A COMBINED FUNCTION BEAM EMITTANCE AND PROFILE MEASURING SYSTEM FOR THE ISIS 665 keV H⁻ PRE-INJECTOR

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Abstract

A description is given of the combined function, beam emittance and profile measuring system, installed on the 665 keV H– pre-injector at ISIS, the high intensity pulsed neutron source at the Rutherford Appleton Laboratory. The computer controlled system, consisting of in-vacuum beam analysing slits, and multiwire detectors, linear actuators, position encoders, motor drives, and signal conditioning electronics, measures the transverse emittance and profile of the 300 µs, 35 mA, 665 keV H– beam, with high precision.

1 INTRODUCTION

The concept and accurate measurement of beam emittance are of fundamental importance to the design and operation of particle accelerators. This description of the beam, when combined with a knowledge of those forces and processes that act on the beam (e.g. acceleration, space charge, scattering), enables the accurate prediction, and modelling of beam dynamics to be made, in accelerators and transport beamlines.

A particle beam, consisting of an ensemble of particles, each defined in terms of a total energy function, or Hamiltonian (H), is characterised by defining beam emittance, as the volume of a hyper-ellipsoid in six dimensional phase space, with the canonical coordinates x, p_x, y, p_y, z, p_z [1].

In practise, emittance is measured at constant beam energy, and by techniques that evaluate the 'root mean square' (rms) density distribution in the six dimensional phase space, in terms of elliptical area projections in the two dimensional longitudinal sub-space, with phase and energy coordinates (φ, *W)* , and the four dimensional transverse sub-space, with position and divergence coordinates (x, x', y, y') or (r, r').

Measurement systems, fall into two distinct groups, those for the determination of longitudinal emittance ($\Delta\varphi/\varphi$, $\Delta p_z/p_z$) [2], and those for the determination of transverse emittance (x, x', y, y') or (r, r') [3]. Systems can be non-destructive or destructive to the beam. The former include the wire-shadow and tomographic methods [3], both capable of being implemented in H- beams using the laser detachment method [4]. The latter systems include the pepper pot, electric sweep, slit-slit, and slit-harp [3]. A computer controlled, slit-harp emittance, and profile measurement system has been installed on the 665 keV H- pre-injector at ISIS.

2 EMITTANCE MEASUREMENT

The transverse beam emittance ε is defined as the volume of a four dimensional hyper-ellipsoid given by :

$$\varepsilon_{x,y} = \tfrac{1}{\pi}\iiiint dx\,dx'\,dy\,dy'$$

The measurement evaluates $\varepsilon_{x,y}$ in terms of the two dimensional projections in the x, x' , and y, y' planes :

$$\varepsilon_x = \tfrac{1}{\pi}\int dx\,dx' = \tfrac{1}{\pi}\cdot A_x\ , \quad \varepsilon_y = \tfrac{1}{\pi}\int dy\,dy' = \tfrac{1}{\pi}\cdot A_y$$

where A_x and A_y are elliptical areas in the x, x' , and y, y' planes, for 'normal', or 'perfect' beams [1]. For real beams, the evaluation of rms emittance, defines the ellipse area, of a transportable 'equivalent perfect beam', that is an invariant of motion in linear focusing transport systems [1]. This area is defined in terms of the second order moments, $\overline{y^2}$, $\overline{y'^2}$, $\overline{y \cdot y'}$, of the density distribution $\rho_2(y, y')$ as : $\varepsilon_{rms} = \sqrt{\overline{y^2}\cdot\overline{y'^2} - (\overline{y\cdot y'})^2}$

Evaluation of ε_{rms}, and the related Twiss parameters, at one point in a beam transport system, enables an accurate prediction of the 'transported' ellipse parameters to be made at any other point in the system, by means of a 'sigma' matrix manipulation [5].

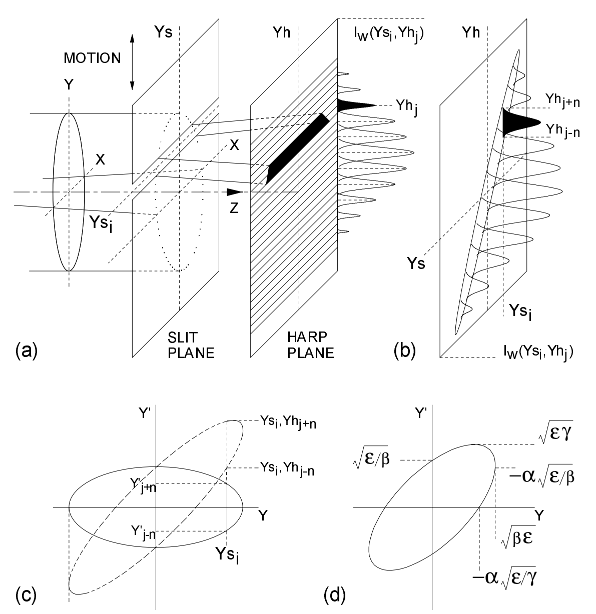

Figure 1. (a) Slit-harp measurement schematic. (b) Beam density distribution in (Ys,Yh) plane. (c) Phase space contour for a gaussian beam with a y-plane waist. (d) Definition of Twiss parameters

