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A NOVEL FIBER-OPTIC BEAM MONITOR

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Abstract

A novel beam monitor based on Ce-doped silica optical fibers is being presented. Four fibers are mounted on the outside of a beam transport pipe, at the location of a beam stop at a proton cyclotron. The secondary radiation caused by the proton beam interaction with the beam stop is measured by the optical fibers via Radiation-Induced Emission (RIE). The light signal in the individual fibers is correlated to the proton flux closest to the fiber and can therefore be used as a detector to monitor the position of the proton beam in the beam stop. Initial testing shows that monitoring of a 150 nA beam of 18 MeV protons into a beam dump is possible. The monitor can measure relative beam current and beam displacement in X and Y as a function of magnetic steering.

INTRODUCTION

Measuring the position and profile of a particle beam, especially at low energy where the deposited beam power is large, can be difficult and is typically done by several methods: this includes measuring the beam current and profile on a wire either being stationary in the beam or traversing quickly through the beam [1], radiographic analysis of irradiated foils using a radiosensitive film [2, 3], impinging the beam onto a scintillating material and observing the pattern with a camera [4–6], and some combination of non-intercepting electrically-isolated material in the beam [7]. All these techniques have limitations, either in providing only a snapshot of the beam, recording the beam averaged over a period of time, being non-linear over the whole intensity spectrum of the beam, or only measuring the tails of the beam.

Organic and inorganic Optical Fibers (OFs) are increasingly utilized in space and medical applications, including accelerator and reactor environments to monitor beam currents and shapes, doses, temperatures, and pressures [8–12]. OFs are ideal as they can be radiation hard, small in size, independent from electromagnetic environments, and linear over a large measurement range. Here we present a new application in conjunction with a medical cyclotron, where a collar of four Ce-doped silica fibers is mounted onto a beamline. This External Fiber Monitor (EFM) is able to measure the position of the beam at the monitor position.

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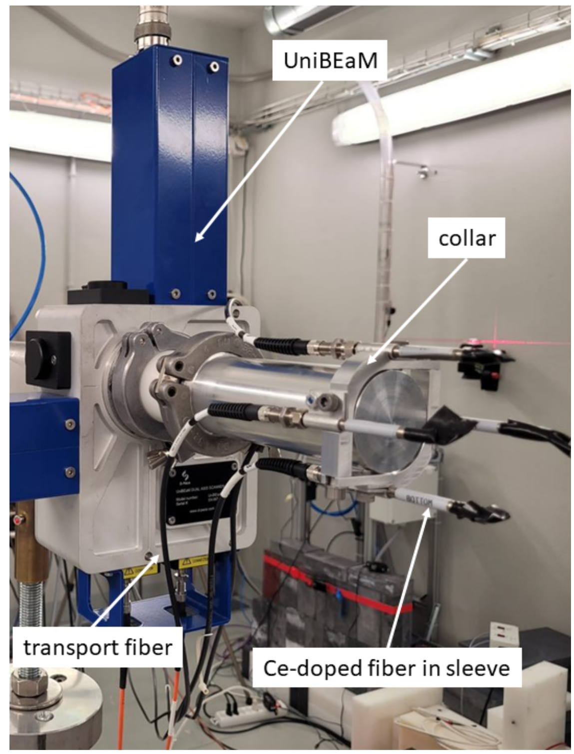

Figure 1: EFM mounted at the end of the beamline at the beam stop.

In our experiments, measurements of the OF RIE signal from prompt neutrons and gammas produced by the proton beam as its bombardment position changes in a beam dump are made. This is an extension of our previous work with a similar setup to monitor beam delivery onto a medical isotope target at a cyclotron [13]. The advantage is that the OFs are outside of the vacuum and do not need to intercept the beam.

MATERIALS AND METHODS

Irradiations

The experiment took place at the Bern medical cyclotron laboratory at the Bern University Hospital (Inselspital) [9]. The cyclotron is an 18 MeV IBA Cyclone which is capable of extracting proton beam currents from a few pA [14] up to 150 µA. The cyclotron facility is equipped with a Beam Transfer Line (BTL) with dedicated steering and quadrupole magnets, leading to a separate bunker for research purposes,

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where the EFM was mounted at the end of the beamline at the position of the beam stop, see Fig. 1.

The beam position was independently monitored with the UniBEaM, a fiber-based beam monitor developed by the Bern group [12] and commercialized by D-Pace [15]. The UniBEaM utilizes optical fibers installed in the vacuum envelope, which are moved through the beam to extract the beam shape and position. It is mounted upstream of the EFM, see Fig. 1.

