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DEVELOPMENT OF MODULAR SPARE PARTS FOR THE PROFILE AND POSITION MONITORS OF THE 590 MeV BEAM LINE AT HIPA

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Abstract

A new generation of monitor plugs is under development for the ageing wire profile monitors and beam position monitors which are inserted into massive shielding of the 590 MeV proton beam line at HIPA. The modular mechanical design, aspects of handling, vacuum compatibility, radiation hardness, shielding, cabling and monitor environment are discussed.

INTRODUCTION

Near to the meson production targets M and E, profile monitors (PM) and beam position monitors (BPM) in the 590 MeV beam line from the Ring cyclotron to the spallation neutron source SINQ are inserted into chimneys of the beam vacuum chamber, surrounded by the first shielding (Fig. 1). Monitor plugs contain motors, vacuum flange and feedthroughs at the top, accessible from the service floor, shielding iron, cables and mechanical transmissions in the middle, and wire forks and position pick-ups at the bottom, close to the beam pipe and exposed to much stronger radiation background. Three generations of plugs were designed in the 1980's and 90's, following different mechanical concepts, and after initial improvements all monitors were operated for many years with very few defects. However, in case of a defect, a repair of the lower parts of the plug is hardly possible due to the high activation level and the incongruous manipulator-compatible and modular design. Hence, a defect of a small part may lead to the disposal of a plug of, e.g., 1.7 tons. No complete spare plugs are available for the nine different types of plugs, which are adapted to the local environment. Four types do not include BPMs, which would allow automated centring of the beam to Target E and downstream. They may also contribute to an improved safety of SINQ operation [1]. This still has to be specified as part of a comprehensive evaluation of safety measures.

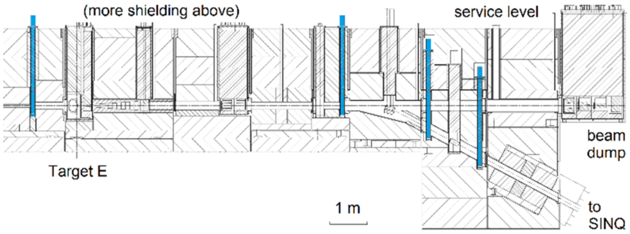

Figure 1: Generation 3 [2] monitor plugs at Target E and downstream. Generation 1 and 2 plugs are located upstream.

After two recent defects, we decided to develop a new generation of monitor plugs instead of copying the old designs, which are not documented in detail [3]. A single concept will be adapted to the different insertion environments. A strict modularity and manipulator compatibility will allow to exchange individual modules from a plug in case of a defect. This also enables later improvements and modifications. The new plug will include BPMs. With an ageing machine and limited resources, the affordability of such a development remains a point of controversial discussion.

MECHANICAL CONCEPT

The new monitor plug will consist of five building blocks [4]:

1. *PM module*, attachable by manipulator to the bottom of the shielding block. With a manipulator-detachable long *transmission rod* and a connector to which a cable module can be plugged into.
2. *BPM module*, attachable by manipulator to the shielding block. With a connector to which a cable module can be plugged into.
3. Two long, from top vertically removable *cable modules*, each housing four conductors. With electrical feedthroughs at the vacuum flange.
4. The main *vacuum flange* with the large *shielding block* mounted. Block with channels for cable inserts and transmission rod, plus a spare channel for later use (e.g., for a loss monitor). Flange with openings for drive module and cable inserts.
5. *Drive module* with motor, rotary vacuum feedthrough and linear stage with end switches, to which a transmission rod can be adapted.

