Design of an Iso-Perimetric Coil for a Transversal Field Scanner

Gianni Caiafa
CERN – Geneva, Switzerland
gianni.caiafa@cern.ch

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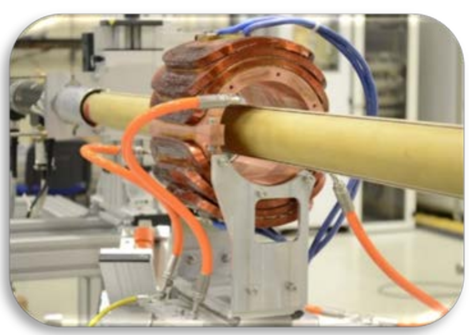
- Measurement of local field distribution
- Sensor design
- Sensor production
- Sensitivity analysis of manufacturing errors
- Measurement system design for proof of principle

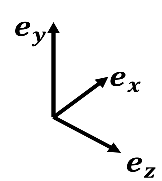
Measurement of local field distribution

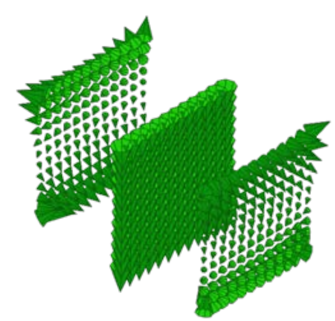
Higher order imperfections in magnetic fields of short magnets play an important role in particle dynamics.

Local field distribution on the magnetic extremities is required for:

- Describing the longitudinal field profile
- Studying the particle-beam dynamics





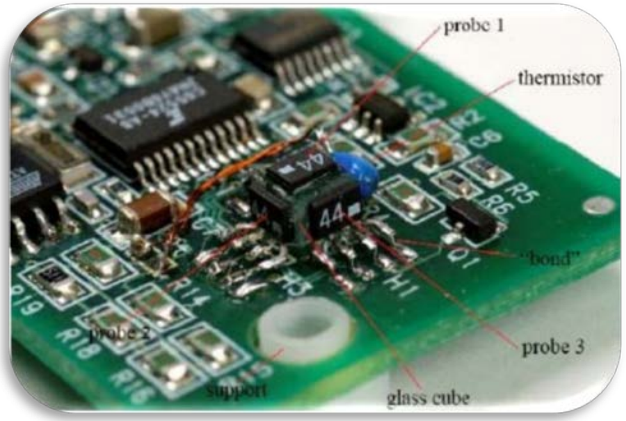


S. Russenschuck, "*Field Computation for Accelerator Magnets*"

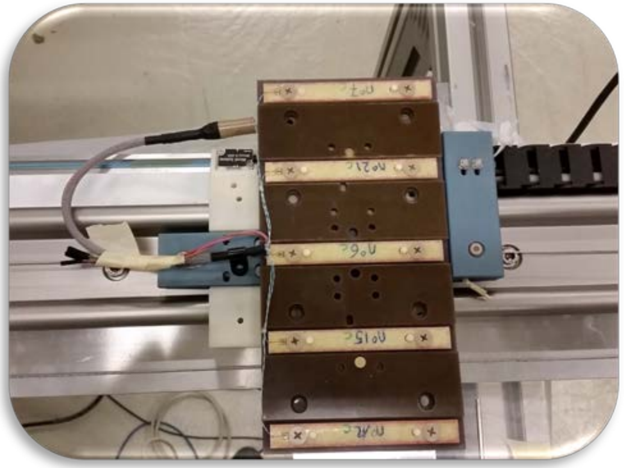
Measurement of local field distribution

Available techniques for acquiring the local field distribution (1)

- Full mapping using a 3D Hall sensor
  - *Not always suitable to get harmonics*



- Translating-coil scanner on the magnet's mid-plane
  - *Harmonics number limited by the transversal resolution (number of induction coils)*



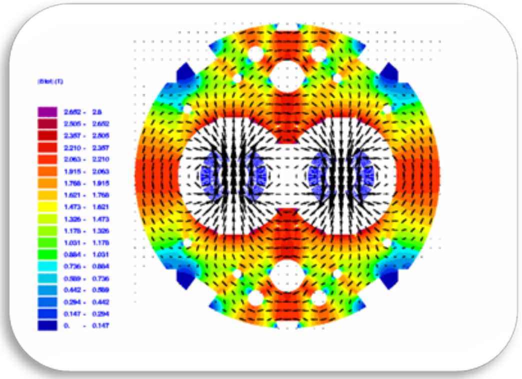
S. Sanfilippo, "*Hall Devices: Physic & Application to Field Measurements* "

S. Russenschuck, "*Field Computation for Accelerator Magnets*"

Measurement of local field distribution

Available techniques for acquiring the local field distribution (2)

- FEM/BEM validated by integral measurements
  - *Manufacturing errors and dynamic effects are not evaluated*



- Measuring on the boundary surface and applying the concept of pseudo-multipoles

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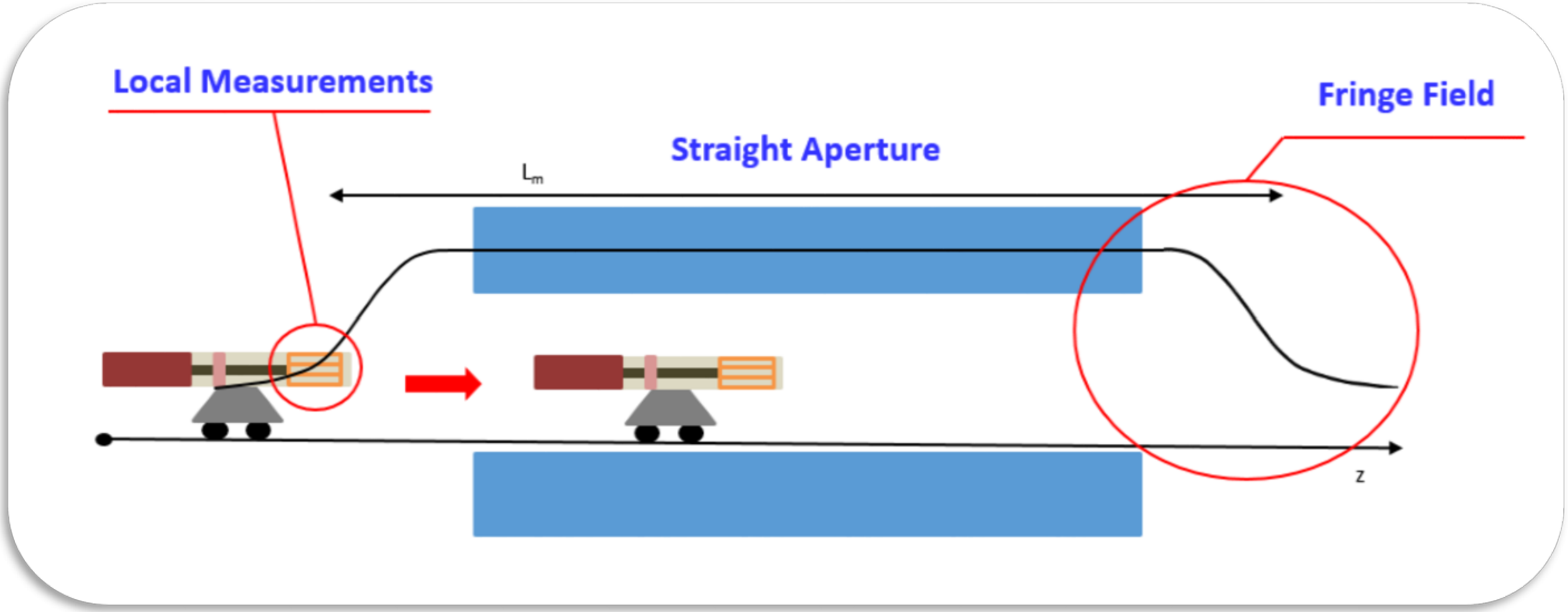
The proposed solution is based on the **pseudo-multipoles analysis**

S. Russenschuck, "*Field Computation for Accelerator Magnets*"

Measurement of local field distribution

Measuring the transversal field harmonics along **z** using an “infinitely” short rotating coil, we obtain the entire field description



Measurement of local field distribution

To perform this measurement, the coil magnetometer must be non-sensitive to the longitudinal (B_z) field component. This requires a **saddle design** coil.

