SUPERHILAC REAL-TIME VELOCITY MEASUREMENTS*

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Summary

Phase probes have been placed in several external beam lines at the LBL heavy ion linear accelerator (SuperHILAC) to provide non-destructive velocity measurements independent of the ion being accelerated.[1] The existing system has been improved to provide the following features: a display refresh rate better than twice per second, a sensitive pseudo-correlation technique to pick out the signal from the noise, simultaneous measurements of up to four ion velocities when more than one beam is being accelerated, and a touch-screen operator interface. These improvements allow the system to be used as a routine tuning aid and beam velocity monitor.

Introduction

The SuperHILAC is capable of accelerating elements ranging in mass from hydrogen to uranium. As the accelerator can accelerate ions to different velocities ranging from 1.2 MeV/AMU to 8.5 MeV/AMU, it is essential to have an unambiguous measurement of the beam velocity to satisfy the experimental requirements. Under normal operation as many as three different ions are accelerated on a pulse to pulse basis with a maximum repetition rate of 36 Hz, so the measurements must be made during the appropriate machine pulse.

A system of capacitive electrodes called phase probes has been installed at the SuperHILAC to provide unambiguous velocity measurements for all ion beams irrespective of their mass. These phase probes were described at the 1985 Particle Accelerator Conference.[1] A brief summary of their operation will be provided, but the main emphasis of the paper will be on the improvements made to the system that enable it to be used as a real-time tuning aid and non-destructive velocity monitor.

Principles of Operation

Five phase probe systems have been set up in the SuperHILAC experimental area. Each system consists of three pick-up electrodes spaced along the beamline. The beam, bunched at 70 MHz, generates a signal by capacitively coupling to each cylindrical probe as it passes along the probe axis. This signal is sampled at a rate of about 2 MHz and then amplified, digitized, and transmitted to a microcomputer where analysis takes place.

The three electrodes are unequally spaced, with a short distance between two of the electrodes to provide a coarse estimate of the beam velocity, and a longer distance to provide the final accurate measurement. All times are referenced to the RF period, so that probe signals separated by an integral number of RF periods appear identical. The short distance ensures that the transit time is between 0.5 and 1.5 RF periods for beam velocities between 1.2 and 10 MeV/AMU. The energy calculation makes use of this coarse velocity to determine the correct number of integral RF periods to add to the fractional period obtained from the time difference between the signals of probes 1 and 3, the longest separation in a system. This procedure results in an accurate, unambiguous determination of the beam velocity, with a system accuracy of $\pm 0.25\%$. Other sources of error, such as the long term drift of delay lines, are ruled out since the system calibration is checked automatically whenever a new beamline is chosen, as is described below.

The system is fully computerized, with all controls accessible from a console in the main control room. During normal operation the beam energy/nucleon is displayed on a vector graphics display in the control room along with a representative probe signal, and updated twice per second. This rapid update rate is essential for using the phase probes as a real-time tuning aid. The operator has the option of choosing which set of probes to use and which of the 36 pulses/sec to observe, and can change the gain of individual probe amplifiers to match the beam intensity.