External Fiber Monitor

For the EFM, doped silica fibers provided by D-Pace were fabricated by the University of Milano-Bicocca's Department of Material Science (UMB-DMS) using the sol–gel process [12]. The fibers are SiO_2-doped with Ce^{3+} ions and are drawn to a diameter of 200 µm. Each fiber is placed into an aluminum sleeve for mechanical protection which is closed with black electrical tape to prevent stray light from entering, see Fig. 1. The four sleeves are either mounted on a 2D stage behind the end of the beamline for calibration or on an aluminum collar which is designed to fit around the beam stop at the end of the beamline to function as beam monitor. The fibers are terminated with SMA connectors. Transport cables from Thorlabs (model UM22-200, 0.22 NA, 200 µm diameter, multimode, 20 m long) with SMA connectors bring the light outside of the irradiation bunker and connect to four IDQ ID-100 visible photon counters. The signal is then fed into a Vertilon MCPC618 Multichannel Pulse Counting System for processing.

RESULTS AND DISCUSSION

Normalization

Each individual fiber with SMA connector as well as transport cable has a slightly different RIE and transmission efficiency. To correct for this difference, the four fibers were mounted on a 2D stage right behind the beam stop. During an irradiation of the beam stop with a beam of constant current the fibers were moved horizontally by controlling the 2D stage. After subtracting the background signal for each fiber, measured prior to irradiation, and normalizing to the current measured on target, a fourth-degree polynomial fit was applied to each fiber. The results are shown in Fig. 2. The amplitude at the polynomial peak, normalized to the Top fiber by convention, was considered to be the correction factor for each fiber. This allowed us to assign correction factors to the different channels: top fiber $T = 1.0 \pm 0.1$, bottom fiber $B = 1.3 \pm 0.2$, right fiber $R = 1.4 \pm 0.2$, left fiber $L = 2.2 \pm 0.2$.

Beam Steering

To test the beam-steering monitoring capabilities of the EFM, experiments were conducted with the fibers mounted on the collar. The proton beam of ~150 nA was steered horizontally, and the beam profile was simultaneously measured via the UniBEaM. To obtain the beam position from the beam profile, a spline with 500 data points was created and integrated. The position in millimetres of the integral's half-sum was considered as the average beam position. The results are shown in Fig. 3. The beam position as measured

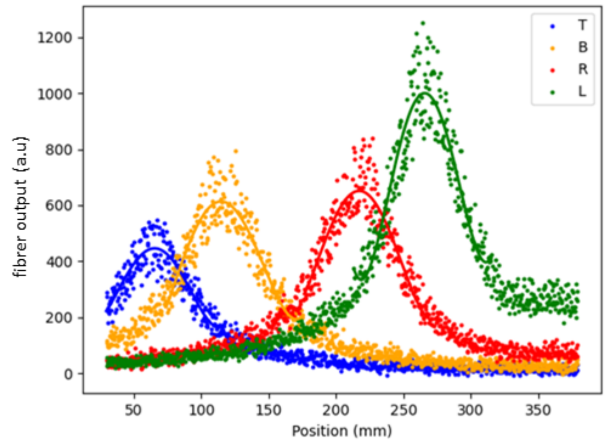

Figure 2: Light output of the four fibers to be mounted at the top (T), bottom (B), right (R) and left (L) of the beam stop, before normalization. Solid lines indicate the fourth-degree polynomial fit.

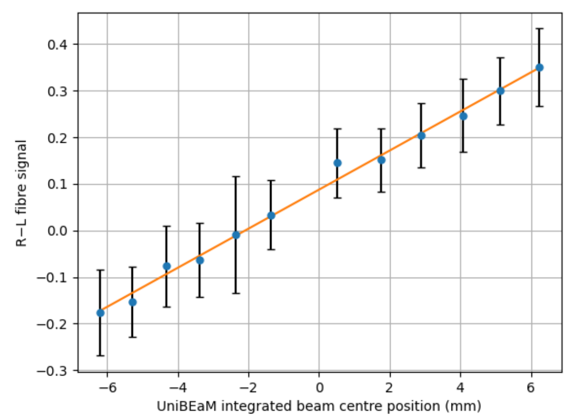

Figure 3: Difference in normalized light yield between the right (R) and left (L) fibers against the beam position as measured via the UniBEaM. The linear fit has a coefficient of determination of $R^2 = 0.993$, slope = 0.042, intercept = 0.09.

with the UniBEaM is plotted against the difference in the light yield between the right and left fibers. The fiber outputs are background-subtracted, corrected according to the correction factors obtained, and normalized to the current on target. The error bars indicate the propagated standard deviation for the R-L calculation based on the standard deviations in the fiber output data points for each UniBEaM position. While there is a small offset at position zero, overall a linear correlation between the UniBEaM and the EFM is observed, with a spatial resolution of < 0.2 mm. This confirms that the EFM can be utilized to measure the beam position in

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the beam stop, after calibration against a secondary beam monitor.

Dose Rate Linearity

To test the dose rate-measuring capability of the EFM, the fibers were mounted on the collar and the current on the beam stop was varied. The sum of all four fiber signals was plotted against the current. The result is shown in Fig. 4. Very good linearity is observed, demonstrating the ability of the EFM to function as a beam-current monitor.