Moreover, the compensation (bucking) scheme with coils at different radii will not work (the $\left(\frac{r}{r_0}\right)^{(n-1)}$ scaling law is no more valid)

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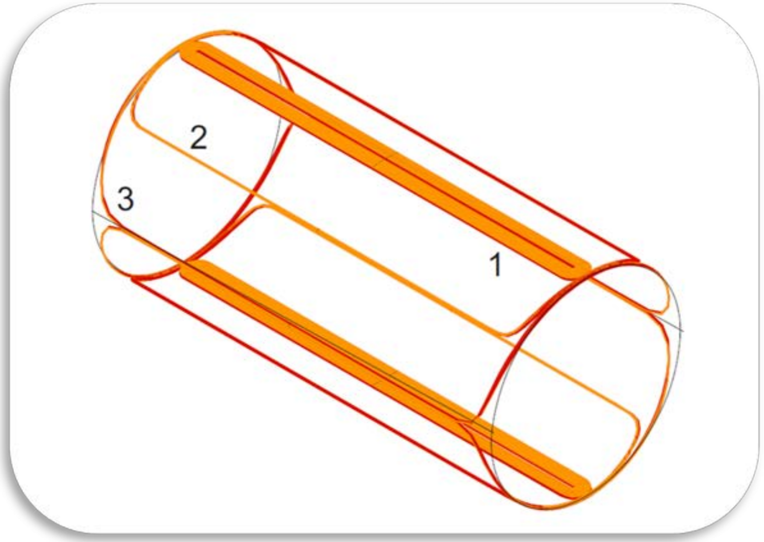
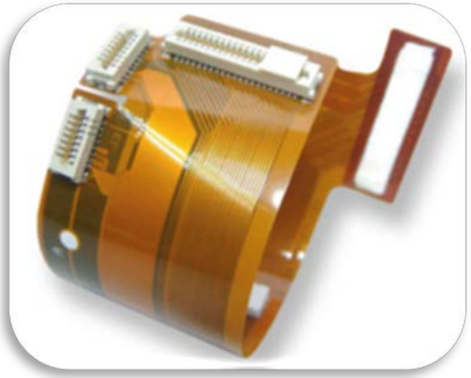


- Winding on a mandrel
- Sputtering deposition
- Flexible printed-circuit board technology

S. Russenschuck, "*Field Computation for Accelerator Magnets*"

Sensor design

Flexible printed-circuit board technology



- High precision in track positioning
- Reproducibility
- Negligible thickness (~ 0.25 mm 4 layers)
- Relatively cheap (considering the achievable precision)

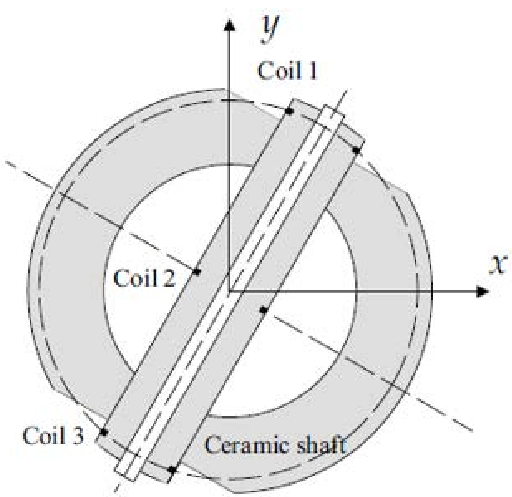
Sensor design

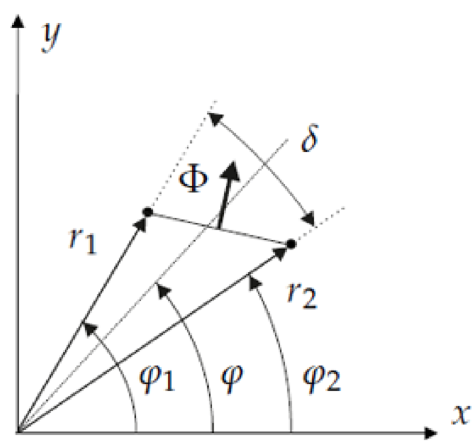
Design optimized by Roxie using the coil sensitivity factor equation

$$K_n = \frac{N l_{(z)}}{n}\left(r_2^n e^{in\varphi_2} - r_1^n e^{in\varphi_1}\right)$$

$$S_n^{tan} = \frac{2 N l_{(z)} r_0}{n} \sin\left(\frac{n\delta}{2}\right)$$

r_0	Measurement coil radius
N	Number of turns
$l_{(z)}$	Coil length
n	Harmonic order
δ	Opening angle

