THE MULTIWIRE SECONDARY EMISSION MONITOR AND THE EMITTANCE MEASUREMENT OF THE AGS BEAM*

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Summary

For CBA injection the transverse emittances and the Twiss parameters of the AGS beam have to be well defined to minimize the phase space dilution in CBA.[1] Although there exists a profile monitor device at U165, there are three reasons why construction of a multiwire profile monitor system at three locations from U500 to U168 is required. 1) The dispersion function is not zero at U165 which makes it harder to interpret the measurement. 2) The original single wire device takes five minutes to traverse the whole beam. 3) A three station multiwire system can provide the profile information at all locations in one pulse which makes on-line analysis possible.

In summary, a set of three stations of Multiwire Secondary Emission Monitor (MSEM) has been built and installed in the fast external beam line for the measurement of beam profiles. Each unit consists of two planes each with 30 nickel wires having a diameter of 5 mils. The signal is linear within the range of 10^{10} to 10^{13} incident protons on the wire and the resolution of the signal is well within a few percent. A least-square fitting routine has been used to extract the emittance and phase space parameters of the beam. The emittances obtained at various intensities will help us to understand the AGS acceleration process and to choose the optimal injection scheme for CBA.

The Construction of the MSEM

Each MSEM unit consists of a stack of five C-shaped G10 planes with an opening of 3 3/4" × 4 7/8": A signal plane in the center, two spacer planes, and two bias planes on the outside. They are clamped together to form a rigid assembly of 7" high, 7½" wide, and 5/8" thick. A final wired assembly mounted on a motor drive is shown in Fig. 1.

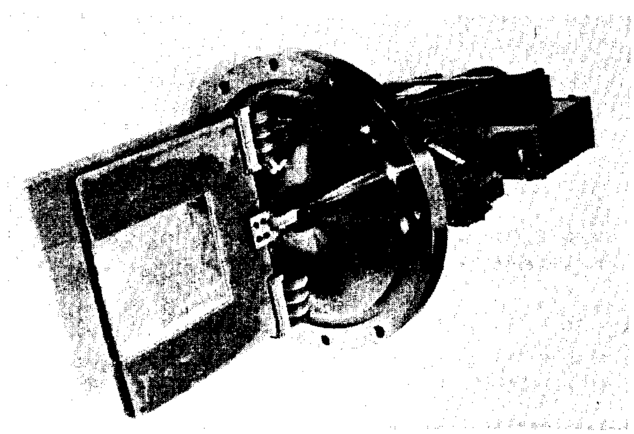

Fig. 1. The final assembly of the MSEM

The signal plane is constructed in the same fashion as a proportional wire chamber signal plane. Thirty 0.005 in. diameter nickel wires, spaced 0.06 in. apart, are cleaned with acetone and wound on a frame. The tension on the wire is 140 grams. The wires are then transferred and epoxied in place across the throat of the C-opening and soldered to the signal conduction path printed on the signal plane board. The board is made of 1/8" thick G10 and has a ground plane printed on the side opposite the signal wires.

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The bias planes are made by stretching and epoxying 0.00025 in. thick aluminum foil onto a 1/8" thick C-shaped G10 frame. Conductive epoxy is used so that electrical contact is made with the copper path on the G10 board to which the bias voltage supply is connected. When installed, the MSEM device resides in an instrumentation box which is part of the U-line vacuum system. It is mounted on a movable shaft which is driven by a stepping motordrive unit outside of the vacuum box. Total travel of the device is greater than 5 in. allowing the device to be fully withdrawn when not in use.

Signal Generation

The device is based on the principle of secondary emission of loosely bound electrons on the surface of the wires as the proton beam passes through them.[2] The secondary emission signal is linear over a wide dynamic range of incident protons and is measured by the electronics connected to each wire.

