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DEVELOPMENT OF AN AUTOMATED BPM TEST BENCH

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Abstract

The Institute for Applied Physics (IAP) of Goethe University Frankfurt has a long history in developing DTL-cavities and further essential components of particle accelerators from design and simulation up to tuning and final testing. In recent times, the development of beam diagnostic components for the hadron accelerator projects has become increasingly important. BEVATECH is designing and setting up linear accelerators, RF and vacuum technology for research laboratories and enterprises worldwide. In a joint effort a simple, efficient and mobile beam position monitor (BPM) test bench has been developed and will be further improved for future tests and the calibration of beam position monitors. It is fully automated using single-board computers and microcontrollers to obtain the essential calibration data like electrical offset, button sensitivity and the 2D response map. In addition, initial tests with the implementation and evaluation of the Libera signal processing units Single Pass H and Spark were promising.

INTRODUCTION

Beam position monitors are an essential tool for the operation of a particle accelerator. As a non-destructive diagnostic device, they are used very frequently in nearly all linacs, cyclotrons and synchrotrons worldwide. Providing the beam's center of mass position as well as a monitor for longitudinal beam position and shape, the BPM is an indispensable component of beam diagnostic strategies.

BPMs for several projects and a corresponding BPM test bench (see Fig. 1) have already been developed or are currently under development by IAP and BEVATECH. These include for example the MYRRHA (Multipurpose hYbrid Research Reactor for High-end Applications) project [1] which aims at realizing a pre-industrial Accelerator Driven System (ADS) to explore the transmutation of long lived nuclear waste. Furthermore, it will also be used as multipurpose irradiation facility applying fast neutrons. The linac for this ADS will be a high-power proton accelerator delivering 2.4 MW CW beam at 600 MeV [2, 3].

Further BPM developments are related to NICA (Nuclotron-based Ion Collider fAcility) at JINR (Joint Institute for Nuclear Research) in Dubna, Russia. The NICA facility aims to perform a wide program of fundamental and applied research with ion beams from p to Au at energies from a few hundred MeV/u up to a few GeV/u. As an injector for heavy ions into the Booster synchrotron of the NICA accelerator facility the Heavy Ion Linac (HILac) has recently been put into operation. The HILac consists of three accelerating sections (RFQ and two DTL sections based on IH-DTL cavities) and a medium energy beam transport (MEBT) section [4].

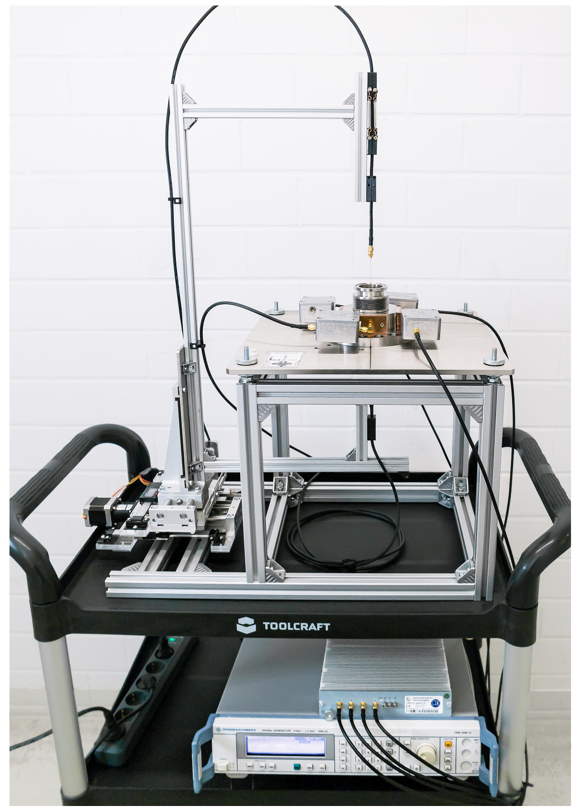

Figure 1: View of the BPM test bench with Libera Spark for data acquisition.

In the frame of the NICA ion collider upgrade a new light ion frontend linac (LILac) for protons and ions with a mass-to-charge ratio of up to 3 will be built [5–7]. Consisting of three parts - a normal conducting linac up to 7 MeV/u, a normal conducting energy upgrade up to 13 MeV/u and a superconducting section - the first part will be built in collaboration between JINR and BEVATECH. This also includes beam diagnostic devices like beam position monitors.

After manufacturing of a BPM, it should be tested to measure the button's sensitivity, the deviation of its mechanical and electrical center as well as non-linearities in the format of a 2-dimensional response map. The latter is used to determine the differences between the theoretical and measured beam positions. For these calibration measurements, many laboratories worldwide use a wire-based approach [8–24]. By feeding the copper wire with an RF-sine signal, which

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is aligned parallel to the ideal beam axis and terminated by 50 Ohm at the other end, the beam's *E*-field radiation is simulated. The signal picked up by the BPM electrodes is then read and processed. By moving the beam position monitor or the wire in the transversal plane, different horizontal and vertical beam positions can be simulated and thus the influence on the button signals can be measured.