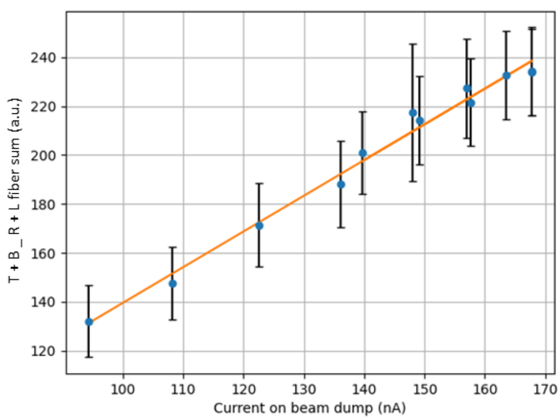

Figure 4: Sum of fiber signals (T+B+R+L) vs. current on target for the R-L steer experiment. Fiber correction factors and background subtraction are applied. Error bars indicate the summed, propagated standard deviation for all four fibers. $R^2 = 0.987$, slope = 1.46, intercept = −6.6.

CONCLUSION

We demonstrated that our new EFM can measure relative beam current, as well as relative beam position. This can be achieved by mounting the EFM on the outside of a beam pipe or structure, without breaking the vacuum envelope. The measurements are in real time, and can be calibrated to absolute beam current and position with a secondary measurement, for example a Faraday cup and the UniBEaM.

We envision that the EFM can also be used in locations of a collimator or other structures where a small amount of the beam is stopped or scattered. Further experiments to improve the EFM, including testing at lower and higher beam currents, and to expand the applications are planned.

ACKNOWLEDGEMENTS

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REFERENCES

[1] W. Gelbart *et al.*, "Simple Beam Profile Monitor", *AIP Conf. Proc.*, vol. 1509, p. 38, 2012. doi:10.1063/1.4773936

[2] M. A. Avila-Rodriguez *et al.*, "A simple method for measuring the beam profile of charged particle accelerators", in *Proc. the Twelfth Workshop on Targetry and Target Chemistry*, University of Washington, Seattle, 2008, p. 54.

[3] M. A. Avila-Rodriguez, J. S. Wilson, and S. A. McQuarrie, "The use of radiochromic films to measure and analyze the beam profile of charged particle accelerators", *Appl. Radiat. Isot.*, vol. 67, p. 2025, 2009. doi:10.1016/j.apradiso.2008.10.009

[4] R. E. Laxdal, A. Altman, T. Kadantsev, and T. Kuo, "Beam Measurements on a Small Commercial Cyclotron", in *Proc. EPAC'94*, London, UK, Jun.-Jul. 1994, pp. 545–548.

[5] S. Braccini *et al.*, "A two-dimensional non-destructive beam monitoring detector for ion beams", *Appl. Sci.*, vol. 13, p. 3657, 2023. doi:10.3390/app13063657

[6] C. Belver-Aguilar *et al.*, "A Novel Three-Dimensional Non-Destructive Beam-Monitoring Detector", *Appl. Sci.*, vol. 10, p. 8217, 2020. doi:10.3390/app10228217

[7] J. S. Wilson *et al.*, "A simple target modification to allow for 3D- beam tuning", in *Proc. the 13th Workshop on Targetry and Target Chemistry*, Technical University of Denmark, 2010, no. 033.

[8] S. Girard *et al.*, "Atmospheric Neutron Monitoring through Optical Fiber-Based Sensing", *Sensors*, vol. 20, p. 4510, 2020. doi:10.3390/s20164510

[9] S. Braccini, "The new Bern PET cyclotron, its research beam line, and the development of an innovative beam monitor detector", *AIP Conf. Proc.*, vol. 1525, pp. 144–150, 2013. doi:10.1063/1.4802308

[10] C. Penner *et al.*, "Characterization of a Terbium-Activated Gadolinium Oxysulfide Plastic Optical Fiber Sensor in Photons and Protons", *IEEE Sensors*, vol. 18, p. 1513, 2018. doi:10.1109/ICSENS.2018.8589672

[11] C. Hoehr *et al.*, "Novel Gd^{3+}-doped silica-based optical fiber material for dosimetry in proton therapy", *Sci. Rep.*, vol. 9, p. 16376, 2019. doi:10.1038/s41598-019-52608-5

[12] M. Auger *et al.*, "A detector based on silica fibers for ion beam monitoring in a wide current range", *J. Instrum.*, vol. 11, p. P03027, 2016. doi:10.1088/1748-0221/11/03/P03027

[13] C. Hoehr *et al.*, "Ce- and B-Doped Silica Fibers for Monitoring Low-Energy Proton Beams on a Medical Cyclotron", *Appl. Sci.*, vol. 10, p. 4488, 2020. doi:10.3390/app10134488

[14] M. Auger *et al.*, "Low current performance of the Bern medical cyclotron down to the pA range", *Meas. Si. Technol.*, vol. 26, p. 094006, 2015. doi:10.1088/0957-0233/26/9/094006

[15] D. E. Potkins *et al.*, "Low-cost Beam Profiler Based on Cerium-doped Silica Fibers", *Phys. Procedia*, vol. 90, pp. 215–222, 2017. doi:10.1016/j.phpro.2017.09.061