Assuming that the proton beam is Gaussian and approximately 1 to 2 in. wide (region including 95% of the particles), then a 5 mil diameter wire intercepts about 2 to 4% of the protons when placed in the center of the beam. The secondary emission coefficient has been measured for many materials and which for nickel[3] has been found to be about 2%. For a proton beam with an intensity of 10^{13} protons per pulse and the capacitance of 1000 pf of the capacitor used in the integrator, the expected signal level would be:

$$V = Q/C = 10^{13} \times 0.04 \times 0.02 \times 1.6 \times 10^{19}/10^{-9} \quad (1)$$
$$= 1.3 \text{ volts}$$

The estimate is consistent with the measurement of a single wire prototype unit which provided the initial information and confidence for the final design of the data acquisition electronics for the MSEM.

The electronics associated with one plane of the MSEM is shown in Fig. 2. Its function is to measure, digitize, and send to the PDP-10, the AGS control computer, a number proportional to the secondary emission from each wire during one beam spill. Each wire has its own integrator which contains a Burr Brown 3527 operational amplifier. The integrating capacitors are chosen to be nominally 1000 pf and matched to a capacitance variation for each plane of less than 1%. The circuit also provides for reset and hold by incorporating FET switches. Timing for these switches is derived from computer controlled predets and can be selected in 1 msec. increments.

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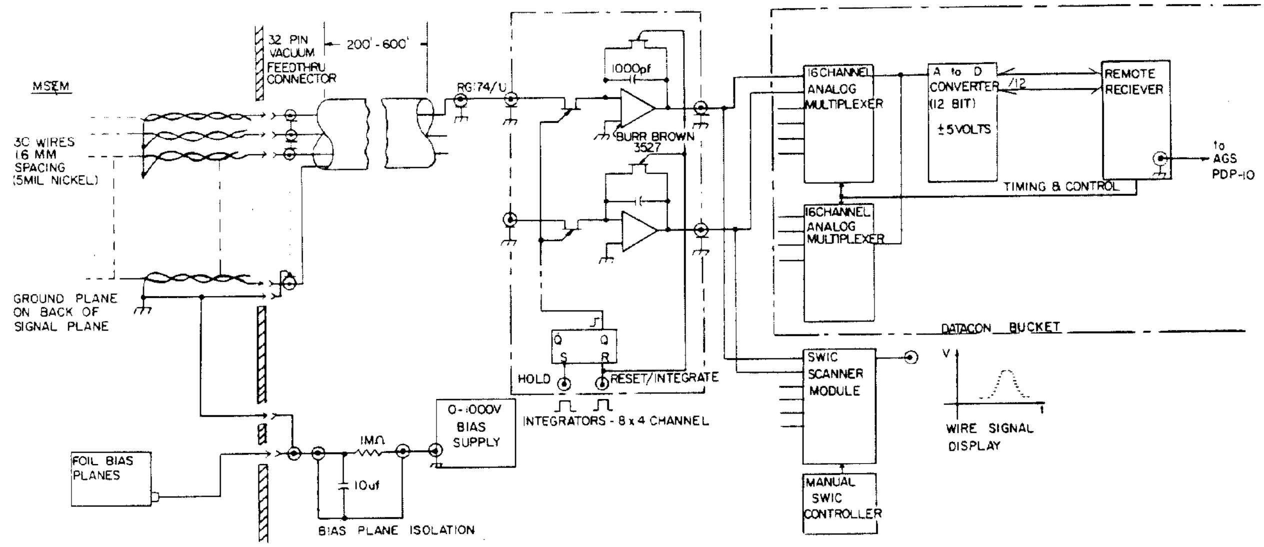
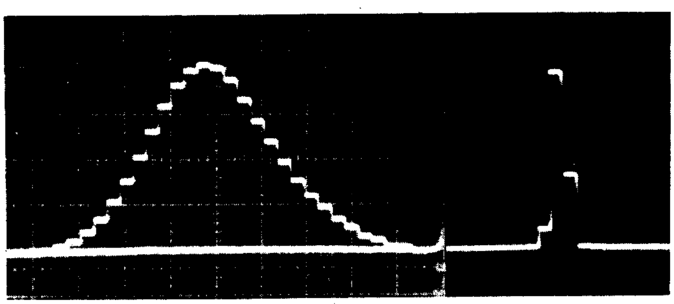


Fig. 2. The data acquisition electronics for the MSEM

The integrators are packaged four to a single width NIM module so that eight of them are required to handle the 30 wires in one plane of a MSEM. The output of the integrators are connected to a 12 bit, ±5 volts analog to digital converter module via two 16-channel multiplexers. These modules, part of a data communication scheme used in the AGS called DATACON, communicate with the PDP-10. Under computer control the multiplexer connects each integrator output to the ADC for digitization which in total takes less than 6 msec.

