IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

MEASUREMENT OF THE INSTANTANEOUS 200-MHz BUNCH CURRENTS AT 750 keV FOR THE CERN LINAC 2

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Summary

The efficiency of the longitudinal matching of the low energy proton beam with a double drift harmonic buncher (DDHB) depends on the correct setting of RF levels of the first and second harmonic buncher cavities and their respective phase[1]. The adjustment is done by means of a retractable destructive broadband probe situated in front of the Linac input. It is essentially a piece of a well matched 50 Ω line intercepting the beam perpendicular to its axis (Fig. 1). At the beam side it is an asymmetric double strip line, forming a 1 mm gap between a highly transparent grid (90%) and a tantalum insert stopping the incoming beam on the inner conductor. One side of the line is open ended, the other smoothly tapered over a length of 30 mm into a coaxial line, continued outside the vacuum with a flexible low loss cable to observe the bunch signal on a 1.2 GHz real time oscilloscope. This signal should give the longitudinal proton density distribution and permits to optimize the bunching efficiency and to adjust the phase between the two buncher cavities to about 1° at 200 MHz. For high intensity beams the interpretation of the bunch shape requires some precaution as secondary and thermal electrons modify considerably the form of the expected signals.

Design Criteria of the Broadband Probe

General

The choice of the probe parameters needs some compromise among several requirements as there are e.g. the useful bandwidth, a limited temporal resolution due to a highly non-relativistic beam, the required aperture as well as unavoidable mismatches and mechanical tolerances.

For example, to hold safely a bias of 1 kV requires the gap for the incoming beam to be about 1 mm, leading to a transit time of 80 ps for 750 keV protons. The size of the aperture allows to intercept a large amount of beam for an acceptable uncertainty (25 ps) caused by different signal propagation along the line.

Signal Symmetry

With earlier bunch form measurements the analysis of the bunching efficiency, as well as the precise phase adjustment, suffered from signal asymmetries, as normally caused by reflection[2].

The present design intended to eliminate as far as possible errors introduced by imperfect transmission line matching and it has profited from the experience gained with a higher bandwidth device designed for measurements at 10 MeV during the commissioning of Linac 2. One essential difference is the bias of the entry gap via an easily removable d.c. block, connected beyond the vacuum feedthrough in the transmission line to the oscilloscope. This avoids to insulate the grid with a bypass capacitor, suspected to introduce reflections and signal asymmetry.

Transmission Line Matching

Further one tried to limit all possible reflections from the line itself to be a magnitude smaller than the bandwidth of the oscilloscope, corresponding to less than 30 ps in the time domain. In fact the open ended structure introduces reflections of the same order. In addition the line contains two unavoidable mismatches, the first is a MACOR support at 40 mm from the beam axis, necessary to center mechanically the inner conductor and thus defining the 1 mm gap for the incoming beam. The second is the high frequency, ultra high vacuum coaxial feedthrough (using a thin ceramic diaphragm brazed to titanium), followed by another tapered section to match a C-connector at the output of the probe. Both mismatches have been designed to have an electrical length of 30 ps or less and cause below 2% reflections at 2 GHz and 5% at 4 GHz. The overall design

