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A HIGH-RESOLUTION BEAM INTENSITY PROFILE MONITOR*

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Summary

This paper describes an intercepting beam intensity profile and position monitor which was developed at SLAC. It has excellent spacial resolution as well as signal efficiency. The instrument utilizes the electromagnetic cascade shower emission effect. Net charge leakage signals comparable in magnitude to the intercepted beam current are easily obtainable. The latest model of the instrument is described. It consists of an array of closely spaced 0.0025 cm thick tungsten ribbons which are 2 r.l. long in beam direction. Experimental results as well as application of the basic idea to four different instruments are discussed. The instruments are: (1) a spectrum analyzer, (2) a vertical beam position monitor, (3) a ring inflection monitor for the SLAC electron-positron storage ring project, and (4) an accelerator beam phase space measurer.

Introduction

Phosphor screen and Cerenkov light monitors are widely used in the accelerator field to monitor the beam profile. The screen monitors have the advantage that they are easy to fabricate and show reasonably good sensitivity ($\approx 10^{-9}$ A/cm^2 for ZnS). On the other hand, their lifetime is severely limited by loss of luminescence as a result of exposure to the beam. Cerenkov light monitors show very good longevity but are substantially more expensive. Both types of profile monitors share a severe shortcoming that restricts their use to applications where rough, qualitative answers are adequate. They suffer from saturation; and the videcon of the TV camera accentuates this problem. Secondary emission or SEM foils are frequently used for diagnostic and equipment protection purposes. They do not suffer from saturation, are generally inexpensive and show good linearity; however, efficiencies are only approximately 3% per surface or 6% total. This low efficiency restricts their use to high-intensity beams and relatively wide foil widths; otherwise, expensive electronic amplifiers have to be employed. With these ideas in mind, an intercepting beam profile and position monitor was developed that does not saturate and has excellent spacial resolution as well as signal efficiency.

The Monitor

Shower multiplicity in a high-Z material at SLAC energies is substantial and the efficiency ratio of the net electron charge leakage, i.e., the signal from a foil or bar intercepting beam current to the incident charge can be large. This efficiency ratio is a complicated function of the geometry and material of the detector foil. It is dependent on a net excess of electrons (over positrons) leaving the foil. If no other processes would contribute, the number of electrons and positrons would be approximately equal due to pair production. However, knock-on, Compton scattering, photoabsorption and other processes result in transfer of sufficient energy to other electrons in the foil to allow them to escape from the foil. This net charge leakage is substantially larger than that realizable from an SEM, where the signal is solely due to low-energy electrons emitted from the foil surfaces. Normalized shower curves have been published.[1] If tungsten is selected as material for the beam intercepting foils, the following table gives the number of electrons $\Pi^{(e^-)}$ in the shower due to one incident electron at depth of 1 and 2 r.l. for three incident energies E_0. For tungsten the material critical energy is $\epsilon_0 = 8.1$ MeV. These figures do not take into consideration the leakage of positrons and premature loss of particles due to single and multiple scattering. The figures further neglect "cross-talk," i.e., the interception of scattered particles from neighboring foils in a closely spaced array.

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E_0 [GeV]	=	5	10	20
E_0/ϵ_0	≈	6×10^2	10^3	2×10^3
$\Pi^{(e^-)}$ (at 1 r.l.)	≈	5.5	7.0	8.0
$\Pi^{(e^-)}$ (at 2 r.l.)	≈	16	25	31

All of the aforementioned effects plus misalignment of the ribbons tend to reduce the net charge leakage signal.

