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Profile Measurement Of Scanning Proton Beam For LiSoR Using Carbon Fibre Harps

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Abstract. Harps using secondary electron emission from 16 carbon monofilament wires have been built to measure the horizontal and vertical beam profiles of an intense 71 MeV proton beam. A very large dynamic range and good time resolution are achieved by a newly developed 16 channel CAMAC read-out module using logarithmic amplifiers. A first test at low beam current is reported.

INTRODUCTION

The LiSoR (Liquid Solid Reaction) experiment, is carried out at PSI within the framework of the MEGAPIE project (MEGAwatt Pilot Experiment), aiming at a liquid metal spallation target based on a lead-bismuth eutectic mixture [1]. PSI's Philips cyclotron is used to irradiate stressed steel specimens in contact with flowing liquid metal with a 71 MeV proton beam. A nearly homogeneous averaged beam current density over a rectangular area is foreseen. This is provided by suitable horizontal and vertical scanning of the beam over the target. A sinusoidal horizontal deflection is combined with a linear vertical deflection. The frequency ratio is 12:1 and the vertical maximum is synchronised to a horizontal zero deflection. Less than 5 % deviation from homogeneity in the 3 x 12 mm^2 central region is expected for Gaussian beam profiles of $\sigma_{hor} = \sigma_{vert} = 0.6$ mm and ±2.75 mm horizontal and ±7 mm vertical amplitudes [2]. The scanning is performed by upstream steering magnets. The power supplies are controlled by a modified PSI CAMAC-ROAD-C-"KOMBI-Controller" [3]. The amplitudes and the horizontal master frequency can be set and interlock signals are generated in case of malfunction, especially if the measured magnet current amplitudes are below a preset safety limit. The working frequency is 15 Hz, as allowed by the power supply response function.

Horizontal and vertical harps are positioned 17 cm in front of the target for the verification of the momentary and time-integrated beam profiles. The harps and the read-out electronics are discussed in the following.

HARP DESIGN

Two harps of 16 wires each are arranged inside a 30 x 30 mm^2 aperture with a separation of 18 mm in the beam direction. The horizontal wire spacing is 1 mm and the vertical spacing is 1.25 mm. A third grid of 13 diagonal wires with 2 mm spacing

is mounted in the mid-plane between the two harps. These wires, as well as two 30 x 30 mm^2 electrodes (positioned horizontally 16 mm below the beam axis) in front and behind of the aperture, are biased to +300 V. Thereby, the secondary electrons from the harp wires themselves as well as from the target or from a (15 x 19 mm^2) collimator 21 cm in front of the harps are prevented from reaching the harp wires.