Calibration and Performance

A typical analog display of the signal is shown in Fig. 3. The data is also recorded in digital form from each channel. For the data analysis they are



0.2 v/div horizontal 1 v/div vertical

Fig. 3. The analog display of the beam profiles at U12 with $I = 8.5 \times 10^{12}$ ppp

normalized by the beam intensity recorded by U380 current transformer. Assuming that the reading from channel I is YI, I = 1 to 30, then several important parameters can be derived from the information:

$$SUM = \sum_{I} YI \qquad (2)$$

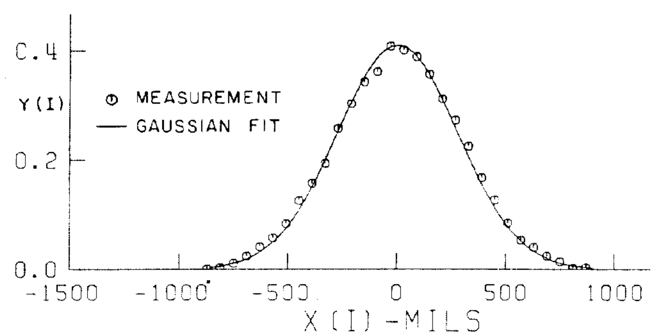
$$XME = \sum_{I} XI * YI/SUM \qquad (3)$$

$$SIG = \left[\frac{1}{SUM} \sum_{I} (XI - XME)^2 * YI\right]^{1/2} \qquad (4)$$

$$GI = \frac{SUM}{SIG\sqrt{2\pi}} \exp - \frac{(XI - XME)^2}{2 * SIG^2} \qquad (5)$$

$$\chi^2 = \sum_{I} (GI - YI)^2/GI \qquad (6)$$

Where XME is the center of the beam, SIG is the RMS beam size, GI is the distribution calculated from two-parameter Gaussian fit, and χ^2 is the test of the goodness of the fit. For example, shown in Fig. 4 is one result from the measurement.



SUM = 4.81 , XME = 3.0 , BFW = 1416.2
SIG = 283.5 , SIG1 = 289.0 , χ^2 = 6.54

Fig. 4. A vertical profile at U618 and its Gaussian fit (in units of 0.001 in.)

From the computer printed display in Fig. 4 we can conclude that for this particular measurement the beam center is at 0.003 in., the RMS beam size is 0.284 in., beam full width defined to contain 95% of the particles is 1.416 in. and the χ^2 of the two-parameter Gaussian fit is 6.54. Usually a fit is considered good if the χ^2 is less than the number of channels involved. In our particular example, the number of channels is 25; therefore, a Gaussian representation of the one dimensional projection of the beam is a very good prescription. Also shown in Fig. 4 is the number SIG1 = 0.289 which is derived from the beam full width at 5% height assuming that the distribution is Gaussian, then

$$SIG1 = BFW(5\%)/4.9 \qquad (7)$$

The agreement between SIG and SIG1 to within 2% is another indication that the Gaussian fit is faithful to the original distribution.