Several models of shower emission monitors were built and tested. Description of the most recent model, as shown in Fig. 1, will suffice. The assembly is made up of an array of 10 closely spaced tungsten ribbons. They are about 2 r.l. (≈0.65 cm) long and 0.0025 cm thick. The ribbons are insulated from each other at two clamping points by mica foils. The closest spacings are 0.005 cm wide; and the spacing distribution is shown in the lower section of Fig. 2. The ribbons are stretched by means of the "guitar tuning" mechanism shown at the top of the picture. The leaf springs visible at the bottom of the picture keep the ribbons always under tension. They take up the thermal expansion that takes place during beam interception. Thus, the spacing stays constant during operation, and adjacent foils cannot short out. The whole assembly is mounted on a heavy ceramic yoke. Heat generated in the foils is in part radiated off and the balance conducted down the ribbons, into the ceramic yoke, and on out into the support frame and instrument vacuum chamber. The power deposited in a $\delta = 0.0025$ cm thick, 2 r.l. long tungsten foil per microampere of beam current intercepted at 20 GeV is $P_{av} \approx 12(dE/dx)I_{av}\rho\delta = 0.7\, I_{av}$ watts/μA, where the 12 accounts for the average shower multiplicity in the target. The monitor was tested on 1/19/71 in beam line 8 of the SLAC B-beam target room. The beam was slightly dispersed in the horizontal plane. The monitor was oriented horizontally to allow sampling of the vertical beam intensity profile. Seven of the ten ribbons were simultaneously displayed on an oscilloscope using a multiplexing system. The signals of adjacent foils were delayed by 1.6 μs. Figure 2 shows three scope traces. The beam parameters were: $E_0 = 19$ GeV, $I_p = 10$ mA, PRR = 10 pps, and $\tau = 0.8$ μs. The top trace shows the beam centered on ribbon #4; additionally, significant signals can be seen on ribbons #2 through 5. If half the spacings between ribbons #1 and 2 on one hand and #5 and 6 on the other are added, then the effective beam height was approximately 0.03 cm. The maximum signal was about 150 mV, which for an impedance of 50Ω corresponds to 3 mA peak current. It is estimated that approximately 12.5% or 1.25 mA of the incident beam were intercepted by foil #4. Thus, the efficiency was about 240%. The center trace of Fig. 2 was taken for the same beam. The only difference was a 0.0003 r.l. long radiator that was placed in the beam approximately 100 meters upbeam of the monitor.

After the radiator was removed, an attempt was made to improve the focussing of the beam. Trace #3 at the bottom was the result. Ribbons #3, 4, and 5 plus half the spacings to the next ribbon on either side contain approximately 90% of the total incident beam. The signal on ribbon #6 was in reality not as large as the trace shows. There was substantial noise due to an external source as evident on the left-hand side of all 3 traces. This was verified by changing the sequence of the ribbon signal display to a mirror image. Thus, the effective beam height was approximately 0.025 cm. It should be pointed out that a nearby Cerenkov light monitor showed the beam to be approximately .3 to .4 cm high or one order of magnitude more than what it was in reality. Approximately 12% or 1.2mA of the incident beam were intercepted by foil #4. This would indicate an efficiency of 250% and is in close agreement with the results from trace #1. This is about 8% of the theoretical current computed from the number of shower electrons at a depth of 2 r.l. The peaks of the signals in trace #3 are plotted

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as a histogram in the lower section of Fig. 2. The resulting curve gives a good representation of the vertical beam profile.

At the end of the experiment the beam was carefully centered first on ribbon #1 and then #9. The incident peak current was increased to 15 mA; all other beam parameters stayed constant. The maximum signal obtained in either case was about 600 mV, corresponding to a peak current of 12 mA. This indicates that cross-talk is negligible for this monitor.

The average power deposited in a foil on which the beam is centered is approximately 10^{-3} watts for $I_p = 15$ mA, this is negligible. However, for a high-power application at SLAC energies the 2 r.l. depth of the ribbons has to be reduced to prevent thermal destruction. Such a reduction can easily be justified due to the high efficiency.

Applications

Four applications of the shower emission monitor are briefly described. Three of these are for the SLAC electron-positron storage ring project (SPEAR) where the advantages of this monitor over other devices are substantial since beam energy and current are low. The following beam parameters are considered: $E_0 = 1.5$ GeV, PRR = 20 pps, $0.05 \leq I_p \leq 5$mA, $\tau = 7$ ns. It should be pointed out that the devices destroy the beam for most applications and have to be retractable from the beam line.