Different from Generation 3, only a single PM module carries both rail guides with wire forks (Fig. 2). Forks with attached wires can still be dismounted separately by manipulator, using a snap fit. Unlike previous generations, horizontal and vertical profiles are measured synchronously. (Temperatures of the molybdenum double wires are well below thermionic emission. Hence, we expect only a minor crosstalk from secondary electrons.) Hereto the fork movement is coupled by a circumferential steel rope guided by four wheels. The use of the transmission rod instead of counter-moving steel ropes or strips, permits a relative simple exchange of the PM module by manipulator. However, at the cost of a slight positioning inaccuracy in the presence of temperature variations. The Generation 2 (see Fig. 9 of [5]) feature, having the forks mounted to a long sword which is retractable from outside through a large channel in the shielding block, was

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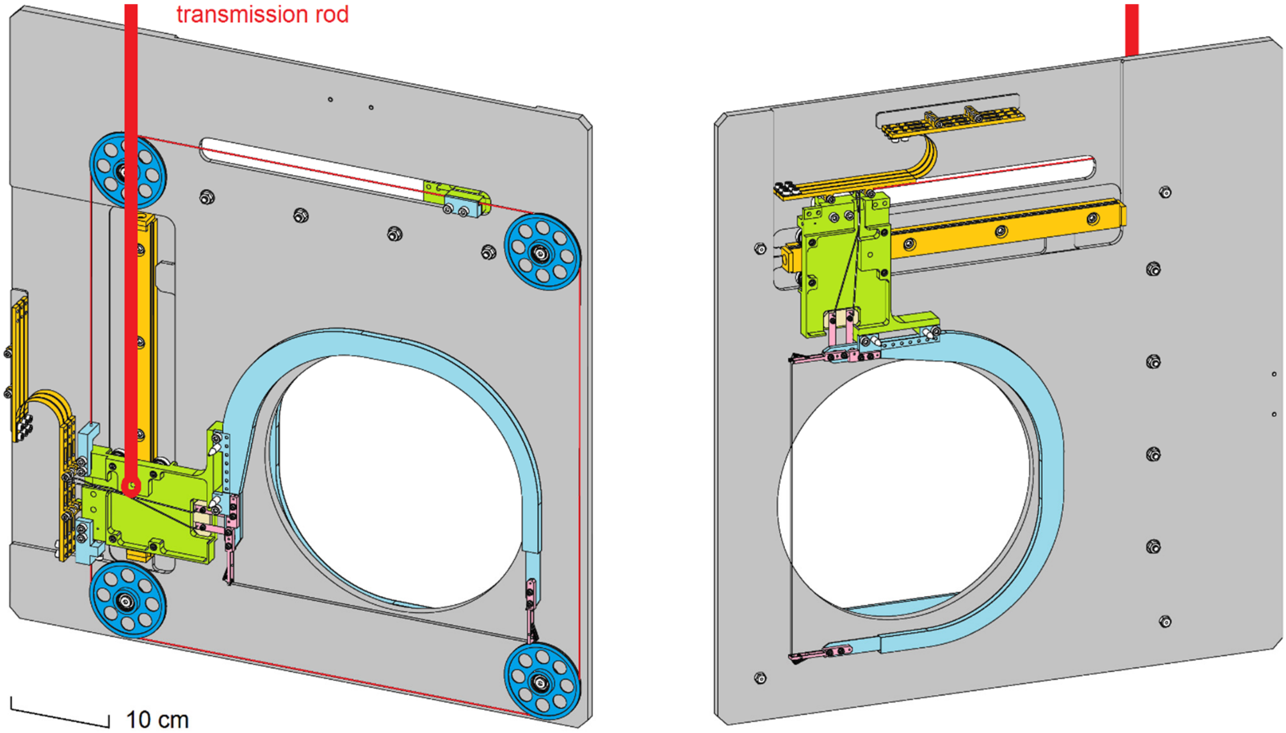

Figure 2: Front and rear side of PM module. The range is hard-limited by the mechanical end stop of the vertical rail guide, which is not reached in normal operation. Signals (from both ends of wires to allow a check of wire and cable integrity) and ground are transferred to the carriage by flexible steel ribbons. (Connection to cable module not shown.)

abandoned to prevent weakening of the shielding. Nearly all parts of the PM module have been used similarly with Generation 3, which reduces the risk to experience defects caused by the high radiation levels at the beam pipe.

