# HIGH-PRECISION BEAM PROFILE MONITOR FOR THE DESY H-MINUS LINAC

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## INTRODUCTION

Three diagnostic boxes (Dbox3, Dbox4 and Dbox5, see Fig.1) with DMH14, DMH17, DMH20 wire harp monitors respectively have been developed in INR and installed in the DESY 50 MeV H$^-$ Beam Transport Line, called HEBT, guide the H$^-$ beam from Linac III over 80 m to the injection part of the synchrotron DESY III.

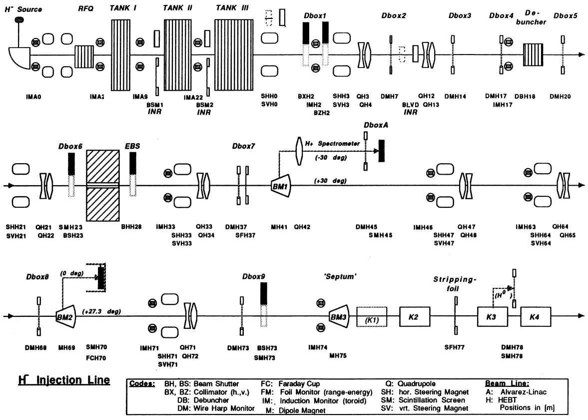

Fig.1. DESY 50 MeV H$^-$ Beam Transport Line (HEBT).

The harp is based on the principle of secondary emission of loosely bound electrons on the surface of the wires as proton beam passes through them. The secondary emission signal is linear over a wide dynamic range of incident protons and is measured by the electronics connected to each wire [2]. The two electrons stripped from the impinging H$^-$ Ions have a range of less than 2 µm and are thus quantitatively collected. The expected charge factor of 2.0 is reduced by secondary electrons leaving the wire; their effect, however, is suppressed by a bias voltage applied to three grids which enclosed the two signal planes [1].

The presented profile monitor is differed in the use of tungsten microwire $d_W$= 20 µm a dia as a irradiated contact elements. Unfortunately, it has presented some difficulties in fixing of wire. The choise of fixing method depends on intensity of beam and corresponding heating balance of wire. The use of more thin wires decrease a temperature of their heating during beam pulse. More thin wires with smaller mass $m$ will absorb to smaller thermal energy $q$ and, in accordance with relation $q = m\cdot c\cdot\theta$, will heat with the smaller temperature drop $\theta$, where $c$ is a specific heat capacity. The long-time stability of a wire heating balance is determined by limitations of maximum heating temperature and a limitation of a temperature gradient during a beam pulse. The maximum heating temperature $T_{max}$ should not exceed melting point of a tungsten. However, first of all, $T_{max}$ should be less than temperature of a distorting signal of a thermionic current, which is determined by magnitude $T_{Max} \leq 1700$ K according to the Richardson - Dashman formula. The safe temperature drop $\theta_{max} \leq 1116$ K is recommended for the tungsten during the cyclic heating by beam pulses. Then the ultimate thermal energy of heating is restricted to magnitude $q_{max} = m\cdot c_T\cdot\theta_{max}$, where $c_T$ is specific heat at $T_{Max}$. Therefore, during a beam pulse $t_0$ [s] the absorbable energy in the wire should be such, that the thermal energy, transferred to a wire, did not exceed the magnitude $q_0 \approx dE\cdot(dz)^{-1}\cdot d_W\cdot\Delta I_a\cdot t_0 < q_{max}$ [3]. In this relation $\Delta I_a$ is the part of a beam current on the active area of one wire [A], power loss $E$ [eV] is evaluated by a specific stopping power of a tungsten $dE\cdot(dz)^{-1}$ on the penetration depth $dz$ [m] according to the Bethe - Bloch formula. Both the heat balance of a wire during cyclic heating by beam pulses and the consecutive cooling by radiation - thermal conduction between adjacent pulses is determined by a step-by-step calculation.. The decrease of wire temperature $T_n$ [K] is determined upon a remainder of unaverted thermal energy $q_{n-1}$ [J] for each time interval $dt_n$ [s] in time interval $\tau$ [s] between adjacent pulses by the relation

