BEAM DIAGNOSTICS AT THE HIGH POWER PROTON BEAM LINES AND TARGETS AT PSI

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Abstract

The protection of beam lines, targets and target windows from proton beam powers of 0.13 MW (@72 MeV) and 1.1 MW (@590 MeV) is based on beam loss monitors, current measurements at collimators and 4-sector apertures as well as the measurement of the current transmission. The new targets also use harps or an optical observation of the thermally emitted light from a metal sieve in front of the target. Online beam centering using inductively coupled position monitors is needed for continuous operation. Wire profile monitors are used temporarily for setup and tuning. The high radiation background requires radiation hard devices, shielding, a suitable handling of the components and remotely positioned electronics.

INTRODUCTION

High power proton beams of 590 MeV are produced at PSI using two consecutive cyclotrons. The beam current has increased over the years to 1.9 mA. After the passage of the graphite targets M and E for meson production, the remaining ~1.3 mA of beam is transported to the spallation neutron source "SINQ", which uses a solid target of stainless steel and lead. Beam is delivered for ~4800 hours per year for ~400 users [1]. A liquid Pb-Bi target "Megapie" is scheduled for 2006 and an additional beam line with a high power target "UCN" for ultra cold neutron production should start operation in 2007.

Melting of beam line/cyclotron components by mis-steered beam can occur within 10 ms @590 MeV or 1 ms @72 MeV (depending on the beam diameter). Such an event could cause 2 to 300 days of shutdown for replacement, repair or remanufacturing of components, since many built-in parts are not easily accessible or deeply buried under densely packed shielding. Furthermore, there are no spare parts for many components, and sometimes there is a lack of documentation, drawings and the knowledge of exact dimensions. Melting of the Megapie target and window by an overly concentrated beam could also cause a long shutdown. This can occur if the beam misses Target E, while the beam will then not be scattered, resulting in an increase of current density at the target and window by a factor ~25, which will melt after ~170 ms. Hence, redundant systems are needed for the fast (<1 ms) generation of interlocks. Therefore, the detector signals are evaluated in the readout electronics and interlock signals are hard wired to the control system.

26		43	15	1	54	30	wire profiles (1 direction)	x		
10							light profiles (1 direction)	x		
						2	harps (both directions)	x		x
		38	14		31	34	bpms (1 direction)	x	x	
1 (DCCT)		3	2		6	1	current monitors	x	x	x
2	1	3	2	2	1		stoppers/dumps	x		
34	23	32	10	18	33	3	collimators (fixed/movable)	x	(1)	x
		2	2	2	17	6	segmented aperture foils (mostly 4 sectors)	x		x
	8	23	9	14	30	15	ionisation chambers	x		x
	5			5			wire probes	x		
	8	1		13			phase probes	x	x	
	1	1		1			time structure			
					1		glowing sieve			x
								setup & tuning	online beam adjust.	machine protection

