±0.3 µm
  - 12 bits on 17 turns → ±½ bit=±51 arc minute→±5.1 µm

Position Sensors

- Analog:
  - Linear
    - Resistive: Not Precise
    - Capacitive: Precise, single sided
    - Inductive: Precise, single sided
    - Hall Effect: Typically semiconductor, Rad hard?
    - Magnetoresistive: Not precise
    - Magnetostrictive: Precise (radar, but close electronics)
    - LVDT: Precise, double sided (ZERO!!!)
  - Rotative
    - Resolver: Precise, absolute measurement only on one turn
    - RVDT: Precise, $< 360°$

Position Sensors

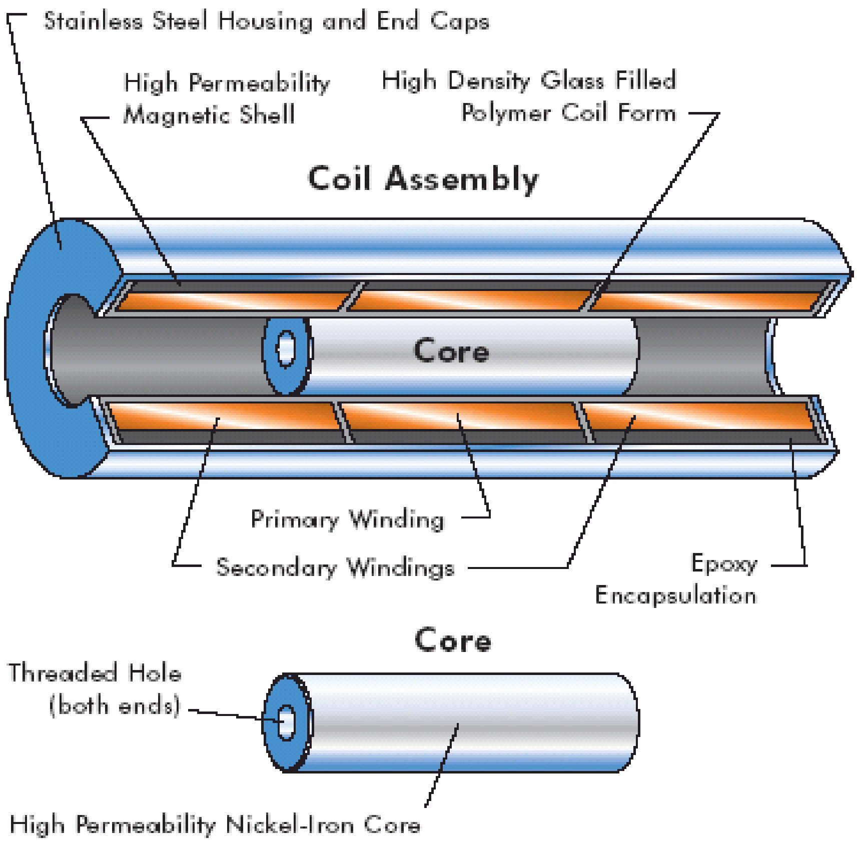
- Analog summary:
  - Linear
    - LVDT: Precise, double sided (ZERO!!!)
  - Rotative
    - Resolver: Precise

Position Sensors

- Analog:
  - LVDT and Resolvers:
    - Radiation hardness: If the motor survives, the LVDT and the Resolvers can survive.
    - Lifetime: “infinite” since contactless (no mechanical stresses)
    - Resolution is determined by ADC in conditioning electronics.
    - 16 bits on ±40 mm= 1.2µm resolution