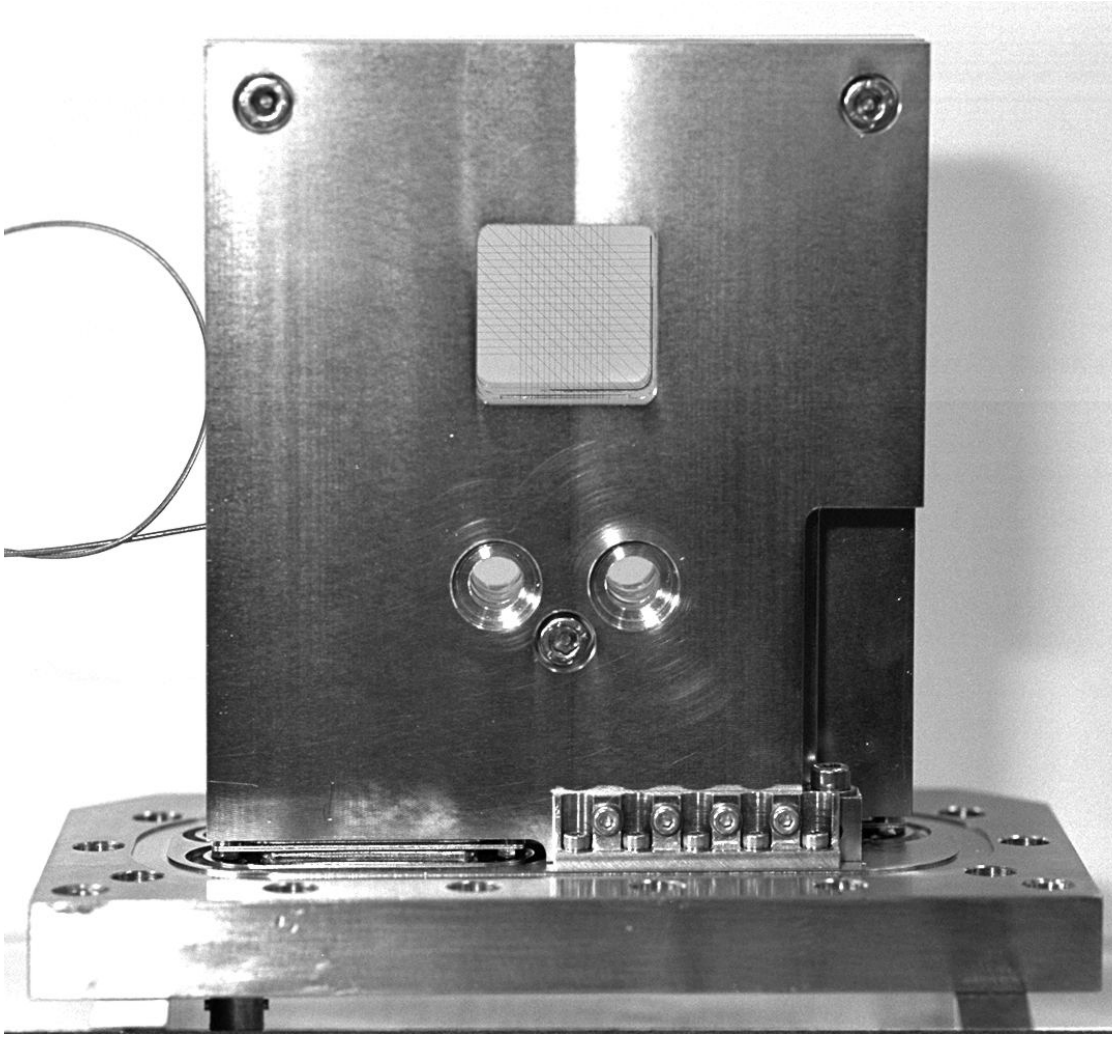

FIGURE 1. Harp assembly. Electrodes for secondary electron suppression not yet mounted.

33 μm diameter carbon monofilament wires (Textron Specialty Materials, Massachussetts) are used. At the working scanning frequency, the wire temperature is estimated to be well below 1000 °C for a 50 μA beam. Hence, no problems with thermionic emission or carbon loss due to its vapour pressure are expected. For a stationary beam, the thermionic emission current would by far exceed the secondary emission current (i. e. the signal) and the wires may be destroyed.

The radiation hardness of the carbon wires is not critical. The same fibre used at the time-structure measurement at the PSI Injector-2 cyclotron [4] has not shown any visible damage after irradiation with 10^{20} protons/mm^2 at 72 MeV.

HARP MANUFACTURE

Due to the small wire spacing a spring tensioning of the wires, as used in [5], seems to be not practical. The elasticity and low thermal expansion of the wires allow a direct mounting as e. g. described in [6, 7].

For reasons of cost and ease of manufacture the carbon wires were glued with conducting epoxy (EPO-TEK H20E) to frames made of 0.5 mm thick ceramic filled printed-circuit board (Rogers RO4350B) with 100 μm copper/gold plating on both sides. Each frame is mounted in a 9 mm thick gold plated aluminium disk (Fig. 2). The stack of four disks (one as a cover) is mounted on a vacuum flange carrying two Caburn 25-pin Sub-D and an MHV feed-through.

