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A Method to Measure Phase Distribution of Charge in Bunch (or Bunch Length)

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There are several different methods available for measuring the bunch length, e.g., the streak camera, the deflecting cavity, and the bending magnet. They are expensive, and some of them don't work well at the low energy region of the injector, and the resolution of some of them is not good enough to measure the bunch length of the well bunched beam at CEBAF (less than 1° at 1.5 GHz). We propose a method to measure the bunch length that is inexpensive, suitable for any energy of beam, and has good resolution as well.

Usually in the design of the injector the output phase distribution is calculated (output phase vs. input phase). Since the initial distribution of electrons in the phase is uniform, one can then compute the output phase spectrum of beam from the injector, giving the bunch length. Figure 1 offers two examples. Actually, the phase distribution of the charge in the bunches provides us with information in addition to the bunch length. The method proposed here is to measure the output phase distribution of the charge in the bunches instead of the length of the whole bunch.

The CEBAF injector is taken as an example to illustrate the method. If the injector is fine-tuned, the bunch length at an entrance (A) to the full cryogenic cavity 15 m downstream from the gun is 0.7° to 0.9°. The initial phase width is 60°. A 6 GHz resonator cavity is placed at point A to pick up a fourth harmonic signal of beam-induced field (beam frequency is 1.5 GHz). The signal from the cavity indicates the central phase of the bunches. The main slot allows 60° of the initial bunch to pass through. The initial bunch is further divided into 6 pieces (6 is an arbitrary number chosen for this example), and therefore, each of them has an initial phase width of 10°. Figure 2 shows a map calculated by PARMELA that indicates the position of each of 6 sub-bunches in the final bunch. Experimentally, an additional 10° slot is added adjacent to the main slot, and this second slot can be rotated by 10° at each step with respect to the 60° slot. The map shows that the maximum difference in the central phases of the 10° sub-bunches is 0.85°, which is consistent with the bunch length of the 60° initial beam at point A, which, as mentioned above, is 0.7° to 0.9°.

In all calculations the space charge effect (SCE) is taken into account. The SCE is not significant at the CEBAF accelerator. The bunch length measured by the method is less than the actual if the SCE becomes important.

The beam loading is nearly constant during the measurement, though only a part of the normal current is run. A feedback system will maintain the fields as they are in the normal state of current, so the phase motion of the electrons remains the same as the normal state (full 60° bunch). Therefore, the beam loading will not affect the result of the measurement.

Resolution

The cavity is made of invar. The thermal expansion coefficient α is $(-2$ to $+5) \times 10^{-6}/°C$ and is very small compared with copper, which has an expansion coefficient of $16.6 \times 10^{-6}/°C$. The loaded Q value of the cavity is about 1000. From the formula $d\phi = 2Q_L\alpha$ dT it can be seen that a 1°F change in the cavity temperature causes only 0.32° phase drift at 6 GHz (0.08° phase drift at 1.5 GHz). Even considering other possible instabilities in the measuring system, it should not be difficult for the system itself to reach a resolution of better than 0.8° at 6 GHz, corresponding to a resolution of better than 0.2° at 1.5 GHz.

Signal Level

The cavity is a simple cylindrical one without nose cone, operating at a TE_{02} mode of 6 GHz. The cavity radius is about 4.51 cm, and its length is 2.5 cm. The R/Q over the cavity length is 24.6 Ω. The radius of beam pipe is 1.2 cm. For a 10 μA current of the sub-bunches the output signal from the cavity is about 10 mV into a 50 Ω load.