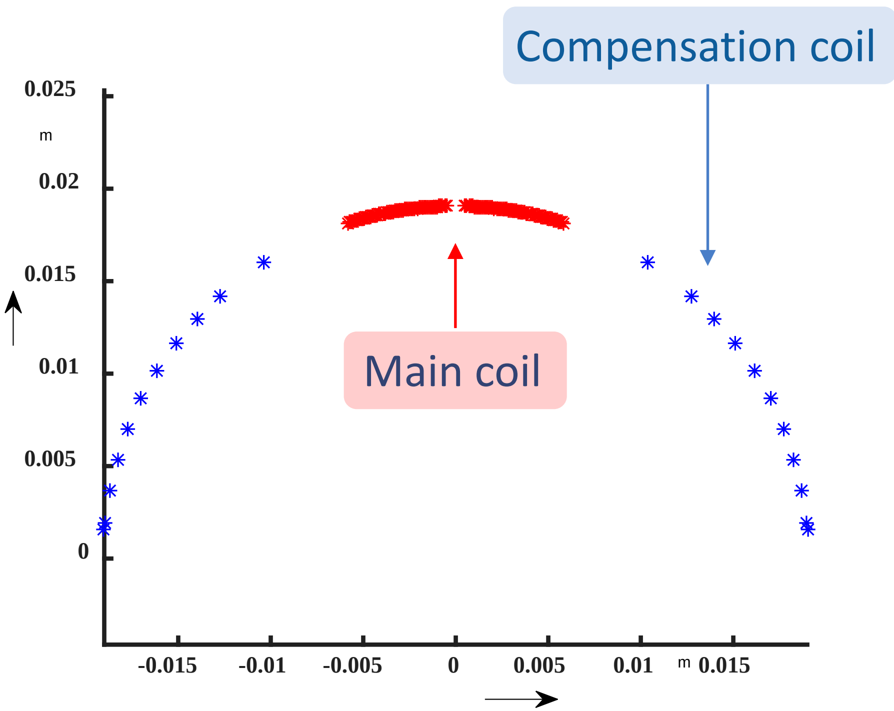




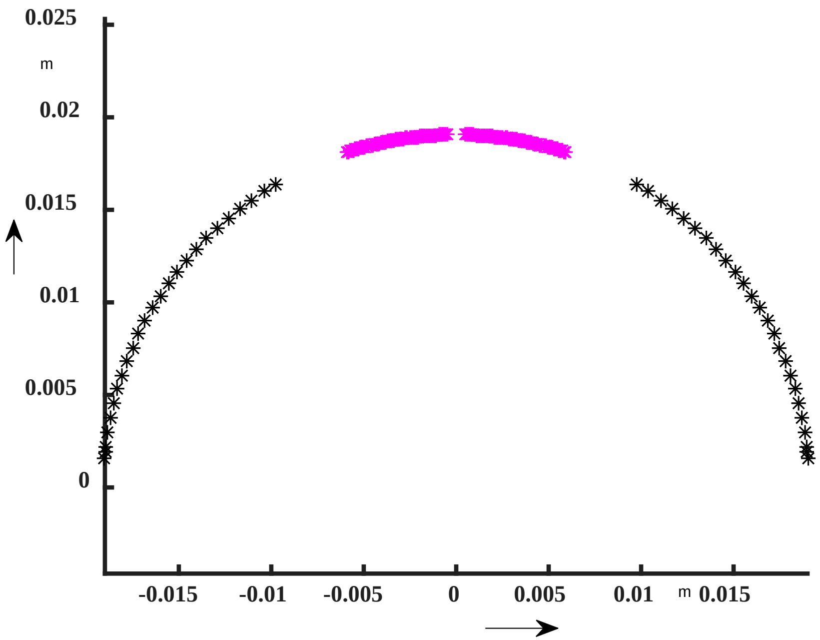
S. Russenschuck, "*Field Computation for Accelerator Magnets*"

Sensor design

Optimization results



Dipole compensated coil



Quadrupole compensated coil

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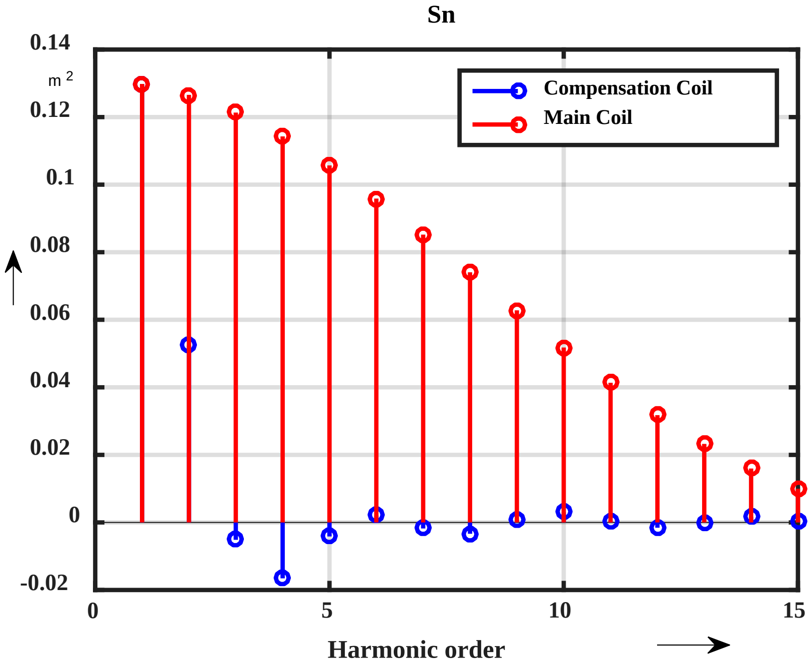
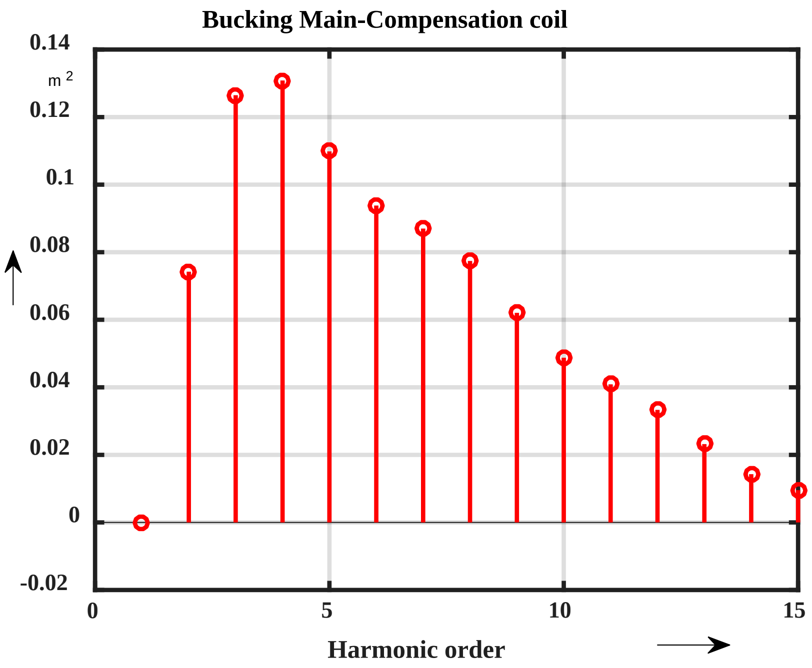
Sensitivity factors for dipole compensated coil



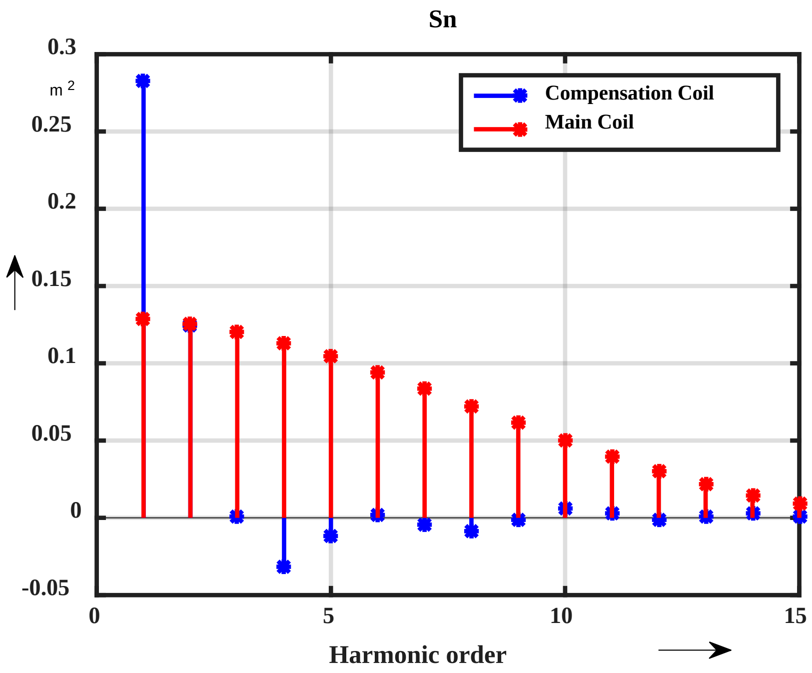


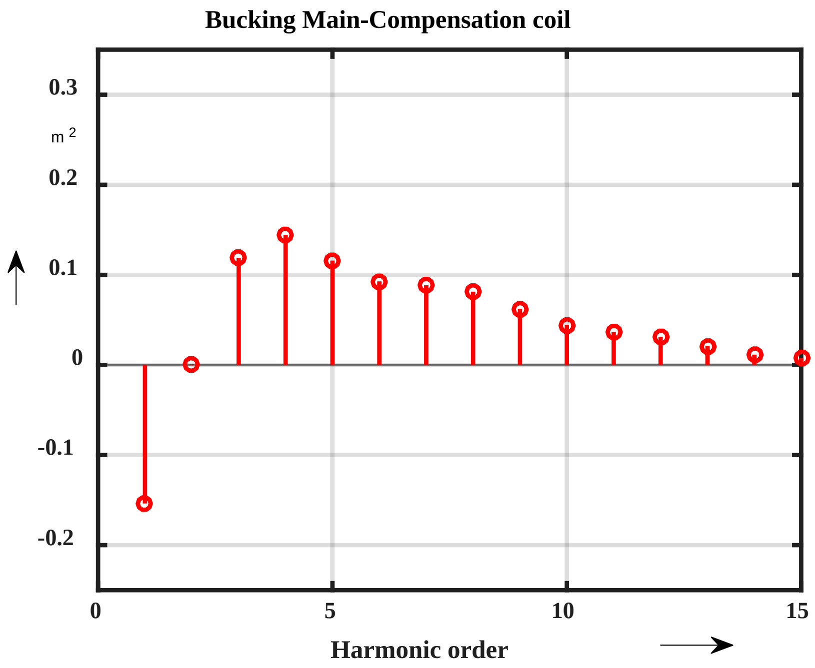
$$Q_c = \frac{S_1^M}{S_1^M - S_1^C} = 1.3\ 10^5$$

