'Invisible' beam profile monitor for precision measurements in medical applications

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Applying detector technologies originally developed for high energy physics experiments for medical applications

Online monitoring of hadron beams during treatment is of paramount. To prevent negative effect of treatment a high precision diagnostic systems should be applied.

Beam monitoring system will improve dose calculation accuracy -> Increase treatment efficiency.

To define the dose distribution and its reliability, detector should have good precision of positioning and beam monitoring, as well as high radiation tolerance, since modern radiotherapy seeks to reduce the beam size (thus increasing the intensity of the beam).
Shaping and monitoring of mini-beams of charged particles and gamma-rays for spatially fractionated radiation therapy

Make Irradiation field inhomogeneous:

Shape it as mini-beams (0.6 mm width and 1.2 mm periodical structure) or micro-beams (50 µm and 100 µm periodical structure)

Developed for the synchrotron radiation at ESRF (Grenoble)

Tested at animals – positive effect due to the increased dose in the open area of the collimator.

Criteria of profit – PVDR

Measured for the first time in real time in 2011 in Collaboration KINR_ESRF_Medipix(CERN) – spatial dose distribution in agreement with gafchromic films (off-line, time consuming procedure, yet with a perfect position accuracy – few micrometers).


New idea (IMNC, Yolanda Prezado) – to implement it for the hadron beams (feasibility studies started at HIT – Heidelberg in 2014 (KINR-IMNC-CERN)

Fractionizing hadron beam

Slit Colimators
(1.0 mm width, 2.5 mm c-t-c distance)

Matrix collimators
(holes of 1.5 x 1.5 mm$^2$ and c-t-c distance of 4 mm)

Material: aluminum, brass, lead

the collimators designed and made in Ukraine – to test the possibility to make multi-beam structure – fractionated hadron therapy.
Metal Microstrip Detectors (MMD)

Advantages of the MMD:

- High Radiation tolerance (>100 MGy)
- Nearly transparent sensor – 1 μm thickness
  the thinnest detector ever made
  for the particle detection
- Low operation voltage (20 V)
- Perfect spatial resolution (10 μm)
- Unique, well advanced production technology
- Commercially available readout hardware
  and software.

MMD applications:

- Non-destructive beam profile monitoring
- Precise dose distribution measurements for micro-biology, medicine etc.
- Imaging X-ray and charged particle beams
- Detectors at the focal plane of mass-spectrometers and electron microscopes

Photo of MMDs. Ni strips: 1 μm thick
**MMD Principle of operation**

**Signal** – positive charge created by the electron emission under the impinging particles.

**Conversion factor** – electrons/particle: ranges from 0.1 (for MIP) to few hundreds (for the fast Heavy Ion)

**Noise** – thermoelectric emission, r/f pickup, fluctuation of the leakage current, …

Determined by the connecting cable and readout electronics:

ENC: (100 – 500) electrons

**Thickness** – 1 μm (transparent, non-destructive device for the measured beam)

**Position resolution** – ~10 μm

This technology works with x-rays, protons and other ion beams!

Radiation hardness - more than 100 MGy

Stable operation at X-ray intensity - up to $10^{16}$ photons·s$^{-1}$·mm$^{-2}$

Stable operation at proton beam intensity - up to $10^{10}$ protons·s$^{-1}$·mm$^{-2}$
Production technology

PRODUCTION TECHNOLOGY

The sensors were prepared by means of microelectronics technology and plasma-chemistry etching. Nickel layers served as films for the photo-lithography shaping of the strip pattern as well as contacting lines and pads. From the back side of the sensor a window was created for the plasma-chemistry etching. The KINR plasma-chemical reactor with variable ion energy has been used.

The strips were bonded to the ceramics based pitch adapter and connected by a flexible kapton isolated cable to the 50-pin connector.

Metal strip sensor is the only object interacting with the radiation beam in the working area.
Earlier applications

- HERA-B Luminosity monitoring
- LHCb Radiation Monitoring system
- BPM for 21 MeV proton beam (tandem MPIfK)
- BPM for the LHCb (ST) test beam studies
- 21 keV Synchrotron BPM at HASYLAB

Metal Foil Detector technology allows for Building any size beam monitoring systems

Metal detectors are suitable for measuring and imaging beams of charged particle in the energy range from keV to TeV as well as synchrotron radiation.
Metal Detector measuring High intensity X-Ray beams

Measurements at the beamline ID17 ESRF (Grenoble)

The experiment (ESRF, MI1056) was carried out at the beamline ID17 with closed wiggler gap (24.8 mm) in the 16-bunches mode and with 200 mA electron beam current in the storage ring with the electrons energy of 6 GeV. X-rays with peak energy of 150 keV (ranging from 20 to 500 keV) were produced with intensity of $2,7 \times 10^9$ photons/(c×mm²×mA).