How to Display the Phase Distribution On Screen

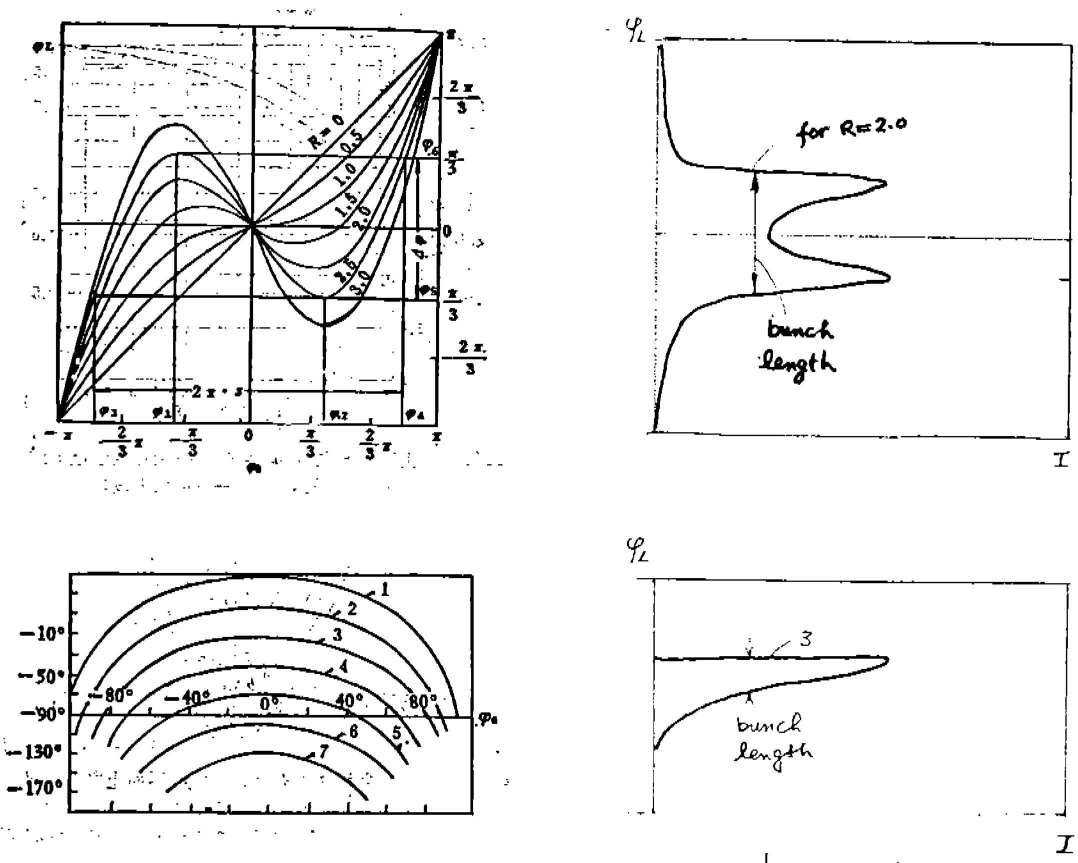
New slot piece, as shown in Figure 3, is placed in the beam line as a replacement of the regular slot. When point B is located in the beam line, the injector is tuned as usual. If the piece is lifted and point C is placed in the beam line, the phase distribution will be directly displayed on the scope screen by sweeping the electronic control phase shift (ECP).

The system provides a powerful tool for tuning the injector. It can also be used to study the stability of the output bunches from the injector, as described in [1].

Reference

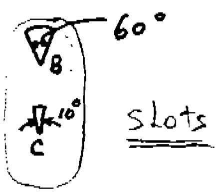
[1] C. G. Yao, CEBAF TN-116, June 1989.

[apd.tn]yaotn.tex



phase distribution → phase Spectrum

Figure 1.