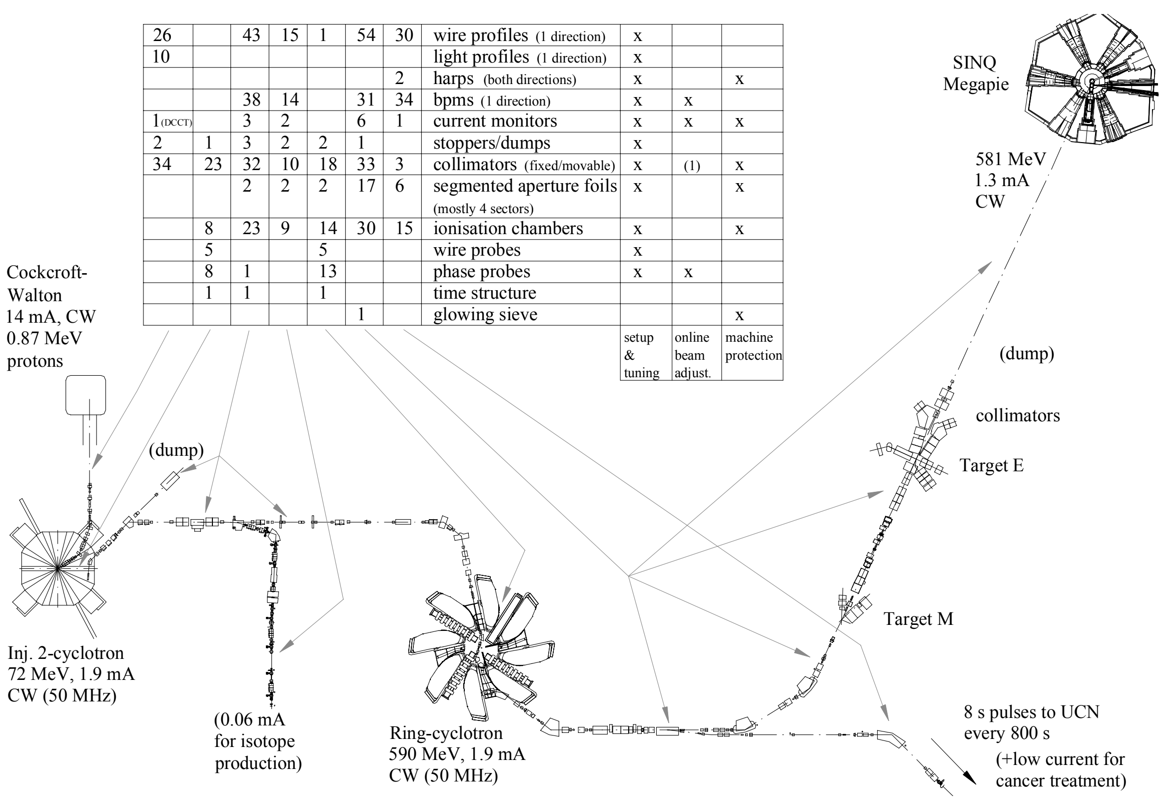

Figure 1: Overview of high power proton facility and diagnostics used.

The diagnostics used for protection, setup and operation are listed in Fig. 1. Most of the systems were introduced decades ago and have since been improved several times.

MACHINE PROTECTION

Collimators and aperture foils

Thick collimators of copper or carbon and thin (mostly 4-segment) nickel or molybdenum aperture foils with current measurements are used for the protection of subsequent components. Additional foils at a bias of +300V are placed adjacent to one or both sides of the foils to remove the secondary electrons (yield ~0.04). The collimators (and sometimes even the vacuum chambers) are cooled if losses occur permanently. The collimators are also used for beam shaping and the signal changes (together with those of the loss monitors) provide useful information for beam setup and tuning.

Loss Monitors

Simple ionisation chambers, formed by two interleaved stacks of metal sheets for high voltage and signal, filled with ambient air are placed next to the beam [2].

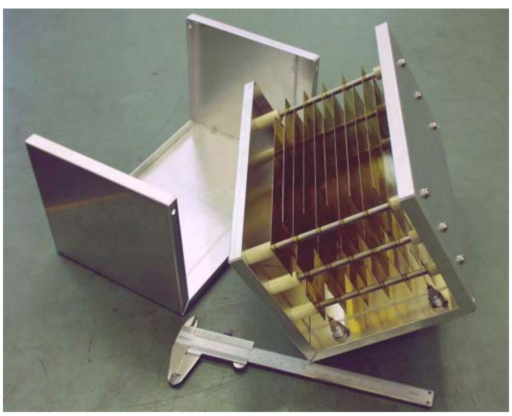

Figure 2: Ionisation chamber (bias +300V, volume 2 liter, separation of sheets 1 cm, 1 nA signal corresponds to a dose rate of ~1.3 Gy/d). Ring-shaped chambers for placement around the beam tube and cylindrical chambers for introduction into concrete shielding are also used.