In February 1982 the first prototype vertical plane unit was installed at U618. A high pumping speed turbomolecular pump produced a local vacuum of better than 10^{-4} Torr. At that time a great concern was placed on the linearity and calibration of the signal. To answer those questions a cross calibration of the MSEM with a more reliable well-understood Al foil activation method was performed. An aluminum foil was exposed to the beam immediately in front of the MSEM device for 10 beam pulses which is equivalent to 10^{14} protons. Then the foil was cut into 1.0 mm strips and the activation of each strip was counted and plotted on top of the MSEM data display sheet. The result showed an excellent agreement in the shape and fine distribution and the calculation further showed that the RMS beam size derived from the two methods were:

	Al foil	MSEM single pulse	MSEM 10 pulses
SIG(in)	0.207	0.196	0.205

Although the single pulse MSEM result is smaller, the comparison between the foil counting and the 10 pulse MSEM results is excellent. This can be explained by the fact that the observable pulse to pulse variation of the beam center is 15 mils.

The Emittance Measurement

The beam characteristics in each transverse dimension is completely defined by three parameters: the emittance and two Twiss parameters. In principle, any three independent measurements can be used to solve for those three unknowns. But in practice we find it is more reliable to take a series of profile measurements and try to solve for the three unknowns by the least-square method. The way we choose to generate a series of profiles is to vary the setting of a quadrupole upstream of the MSEM device.[4]

In the AGS fast external beam U-line, quadrupole UQ10 is located at 483.96 ft. downstream of the H13 straight section. Consequently, the SEM device U550 and U618 are 66 ft. and 134 ft. downstream of the UQ10 quadrupole, respectively. Assuming that the transfer matrix from the entrance of UQ10 to the center of U550 (or U618) is M_i for each UQ10 setting, then the beam size predicted at the device can be expressed as:

$$X_i^2 = \varepsilon \cdot (M_{11}^2 \beta - 2M_{11}M_{12}\alpha + M_{12}^2\gamma)_i \qquad (8)$$

where α, β, and γ are the Twiss parameters of the phase space ellipse of the beam at the entrance of UQ10 and ε is the emittance of the AGS beam at extraction energy.

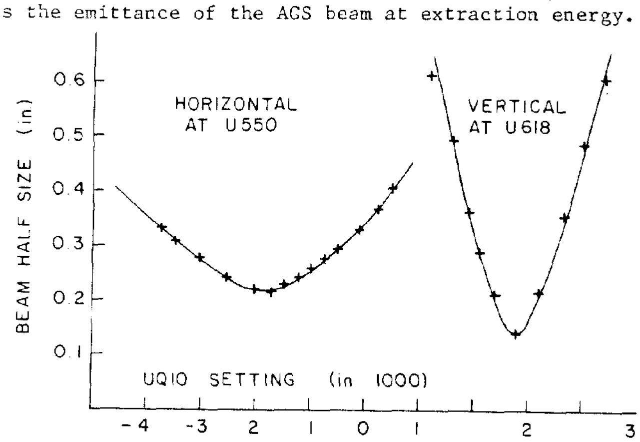


Fig. 5. The beam half-size as the function of UQ10 setting.

By adjusting the strength of UQ10, a series of beam profiles and widths can be obtained. Past experience shows that in order to get good results, the range of the quadrupole strength should generate a waist at the device and cover both sides of the waist equally. A tabulation of two measurements is shown in Fig. 5.

In all, three sets of measurements were taken and the results of the beam emittance and the Twiss parameters predicted by the least-square method are summarized in the following table:

	Vertical		Horizontal
Intensity	7×10^{12}	10×10^{12}	9×10^{12}
ε (mm-mrad)	1.62	2.33	1.78
α	-4.75	-3.61	-0.05
β (m/rad)	229	182	23.3
χ^2	4×10^{-3}	1×10^{-3}	2×10^{-3}

It shows that the normalized vertical emittance is 48 mm-mrad at 7×10^{12} ppp and 70 mm-mrad at 10×10^{12} ppp and the normalized horizontal emittance is 56 mm-mrad at 9×10^{12} ppp which are all consistent with past measurements by the flipping target method in the AGS.

The motivation for building a new set of MSEM stations is to obtain the required resolution and precision, and ease of operation to help in the following investigations: 1) The AGS rf capture and acceleration process in general, 2) the AGS beam quality at the required CBA injection intensity 2.5×10^{12} ppp in particular, and 3) the matching condition into the CBA beam transport line.

Acknowledgments

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