A High Resolution, Non-destructive Energy Detector and Beam Current Monitor for Bunched Beams

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Abstract

A non-destructive energy detector and beam current monitor, based on a set of 3 resonant cavities, was designed and constructed for the linac ALPI, where, due to the achromatic design of the extraction line, magnetic field measurements could give only poor information on the accelerated beam energy. This device will provide a continuous monitoring of the bunched beam current and average energy with a resolution of $\Delta E/E \leq 10^{-4}$.

1 INTRODUCTION

Superconductive heavy ion linacs are specially suited for experiments where a very good energy resolution is needed, since in these accelerators the intrinsic velocity dispersion $\Delta v/v$ can be made as low as 10^{-4} after acceleration and debunching. The extraction line of these accelerators, however, have often an achromatic design due to the need of accepting the high momentum dispersion $\Delta p/p$ of the matched beam during acceleration; this prevents a precise determination of the final beam energy by means of magnetic field measurement.

Time of flight techniques are being widely used for particle velocity measurements, specially in proximity of experimental points where no dispersive device is available; these methods can provide very high resolution - in principle, it could be improved without limit simply by increasing the distance between the detectors. To extend the technique to beam energy measurements in linacs, one can take advantage of the fixed frequency of the bunched beam and use resonant cavities for beam phase detection [1]. This method is non destructive and can be applied also for beam currents as low as 1 nA. Since the rf signal amplitude in resonant phase detectors is proportional to the beam current, such devices can be used also as beam current monitors [2]. Alpi, the superconductive linac of Laboratori Nazionali di Legnaro, has an achromatic extraction line, and the beam energy is being determined with low precision by setting the line in dispersive mode during acceleration. When the beam is to be delivered to the user, all optical elements must be set in achromatic mode and even significant changes of the beam energy (e.g. due to failure of one accelerating cavity) do not prevent the beam from reaching the experimental areas.

We have designed and constructed a non-destructive velocity detector with high resolution, which can provide also beam current measurement.

2 SYSTEM DESIGN

Our system consists of three resonant phase detectors that will be located in the long straight section which is part of the extraction line of ALPI; the first cavity will be placed in the first waist, the second and the third ones in the last waist which is 36.7 m apart. The velocity range of our beam is $0.04 \leq \beta \leq 0.2$ and the bunching frequency is 80 MHz. In such conditions phase differences can be measured reliably with a precision as small as 0.7 degrees (i.e. the resolution of commercial 8-bit phase shifters) and the desired $\Delta E/E = 10^{-4}$ resolution can be obtained by measuring the phase of cavities n.1 and n.3. In this case the measured phase difference includes a $2n\pi$ contribution; the unknown n, however, can be determined by means of cavities n.2 and n.3, placed at such a distance each other (18.7 cm) that the difference in time of flight between the slowest and the fastest possible particles is less than one rf cycle, so to obtain an approximate but unambiguous value of the phase angle and, consequently, of the beam velocity.

As a second feature of the system, taking profit of the fact that the field inside the resonator is proportional to the total current of the bunched beam, we have a non destructive monitoring of the extracted beam current. Provided that the rf amplifier is critically coupled to the resonator, the beam current I_b can be calculated by the formula [3]

$$I_b = \frac{V_o}{S} = \frac{V_0}{2\sqrt{R_{sh}R_L}T(\beta)}$$

where S is called sensitivity of the phase detector, $R_{sh} = V_o^2/2P$ its shunt impedance, R_L the input resistance of the amplifier and $T(\beta)$ is a transit time factor.

Many reasons could affect such measurements: the most important are changes due to thermal drifts. A change in temperature can displace the resonant frequency of the cavities and then the phase shift between the beam phase (the forcing signal) and the rf signal in the pickup. However, this contribution is roughly the same in identical resonators located in the same room, and it should give little effect in the measurement of phase differences. Another contribution is given by the change in phase length of the cables; again, this can be reduced by choosing cables with low thermal constant and with equal length.

The contribution given by possible changes of the optical path of the beam is negligible since the resonators will be located on a straigth line where the beam position can be checked by two different beam profile monitors.

The phase measurement is performed by a computer through a control box.

3 THE RESONATORS

Our phase detectors are three spiral type, 80 MHz resonators with $\beta_o = 0.07$. The resonators are rather compact, 20 cm wide and 18 cm long; the outer shells are made with stainless steel and the spiral is made with 8 mm diameter copper tube. Only the inner part of the drift tube is kept in vacuum by means of teflon tubes and o-rings. The off-line measurement of the resonators have shown a quality factor $Q \simeq 230$ and a shunt impedance $R_{sh} = V^2/2P \simeq 40k\Omega$. We did not search for very high quality factor because we wanted to keep the thermal phase shifts of the output signal of the resonators, which are proportional to Q, within reasonable limits, thus avoiding any need of temperature and umidity stabilization of the resonators. The normalized sensitivity $S \simeq 2.8\mu V/nA$ will be sufficient in our case since very little interest in beams with intensity lower than 5 nA was shown by our users.