THE BPM TEST BENCH

For the automation of the aforementioned tests, a simple, efficient and mobile BPM test bench has been developed. It is based on a Bosch Rexroth aluminum frame paired with a precise stainless-steel plate to accommodate the BPM. Milled markings ensure the positioning of the Beam Position Monitor to place the wire exactly in the geometric center. For control and data acquisition (DAQ), the software TBenS (Test Bench Software) has been written in C# and is completely object-oriented. Motor control is performed by a CNC control kit with two A4988 driver chips, which are controlled by an Arduino UNO R3 via a Grbl implementation [25]. Grbl is a free, open source, high performance software for controlling the motion of machines and is used to position the wire within the BPM.

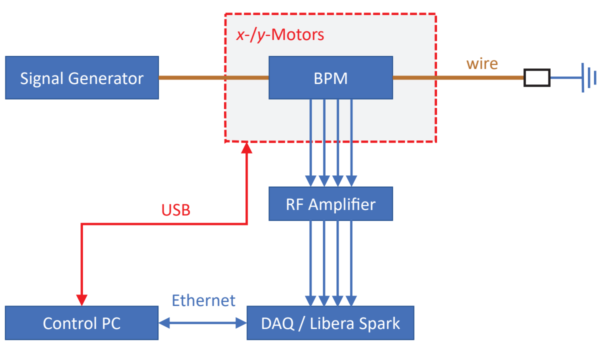

Figure 2: Schematic layout of the BPM test bench cabling.

A schematic layout of the test bench and cabling is shown in Fig. 2. The vertical wire through the BPM can be positioned using a stepper motor controller. Two crossed linear axes form a cross slide and cover a measuring range of 75 · 75 mm. A standard NEMA17 2-phase stepper motor with a resolution of 400 steps per revolution enables a calculated positioning accuracy from one direction of 5 µm. The absolute positioning accuracy coming from one direction is 10 µm. Two additional digital calipers are used for the optical control of the wire position and for adjustment with the computer control.

Positioning of Wire and BPM

One of the crucial questions at a BPM test bench is the positioning and alignment of the BPM relative to the wire passed through. On the one hand an exact positioning, on the other hand the simple assembly and disassembly of the BPM must be given. For this purpose, a high-precision stainless steel plate was manufactured to accommodate the BPM. Two continuous V-grooves in the middle of the plate, which run exactly through the middle of the hole circle cutout, ensure the exact, optical positioning of the wire in the geometric center of the hole circle (see Fig. 3)

The BPM usually has reference surfaces or fitting holes on which it can be aligned relative to the stainless steel plate. Threaded holes in the plate with a DN 63-200 CF bolt circle diameter provide for the fixation of the BPM during the measurement. Special sizes or other BPM geometries can be fixed to the plate using clamping claws. The stainless steel plate itself is adjustable in height at its four edges and can be aligned by means of a bull's eye spirit level. The wire itself is aligned exactly vertically by a second wire that can be mounted as a perpendicular. The Bosch Rexroth profile can be adjusted and fixed accordingly.

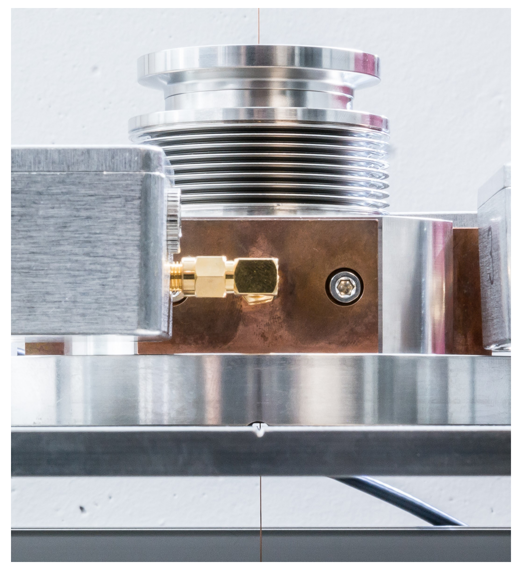

Figure 3: V-groove for wire positioning.

The wire is attached to a top and bottom SMA cable via two SMA plugs. The holders of the SMA cable as well as the tensioning device were created with a 3D printer. The SMA cable is tensioned by 4 parallel, adjustable springs to vary the pre-tension force for different wire thicknesses. For mounting and dismounting the BPM, the wire can be easily separated at the connection to the SMA cable.