M - Main coil

C - Compensation coil

Sensitivity factors for quadrupole compensated coil



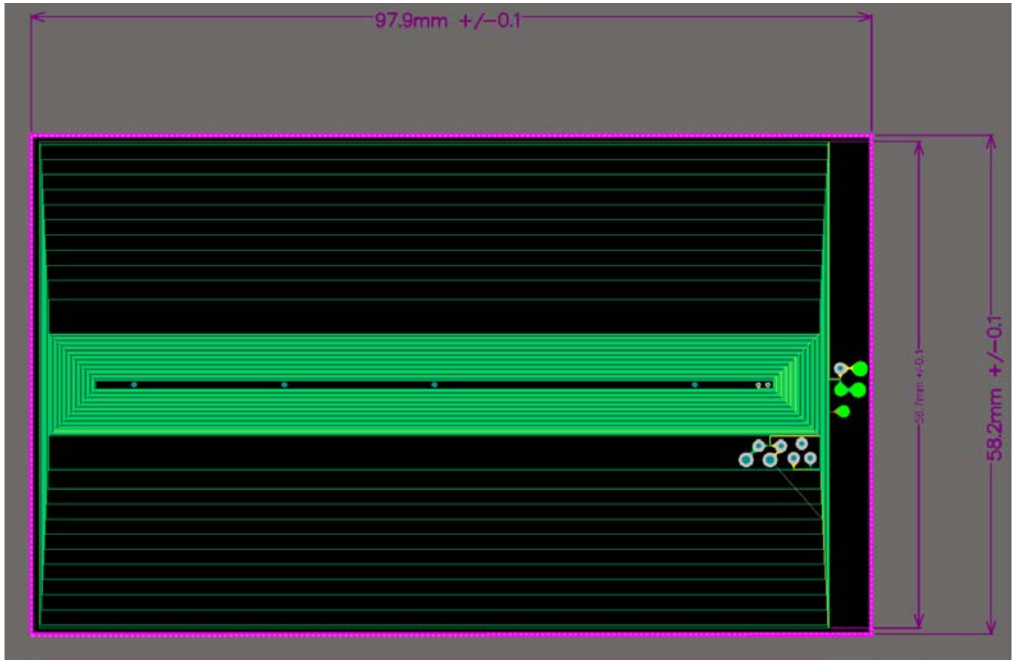


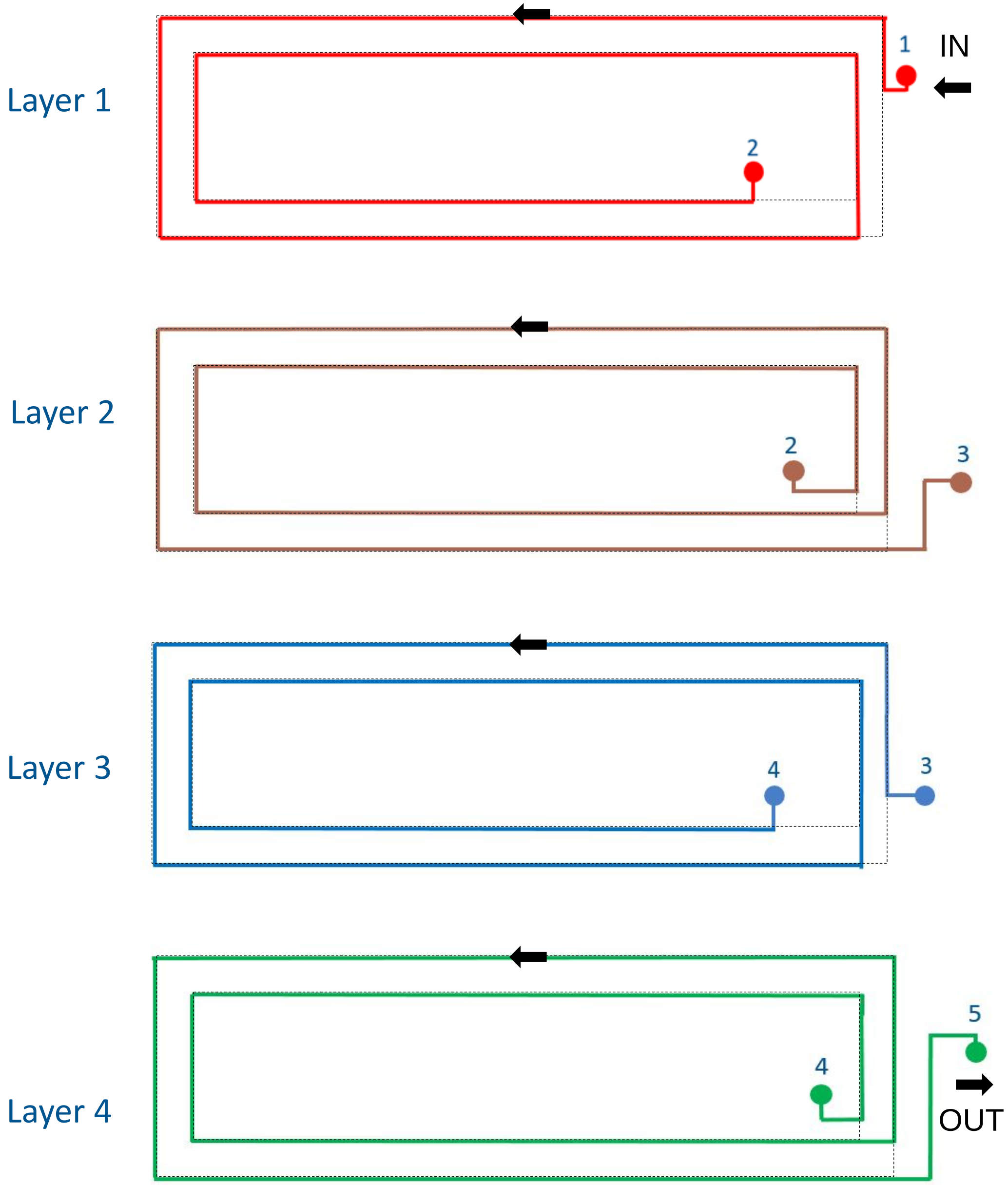
$$Q_c = \frac{S_2^M}{S_2^M - S_2^C} = 1.5\ 10^2$$