$$T_n = \frac{0{,}5\cdot q_{n-1} - \pi\cdot d_W\cdot r_a\cdot\varepsilon_T\cdot\sigma\cdot(T_{n-1}^{\ 4} - 7\cdot 10^9)\cdot dt_n - 0{,}78\cdot d_W^{\ 2}\cdot l_x^{\ -1}\cdot\lambda_T\cdot\theta_{n-1}\cdot dt_n}{0{,}78\cdot d_W^{\ 2}\cdot r_a\cdot\rho_W\cdot c_T}$$

where $r_a$ - radius of a beam [m]; $\varepsilon_T$ - emissive power coefficient of a tungsten; $\sigma$=5,67·10$^{-8}$ J·s$^{-1}$·K$^{-1}$·m$^{-2}$ - Stefan-Boltzmann constant; $l_x$ - length of unirradiated ("cold") wire ends [m]; $\rho_W$ - density of a tungsten [kg·m$^{-3}$]; $\lambda_T$ - thermal conductivity of a tungsten at temperature $T_n$ [J·s$^{-1}$·K$^{-1}$·m$^{-1}$]; $c_T$ - specific heat of a tungsten at temperature $T_n$. [J·kg$^{-1}$·K$^{-1}$].

The diagram of the steady-state heating balance of 20 µm a dia tungsten wire is shown in Fig.2.

## THE DESIGN

The profile monitor has a vacuum chamber with a stand-base plate, an actuator with a stepper motor and a harp unit (Fig 3). The wire harp unit installed on a actuator which is tilted by 45° relative to horizontal in order to provide simultaneous movement in both $x$ and $y$ directions.

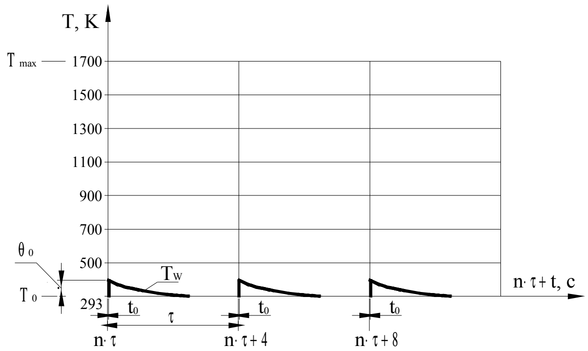

Fig.2. Heating balance diagram for 20 $\mu m$ a dia tungsten wire at steady-state cycling mode during 15 $mA$ 50 $MeV$ $H^-$ beam pulse: $T_W$ – wire remperature [K]; $t_0 = 200\ \mu s$ – pulse length; $\tau = 4\ s$ – interval between adjacent macropulses; $T_{max}$ – maximum adjacent wire temperature [K]; $t$ – measurement time [s].

The vacuum chamber consists of the body and two end plates. The thick-wall forging tube from stainless steel was used for fabrication of the body. It has only one weld seam and two CF-250 connections with end plates through copper gaskets. Other sides of end plates are CF-100 conflat flanges for connection with HEBT flanges.

The actuator uses a 5-phase stepper motor of the VRDM 5913/50 type. It produces 1000/500 steps per turn (0,36°/0,72° ± 3′ per step) for half step / all-step mode respectively [5]. The actuator drives the harp unit at 6.15 mm/s along the *x* and *y* axes when it is operated at its maximum speed. The maximum stroke is 104.5 mm. The rotation of the motor shaft is transformed through rigid branch sleeve into the displacement of the Linear Motion Guide Actuator KR2602A plate, the positioning repeatability is ± 10 µm [6]. The membrane bellows is used as vacuum seal. The rod of the actuator is terminated with the rotatable CF-35 flange to which the CF-35 flange of harp unit is fixed. The minimum displacement per step along the *x*- and *y*-axes is 1.4 (2.8) µm for half-step (all-step) mode respectively.

Each harp unit is a stack of five rings with 130 mm O.D. and 90 mm I.D. from a machinable mica-glass ceramics, which are clamped together to form a rigid assembly of 19 mm thick. A final assembly mounted on a aluminium body is shown in Fig.4. Each harp has two signal and three bias grids of sixteen and 26 gold-plated thin (20 $\mu m$) tungsten wires respectively. As the heating is insignificant during a beam pulse (see Fig. 2), the wires was soldered by chemically pure tin with a tension on each wire ~ 30 *g*. The contact lands was made by printed-circuit technique after vacuum evaporation of 2-6 µm copper. Then copper layer of obtained lands was increased up to ~20 µm by electroplating. A grounded 2-6 $\mu m$ layer of silver is evaporated on the backside of every bias and signal ceramic ring to intercept possible leak currents. The wires signal are fed through ∅ 0.5 mm silver-plated copper wire with crimped contacts to 48-pin KYOCERA Ultra High Vacuum Feedthrough and a shielded cable of about 1 *m* length to two 8-hold preamplifiers with a gain of 1 V /30 µA. The output signals of up to +10 V travel on twisted pair lines to active signal distributors (Fig.5) [1].