A schematic showing the essential features of the slit-harp measurement system is shown in figure 1(a). A beamlet, selected by a moveable slit at Ys_i, is intercepted on a downstream multi-wire detector (harp), as a current density distribution $I_w(Ys_i, Yh_j)$, centred on Yh_j. The profile for each slit position is stored in a two dimensional array, Ys_i, Yh_j. The right ellipse, shown in figure 1(c), represents an rms contour in the Y, Y' plane, for a beam with a gaussian density distribution, and a Y-plane waist. The input data ellipse in the Ys_i, Yh_j plane, shown dotted, indicates how the input data is sheared to generate the Y, Y' phase space data.

3 CONTROL PROGRAM STRUCTURE

Three measurement cycles, beam profile (x, I_{BEAM}, and y, I_{BEAM}), and emittance in the two transverse planes (x, x'), or (y, y'), are initiated and run under program control on an ISIS control system computer.

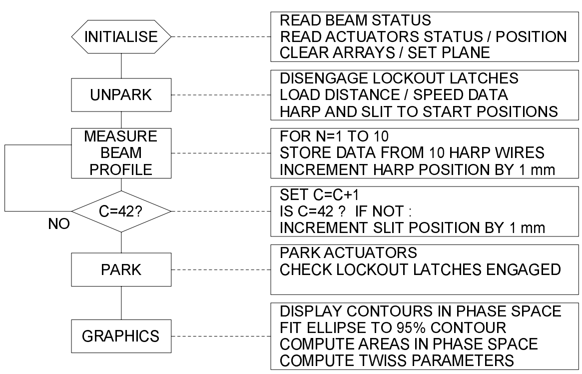

Figure 2: Emittance measurement code structure

The emittance measurement code structure is shown in figure 2. The measurement stores harp data in a two dimensional (42,100) input array, where, for each of 42 x 1 mm slit positions, a beam profile consisting of 100 x 1 mm measurements is made. Input array data is processed (sheared, noise rejected, amplitude normalised), to produce the phase space data array.

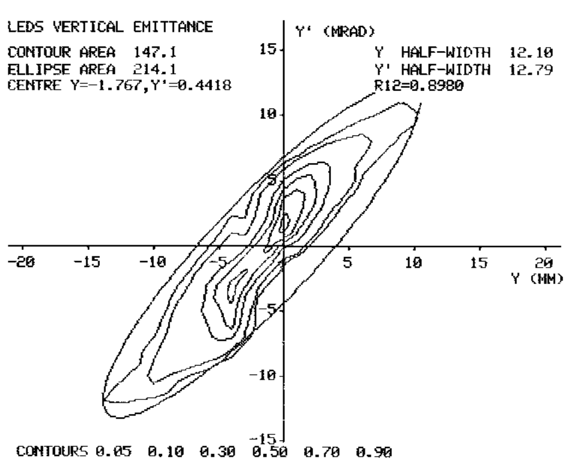

Figure 3: ISIS 665 keV H- Y- plane emittance plot

The phase space data is processed to produce plotting coordinates for a 2D contour map, with contours at 5, 10, 30, 50, 70, and 90% of the normalised peak beam intensity. The area inside the coordinates of the outermost contour is computed, by summing the areas of all the triangles formed by the centroid and successive pairs of contour coordinates. An ellipse is fitted to the coordinates of the outermost contour by first performing a least squares fit, to determine the slope of the major axis, and then, setting the length of the major axis, equal to the maximum width of the contour in the x direction, and the length of the minor axis equal to the maximum width of the contour in the x' direction. Computation of rms emittance is currently performed off-line.

4 MECHANICAL DESIGN

A plan view of the ISIS 665 keV H- beam transport area, showing the location of the emittance measurement installation, is shown in figure 4.

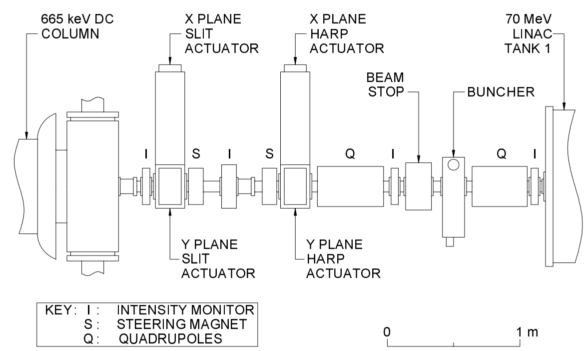

Figure 4: Plan view of ISIS 665 keV H- Beam Transport

The x and y plane harp actuators are located 980 mm downstream from the x and y plane slit actuators. The 1 mm wide, beam analysing slits are formed from copper plate, and are water cooled. ISIS beam prf is reduced from the operational 50, to 50/32 p.p.s. for the measurement duration, resulting in an average beam power of ~ 12 Watts (~ 25 kW peak). The harp assemblies are designed to withstand beam heating during the profile monitoring function at this reduced prf. They consist of ten, 1mm diameter tungsten wires, on a 10 mm pitch, supported by beryllium-copper spring fingers. These are attached to machineable ceramic (macor) blocks, mounted on a stainless steel 'C' frame. The mechanical construction of a linear actuator (y- plane harp) is shown in figure 5. The precision mechanism has a setting accuracy of +/- 1/64 mm. The static load imposed by the vacuum is balanced by an equal and opposite force exerted by a constant tension spring. Reduction of this load has permitted the use of lighter weight, lower inertia components in the drive train. As a typical measurement cycle consists of many small movements, the reduction in drive train inertia, results in a significant reduction in measurement time.