M - Main coil

C - Compensation coil

Altium production design

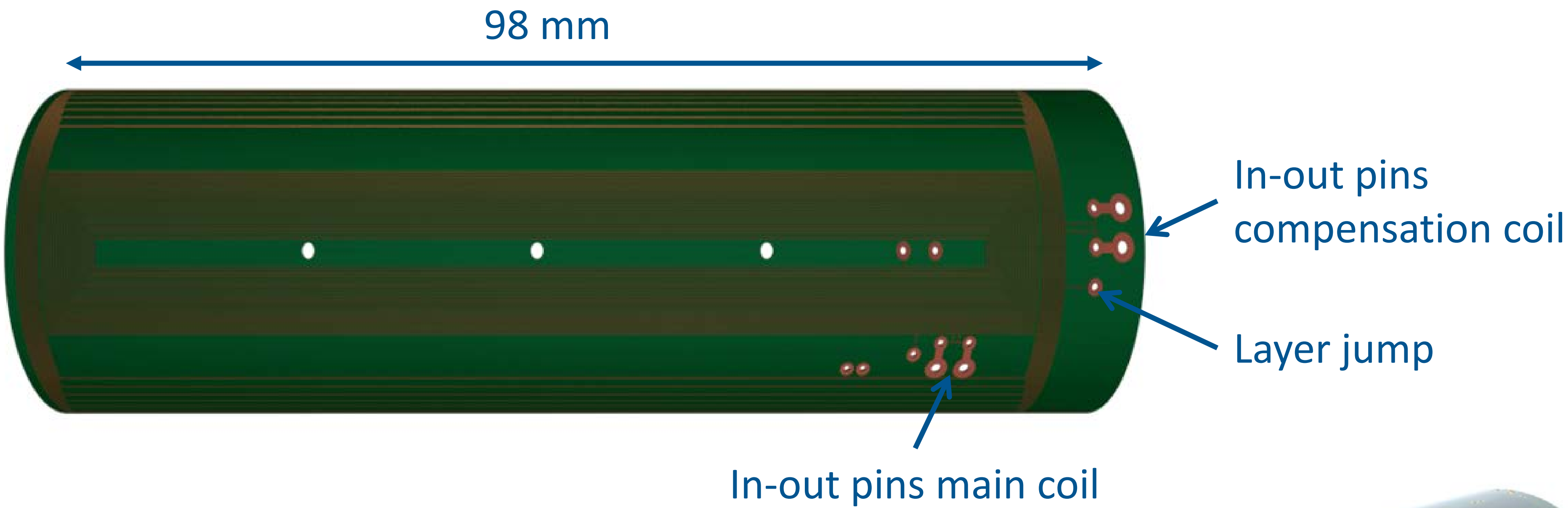


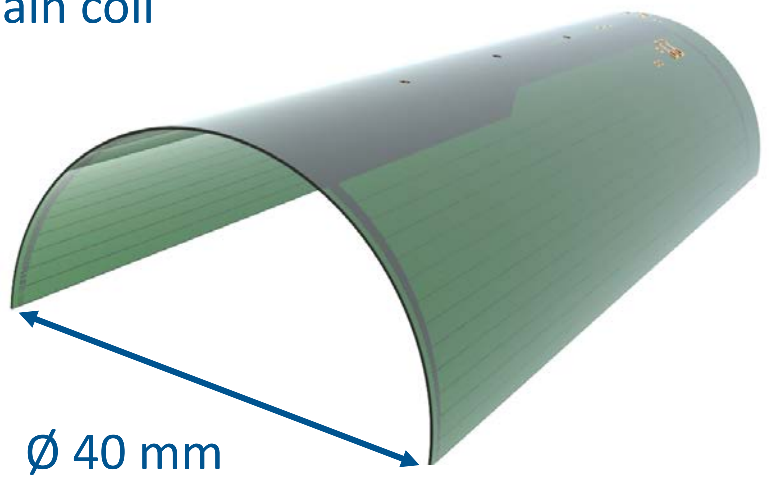


$$QF = \frac{ES - LS}{NS} < 1\ 10^4$$

Extra Surface (ES)
Lost Surface (LS)
Nominal Surface (NS)

Main dimension



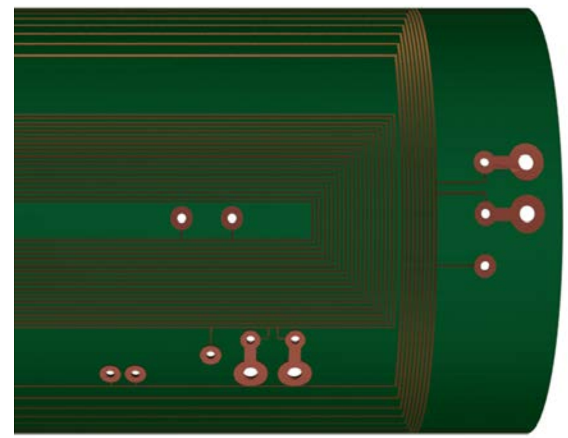


Sensor Production

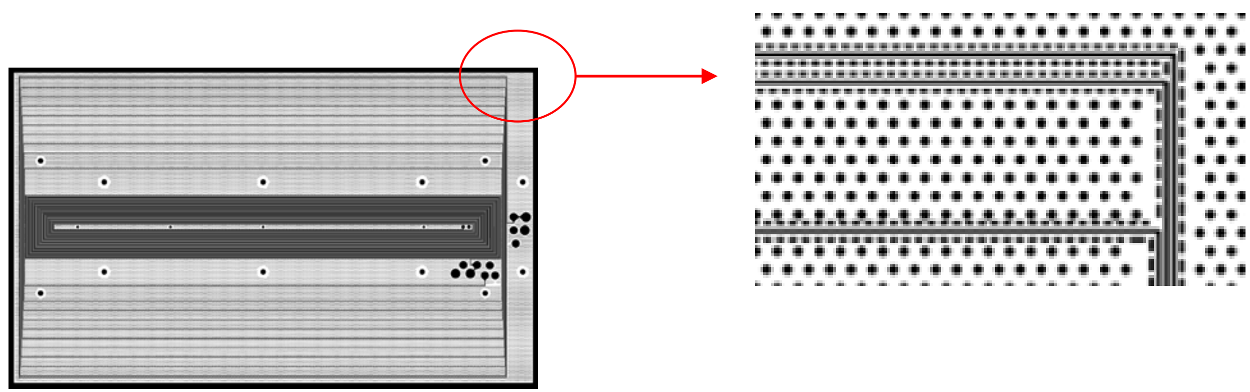
First layer produced

Insulation width 50 µm (main coil)

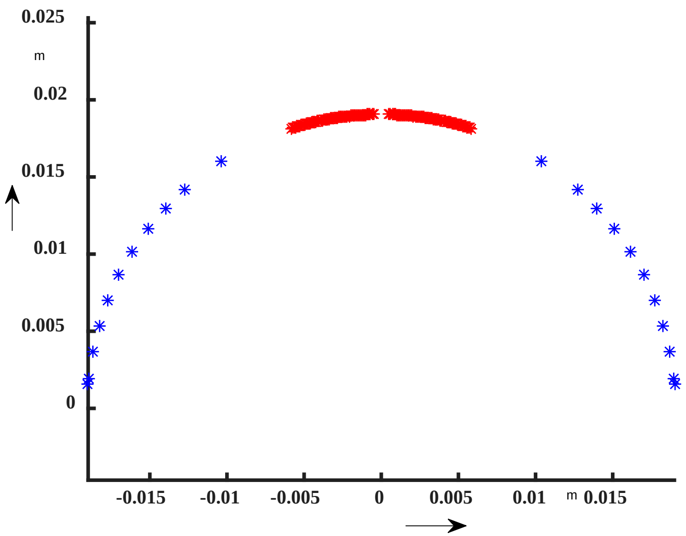
Tracks width 40 µm



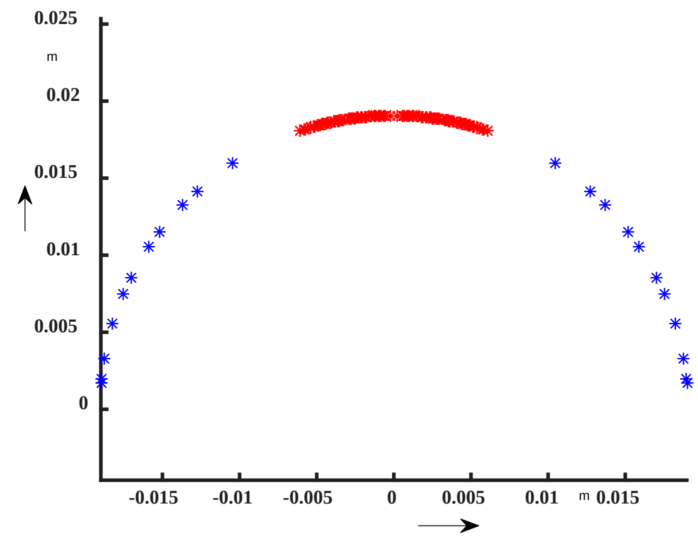
Production solution



Tracks position error



+ Random gaussian error =



PCB insulation thickness between tracks 50 µm
Maximum positioning simulated error of ±30 µm
Bucking ratio acceptable in all the cases

