A GAMMA RAY PROBE FOR INTERNAL BEAM PHASE MEASUREMENTS*

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Abstract

We have constructed an inexpensive and extremely compact device for measuring the phase of the beam inside the cyclotron with respect to the R.F. This device uses a PIN diode to detect gamma rays which are produced when the beam is stopped. The gamma rays are timed relative to the zero crossing of the R.F. signal giving a measurement of the time of production. In the current design the diode is located in the tip of a probe which intercepts the beam so that there is negligible time of flight for the gamma rays between the point of production and that of detection by the diode. This location also minimizes the chance of picking up gamma rays from sources other than the beam probe. Measurements of phase widths in the K500 cyclotron will be presented.

Introduction

In the fall of 1985 a general purpose probe drive was added to the K500 cyclotron. This drive was provided with an air-lock so that probe heads could be easily changed. This then allowed us to examine the possibility of detecting the gamma rays which are generated when the beam hits the probe head. Previous attempts[1] to detect the gamma rays from a distance had been hindered because of the high gamma background inside the cyclotron. In most cases the count rates were low because of poor solid angle, so locating the detector as close to source as possible was the obvious solution. Photomultiplier tubes are difficult to use in the vicinity of the cyclotron because of the high magnetic field, and attempts to use light pipes to bring the signal out to the photomultiplier tube failed because of large signal losses.

One limitation of using the general purpose probe drive is that the inner diameter of the probe tube is 0.5" so a detector needs to be compact. It also should not be affected by the high magnetic field (5T) in the probe head region. On the other hand, the probe tube will shield the detector from other gamma sources inside the machine, thus reducing the background.

Equipment

The solution to these difficulties was to use a PIN diode located just behind the probe tip. A schematic of the phase probe is shown in Fig. 1. The probe consists of a PIN diode and a small, single chip, pre-amp (X10) mounted on a 0.5" by 2." wafer board. The diode chosen was a Hewlet-Packard HP-2-4203, and the pre-amp is an NEC μPC1651G. Power and the signal are carried along the 58" tube length on RG-174 cables. At the exit of the probe the signal is again amplified, and then sent to the control room. Power requirements are -20V for the diode, +6V for the pre-amp, and +12V for the second pre-amp. Cooling of the probe tip, and electronics is done by blowing dry nitrogen inside the probe tube. As shown in Fig. 2, after the signal reaches the control room it is fed into a constant fraction discriminator (CFD). The output of the CFD is then used as the start signal for a time-to-amplitude converter (TAC). The stop signal for the TAC is a pulse generated at every second positive zero crossing of the RF signal. Dividing the stop signal by two means that all the features in the time spectrum will appear twice, 360° apart. This then gives an immediate calibration between channels and degrees of phase, without any worry about cable length. The TAC output is digitized using a multi channel analyser (MCA). A sample output is shown in Fig. 3.

The peak width in Fig. 3 is the sum of the time response of the diode and the phase width of the beam, added in quadrature. It is thus necessary to know the time resolution of the PIN diode. This proved difficult because of the diode's low efficiency for γ rays. A coincidence measurement using standard γ sources is impractical so instead, we measured the rise time of

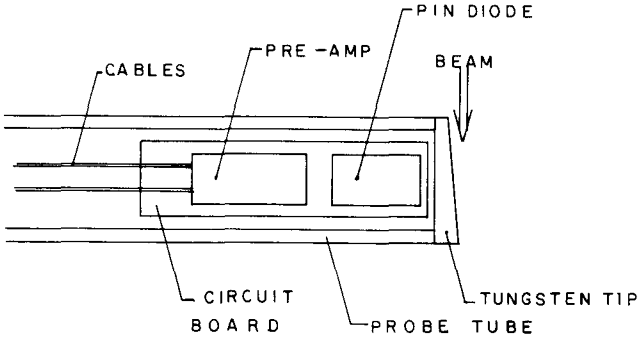

Fig. 1 A schematic drawing of the phase probe. The PIN diode is used to detect gamma rays produced when the beam strikes the probe tip. The small size of the diode and amplifier allows it to be located near the source so the count rates are high and the source is distinct from the background.

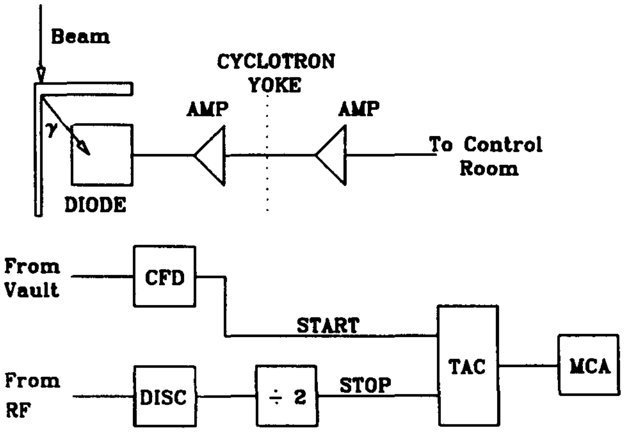

Fig. 2. Once the cables exit the probe body the signal is again amplified before being sent to the control room. In the control room the signal is discriminated using a CFD and the resulting signal is used as a start for the TAC. The TAC stop signal is a pulse generated every second positive zero crossing of the RF system synthesizer signal.

the diode using a sampling oscilloscope and a fast pulsed laser. The rise time was measured to be better than 500 ps. In Fig. 4 the time spectrum of the external beam, as measured with the PIN diode, is compared to a measurement of the same beam made with a BaF detector. The time resolution of the BaF was known to be better than 300 ps, and the two detectors produced very similar results.