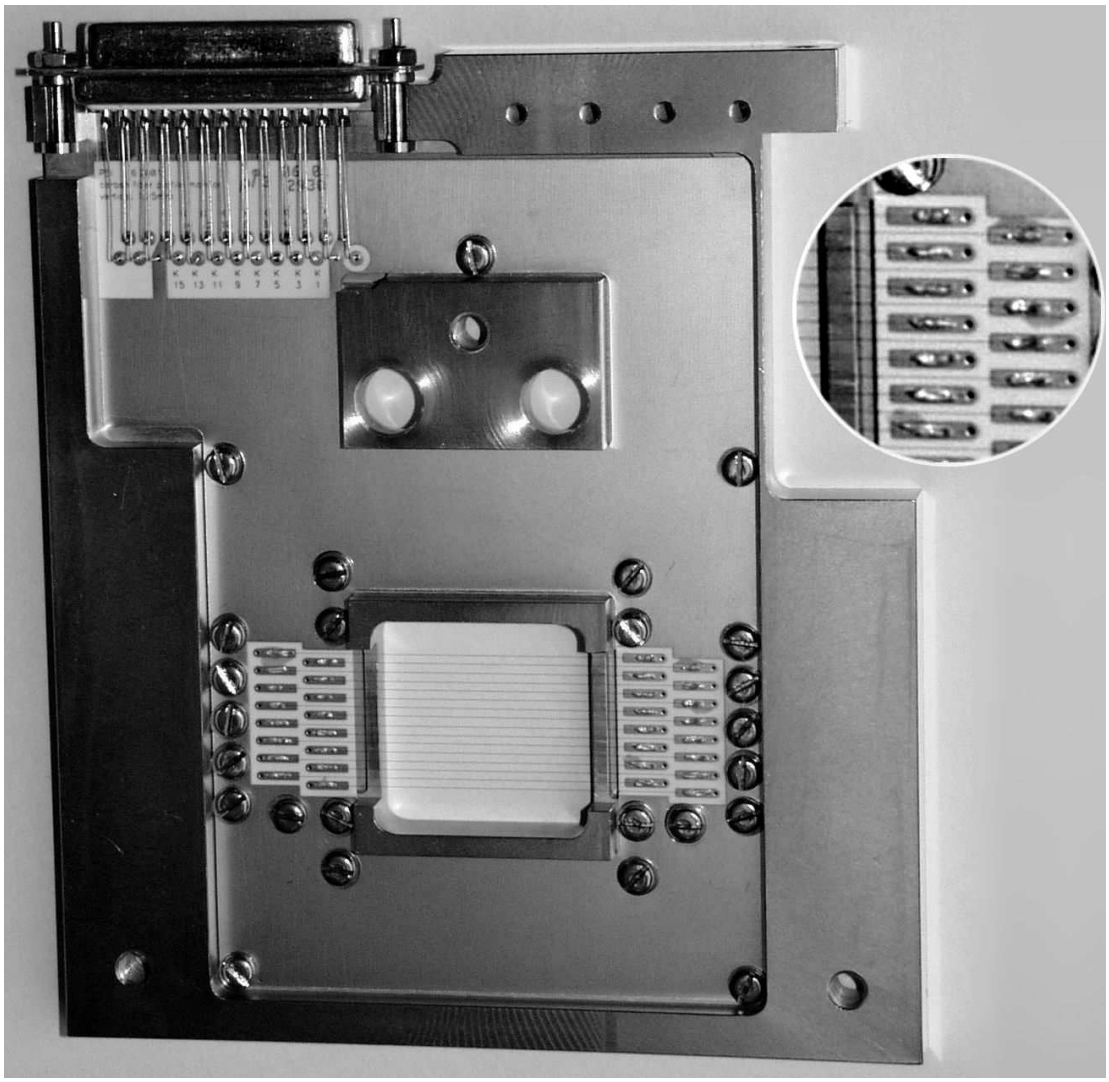

FIGURE 2. Harp for the measurement of the vertical beam profile. The discolouration of the white RO4350B around some of the mounting pads (inset) stems from the solvent of the conducting epoxy and does not deteriorate the isolation.

For the positioning of the wires during assembly, the printed-circuit board is mounted on a support together with two M6 (resp. M8) screws parallel to opposite sides of the aperture. Overlength monofilament with small weights attached with adhesive tape to both ends is then laid over the screws ensuring a defined tension. It is then attached in the threads with cyanacrylat glue. Afterwards, the conducting epoxy is applied with a syringe and cured for one hour at 100 °C and one hour at 160 °C.

This treatment should allow for a permanent operation at 200 °C in vacuum. However, the operation temperature is limited to approximately 170 °C by the Sub-D connectors used. This is well above the expected operating temperature due to heat transfer from the neighbouring lead-bismuth circuit.

READ-OUT ELECTRONICS

The 16 currents of each harp are transferred via 50 m of 10 x 2 twisted-pair cable with double outer shielding to an in house developed CAMAC module (Fig. 3). The 16-channel analogue front-end print was originally developed for the PSI Ultra-Cold-Neutron (UCN) experiment. It uses logarithmic current-to-voltage converters, as our standard LOGCAM and LLCAM modules, but with an extended range. According to first tests the deviation from linearity is within 1 % from 20 pA to 200 µA. The cut-off frequency is approximately 40 Hz at 100 pA, 400 Hz at 1 nA, 4 kHz at 10 nA and 8 kHz above 40 nA with cable and only slightly better without. This measured dependency agrees well with the response to a short current pulse depicted in Fig. 4.