Spectrum Analyzer

A spectrum analyzer operating in conjunction with a momentum-defining slit in the SPEAR transport system was designed and fabricated. It consists of ten 1 r.l. long tungsten bars and covers $\pm$ 0.7% $\Delta p/p$. The center six bars are 0.1% $\Delta p/p$ wide and the four outer bars 0.2% $\Delta p/p$; where 1% $\Delta p/p$ corresponds to about 20 cm.

Vertical Beam Position Monitor

An intercepting vertical beam position monitor was designed and fabricated to aid steering in the vicinity of the slit in the SPEAR transport system. Its signal-generating foils are two horizontally-oriented 1 r.l. thick tungsten sheets. They are separated by 2 cm to allow for easy transmission of a beam with a .15 π(MeV/c) cm phase space. The monitor is intended to be used either as a nulling device or, more likely, with a dual beam oscilloscope display.

Ring Inflection Monitor

A monitor is needed to aid in beam injection into the storage ring. Present plans are to use a single, 0.0025 cm thick, 2 r.l. long vertically oriented tungsten foil. The procedure is first to establish beam position by maximizing the signal on the foil; then the beam will be horizontally deflected a predetermined amount with a steering magnet.

Use of Profile Monitor in a Beam Emittance Measuring System

One of the initial motivations for the development of the profile monitor was for use in a beam emittance measuring system for the purpose of determining the geometrical phase space configuration of the accelerator beam as it enters the SLAC beam switchyard (BSY) transport system. At present this phase space configuration is essentially completely unknown to the operators during the setup of any particular beam and can only be inferred by observing the characteristics of the accelerator beam at various points in the BSY and the end stations. For experiments with crucial incident phase configuration requirements on the beam, this situation presents difficult operational problems. The latter would be eased by instantaneous knoledge of the phase space configuration of the beam from the accelerator and how it is affected by the numerous controls available to the operator.

A preliminary conceptual form for the beam emittance measuring system consists of a horizontal slit placed near the entrance to the BSY transport system. This slit would define a narrow horizontal slice in the vertical phase space. The profile monitor would be placed downbeam of this slit. Sufficient space is available to allow 80 to 100 meters of drift space for the beam. Through the use of pulse steering magnets, which serve the purpose of sweeping the beam across the slit, or by using a movable slit, a measurement of the vertical emittance configuration of the beam could be made and displayed to the operator on a display screen. The horizontal configuration could be measured using an identical detection system rotated 90°.

The phase space of the beam from the accelerator is nominally 0.1 π(MeV/c) cm. For typical beam phase space configurations the dimensions of the monitor which was previously described will provide satisfactory emittance measurement data. In fact, the total beam height given above (0.025 to 0.03 cm) can be combined with the observed spot size on a zinc sulfide screen at an upbeam position to determine the phase space area of the beam. The result obtained is consistent with the nominal value given above.

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Reference

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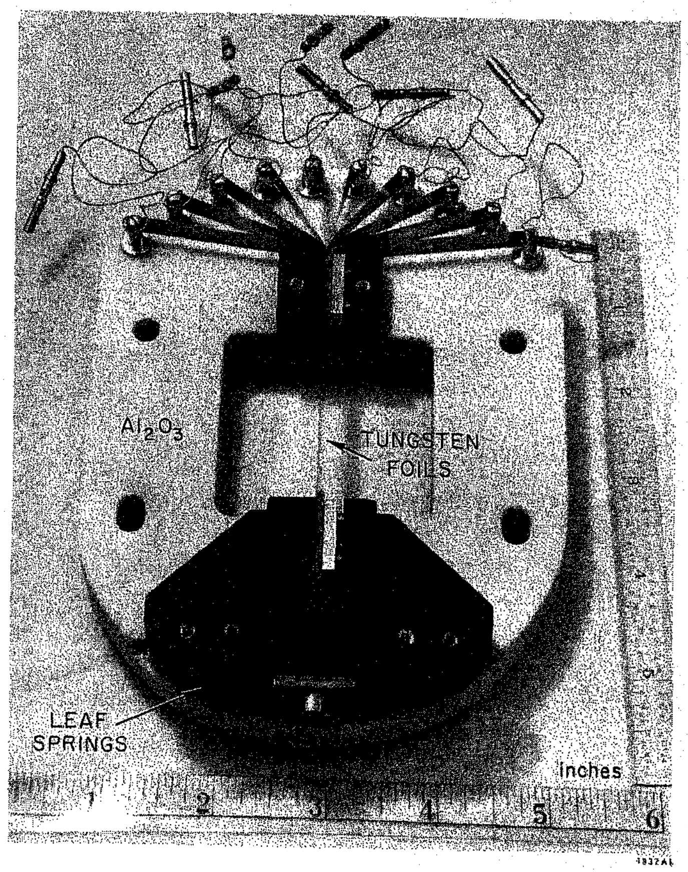