Position uncertainty	Dipole bucking ratio	Quadrupole bucking ratio
0 µm	130000	150
±20 µm	17000	150
±30 µm	16000	170

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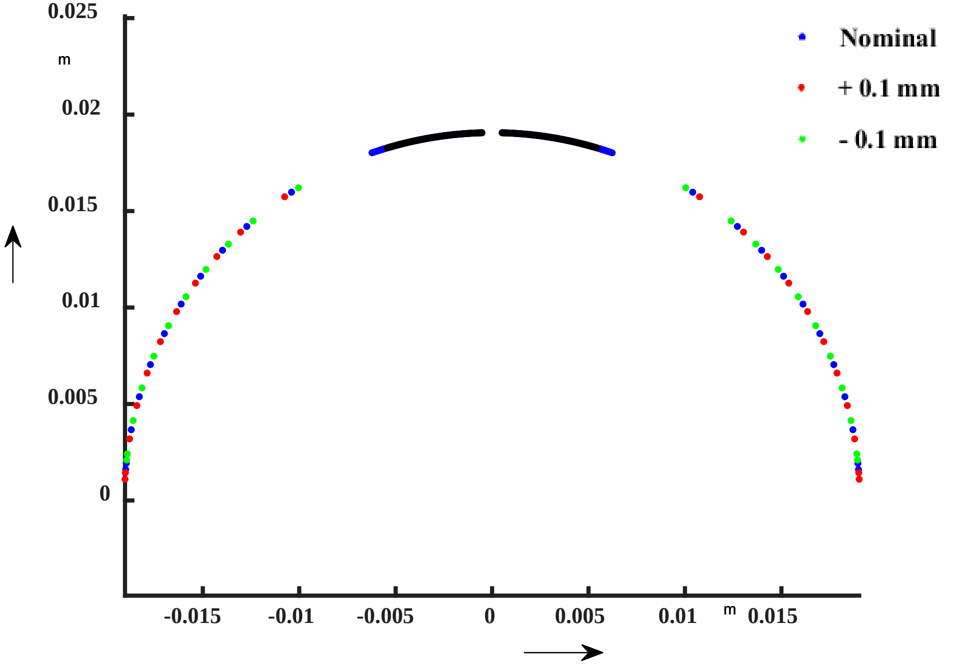
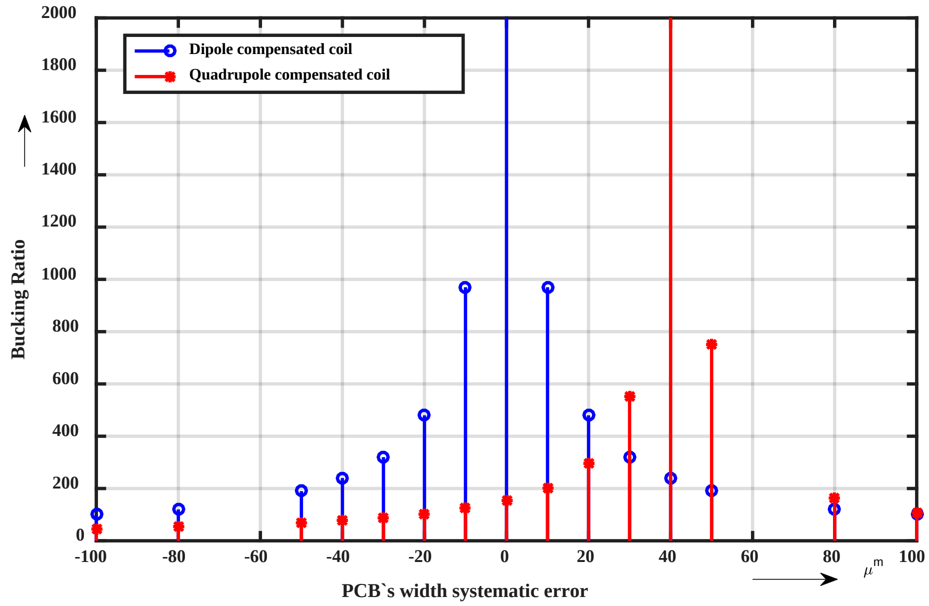
PCB's width tolerance





Suitable bucking ratio >100
PCB's width tolerance -20 ,+100 µm

Sensitivity analysis of manufacturing errors

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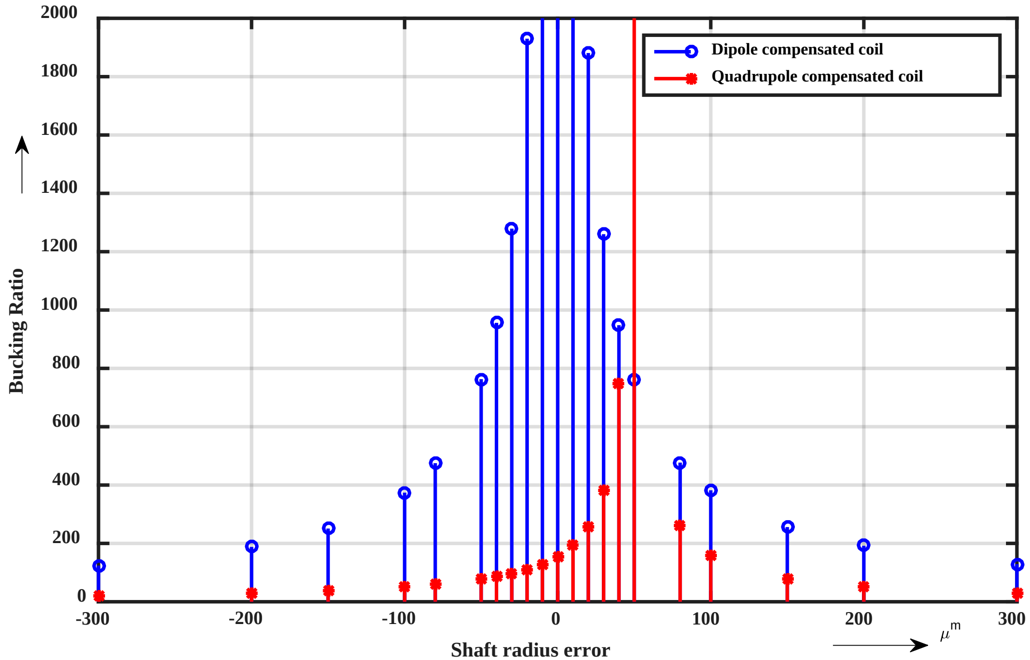
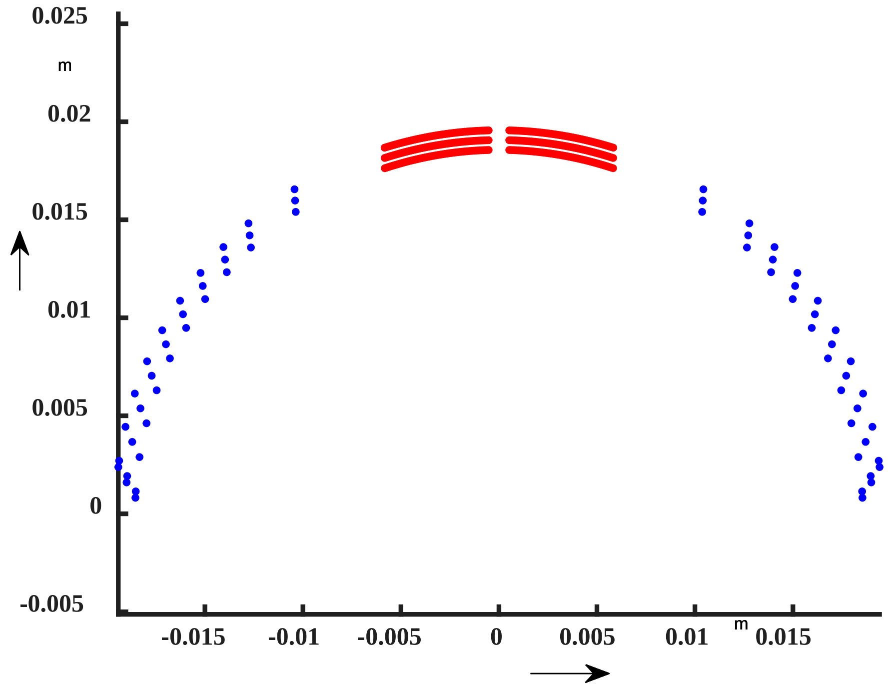
Shaft radius tolerance



