Introduction to Frequency Scanning Interferometry (FSI) systems

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Outline

- Frequency Scanning Interferometry, Etalon FSI system
- Crab-cavity position monitoring - First FSI project
- Inner triplet FSI position monitoring
- Crab, Inner triplet tests outcome and Etalon FSI drawbacks
- Multi-target Frequency Scanning Interferometry (MT-FSI)
- FSI system choice – Etalon vs. Multi-Target FSI
- MT-FSI development at CERN
- Conclusions
Frequency Scanning (Sweeping) Interferometry

FSI allows absolute distance measurement
- With high accuracy (\(\mu m\) level)
- With no contact
- Without need of homing of measured component
Etalon FSI – classical approach

- Uncertainty (95%) = 0.5 µm/m
- Measurement distance: 0.2 – 20 m

\[ D = \frac{N}{2\Delta v n} \]

, where:
- \( \Delta v \) – change of the laser frequency during sweep;
- \( n \) – refractive index of light transmission medium;
- \( N \) – number of cycles of signal measured during laser sweep;
Crab-cavity position monitoring

- First FSI implementation – Crab-cavity position monitoring under different conditions
- Use of Etalon FSI
Crab-cavity position monitoring

Frequency Scanning Interferometry – main measurement system

- Cavity position/orientation known thanks to absolute distance measurements between cryostat FSI heads and cavity Corner Cube Reflectors (CCR)
- System for HL-LHC use (cold, vacuum and radiation compatible)
Crab-cavity position monitoring

Brandeis Camera Angle Monitoring (BCAM) – only for tests (no radiation hard)

- Cavity position/orientation known thanks to **reflective targets**
  angular position measured by **BCAM cameras** (triangulation method)
- System used for FSI measurements crosscheck - only for SPS prototype alignment validation
Crab cavity monitoring system - conclusions

- Etalon FSI system used with specially designed optics
- System allows to follow the cooled crab cavity position/orientation
- Precision better than 60µm (1σ)

- Several cool-down cycles performed
- Micrometric resolution of objects moves observation
- FSI deployed in SPS crab cavity test stand
- Continuous measurement by over 6 months
- However! 2 targets visibility lost during measurements (Cryocondensation? Target displacement?)

- See results in later V. Rude presentation
Inner Triplet FSI monitoring system

- Needed continuous position measurement of 12 reflectors installed on the cold mass from the vacuum vessel level

- Main constraints
  - Available space (integration)
  - Target thermal loss have to be minimized (cost of cryogenics)
  - Cryo-condensation effect on the reflectors
  - Extremity reflectors move ~10mm with cold mass contraction
  - Equipment handling, installation and alignment
  - Cost of overall installation
Inner Triplet FSI monitoring system – first tests

- DIPOLE test campaign
- Cryo-condensation issue
Inner triplet FSI monitoring – first tests conclusions

- Etalon FSI system is very sensitive to cryo-condensation effect
- Cryo-condensation observed on optical reflectors
- Higher reflector temperature helps with cryo-condensation issue

New Multi-target FSI (MT-FSI) preliminary tested:
- All targets frequency peaks visible in reflected light spectrum (with small cryo-condensation layer)
Inner triplet FSI monitoring – cryocondensation solution

- The special design of targets (temperature optimized)
- Target supports tested on the DIPOLE with Newport hollow retroreflector and coated glass ball reflector tested
- Crab-cavity heads / External collimator through window / Dedicated MT-FSI heads tested on the DIPOLE (see later slides)

F. Micolon – TE/MSC-CMI
Etalon FSI – drawbacks

FSI – absolute interferometric distance measurement

- System sensitive to return signal intensity level
  - Reflector lateral position or dust on the mirror have big impact on measurement performance
- Beam diameter defines the transversal movement range of the target (for typical collimators limited ~ +/-3.5mm)
- Optical feedthroughs needs to include tip-tilt adjustment functionality for initial beam position targeting into retroreflector (higher cost of feedthrough)
- Only collimated beams and observation single target
Multi-target FSI

- New approach to FSI signal analysis – Fourier based distance calculation from detected beat frequencies

\[ D_n = c \frac{f_{\text{beat}[m]}}{2 \frac{dv}{dt} n} \]

- \( \alpha \) – is a sweep rate of the laser (\( \alpha = \frac{dv}{dt} \) – laser frequency change in time);
- \( c \) – speed of light;
- \( n \) – refractive index of light transmission medium;
- \( \tau \) – time of flight of laser to the target
Multi-Target FSI

- First prototype setup tested at CERN since autumn 2017
- Allows for flexible optical connections and scalability of the interferometer channel number
Multi-target FSI

- Very robust measurement method – almost insensitive to the light intensity (high and very small power reflections visible over the noise background)
- Possible to use cheap glass balls as a reflectors
- Possible to measure multiple targets within single laser scan
- Beam delivery optics can be very simple
- **Possible to use with the collimated and divergent beams**
- Simple and scalable Optics
Multi-target FSI

- Divergent beam use example

- CMM vs. MT-FSI measurements
- Uncertainty estimated to 5 µm (single laser configuration, no vibrations)
- Repeatability +/- 1..2 µm
Multi-target FSI

First use of MT-FSI in accelerator environment in the World!

Allows construction of divergent beam FSI heads

- Space constraint problem solved (compact and easy construction)
- Wide PATROL field – big lateral reflector movement range
- Low cost (simple optics)
Multi-Target FSI

Multi-reflection from various surfaces

- Possible multi-distance sensors design

Measurements to water surface

- Possibility of construction of simple Hydrostatic Levelling Sensors
Multi-target FSI

Multiple-distance, cheap reflectors
- Possible multi-sensor/multi-distance solutions
- Measurements to glass ball reflectors
Multi channel prototype to optimize future "production" design:

- 32 measurement channels organized in two banks of different architecture.
- Integrated temperature/pressure/humidity measurement.
- Fits inside a 4U 19” rack.
- Power consumption around 200 W
**Multi Target FSI – Compact measurement unit**

- Photodetection module – 16 channels multiplexed electrically
- Fiber optic switch - 16 channels multiplexed mechanically

**Chassis during assembly**

**Assembled photodetection module**

**Status**
- Chassis under assembly
- Software „BETA” version ready and under tests on 2nd interferometer prototype
- Initial tests of new module - pending
Summary

Multi-target FSI allows to fulfil all requirements of IT and crab-cavity application

- Allow for small space integration (space constraint)
- No issues with optics alignment
- Tolerance to big lateral target(s) movements
- Simple and cheap optical components
- Interferometer is not a BLACK BOX
- Big potential of MT-FSI use for future sensors design
Thank you for your attention