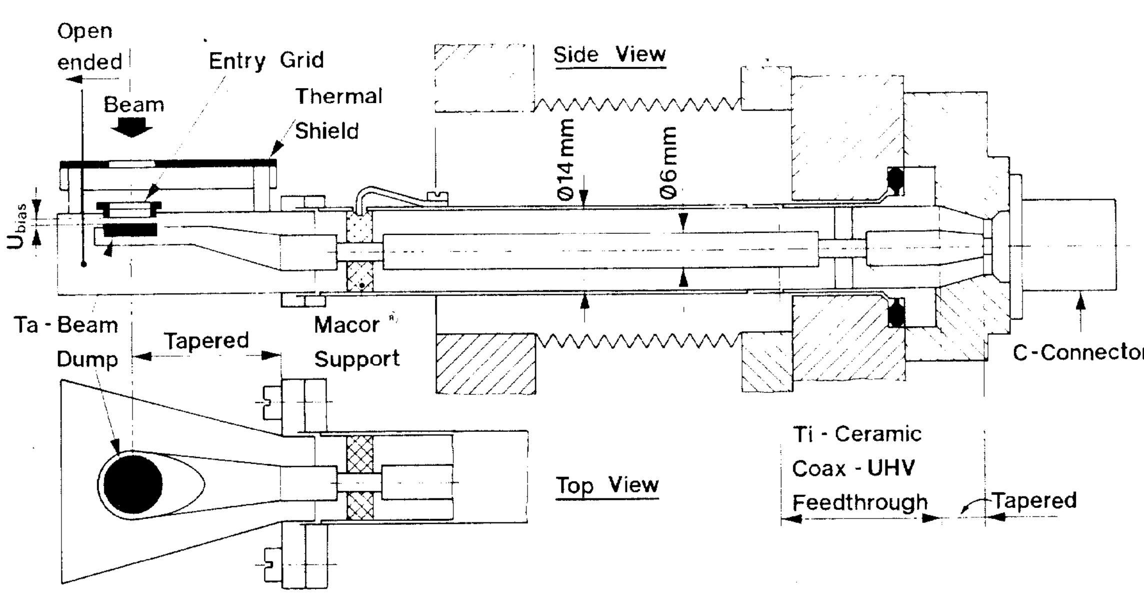

Figure 1 - Cross section of the probe head, transmission line, vacuum feedthrough and output connector matching.

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thus permits a signal observation practically free from transmission line dependent distortions.

One observes that the signal asymmetry reported in earlier publications is caused by electrons emitted from the entry grid and accelerated by the bias voltage towards the center conductor of the line (See next par.).

High Intensity Considerations

Thermal Electrons

When measuring high intensity, especially high density beams, the protons are not the only particles to contribute to the signal received on the probe. In the case of CERN Linac 2, beam densities of several A/cm^2 or $MJ/cm^2.s$ have been measured around the bunching section of the low energy beam transport system. This leads within a few µs to very high temperatures and an important electron emission, eventually melting the measuring devices. The bias, normally applied to retract secondary and thermal electrons escaping from the inner conductor, causes electrons produced on the aperture defining grid to reach the inner conductor within less than one nanosecond after the real bunch signal. This results in a negative signal between bunches and disturbed bunch forms (negative blacklash) already for medium intensity beams (∿50 mA). If the bias is reversed one observes as expected a long decay of the bunch signal caused by the thermal electrons emitted from the hot parts of the inner conductor, hit by the center of the beam (Fig. 2).

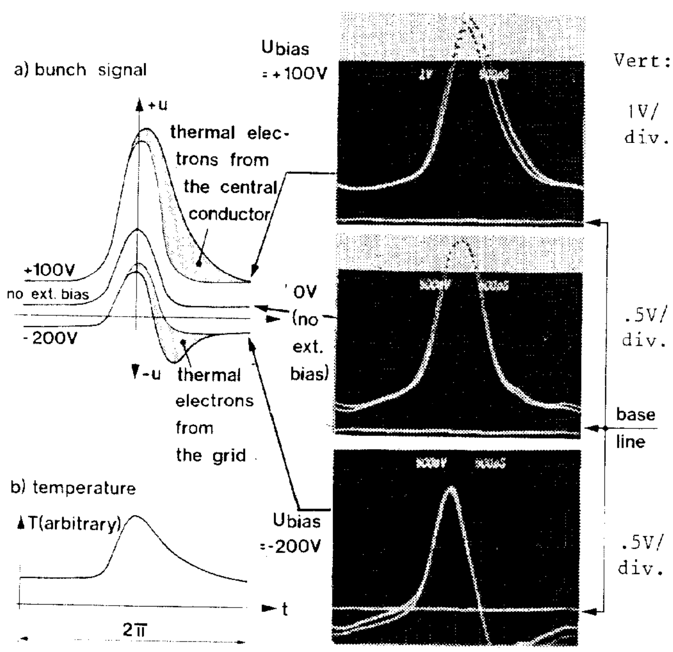

Figure 2 - Influence of the polarization voltage across the entry gap.