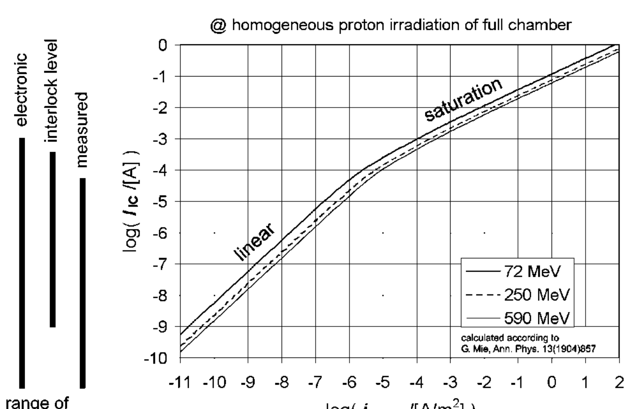

Figure 3: The response of the ionisation chamber is linear in the used regime [3].

Current Monitors and Transmission

Capacitively loaded quarter-wave coaxial resonators working at the double bunch frequency are used as current monitors [4]. The long-term stability of the current reading is limited due to temperature effects in the resonator (±1%), the long cables (±2%) and the electronics (±1%). Hence, calibration to the beam dump current is regularly performed. During this process, the loss monitors are observed in order to ensure that the losses are "correctly low".

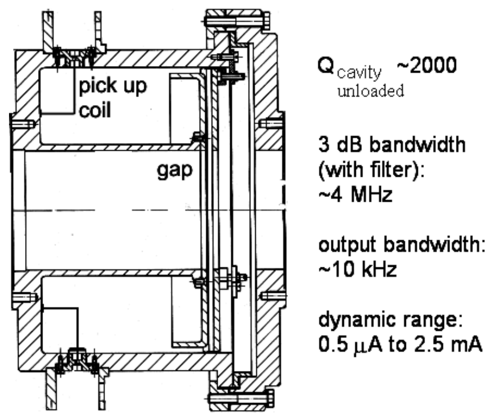

Figure 4: Current monitor.

The transmission is determined by comparing the currents of two or more current monitors (Fig. 5) [5, 6]. The currents are filtered with a current dependent time constant (110 ms to 10 ms for 0 to 1.5 mA) to reduce noise. An interlock is generated if the actual losses deviate significantly from the "usual losses" (Fig. 5, upper left diagram).

In addition, another type of transmission measurement is done around Target E: The signals of the downstream loss monitors are roughly proportional to the beam current and can be used instead of the second current monitor. Hence interlocks are generated if the losses are too low [6]. This system is applied at beam currents above 100 µA and has a response time of ~1 ms.

SPALLATION TARGET PROTECTION

Dispersive Shift onto a Collimator

In the case that the beam misses Target E, the transmission measurements will respond. Another redundant technique was implemented for the same situation: The beam fraction missing the target undergoes no energy degradation. Hence, it follows a different path in a dispersive transport section where it is intercepted by a collimator. The current readings from the collimator and a nearby loss monitor cause an interlock, even if only 0.1% of the beam misses the target [7].

Harps

4 and 8 meters in front of the UCN target, retractable harps will be placed for online supervision of beam size and position. The profiles result from the measured