4 ELECTRONICS AND COMPUTER CONTROL

The signal produced by each resonator is amplified by two cascaded low-noise linear amplifiers (Cougar AC383) connected directly to the cavity, followed by two cascaded logarithmic amplifiers (Analog Devices AD640). Two different outputs are produced: the rf output signal has constant amplitude and preserves the phase information of the rf signal in the resonator; the dc output signal has an amplitude which is proportional to the logarithm of the resonator signal amplitude, preserving the information on the beam current. The minimum beam current giving a usable signal was calculated to be 1.3 nA at the optimim velocity.

The control box contains two phase shifters and two phase comparators needed for the phase measurements, as well as the ADC's and the power supplies for the amplifiers. The phase difference between two signals is being measured by nulling the phase error in a double balanced mixer by means of a 8 bit phase shifter located at one of the inputs of the mixer. The measurement procedure is the following: the computer changes step by step the digital phase shifter position acquiring, at the same time, the sinelike mixer output signal through an ADC. The rule is that negative mixer signals induce negative steps and vice versa. When the signal crosses the zero the measurement starts; the phase shifter position is moved backward by a 10 steps "kick" (14 degrees) and then it is moved step by step forward by 28 degrees; mixer output value and phase shifter angle are being acquired every step. At the end of the procedure the computer performs a linear fit of the 20 points and extracts the phase angle Φ_1 at which the mixer output signal is zero. This procedure allows averaging the noise contribution over 20 points and pushing the resolution farther on with respect of the 0.7 degrees resolution of the digital phase shifter.

The phase difference between signals coming from two different resonators, then, is given by $\Phi_1 + \Phi_0$, where Φ_0 is a constant which includes many contributions (e.g . phase length of the rf cables, delay induced by the electronics, errors in resonators tuning) and has to be determined once forever by a calibration measurement. The logarithmic output of each of the AD640 pairs is read by an ADC and used by the computer to calculate the beam current. The computer is the same used for controlling all the diagnostic boxes of the linac [4]; it is performing control of the system, measurements, calculations and it is displaying continuously the values of beam velocity and beam current. The values are displayed if the signal level is in the allowed range in all three resonators; if not, the computer gives a diagnostics warning indicating which cavity fails.

The system is near completion; we expect to install it in the linac during autumn 1996.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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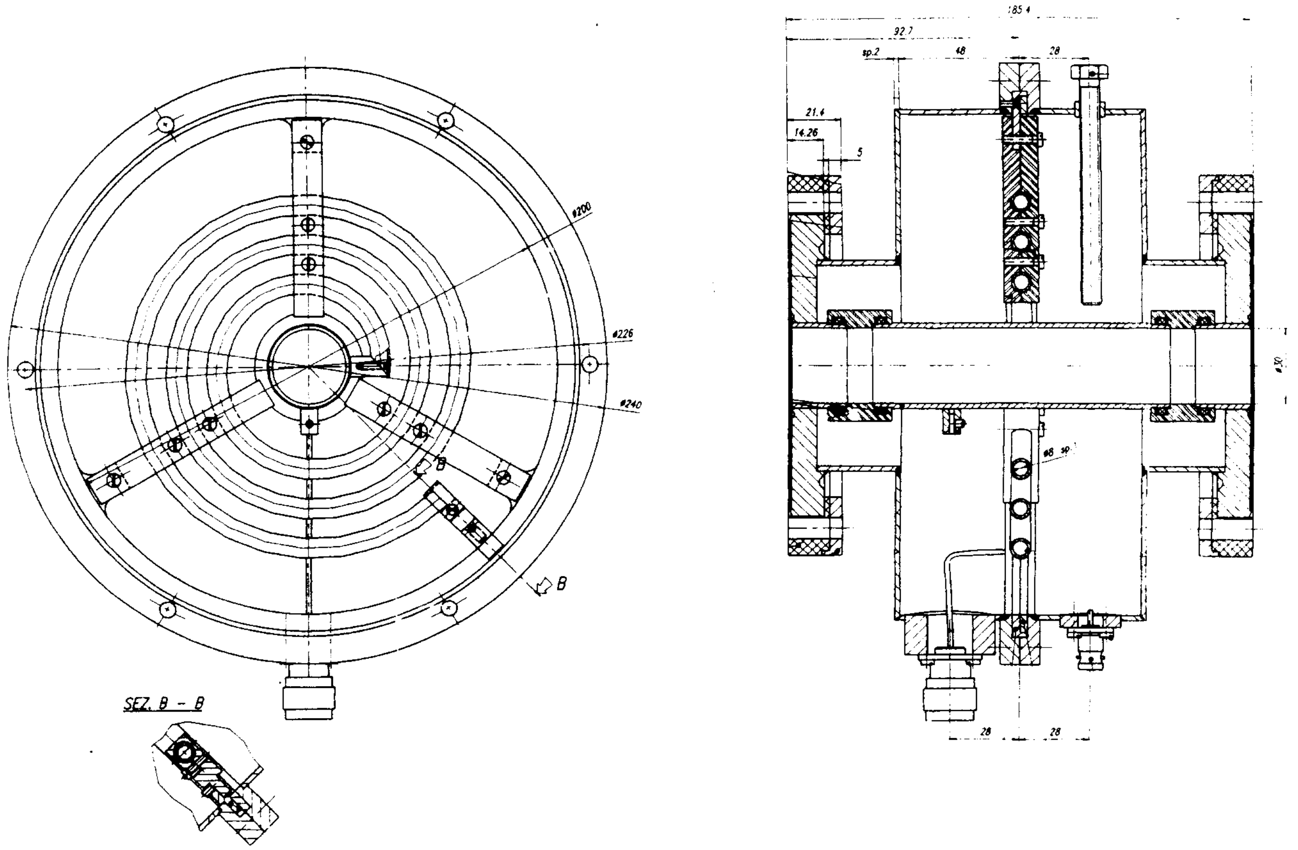