The new drive module uses a rotary feedthrough in order to have the motor in air, and not in vacuum as with Generation 3 (Fig. 3). The motor can easily be decoupled, which allows to manually check the positioning of the end switches with reference to the fork carriage, as well as the actual degree of friction of the whole mechanism, without breaking the vacuum. Unlike with the previous generations, the use of the transmission rod allows to dismount all drive module parts individually, even without transferring the whole plug to the manipulator cell. Of course with braking of vacuum and the corresponding radiological safety measures.

In the same way, the cable modules, which are plugged vertically into PM and BPM modules, will be exchanged by pulling it into a small exchange flask [6]. This will allow the replacement of BPMs, which is hardly possible with Generation 1 and 2 with its preformed mineral insulated semirigid cables with screwed SMA plugs. It is yet not decided if an assembly of semirigid cables or of unsealed metal tubes containing ceramic pipes as isolator with an inner metal conductor will be used.

PM and BPM module, as well as the forks and the lower end of the transmission rod, will have form-fitting handles and guiding pins to be positioned by manipulator.

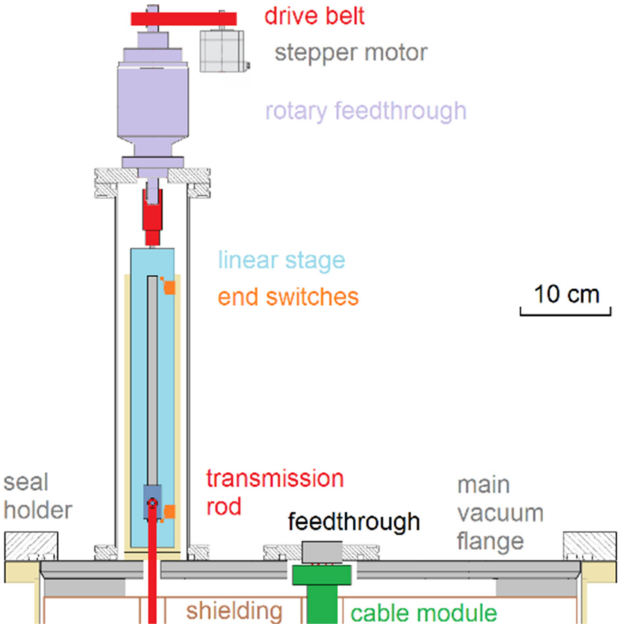

Figure 3: Main vacuum flange with drive module (schematic). End switches limit the range during normal operation. The actual position is determined from the number of steps requested from the 2-phase stepper motor since leaving the upper switch. The double-seal frame allows an easy exchange of aged seals.

RADIATION ASPECTS

Due to the high radiation levels close to the beam pipe of an order of up to 1 MGray/d, only metal or ceramic parts will be used for PM, BPM and cable modules, with no organic lubrication of the bearings of the PM module.

The shielding block fits into the chimney, leaving a slit of only 3 mm or 5 mm. In addition, the channels for cable inserts and transmission rod, which are filled only to a small percentage, lead to a weakening of the shielding. At the service platform this has two effects: Increased activation of components and shielding material by neutrons generated during operation, and increased dose rate when the beam is switched off from photons from highly activated parts under the shielding. Both complicate service work, and the former increase the amount of material for later disposal.

Hence, the area of apertures must be limited. We roughly estimated the "shielding" which a channel in an ideal shield of given thickness provides just by its limited area (Table 1) [7]. With respect to neutrons, this is compared to a tight iron shielding, and with respect to photons with the need from hands-on service at the top of the monitor plug. The foreseen channels of the order of 10 cm^2 should not alter the shielding properties significantly.