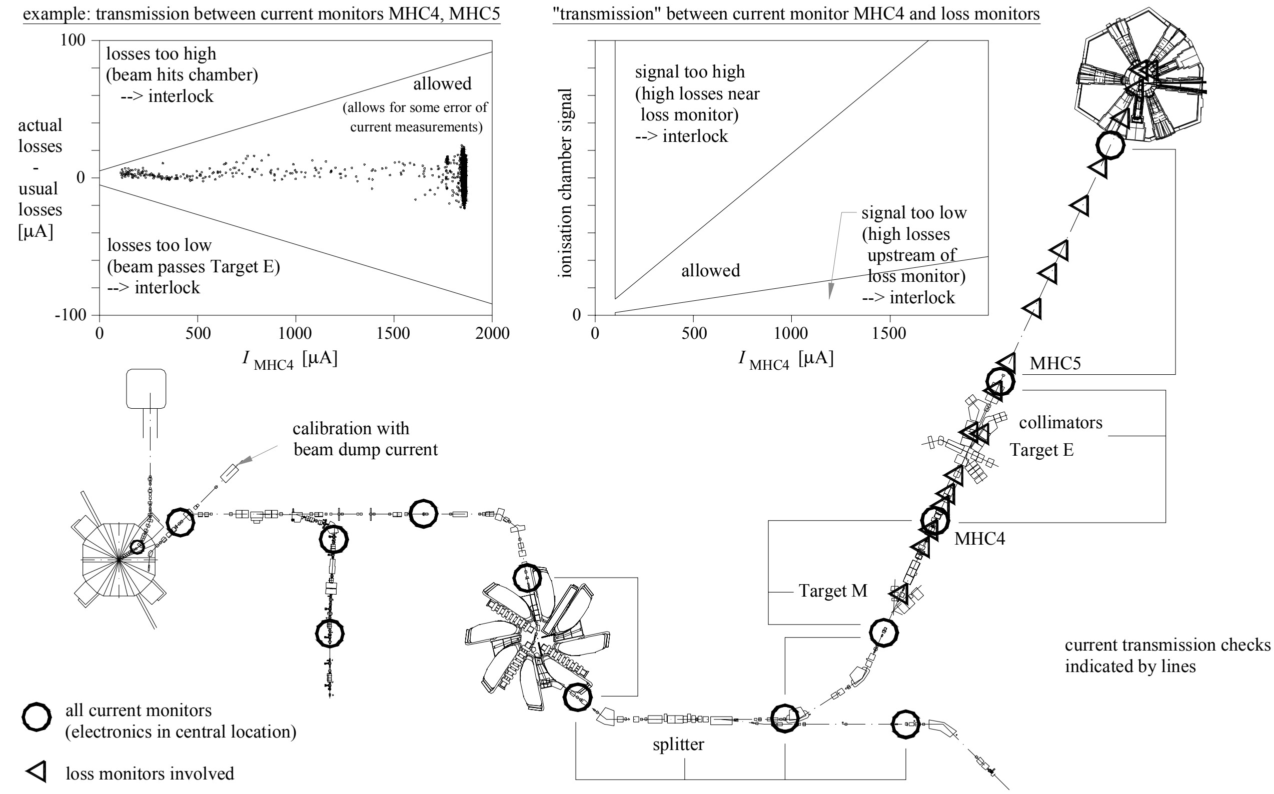

Figure 5: Transmission measurement with current monitors (upper left diagram, which also shows experimental values over a period of 3 hours) and with current and loss monitors (upper right diagram).

secondary emission currents from 16 horizontal and 16 vertical wires. 16 intermediate diagonal wires are biased to +300V for electron pulling. 40 μm molybdenum wires are used although the operation temperature will rise nearly to the onset of thermionic emission.

Glowing Sieve

The most direct control of the beam current density in front of the spallation source target is provided by video observation of the thermal radiation from a tungsten sieve placed in the beam tube and heated by the beam.

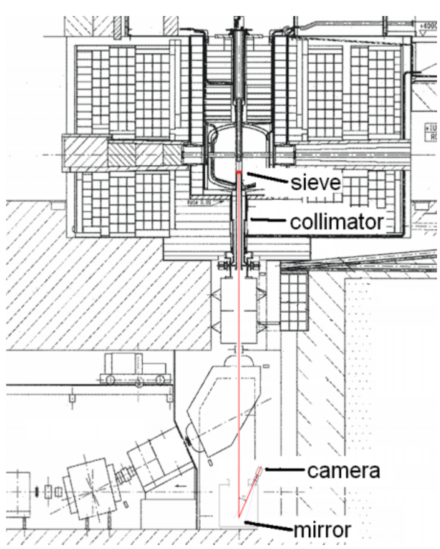

Figure 6: Glowing sieve under the spallation target.