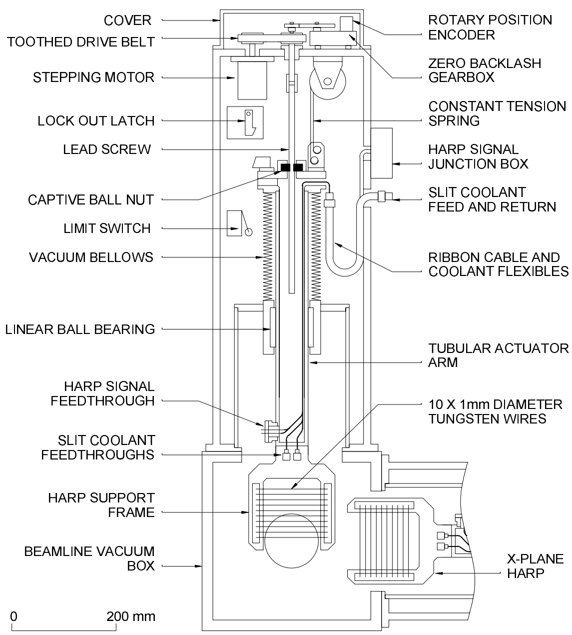

Figure 5: Actuator construction (schematic)

Limit switches prevent actuator movement beyond predefined limits. Lock out latches prevent the possibility of positional 'creep' in the parked position, when the stepping motors, in the de-selected plane, are disconnected from the multiplexed motor drive units.

5 ELECTRONIC DESIGN

The important features of the emittance measuring system drive control, and signal conditioning electronics, are shown in figure 6.

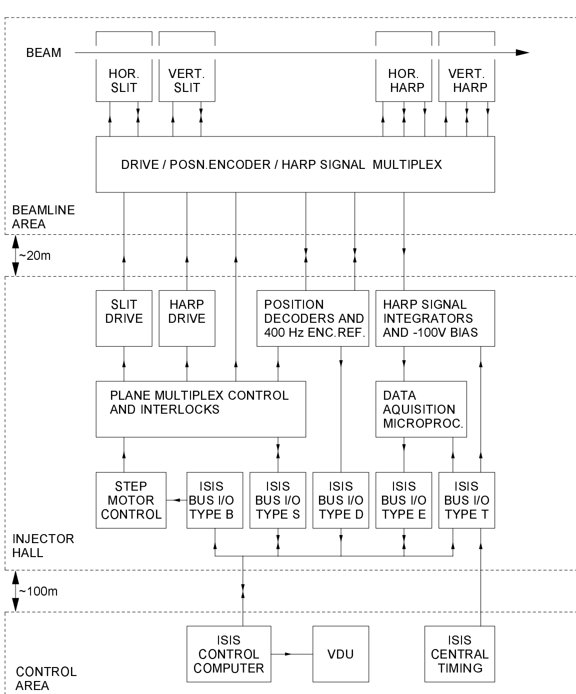

Figure 6: Electronic system schematic

Each linear actuator is powered by a 16 watt, two phase stepping motor [6]. The output of a programmable stepping motor controller, with a pre-set acceleration / deceleration slope [6], is multiplexed via two motor drive units [6], to control the positioning of the pre-selected slit / harp actuator pair. Plane selected slit / harp position measurement signals, derived from rotary, absolute position resolvers, are multiplexed to two resolver to digital decoders with 14 bit output resolution (1 LSB = 1/64 mm). Signals from limit switches and lock-out latches provide status information, and are hard wired to prevent damage under fault conditions.

Harp signal wires are biased at -100 volts, to repel thermionic and secondary electrons, stripped from the H- beam. Signals from the ten harp wires are plane multiplexed to a ten channel gated integrator. Integration time is synchronised to the beam pulse length. Integrated signals are output to the data acquisition microcomputer, where the analogue signals are stored as 12 bit data words, that are subsequently transferred to the control computer under program control.

6 OPERATIONAL EXPERIENCE

A routine measurement of beam alignment in the 665 keV H- transport line, is made after each ISIS ion source change (lifetime ~ 30 days), and normally, a full emittance measurement, taking about 20 minutes, will be made. The profile measurement, enables a more rapid (~30 s) check of beam position and width to be made.

7 ACKNOWLEDGEMENT

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