Table 1: Shielding Factors for Different Channels

		for shielding thickness [cm]			
		212	110	212	110
		shielding factor for			
		neutrons		photons	
type of channel in ideal shield	channel area [cm^2]				
channel A	10	7.7E-08	1.5E-05	3.5E-05	1.3E-04
channel B	20	1.6E-06	1.3E-04	7.1E-05	2.6E-04
circumferential slit (gen. 2)	49	3.7E-05	1.3E-03	1.7E-04	6.4E-04
circumferential slit (gen. 3)	109	3.7E-04	6.8E-03	3.9E-04	1.4E-03
large channel for sword (gen. 2)	226	2.1E-03	2.3E-02	8.0E-04	3.0E-03
bulk iron with no channels (reference for neutrons)		**4.1E-05**	**5.3E-03**	~0	~0
assumed max. dose rate at beam pipe with beam switched off [mSv/h]				1000	30
for dose rate <100 uSv/h at service platform (reference for photons)				**1.0E-04**	**3.3E-03**

The use of materials with low activation both at top and bottom of the monitor plug leads to a lower personnel dose when working hands-on at the top, and eventually, after a longer cooling period, at exchanged PM or BPM modules. We estimated the residual dose rate for aluminium, steel and Armco. Three different neutron spectra were used, representing the situation at top, middle and bottom of the monitor plug for a cooling time of three months, which is typical for shut-down work (Table 2) [7]. At the bottom, the materials do not differ much with respect to handling. In the long term, aluminium will decay faster, but starting activation will be probably too high to evade disposal, where it is disadvantageous due to its hydrogen generating reaction with mortar. At the top, steel is disadvantageous while aluminium and Armco are comparable with respect to handling, both dominated by its cobalt content. There the chance to evade disposal is better for aluminium if its Co content is low. We will prefer low Co aluminium for the drive module and vacuum flange, and Armco for shielding block and PM and BPM module base plates. All parts except from shielding block will be designed for a low amount of material. The long shielding block will be split to segments in order to allow a later disposal in standard size containers without the need for sawing.

Table 2: Dose Rate of Construction Materials

		location in plug	bottom			middle			top			
		n-spectrum	211			232			234			
			Na22	Mn54	Co60	Na22	Mn54	Co60	Na22	Mn54	Co60	Fe59
	ppm Co	half life [a]	2.6	0.85	5.3	2.6	0.85	5.3	2.6	0.85	5.3	0.15
Aluminium	15	dose rate fraction [%]	91	-	-	83	-	-	7	-	43	-
		dose rate [a.u.]	5000			890			820			
Aluminium (no Co)	0	dose rate fraction [%]	91	-	-	83	-	-	7	-	-	-
		dose rate [a.u.]	5000			890			467			
Steel	170	dose rate fraction [%]	-	50	43	-	39	53	-	-	88	-
		dose rate [a.u.]	7600			1400			4600			
Armco	33	dose rate fraction [%]	-	81	14	-	75	20	-	-	80	15
		dose rate [a.u.]	4700			750			975			
Armco (no Co)	0	dose rate fraction [%]	-	94	-	-	94	-	-	22	-	74
		dose rate [a.u.]	4060			600			194			

A more complex bellow-based rotary feedthrough will be used, since with Sm_2Co_{17} magnets, as used in alternative magnet feedthroughs, we see activation dose rates locally enhanced by more than one order of magnitude to several mSv/h at comparable locations.

BPM MODULE

The present Generation 2 BPM (see [8] and Fig. 9 of [5]) use inductive pick-up loops with an aperture of 100 mm, where the present narrowband BPM electronics [9] has a working frequency of 101.26 MHz, the 1st harmonic of the bunch repetition rate of 50.63 MHz. Horizontal and vertical measurement are axially separated to prevent coupling. Downstream Target E, there is axially too little space to accommodate this. Therefore, we investigate capacitive 4-button pick-ups with short axial length and a larger aperture, which is needed there (Fig. 4). First comparative simulations [10] have been performed using CST [11].