No Bias

In both cases the observed bunch signal does not at all correspond to reality. Bunch measurements were continued without an external bias, leaving the electrons to be influenced only by the few volts produced by the proton signal. The electrons from the grid move then only within a few nanoseconds, and highly dispersed, to the inner conductor. But the absence of an external bias causes beam neutralisation and the observed signals do not exactly correspond to a non-neutralised bunch. To avoid this problem adding a strong electron trap in the unfortunately limited longitudinal space in front of the probe is being investigated.

Results of Measurements

The two purposes of the measurements were: i) to study the bunching efficiency by measuring the longitudinal particle distribution as a function of the two buncher voltages for all operational intensities, and ii) to adjust the correct phase between the two buncher cavities and see the influence of phase errors.

At medium and high intensities there are some inconveniences concerning the analysis of the true bunch form, as described before. But the important adjustment of the phase between the two buncher cavities can already be done at rather low beam currents as it remains valid for higher intensities provided that the signal obtained with the probe is sufficient for the vertical sensitivity of the scope.

Procedure

The signal obtained with only the 200 MHz cavity (Fig. 3a) is centered between bunches obtained with only the 400 MHz buncher (Fig. 3b) to within ±5°. The required stable repetitive display of the signals on the scope is obtained by triggering the time base with a precise RF phase locked device[3]. The final adjustment to within 1° of phase is then done by optimizing on the symmetry of the resulting 200 and 400 MHz signal.

Misadjustments of a few degrees give immediately a noticeable change in the bunch signal, but it is interesting to note that for phase errors as high as ±20° a still important amount of particles remains near the center of the bunch (Fig. 4 compared with computations).

This is confirmed in practice by the fact that the accelerated beam intensity drops only by a few percent, and a change in emittance or energy distribution is not perceptible with the instrumentation available at the 50 MeV output. This proves the broadband bunch probe to be a useful instrument for optimizing the performance of Linac 2. The DDHB turns out to be a less critical element than thought initially.

Acknowledgements

My thanks are due to D.J. Warner, who introduced me to the subject, as well as to M. Weiss for many helpful discussions concerning the use of bunch measurements for DDHB settings, to Mrs. B. Hadorn for the mechanical design, A. Magnenat for making the probe, A. Bellanger for calculating the coaxial feedthrough, and B. Trincat for its manufacture.