This device has been developed and tested recently [8]. The light from the sieve passes several meters through the beam pipe and is projected by a parabolic mirror, as the only optical element, onto the sensor of a chalnicon radiation hard camera (Fig. 6).

For temperatures above 1000 °C, which are reached already at nominal beam current and size, a signal is detected above the background level which increases rapidly with beam current density (Fig. 8).

Figure 7: Sieve woven from diameter 0.1 mm and 0.3 mm tungsten wire.

Using the total signal, the system is sensitive and fast (~40 ms) enough to protect the Megapie target from an overly concentrated beam. In addition, the position resolution of ~±1 mm is sufficient to detect the beam shift associated with a beam fraction missing the Target E.

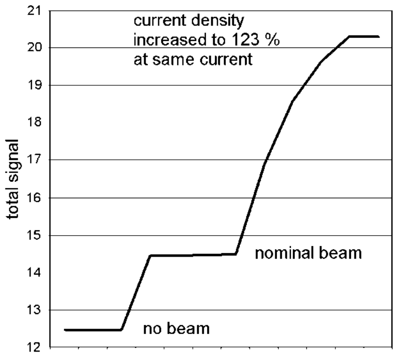

Figure 8: Response to beam current density. The temporal dependency (horizontal axis) stems from the beam adjustment and not from the detector system.

MACHINE OPERATION

BPMs

The frequent (~20 to 500 per day) sparking of the electrostatic septa, used for injection and extraction in the cyclotrons, causes beam trips. The beam is switched off and the current then ramped up in ~20 s. The beam optic is current dependent due to space charge effects and due to the way the beam current is regulated by cutting into the beam with a moving collimator. An automatic beam centering is therefore required and is provided by BPMs and steerers.

The BPMs use single turn coils to couple inductively to the bunched beam (Fig. 9). A preamplifier is located ~1 m from the BPM in the vault. At present, the device works with beam currents above ~5 µA. With an output bandwidth of ~10 Hz, a centering response of ~1 Hz is reached. The position accuracy is ~±1 mm over the full current range. New electronics based on digital receivers are under development with a larger dynamic range down to 0.5 µA and larger bandwidth of ~10 kHz.

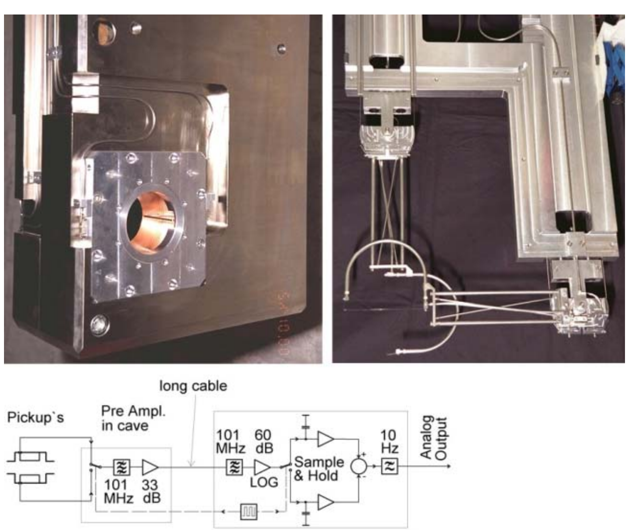

Figure 9: left: BPM, section for the horizontal position (only one coil visible) mounted in shielding. Another section placed behind it is used for the vertical position. The space in between is used for wire monitors (right).

Profile Monitors

The wire monitors measure the secondary emission current from (one or two) 40 µm molybdenum wires, 33 µm carbon fibres or 25 µm molybdenum foils. In the 72 MeV transfer line, thermionic electron emission can occur at small beam diameters, leading to higher signal currents and an interlock to prevent the wire from melting. In the 0.87 MeV injection line, only a 15% duty cycle of the beam is possible without damaging the wires. Here, additional profile monitors based on the fluorescence of the residual gas are used [9].

ELECTRONICS

Nearly all the electronics are located outside the vaults. Hence, no radiation damage occurs and access for service is easy. The drawback is long cables (30 to 300 m).