The ability of the PIN diode to perform in a high magnetic field was also checked. To do this the diode was placed in the K800 central region, where the magnetic field is as high as 5T. A light pulser was used to trigger the PIN diode and the pulse height was measured. The pulse height in full magnetic field was 20% lower than that when there was no field present. When using the diode in the K500 the second X10 pre-amp was necessary to amplify the signal above the constant fraction minimum discrimination level (5mV). There was still a sufficiently large signal that it could be easily distinguished from the background noise.

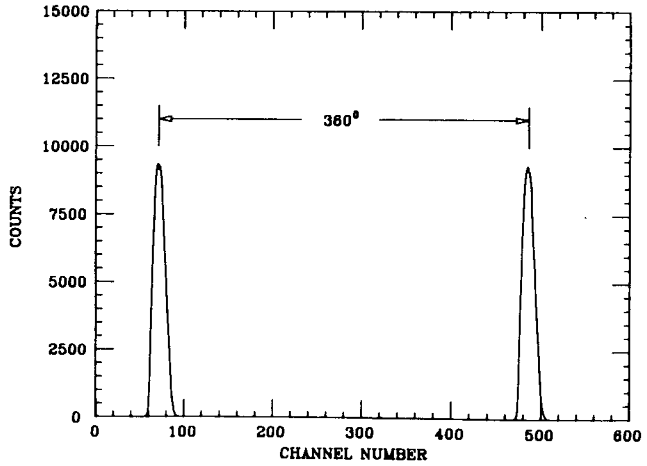

Fig. 3. A typical spectrum of intensity versus time, as measured with the gamma probe. Notice that the divide by two of the stop signal causes all features to appear 360° apart.

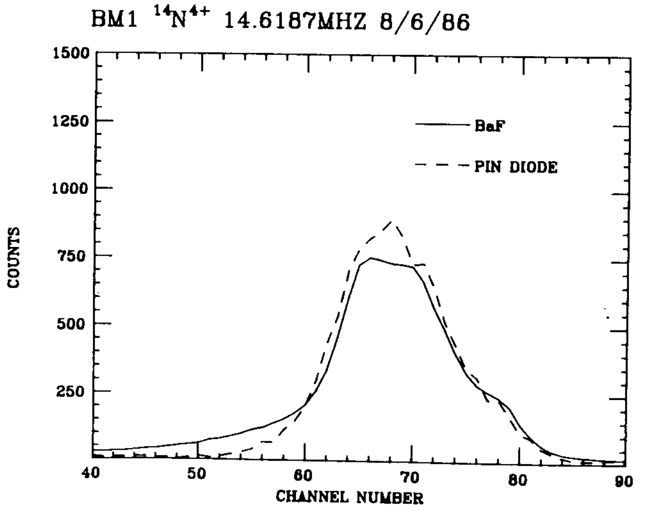
BM1 $^{14}N^{4+}$ 14.6187MHZ 8/6/86

Fig. 4. A comparison between the PIN diode and a BaF detector. Both detectors measured the same beam, which was striking beam stop 1. The measured beam widths are very similar.

Results

Once it was found that the PIN diode would work under these conditions, phase measurements became easy. In its present configuration the device can be used to measure the phase width of the beam between 20" and extraction radius. It can also be used to measure changes in the phase as a function of radius. Determination of the absolute value of the phase must be done with a different technique, such as frequency detuning method of Garren and Smith[2], but it need only be done at one radius.

In one recent test the gamma probe was used to determine the phase width of the internal beam when the phase selection slits were in place. A sample output is shown in Fig. 5. During this run it was found that short collection periods (approx. 1 minute) could be used to determine the effect of a given slit position. Once a good slit position was found the collection interval was raised to 3 minutes and a quantitative measurement such as those shown in Fig. 5 were made. This proved to be a very effective technique for setting up the phase selection system.

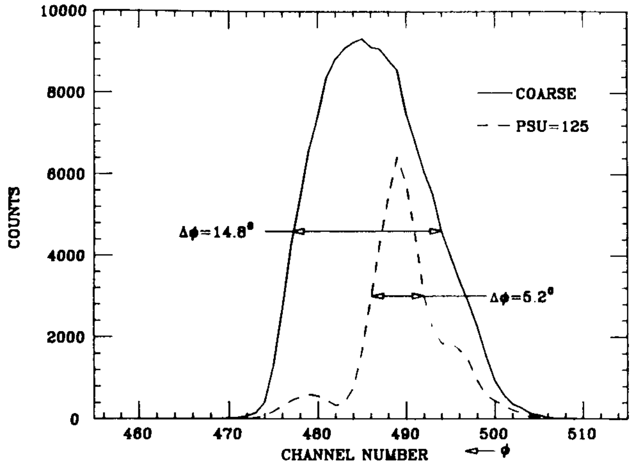

Fig. 5. An example of measurements taken with the probe inside the cyclotron. In this case one measurement was taken with the phase selection slit in place, and another with the slit removed.

References

1. B.F. Milton et al., pg. 55, Proc. Tenth Int. Cyclotron Conf., F. Marti ed., 1984.
2. Garren and Smith , Proc. of the Int. Conf. on Sector-Focused Cyclotrons and Meson Factories, CERN, April 1963.

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