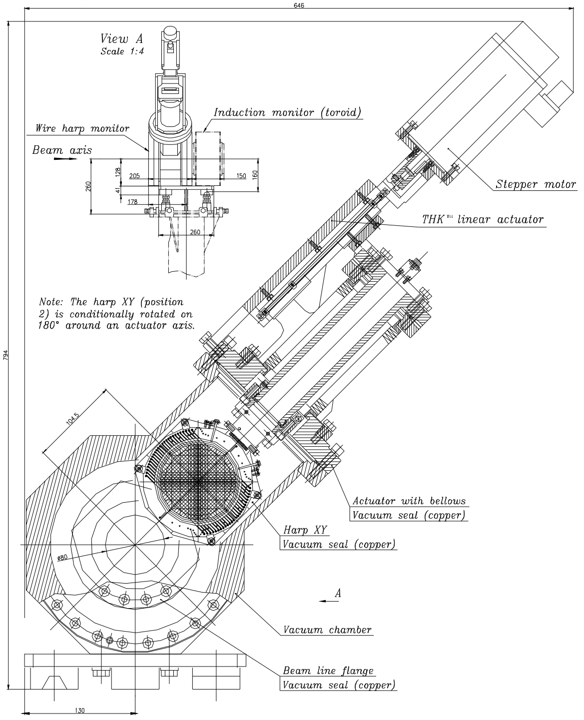

Fig.3. Beam profile monitor for DESY $H^-$ Linac III.

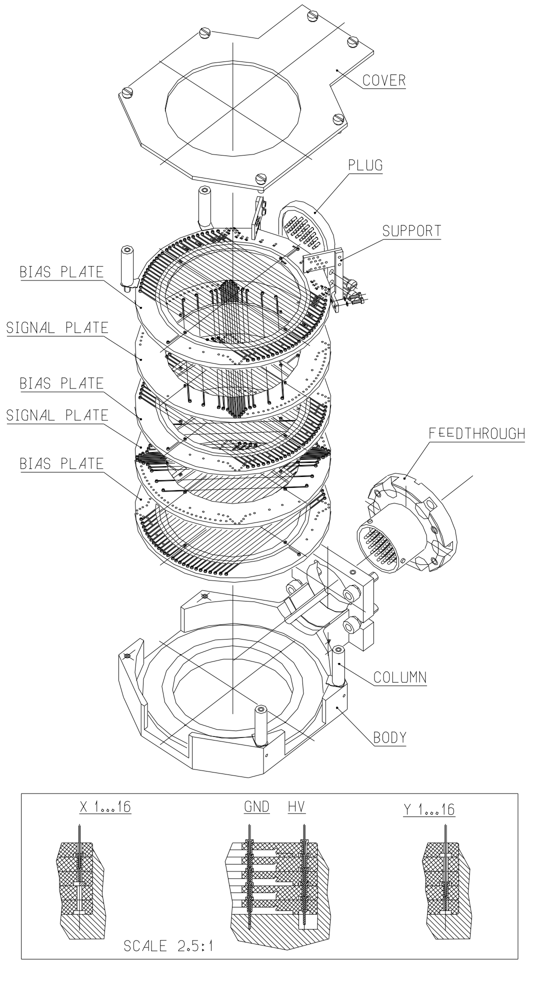

Fig.4. Assembly view of the harp unit.