Radiation hard detectors are required!

Metal TimePix detector imaging the X-ray beam. Color grade indicates the relative beam intensity.
Characterization studies of the Metal TimePix measuring in real time dose distribution at the Mini-beam Radiation Therapy setup (ESRF, Bio-Medical Beamline ID17) were performed.

The results obtained for high intensity synchrotron radiation mini-beams illustrate an excellent performance of the TimePix providing 2D image of the high level dose distribution over many beams in (14 x 14) mm² area.

Peak-Valley-Ratios measured by TimePix and gafchromic films agree well.
**MMD Tests**

3 MeV Proton beam profile monitoring. Tandem-generator at INR (Kyiv)

Spatial (Horizontal and Vertical) Proton Beam Profiles

MMD64: 64 strips, 100 μm pitch, 40 μm width, 1 μm thick
Feasibility studies of the spatially fractionated hadron therapy. HIT (Heidelberg)

Primary carbon ion beam time and spatial structure measured by MMD

Graph

Time structure

Spatial distribution of the intensity of the primary beam in X- and Y-direction.

Fixed horizontal beam station of the Heidelberg Ion Therapy center (Germany)

Setting up the collimators designed and made in Ukraine - to test the possibility to make multi-beam structure - fractionated hadron therapy.

MMD was installed for monitoring of the overall beam profile monitoring.

Slit Colimators
(1.0 mm width, 2.5 mm c-t-c distance)

Matrix collimators
(holes of 1.5 x 1.5 mm² and c-t-c distance of 4 mm)

Material: aluminum, brass, lead
HIT. Beam profile monitor

Working area: 80x80 mm²
Channels: 64+64
Resolution: 0.4 mm
Sensitivity: $>10^3 \text{ p/(strip*s)}$
Dynamic range: $10^3$

performance of the MMD in measuring and imaging the primary carbon ions beam features

Spatial (Horizontal and Vertical) Ion Beam Profiles
Detectorized Phantom

Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).

*A few prototype have been produced and tested*
Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).

Detectorized Phantom

Modular imaging system (Up to 168 Detector modules).
The layers of the phantom medium (Plexiglas) and “transparent” detectors follow one another.

XDAS - data acquisition system (SENS-TECH, UK)
MMD for Detectorized Phantom

MMD sensor:
• Size – 35x35 mm²
• Working area – 15x15 mm²
• Strip thickness – 3um
• Strip width – 90 um
• Strip pitch – 110 um

MMD-HV:
• Size – 35x28 mm²
• Working area – 15x15 mm²
• Strip thickness – 3um
• Strip width – 200 um
• Strip pitch – 3000 um

MMD-adapter for XDAS:
• Size – 52x17 mm²
• Input pitch – 110 um
• Output pitch – 400 um

MMD-adapter for Alibava:
• Size – 16x8 mm²
• Input pitch – 110 um
• Output pitch – 80 um

Multiple boards can be connected in series and detectors can be butted end-to-end to provide a continuous array.
XDAS - X-ray data acquisition system

XDAS is a modular system of boards for use in any X-ray linescan applications. Each board has 64 or 128 channels, corresponding to a detector pitch of 2.5, 1.6, 0.8 or 0.4 mm. Multiple boards can be connected in series and detectors can be butted end-to-end to provide a continuous array.

2.5, 1.6, 0.8 or 0.4 mm detector pitch
up to 21504 (128x24DHx7SP) channels in a system
simultaneous data acquisition and read-out
dual energy option
wide dynamic range
16 bit output
high speed USB2 or parallel RS485 link to CPU
Detectorized Phantom. Status

Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).

The MMD sensor as well as HV-plates and adapters for detectorized phantom are designed. Detector module is designed.

First prototypes are under production:
- photolithography – done
- gilding contacts – in work
- plasma etching – in work

Readout system tests:
XDAS – ready to use
Timepix – ready to use
Alibava - testing
Summary

- Metal Micro-detectors is a reliable tool for online measurements of radiation beam parameters.
- Physical features of the MMD makes it applicable for beam diagnostics at any accelerators of charged particles.
- Main advantages of MMD: transparency, radiation hardness, high position resolution.
- MMD have been successfully explored for measuring beam position and beam profile.
- Development of the detectorized phantom for dose delivery verification based on MMD has been started.
Thank You For Your Attention