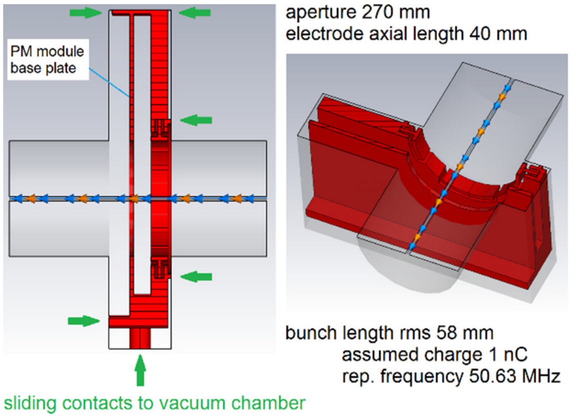

Figure 4: Simplified geometry used for the simulation of the proposed BPM and its environment.

At higher frequencies, the signal is dominated by undesired modes, which are defined by the neighbouring asymmetric structures and decay slowly over many bunch periods (Fig. 5 left). The simulation for the Generation 2 BPM does not include these external structures. Modes located there will have less impact to the BPM signal, since its aperture is much smaller. Higher-order modes are mostly defined by the pickup itself and decay fast.

In case of a resonance of one of these modes with a multiple of the bunch repetition frequency, the power dissipated in the structure and the voltages generated may unduly increase. Without a resonance (Fig. 5 upper right), the maximum amplitude in response to a CW bunch train is still of the same order as in response to a single bunch. At present, the simulation is not detailed enough to determine if a resonance will be excited. Adding more short-cut contacts closer to the beam pipe would improve the situation, but we are limited by the fact that the PM needs space for moving. We could think of damping these modes by adding electromagnetic absorbers to the external structures. Although we have never experienced beam induced damage in the PM, except for the direct heating by proton stopping power, this has to be studied further.

To use such a pickup with the present BPM electronics, the undesired modes would need to be sufficiently suppressed by suitable filters in front of the electronics. A changing of the working frequency to higher harmonics, which is an option for a next generation of BPM electronics, would not be advisable with this type of pickup.

At the operating frequency of the current electronics, 101.26 MHz, the amplitude is lower by a factor of 3.2 compared to the Generation 2 BPM (Fig. 5 bottom left), which leads to a 10 dB lower current sensitivity. The intensities of the four pickups differ only slightly at a centred beam, corresponding to a position offset of 0.8 mm. A shift of the beam has a clear impact (Fig. 5 bottom right). The simulation indicates a position sensitivity of 0.245 dB/mm, which is roughly half of the 0.464 dB/mm of the Generation 2 pickups. The reduction of sensitivities corresponds roughly to the ratio of apertures of the pickups. A BPM system with a correspondingly higher charge and position noise would still be a useful tool for the operation of the beam line.

At the upstream locations, with an aperture of 100 mm and an available axial length of ~160 mm, the added space may allow a better shielding of capacitive pick-ups against undesired modes in the neighbouring structures.

As an alternative to BPM modules, secondary emission monitors [12] or even harps could be installed, if an online supervision of the beam halo or beam shape is required, albeit at the cost of some scattering of the beam.

OUTLOOK

After completing the detailed design, we plan to build a shorter test sample with a light supporting structure instead of the shielding block, which can be tested with beam in a smaller vacuum chamber at a location with less radiation.