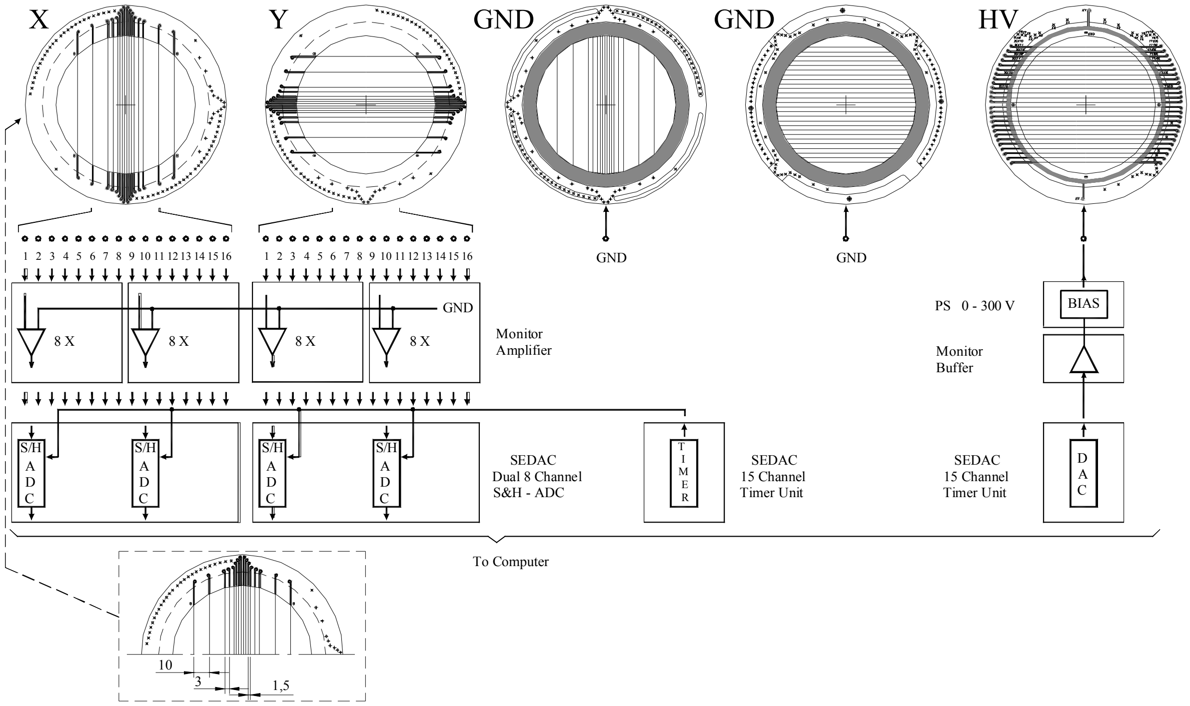

Fig.5. Simplified block diagram of the harp electronics.

## BEAM MEASUREMENTS

A special drift space with three double wire harps, is foreseen to measure all six transverse beam parameters. The profiles recorded by the harps are approximated by a Gaussian plus a flat background. The fitted 90% widths are used to compute the beam parameters $\beta$, $\alpha$ and $\varepsilon$ on-line [1].

The secondary emission current is integrated and digitized for each proton beam macropulse. The computer-controlled data-acquisition system has the capability of subtracting a costant level of background and of averiging several measurements. Fig.6 shows a set of profiles obtained by harp monitors. The proton beam had a peak intensity of 25 mA and consisted of 200 µs macropulses at 0.25 Hz.

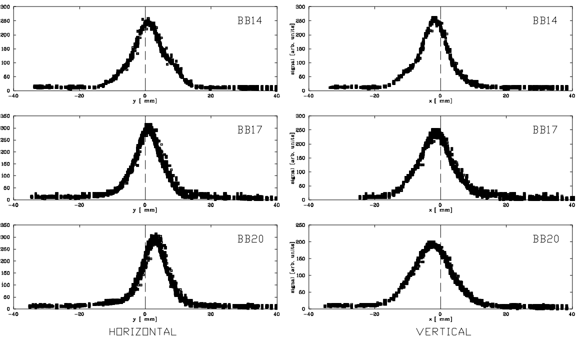

Fig.6. Wire harp profiles.

## CONCLUSION

The presented harp monitor allows an almost non-destructive observation of the beam profiles, and therefore a permanent online evaluation of the beam parameters. Every (double) harp intercepts about 3% of the beam, resulting in a 9% for the 3-harp measurements [1]. Given all parts and details of monitor has been made from inorganic materials, we succeeded to obtain high vacuum properties (the minimum number of weld seems and conflat-type connections also assisted in it). We tried to standardize elements of a profile monitor as much as possible. All movable elements may be remotely controllable and position may be measurable with appropriate precision by computer. The spatial resolution of harp monitors reaches a 1.4 µm and with fast electronics, bunches can be observed individually. Their great sensitivity followed by the multi-gain amplifier allows the study of halos [7]. The designed profile monitors is a precision device for adjusting the beam, for emittance measurements [4] and for matching the phase space ellipses of the beam to the phase space ellipses of the HEBT line.

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