In order to minimize the vibrations on the test bench and thus on the wire, the starting and stopping curve of the stepper motors was optimized. In addition, the waiting time until the measurement of the signal from the electronics (e.g. an oscilloscope or Libera Single Pass H / Spark) can be adjusted in the TBenS program.

Automated Data Acquisition

The BPM measurement is automated via the software TBenS (as shown in Fig. 4), which has been specially developed with the BPM test bench. After positioning the BPM, the wire is exactly in the middle at zero position. The stepper motor driver is controlled via USB cable and the measuring electronics connected via Ethernet. At the oscil-

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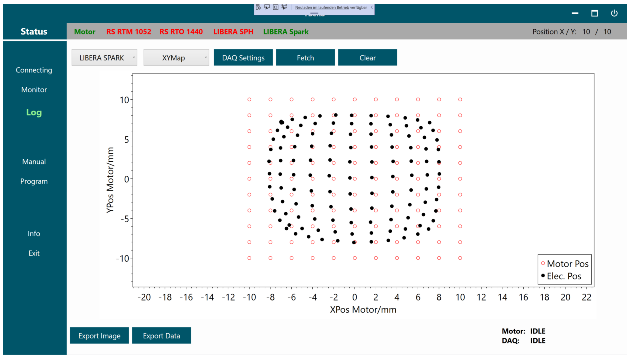

Figure 4: Screenshot of a TBenS data acquisition window showing a 2D response map.

loscopes an IVI.NET interface is used for communication, with the Libera Single Pass H and Libera Spark commands via SSH connections are used. After successful initialization the program is given a file with *x*-*y* coordinates to be approached. The data recorded when moving the position can be visualized directly on the screen and saved in a file for further processing. Two digital calipers are used to check the approached positions. In numerous tests an absolute and reproducible positioning precision to ± 0.05 mm was achieved.

Conclusion

The aim of this development was to set up and commission an automated BPM test bench. With a few exceptions, only of-the-shelf components were used. Open source software was implemented to control the stepper motors and additionally needed small parts were created directly with a 3D printer. Thus, the mechanical part of the test bench could be realized very precisely and at the same time cost-effectively. The interaction of the electronic components was done with the developed program TBenS. After an easy process of setting the measurement range, the BPM test bench carries out the necessary steps itself, provides the results directly visually and saves them for subsequent processing.

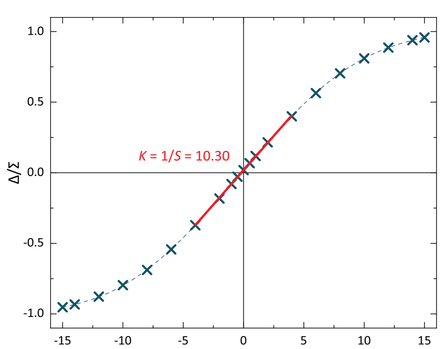

Figure 5: Exemplary BPM sensitivity measurement with a linear fit for the centre region *(red)*.

Exemplary measurements of the linearity of 4-button BPMs (see Fig. 5), the deviation of the geometrical from the electrical centre and of 2D response maps for checking the correction coefficients between the geometrical and electrical positions were done. Through automation, the results can be obtained quickly. Further developments will focus on enhancing the user experience even more.

REFERENCES

[1] D. Maeder *et al.*, "Construction of the MYRRHA Injector", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2221–2223. doi:10.18429/JACoW-IPAC2017-TUPVA062

[2] D. Vandeplassche *et al.*, "Integrated Prototyping in View of the 100 MeV Linac for Myrrha Phase 1", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 661–664. doi:10.18429/JACoW-IPAC2018-TUPAF003

[3] D. Maeder *et al.*, "Status and Development of the MYRRHA Injector", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 432–434. doi:10.18429/JACoW-IPAC2018-MOPML017

[4] A. V. Butenko *et al.*, "Development of NICA Injection Complex", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 2103–2105. doi:10.18429/JACoW-IPAC2014-WEPRO067

[5] E. Syresin *et al.*, "NICA Accelerator Complex at JINR", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 452–454. doi:10.18429/JACoW-IPAC2019-MOPMP014

[6] B. Koubek *et al.*, "The New Light Ion Injector for NICA", in *Proc. 29th Linear Accelerator Conf. (LINAC'18)*, Beijing, China, Sep. 2018, pp. 362–365. doi:10.18429/JACoW-LINAC2018-TUPO017

[7] H. Hoeltermann *et al.*, "Light Ion Linear Accelerator up to 7 AMeV for NICA", in *Proc. 26th Russian Particle Accelerator Conf. (RuPAC'18)*, Protvino, Russia, Oct. 2018, pp. 68–71. doi:10.18429/JACoW-RUPAC2018-WECAMH02

[8] N. Delerue, D. Auguste, J. Bonis, F. Gauthier, S. Jenzer, and A. M. Moutardier, "Tests of a 3D Printed BPM with a Stretched Wire and with a Particle Beam", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 4368–4371. doi:10.18429/JACoW-IPAC2019-FRXXPLS1

[9] M. Ben Abdillah *et al.*, "Development of the Beam Position Monitors for the SPIRAL2 Linac", in *Proc. 1st Int. Beam Instrumentation Conf. (IBIC'12)*, Tsukuba, Japan, Oct. 2012, paper TUPA18, pp. 374–377.