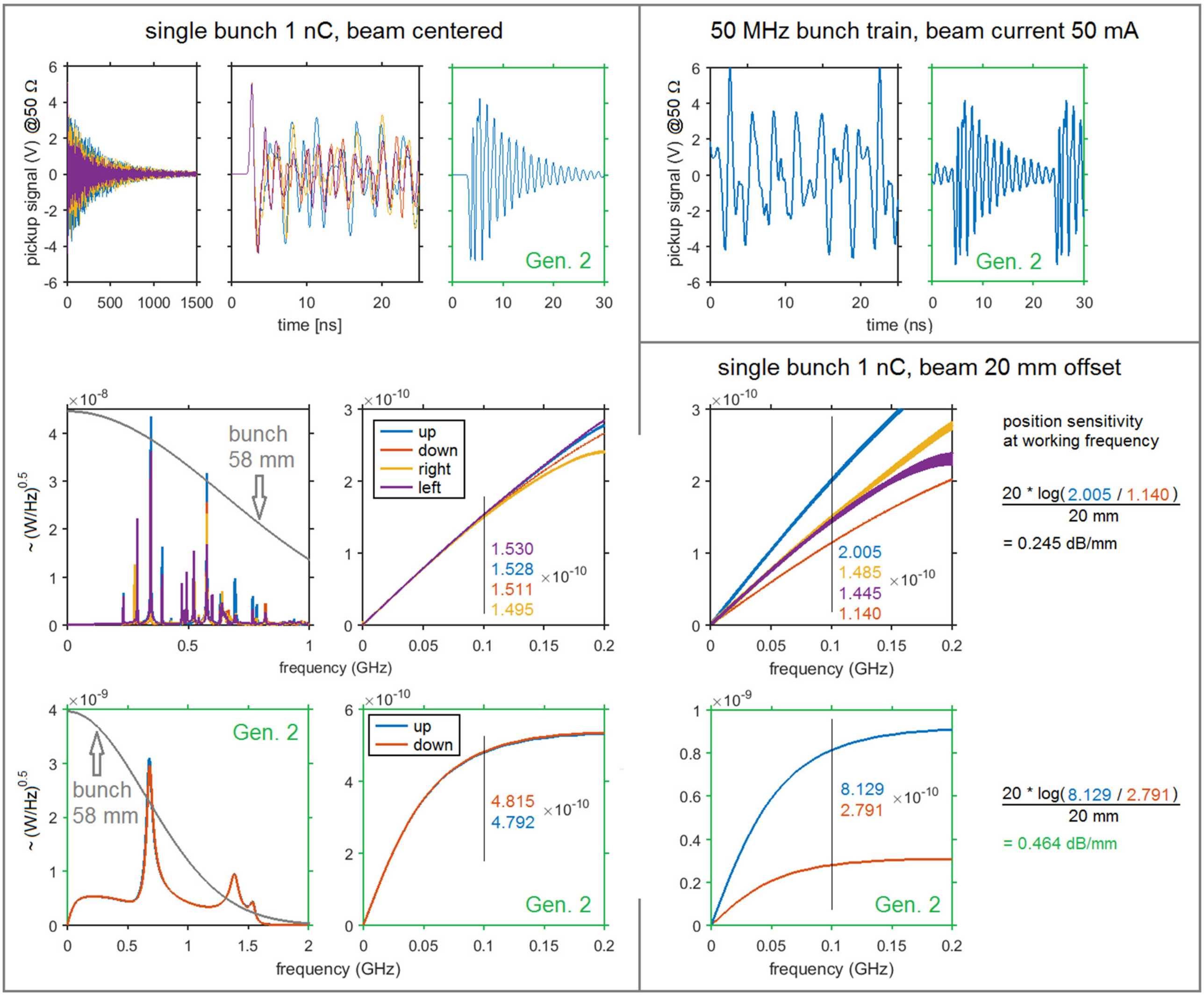

Figure 5: Simulation results for the proposed pickup design (black) in comparison to the Generation 2 BPM (green).

AUTHOR CONTRIBUTIONS

RD provided the specifications, guided the development, contributed to the design and wrote the paper. KZ, DB, JG developed the mechanical design. DK contributed the estimations on shielding and activation. FM contributed the BPM simulations.

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