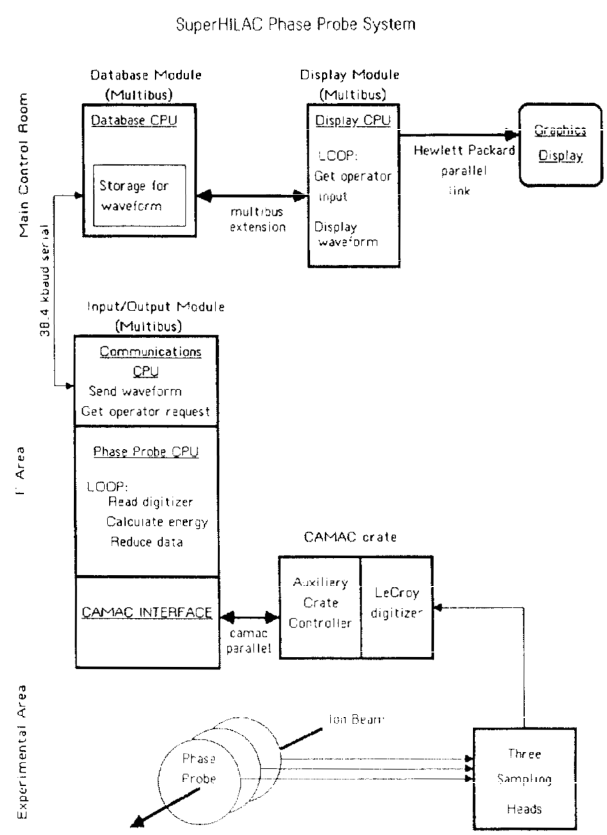

Figure 1 - Block diagram of the phase probe system, showing the control console and the vector graphics display in the control room, the electronics and the microcomputer in the "F" area, and the sampling heads and probes in the experimental area.

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Hardware

The distribution of the phase probe hardware is illustrated in Figure 1. There are four major components. The probes themselves are located in the experimental areas along with the sampling heads which sample the signals at a rate of about 2 MHz. The aliased signals from all the probes are collected and brought to a camac crate where they are digitized. The digitized waveforms are then read using a parallel connection into a multibus-based controller called an Input/Output Micro-Module (IOMM) where the processing and data reduction are performed. This module contains two 8086 based single-board computers and a camac interface. One computer is used for communication to the control room, the other, which contains a math coprocessor and the phase probe programs in EPROM, actually performs the correlation and data reduction. Finally, the reduced data is sent, via a 38.4 kbaud serial link, to the control room where the display computer receives it and displays the waveforms and velocity on a vector graphics display (HP1350 and HP1340). The operator makes selections and controls the displays from a touch-screen. The display hardware, touch-screen, and IOMM hardware are all part of the existing control system for the SuperHILAC, so the phase probe control was easily integrated.

Before the latest modifications the signal analysis was performed by an Intel Development Microcomputer in the control room. Extensive testing showed that the accuracy of the measurement decreased when less than 500 time points were used to represent one RF period. This means that three times 500, or 1500 points are needed to represent the three phase probe signals, and another 500 points are needed to provide an RF reference signal. Shipping the 2,000 data points from the digitizer to the control room by means of the serial link requires about seven seconds. To reduce this time all signal analysis is now performed in the IOMM. Only the 50 points needed for the phase probe signal display, and the final beam velocity are transmitted by means of the serial link. This reduces the transit time to a small fraction of a second, so that the calculation time (to be discussed in the next section) becomes the primary impediment to increasing the update rate of the system.

A calibration chassis is located in the experimental area to provide reference signals to check out the system. This chassis sends mock beam signals to the phase probes each time a new phase probe line is chosen, or whenever a calibration of the system is desired by the operator. Delay lines are cut to simulate the arrival times of an 8.3 MeV/AMU beam at each probe, with different delays needed for each set of probes since the probe separations are not the same. The simulated signal from the calibration chassis that is sent to the phase probes is analyzed by the standard data acquisition system. The system is considered to be functioning correctly if the result is between 8.27 and 8.33 MeV/AMU. If the result is outside the acceptable range then the system remains in the calibration mode so that the problem can be diagnosed by the operator.

The control console is shown in Figure 2. This console allows the operator to determine which of the phase probe systems is active. Up to four systems can be active at a time, with the beam velocity displayed on the console for each active system. Each probe's gain can be set from the console, or an autoranging option can be chosen. The operator can decide which of the three probe signals is to be displayed on the vector graphics display, or can display all three signals at one time. In addition, since there are two sets of vector graphics displays, signals from two probe systems can be displayed simultaneously. A sample signal display is shown in Figure 3. In addition to the phase probe signal, the velocity, beamline name, and the operating mode are displayed. The mode determines which of the 36 pulses per second are being displayed at any one time.