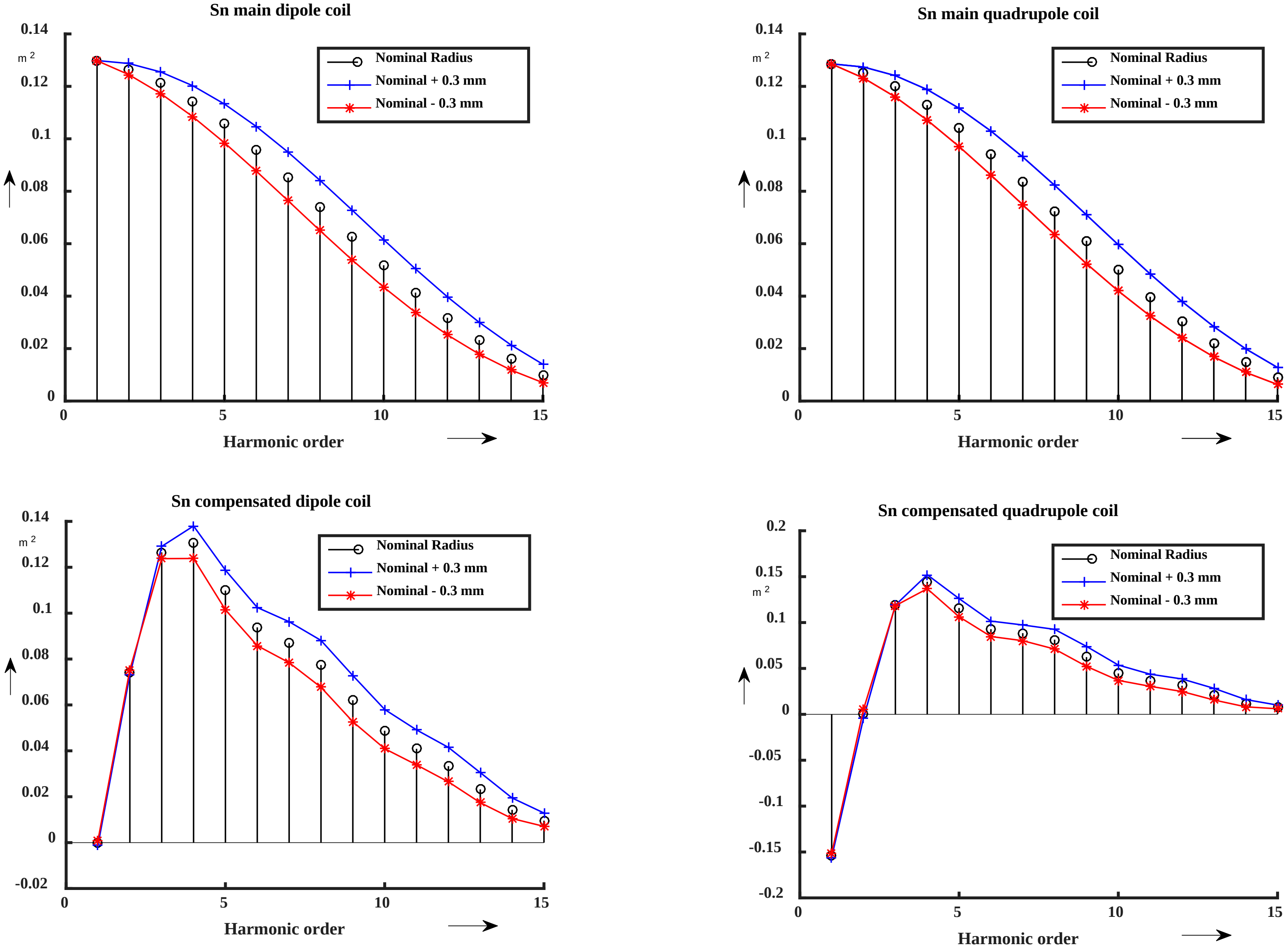


Suitable bucking ratio >100
Shaft radius tolerance -20 ,+100 µm

Acceptable shaft radius tolerance ±0.05 mm

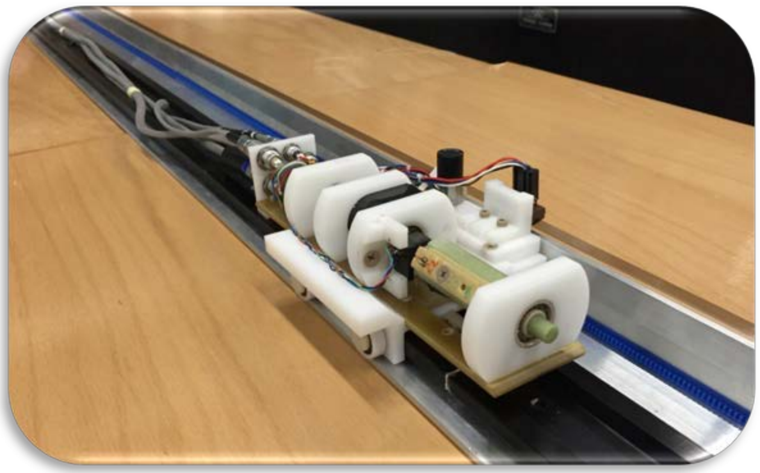
Sensitivity analysis of manufacturing errors

Sn values computed in the radius tolerance range (-0.3 mm; +0.3 mm)