[10] I. Podadera *et al.*, "Developments for IFMIF/EVEDA LIPAc Beam Position Monitors: The Sensors at the MEBT and the Wire Test Bench", in *Proc. 10th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC'11)*, Hamburg, Germany, May 2011, paper TUPD11, pp. 320–322.

[11] M. W. Wang *et al.*, "A Rotation Method to Calibrate BPM Electric Offsets", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 2595–2597. doi:10.18429/JACoW-IPAC2019-WEPGW052

ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-WEPP045

[12] S. Zorzetti, N. Galindo Munoz, M. Wendt, and L. Fanucci, "Stretched-Wire Techniques and Measurements for the Alignment of a 15GHz RF-BPM for CLIC", in *Proc. 4th Int. Beam Instrumentation Conf. (IBIC'15)*, Melbourne, Australia, Sep. 2015, pp. 487–491. doi:10.18429/JACoW-IBIC2015-TUPB063

[13] A. A. Nosych *et al.*, "Measurements and Calibration of the Stripline BPM for the ELI-NP facility with the Stretched Wire Method", in *Proc. 4th Int. Beam Instrumentation Conf. (IBIC'15)*, Melbourne, Australia, Sep. 2015, pp. 423–427. doi:10.18429/JACoW-IBIC2015-TUPB048

[14] H. Hassanzadegan, A. Jansson, C. A. Thomas, D. Lipka, M. Werner, and A. Young, "System Overview and Current Status of the ESS Beam Position Monitors", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 3653–3655. doi:10.18429/JACoW-IPAC2014-THPME166

[15] W. M. Zhou, Y. Z. Chen, and Y. Yang, "The Calibration of SSRF BPM", in *Proc. 2nd Asian Particle Accelerator Conf. (APAC'01)*, Beijing, China, Sep. 2001, paper THP033, pp. 603–605.

[16] D. Belver *et al.*, "Overview of the BPM System of the ESS-Bilbao", in *Proc. 10th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC'11)*, Hamburg, Germany, May 2011, paper MOPD21, pp. 89–91.

[17] A. Miura, Z. Igarashi, and T. Miyao, "Design and Performances of Phase Monitor in J-PARC Linac", in *Proc. 26th Linear Accelerator Conf. (LINAC'12)*, Tel Aviv, Israel, Sep. 2012, paper TUPB102, pp. 699–701.

[18] S. W. Jang *et al.*, "The Development of Button Type BPM Electronics for RAON", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 362–364. doi:10.18429/JACoW-IPAC2017-MOPAB100

[19] S. Zorzetti *et al.*, "A Wire-Based Methodology to Analyse the Nanometric Resolution of an RF Cavity BPM", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain, Sep. 2016, pp. 63–66. doi:10.18429/JACoW-IBIC2016-MOPG12

[20] M. T. Gundogan, O. Yavas, A. A. Aydin, E. Kasap, and C. Kaya, "Design, Production and Tests of Button Type BPM for TAC-TARLA IR FEL Facility", in *Proc. 5th Int. Beam Instrumentation Conf. (IBIC'16)*, Barcelona, Spain, Sep. 2016, pp. 27–30. doi:10.18429/JACoW-IBIC2016-MOPG01

[21] J. Fitzgerald and J. Crisp, "A Compact BPM for the Fermilab Main Injector", in *Proc. 17th Particle Accelerator Conf. (PAC'97)*, Vancouver, Canada, May 1997, paper 9P071, pp. 2072–2074.

[22] J. Tan, M. Ludwig, L. Soby, M. Sordet, and M. Wendt, "Commissioning of the CERN Linac4 BPM System with 50 MeV Proton Beams", in *Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May 2013, paper MOPWA037, pp. 750–752.

[23] Q. Luo, J. Fang, D. H. He, and B. Sun, "Cold Test of S-band Re-entrant Cavity BPM for HLS", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, paper MOPE029, pp. 1032–1034.

[24] G. E. Boorman, S. M. Gibson, R. T. P. D, S. Jolly, S. R. Lawrie, and A. P. Letchford, "Development of a BPM System using a Commercial FPGA Card and Digitizer Adaptor Module for FETS", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 3716–3718. doi:10.18429/JACoW-IPAC2014-THPME186

[25] Grbl, https://github.com/grbl/grbl