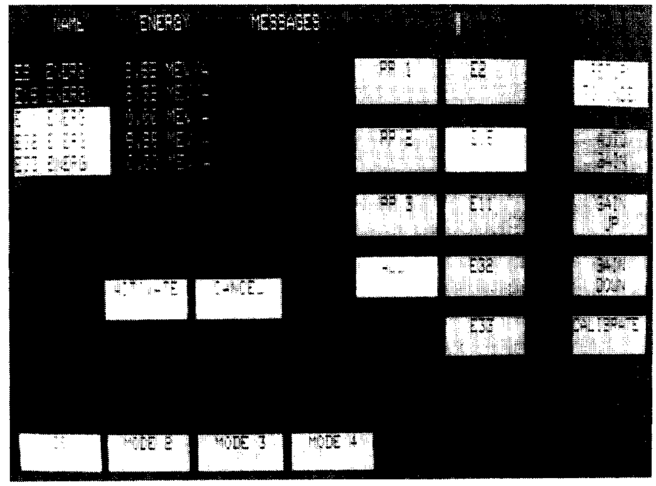

Figure 2 - Photograph of the touch-screen control console in the control room. Note that the individual phase probe systems in operation are highlighted, and that all controls are accessible by means of the touch panel display.

It is important to note that the touch-screen console is extremely simple to use. Rather than typing in the various parameters needed for a computer program to run the system, the entire system can be run with a few touches of the console. This ease of operation ensures that the program is used routinely as a velocity monitor, and also as a diagnostic to monitor the bunch structure both while tuning up the beam and during normal operation.

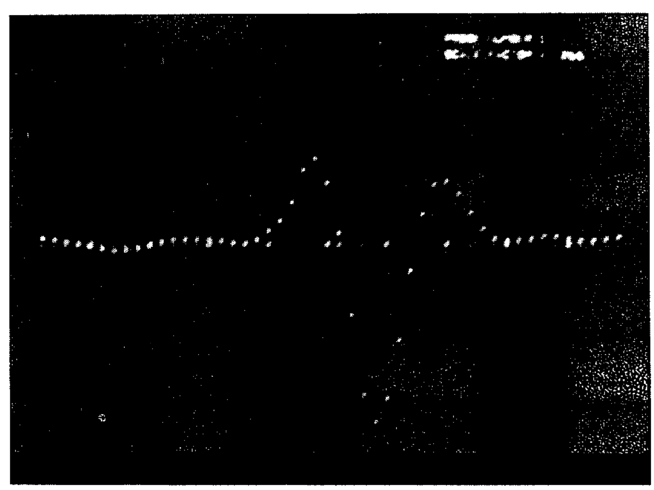

Figure 3 - Photograph of the phase probe signal. The beam velocity (in MeV/AMU) is clearly displayed, along with the beamline name. This display updates about twice per second when only one phase probe system is active.

Data Analysis

An ideal phase probe signal is similar to one full period of a sine wave. The function of the data processing program is to pick out the zero crossing of the signal from each of the three probes. A pseudo-correlation technique helps to pull out the signal from the noise. Conceptually the technique works as follows. The actual phase probe signal is multiplied by an ideal phase probe signal at each point in time, and the sum is taken. The idealized signal is then stepped in time and the process is repeated until the idealized signal is swept through the entire probe signal. When the signals are coincident in time, the sum will be a maximum, so the time step where the sum is maximized represents the zero-crossing time. This pseudo-correlation is performed for each of the three probe signals, and the zero-crossing times are compared. Noise contributions are minimized since only that part of the noise which falls under the ideal signal contributes to the sum.

In practice, doing the requisite number of floating point multiplications takes about two seconds of computer time for each of the three probe signals. Therefore a number of techniques were used to reduce the calculation time. First, it was recognized that the sine wave used as an idealized signal has four-fold symmetry so the number of multiplications could be reduced by a factor of four. Next it was decided that enough accuracy could be achieved using integer multiplications instead of floating point calculations, greatly reducing the time needed. Finally, the idealized signal was digitized in steps to allow the multiplications to be accomplished just by shifting bits in the actual signal, further reducing the calculation time. This combination of improvements has allowed us to calculate the velocity in less than 0.3 seconds, compared with the initial time of six seconds.

Conclusion

On-line real-time velocity measurements are being routinely performed at the SuperHILAC. The phase probe system provides a convenient means of determining the beam velocity to an accuracy of $\pm$0.25%. Operators can easily examine both the velocity and the bunch structure of each of the different beams being accelerated at any one time, regardless of the difference in beam intensities, energies, or masses. The phase probe system, with an update rate of two times per second, provides an accurate velocity monitor and tuning aid.

Acknowledgement

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References

1. B. Leemann, D. Brodzik, B. Feinberg, D. Howard, IEEE Trans. Nucl. Sci., NS-32, 1982, (1985).