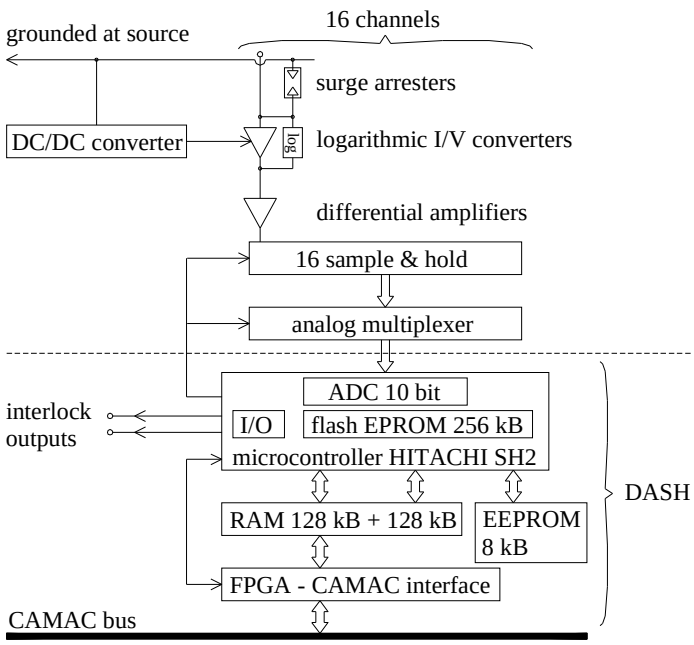

FIGURE 3. Harp read-out electronics. (Unused functionality of DASH not shown.)

Read out and evaluation of the simultaneously sampled currents are performed every millisecond by the DASH back-end electronics. Two modes of operation are implemented: The read out of individual currents (both time averaged and not averaged) via CAMAC and the sampling of up to 4096 profiles every n * 1 ms (with $1 \leq n \leq 65536$) and subsequent read out via CAMAC. Both modes can be used simultaneously.

8 decades of input current range are acquired with the 10-bit ADC of the micro-controller. A single current value is stored in bit position 2 ... 11 of a 2-Byte number according to $\mathrm{nn}[\mathrm{digit}] = 4 \cdot ADC_{out}[\mathrm{digit}] = 4 \cdot 128\,\mathrm{digit} \cdot \log(I[\mathrm{pA}]/10\mathrm{pA})$. (The least significant bits 0 and 1 are set to zero. The 2-bit left shift allows the calculation of averaged values with a factor of 4 improved resolution. That way the same inverse transformation for raw data and for averaged data can be applied: $I[pA] = 10\mathrm{pA} \cdot 10^{\mathrm{nn}[\mathrm{digit}]/512}$.)

The DASH ("CAMAC Data Acquisition module with Hitachi SH2 micro-controller") was recently developed as a standardised universal controller, which can support different front ends for beam diagnostic tasks [8]. It includes a programmable interlock and warning logic with watchdog. In the case of the harp front-end, width and position of the beam evaluated from the measured wire currents are monitored as well as the maximum individual wire current. Interlock limits, low pass digital filter and averaging parameters, sampling settings, etc. can be written via CAMAC to an EEPROM (together with the complement as a safety measure). The present module status as well as the status at the last interlock can be read.

FIRST MEASUREMENTS

The presence of the wires can be checked by analysing the response of the wire currents to switching on the secondary electron suppressor voltage (Fig. 4). The signal amplitudes are similar for all 16 intact wires.

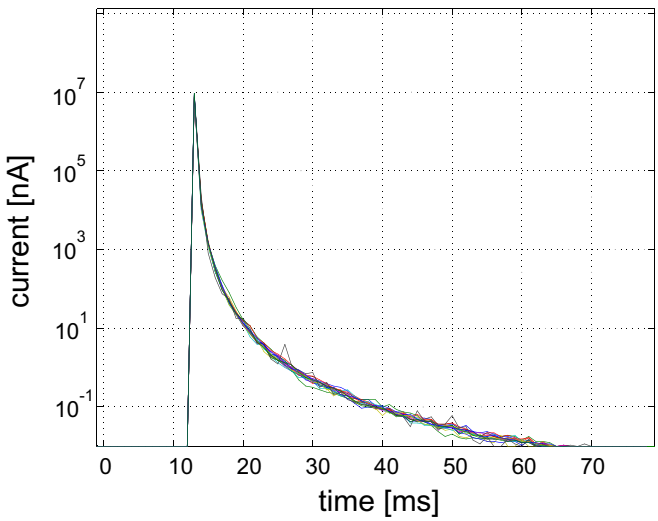

FIGURE 4. Current peak induced to the 16 horizontal wires by switching on the secondary electron suppressor voltage.