Measurement system design for proof of principle

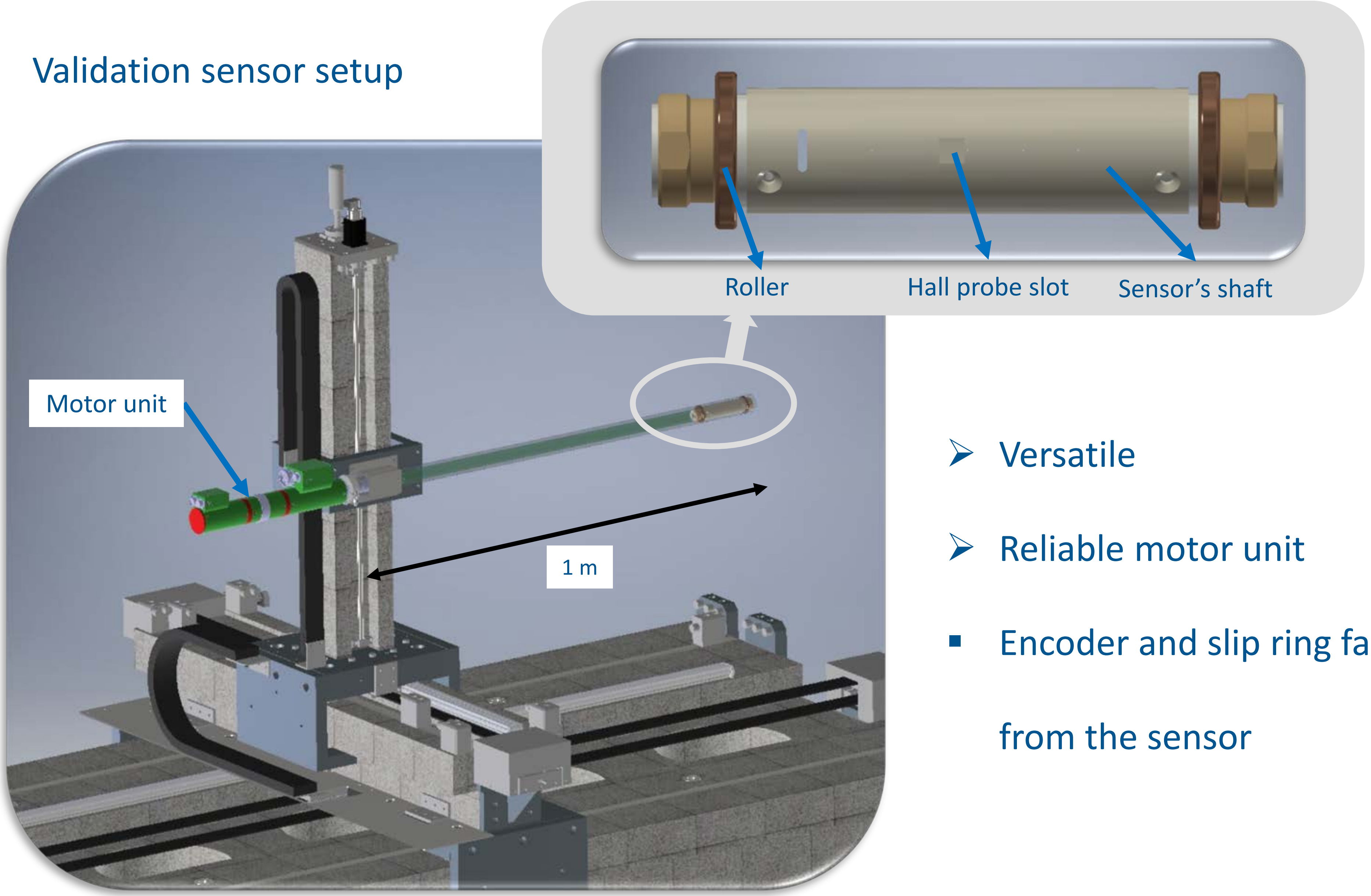
Translating system based on rails



- ➢ Appropriate mechanical stability
- ➢ Transversal position encoder
- ➢ Encoder and slip ring close to the sensor
- Electrical motor onboard
- Bulky structure (reducing the effective measurement radius)

Measurement system design for proof of principle

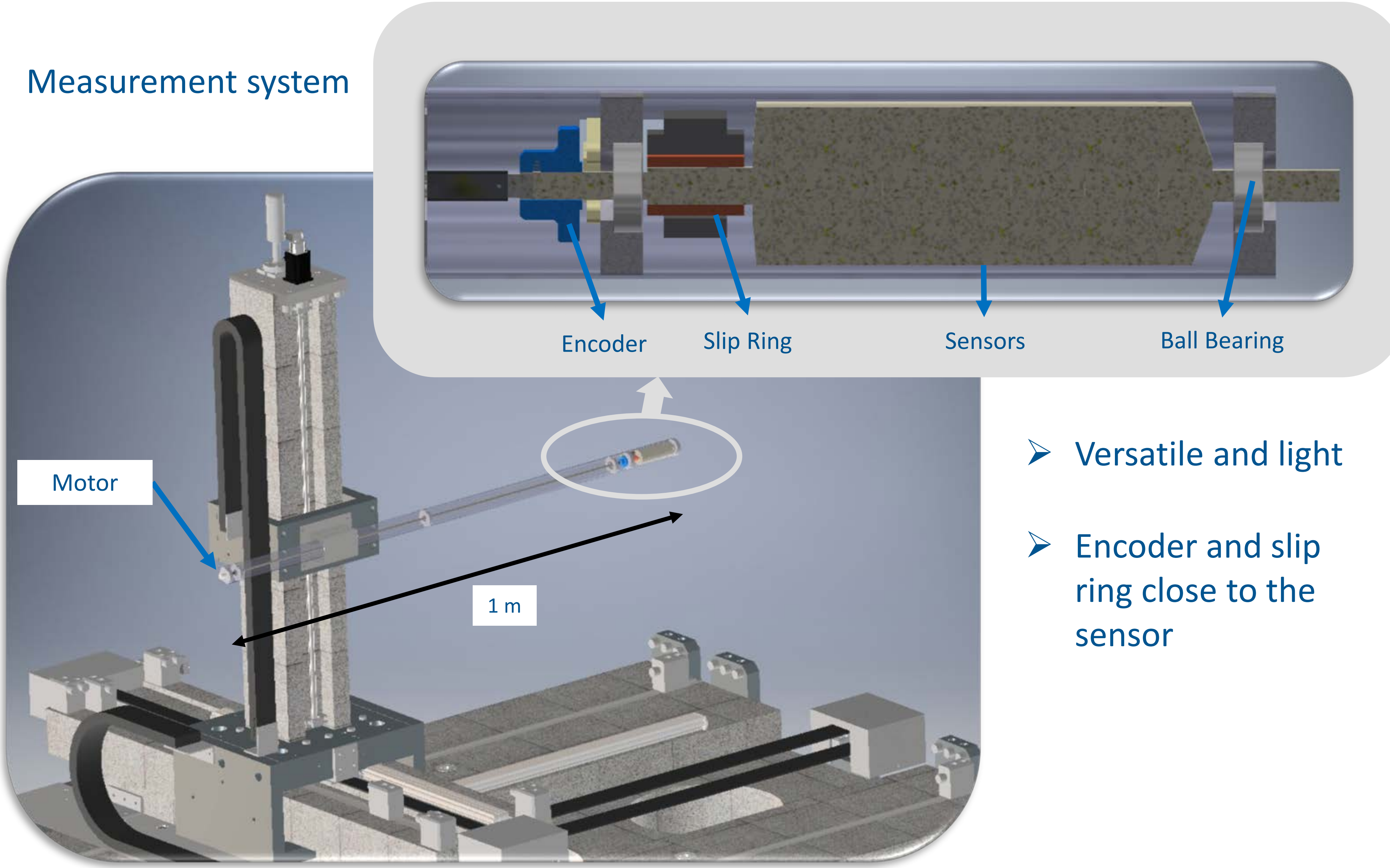
Validation sensor setup



- ➢ Versatile
- ➢ Reliable motor unit
- ▪ Encoder and slip ring far from the sensor

Measurement system design for proof of principle

Measurement system



- Versatile and light
- Encoder and slip ring close to the sensor

Conclusion

Future steps

- Sensor calibration
- Sensor validation
- Optimize design of the transducer
- Transducer production, assembly and commissioning