FIG. 1--Intercepting beam profile monitor.

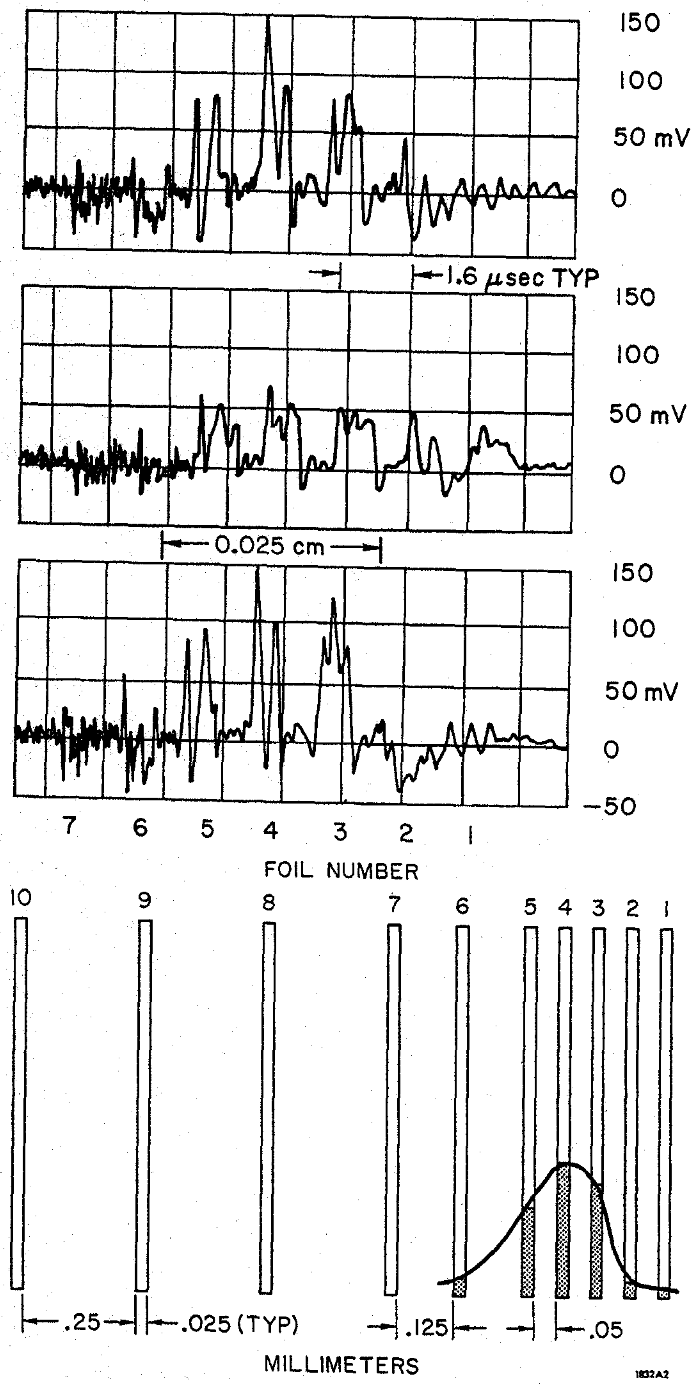

FIG. 2--Oscilloscope traces for $E_0 = 19$ GeV, $I_p = 10$ mA electron beam; and ribbon arrangement.