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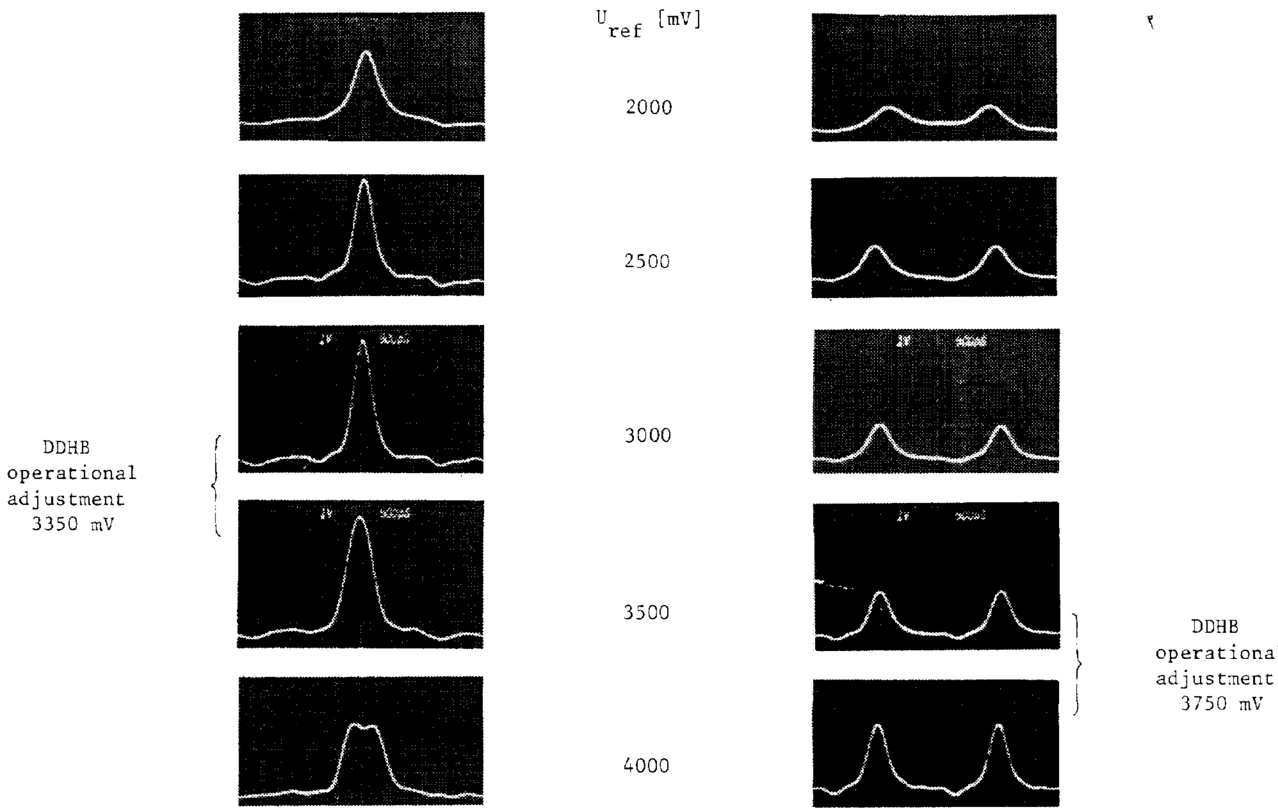
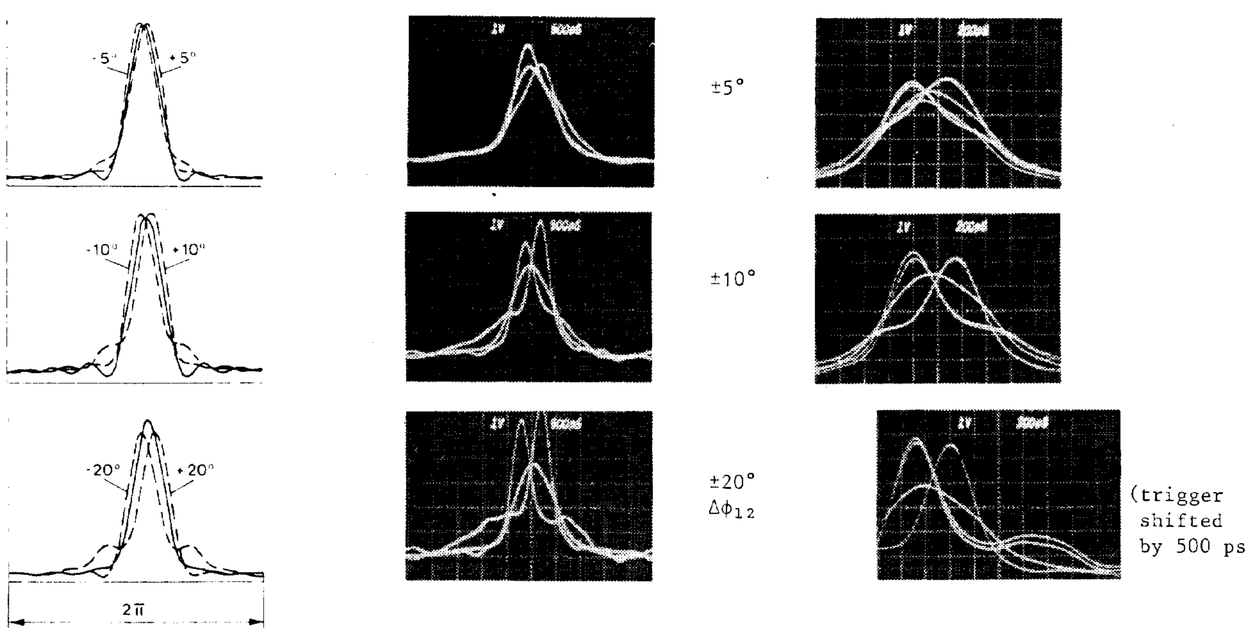


a) 200 MHz cavity only

b) 400 MHz cavity only

Figure 3 - Separate influence of each buncher cavity (vert. = 1 V/div - horiz. = 500 ps/div).



a) calculated

b) measured
hor: 500 ps(36°)/div.

c) measured
hor: 200 ps(14.4°)/div.

Figure 4 - Influence of a phase shift between the two buncher cavities.