Figure 1: The spiral resonators

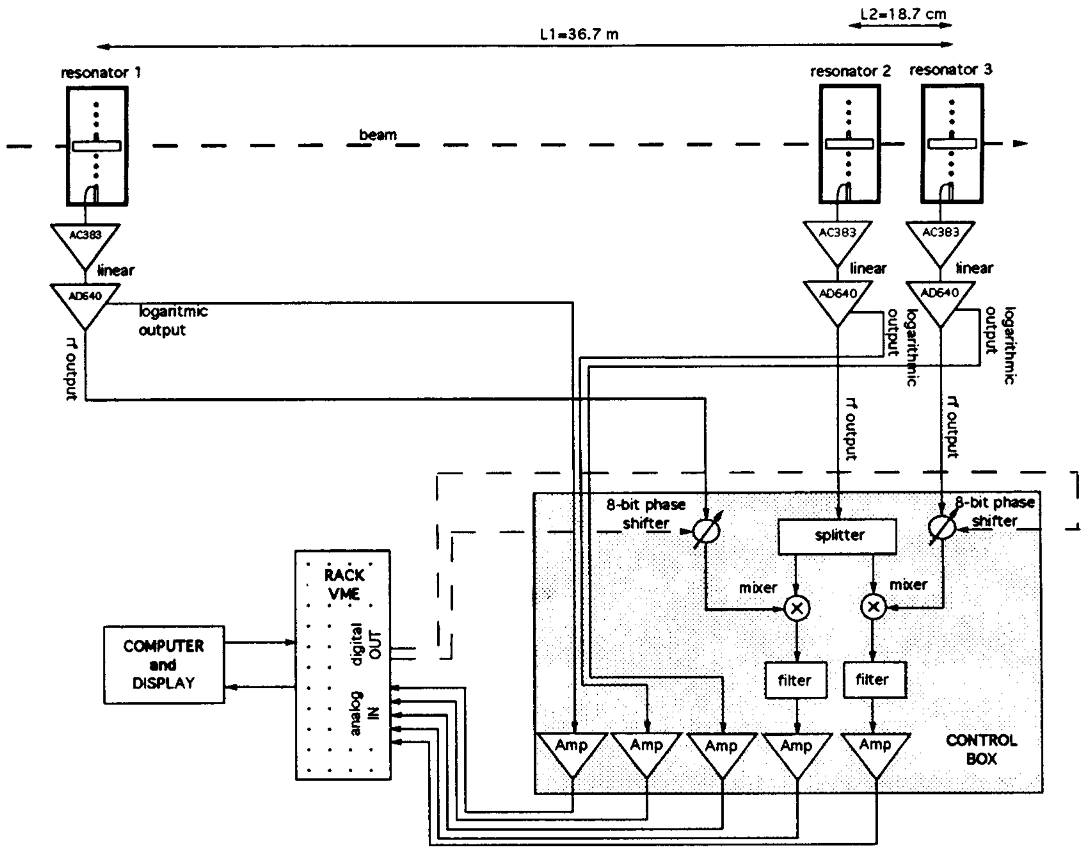

Figure 2: Schematic of the electronics