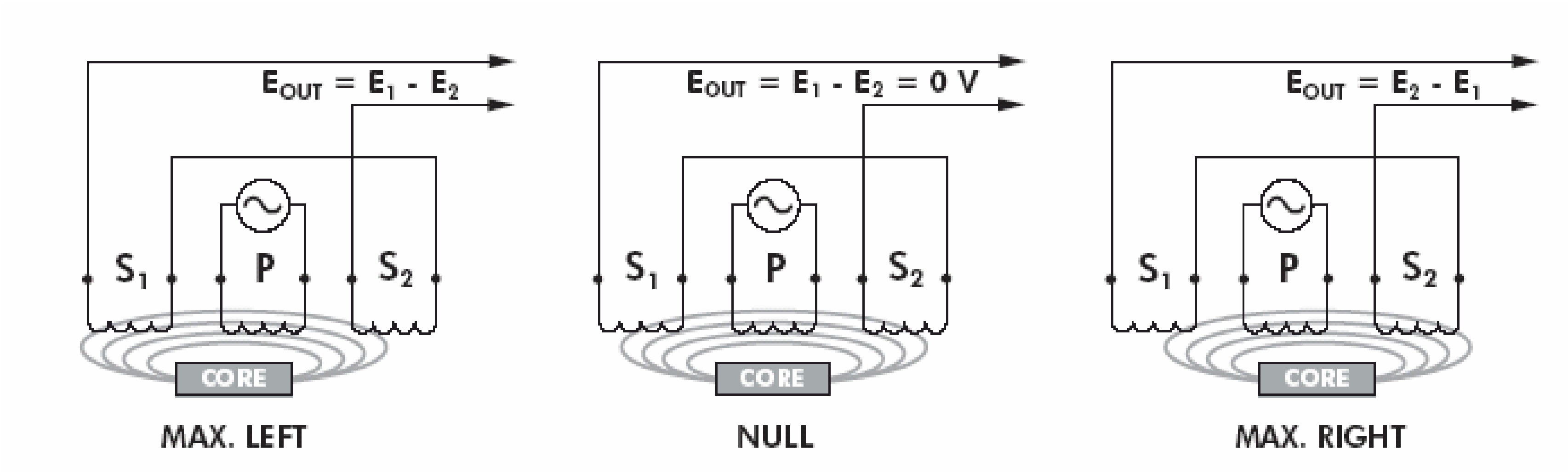
Position Sensors

- LVDT:



Position Sensors

- LVDT:



Position Sensors

- LVDT:
  - LVDT is used in position control applications for "homing" purpose (its zero is used as reference for positioning).
  - Repeatability is intrinsically infinite, only depends on mounting (on us!!!). Commercial (expensive) models (non Rad Hard) are guaranteed for a repeatability of ±0.15μm
  - Linearity depends on uniformity of material and of windings.
  - NON LINEARITIES DO NOT AFFECT ZERO.
  - Non linearities (if not drifting) can be compensated by calibration.

Position Sensors

- LVDT:
  - Measured errors by one of the market leaders:
    - Zero Drift: ±8 µm/ ±30 mm.
    - After one year it tends to reach a stable position. It can probably be reduced by applying aging thermal cycles.

❑ *A +/-30mm*

Caractéristiques	Capteur	Conditionneur	Total
Dérive de zéro	+/-5µm	+/-45µm	+/-50µm
Dérive de sensibilité	+/-3µm	+/-45µm	+/-48µm
Non linéarité	~~+/-60µm~~	+/-24µm	+/-84µm
Stabilité dans le temps	~~+/-8µm~~	+/-40µm	+/-48µm
Précision réglage	/	+/-3µm	+/-3µm
		TOTAL en somme des erreurs	**+/-233µm**
		TOTAL en moyenne quadratique	**+/-119µm**

Position Sensors

- LVDT:
  - Adding a compensation to thermal drift of electronics:

❑ *A +/-30mm*

Caractéristiques	Capteur	Conditionneur	Total
Dérive de zéro	+/-5µm	+/-12µm	+/-17µm
Dérive de sensibilité	+/-3µm	+/-12µm	+/-15µm
Non linéarité	+/-60µm	+/-24µm	+/-84µm
Stabilité dans le temps	+/-8µm	+/-40µm	+/-48µm
Précision réglage	/	+/-3µm	+/-3µm
		TOTAL en somme des erreurs	**+/-167µm**
		TOTAL en moyenne quadratique	**+/-100µm**