All the low current measurements are done with logarithmic amplifiers, which, in the newer versions, span a range from 10 pA to 10 mA. The bandwidth is current dependent (from ~30 Hz at 10 pA to ~30 kHz above 10 nA). 16 or 32 channels with up to 4 separate grounds have been realized in single-slot CAMAC or VME modules [10]. Cables with good shielding and low microphonic noise are important as well as the prevention of ground loops [3].

All the newer electronics are divided into dedicated front ends with signal pre-processing and AD-conversion, and universal back ends with digital processing and bus connection. The signals are simultaneously sampled at a rate of the order of 1 to 10 kHz. Evaluation and interlock generation (hardwired to the control system) are performed in the same time. Information on the current status and the last interlock can be read or interlock levels can be changed via bus. Some modules have external and internal trigger functionality and storage and readout of up to 8 ksamples/channel.

RADIATION AND HANDLING

The main beam losses are roughly (@1900 µA): at 72 MeV: 0.5 µA at extraction of Injector 2, 5 µA at the following beam cleaning, 0.5 µA at injection into the ring cyclotron, and at 590 MeV: 0.5 µA at extraction of the ring cyclotron, 0.3 µA (average) at the following splitter, 28 µA at Target M and 560 µA at Target E.

At locations with very high radiation levels during operation, only metal and ceramic parts are used, e.g. helicoflex or aluminium edge seals, mineral insulated cables, etc. It appears that the observed damage to these components is not due to radiation but is of thermal (beam power) or corrosive (cooling water) nature. In accessible places with lower radiation levels, other materials are also in use: epoxy parts, lubricated bearings, motors, potentiometers, scintillators, radiation hard glass windows, viton seals (which get hard but seldom leak if not moved), standard cables (which get brittle).

In the areas accessible for service, the background radiation can be of the order of mSv/h with higher local hot spots. The background decays to half in approximately 6 hours. Diagnostics, as well as other components, are designed to be fast demountable (few screws, lever mechanisms, guiding rods), easy to handle (no sharp edges, countersunk hexagon socket screws, weak parts guarded, grips, etc.) with a minimum of personnel (local cranes, lifting gear, special trolleys) and easy to clean (smooth surfaces). Nevertheless, reliability is the most important property.

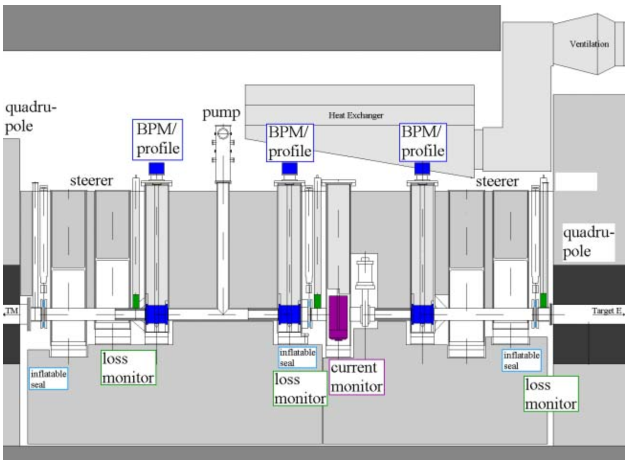

Figure 10: Closely shielded components.

Figure 11: Shielded transport box [11].

In the target regions, the concept of closely shielded components has been applied [12]. After removing 4 m of concrete shielding, access is given to a service level ~2 m above the beam. The diagnostic components are placed under in-vacuum shielding blocks in chimneys (vacuum chambers with seals at the top). The chimneys are densely surrounded by shielding blocks. Drives, feedthroughs, pumps, etc. are located on top and can be easily serviced (Fig. 10).

The components can be extracted vertically into a shielded transport box, after connecting to it with individual adapters (Fig. 11), and transported to a remote handling facility. Even the vacuum chambers, which are connected to each other by inflatable metal seals, can be removed, but this could take some weeks.

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