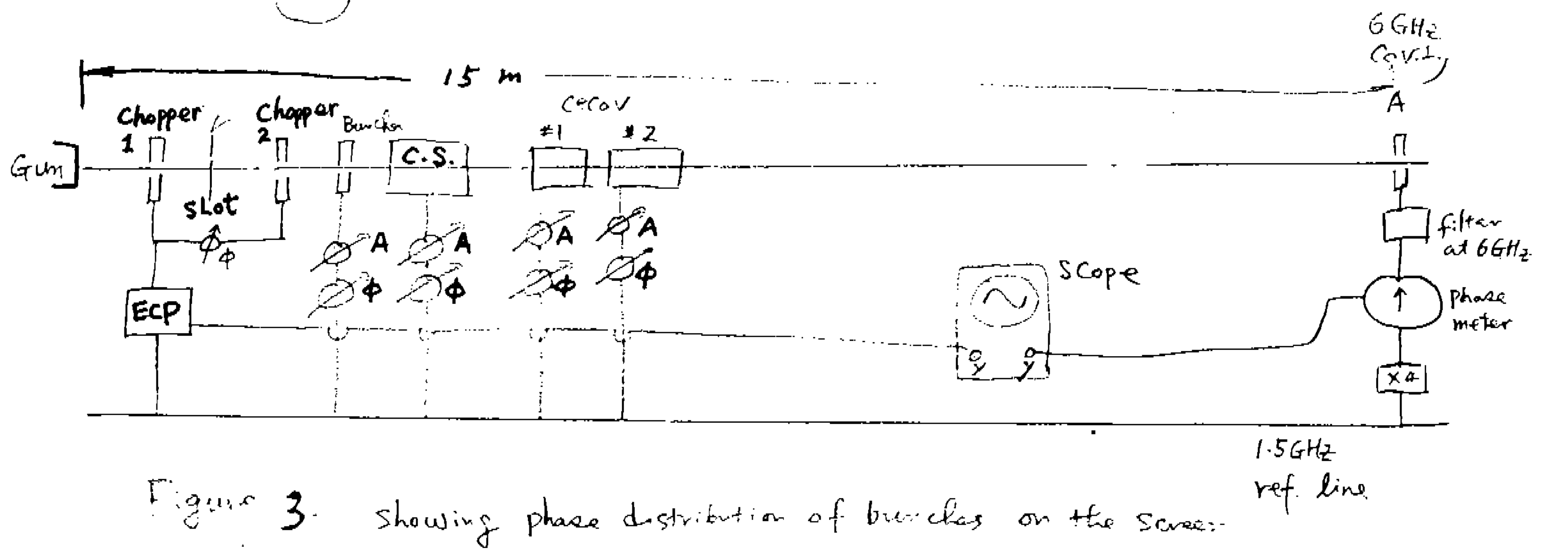
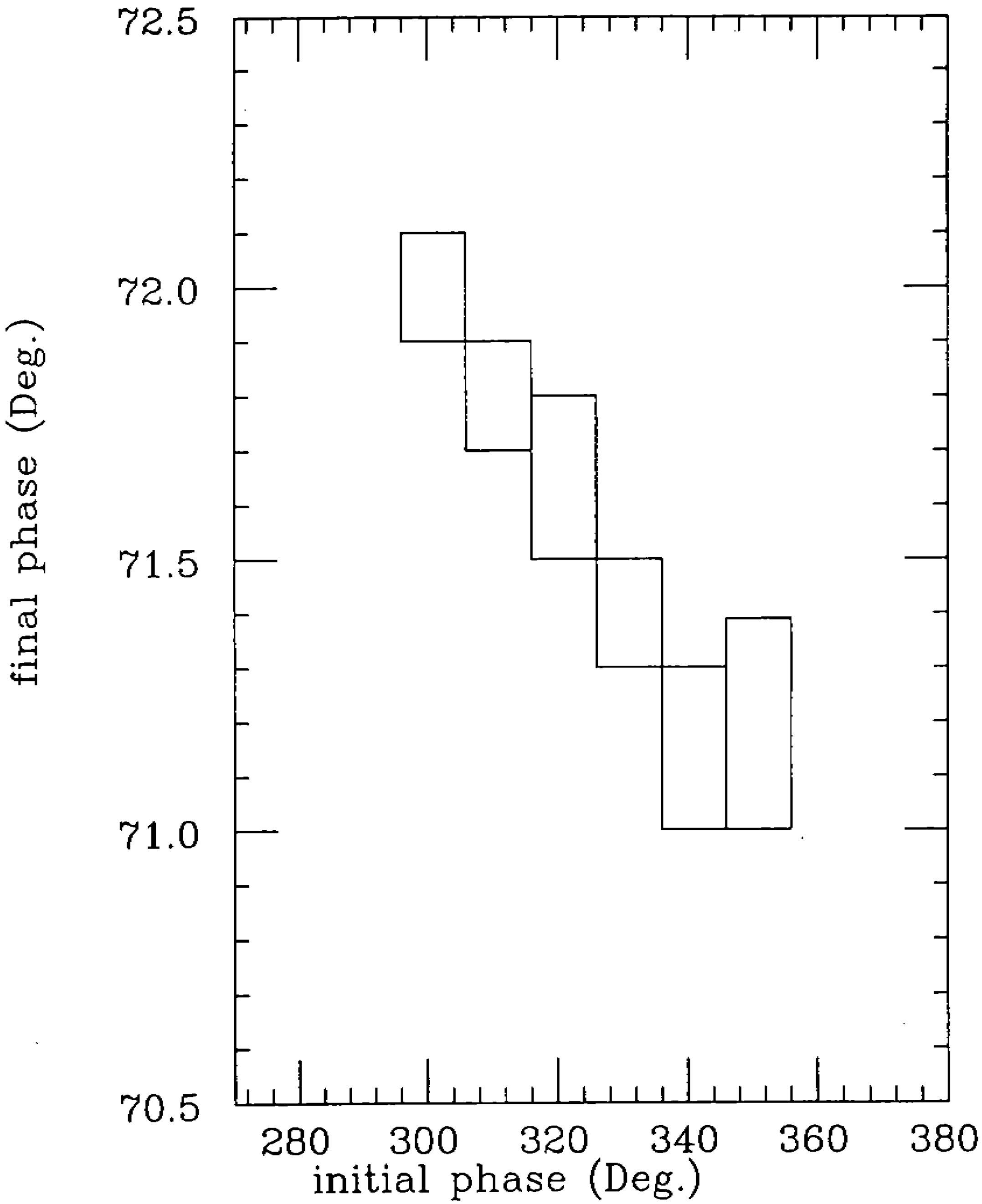


Figure 3. Showing phase distribution of bunches on the Screen.



Initial phase vs. Final phase

Figure 2.