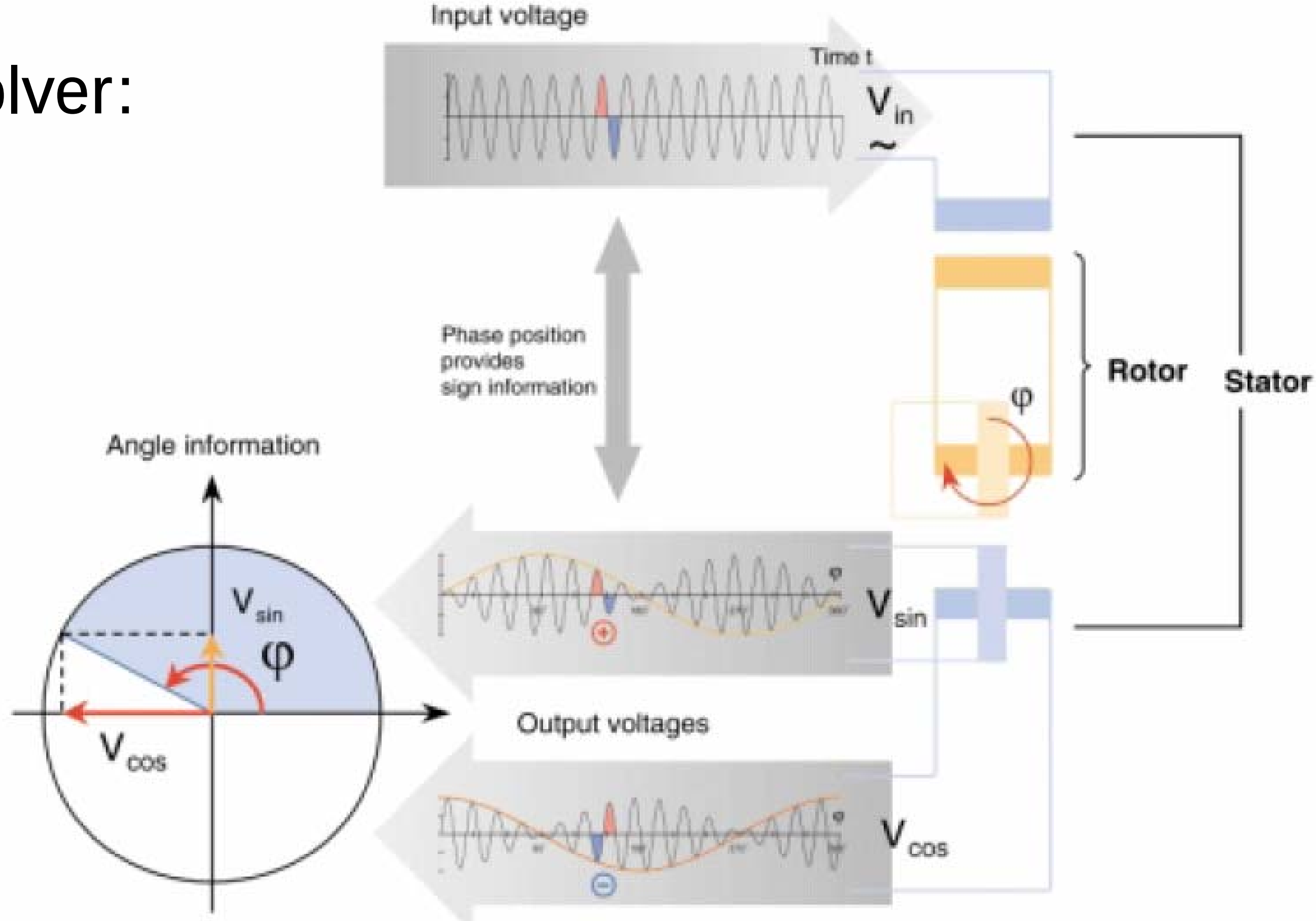
  - $(5^2+12^2+3^2+12^2+3^2)^{½}$ = ±18 µm uncertainity at zero
  - ±51 µm ACCURACY at full scale

Position Sensors

- Resolver:

Position Sensors

- Resolver:



Position Sensors

- Resolver:
  - Errors: No direct measurement available.
  - The resolver itself gives 7 arc minute (0.7 µm on 1 turn)
  - Signal conditioning electronics similar to LVDT: by using the same worst case ppm error we get:
    - Over 1 turn: ±30 arc minutes → ±3 µm ACCURACY
    - Over 17 turn: ±8 degrees → ±45 µm ACCURACY
  - We should probably add something for SNR reduction

Positioning Strategy

- Hypothesis:
  - We can make an accurate calibration before installation
  - Mechanical frame of the collimator does not drift on time
  - Mechanical plays are negligible (if not, they should be added to the numbers in the following slides)
  - Yearly calibration in the tunnel does not require human intervention in the tunnel to mount calibrated reference position sensors (no dose to personnel for the intervention)
  - We have enough time to order and receive the sensors.

Positioning Strategy

- Scenario n. 1:
  - We use Contact rotary encoders demultiplied on 17 turns
  - We use LVDTs for back-up on jaw position and for direct measurement of gap opening
  - We can get:
    - ±5 µm accuracy on jaw position
    - ±10 µm accuracy on gap measured by difference
    - ±30 µm measured directly by LVDT (repeatibility of the measurement will probably be much better)

Positioning Strategy

- Scenario n. 2:
  - We use Resolvers as absolute angle measurement (1 resolver turn=1 motor turn)
  - We use LVDTs for homing and back-up on jaw position and for direct measurement of gap opening
  - We can get:
    - ±20 μm accuracy on jaw position
    - ±30 μm accuracy on gap measured by difference
    - ±30 μm measured directly by LVDT (repeatibility of the measurement will probably be much better)

Conclusions (1)

- Position error due to stepping motors : ±0.5 µm
- Having a reasonable ratio (5) between motor pull-out torque and load (jaw) torque should ensure the motors do not loose steps
- Position sensors can be used to check correct behavior
- Position measured with Analog sensors can give ±30 µm accuracy on gap
- Position measured with encoders can give ±10 µm accuracy on gap
- Mechanical plays will play a role (to be checked on prototypes)

Conclusions (2)

- Repeatability, especially on short term (<1 year), is going to be better, but it is difficult to quantify

- Some MD time has to be foreseen after long shutdown and re-calibration, to find again the working points at low intensity

- The time scale of the project probably does not leave us all the degrees of freedom in the choice of position sensors