Up to now, only a few measurements at low beam intensities (<200 nA) have been performed in order to avoid obstruction of the ongoing installation of LiSoR components by activation. Fig. 5 gives an example of series of horizontal and vertical profile measurements of a scanned beam. (The beam shape was not adjusted to the specifications required for LiSoR in either direction.) Even at the correspondingly low signal levels, the results were very satisfactory. For the given environment, the noise pick-up on the long signal cables was tolerable. Cross-talk was not observed.

Currently the horizontal and vertical series are measured successively. It is foreseen to change the control-system handler to provide nearly simultaneous CAMAC start commands to both CAMAC modules.

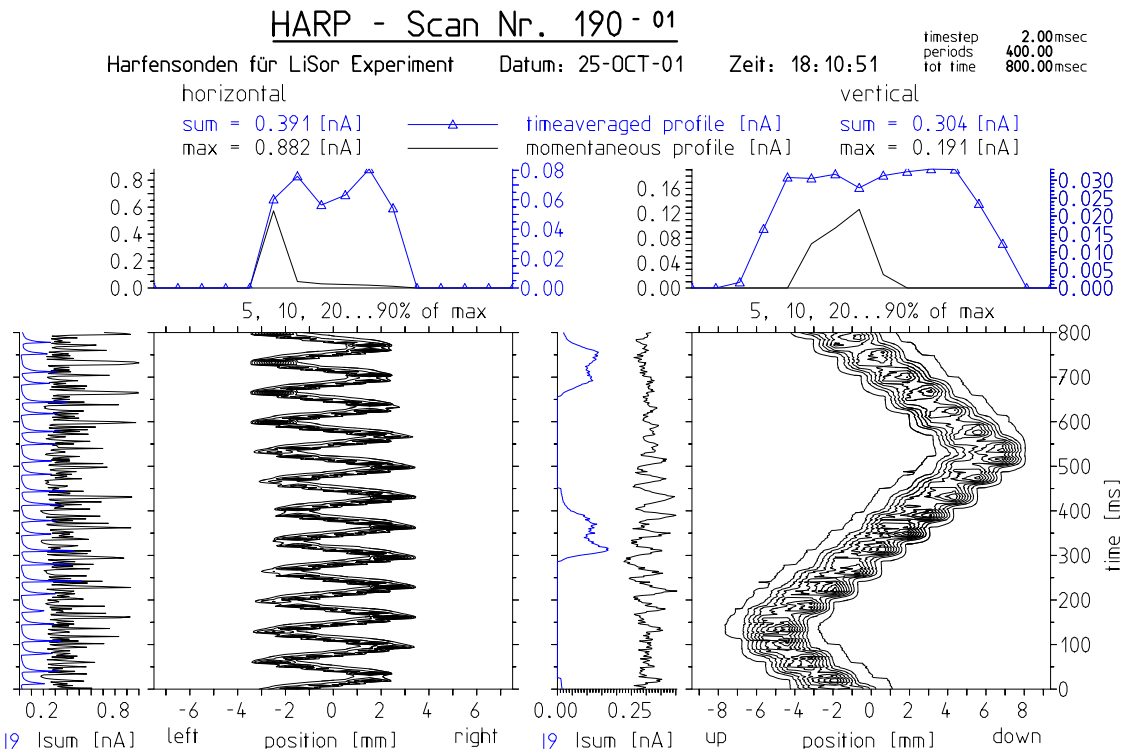

FIGURE 5. 400 horizontal (left column) and 400 vertical (right column) beam profiles. Each series measured (not time-correlated) during 800 ms at a simultaneously horizontally (15 Hz) and vertically (1.25 Hz) scanned beam. In each column: Main graph: time development of profile shown as a contour plot. Top graph: last measured profile (full line) and average of all profiles (broken line with triangles indicating wire positions). Left graph: time development of the sum of the individual currents and of the current on the ninth wire. (Readings $4 \cdot ADC_{out} = 0$ digit which correspond to 10 pA *or less* are depicted as 0 pA.) The temporal fluctuations of the current sums largely stem from the hopping of the beam from one wire to the next. In the present case of a scanned beam, the temporal distribution of the current on a single (here the ninth) wire can give the profile in more detail than the distribution of the momentary individual currents.

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