THE AUTOMATIC PHASING SYSTEM FOR THE LEP INJECTOR LINACS (LIL)

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Summary

The linacs of the LIL preinjector of LEP accelerate 12 ns bunches of electrons and positrons ; the accelerating RF power is produced by power klystrons followed by a pulse compression system. An automatic phasing system shall be used during the operation of the linacs.

The signal of a very stable coaxial line shall be phase locked with a beam induced RF signal. The signal of that line shall be used both to drive the six power klystrons of the linacs and as a phase reference signal for measurements of the RF at the input of the accelerating sections.

Introduction

LIL is a 600 MeV electron and positron linac operating at an RF frequency of 2998.55 MHz. LIL will provide LEP with particles through the injectors chain EPA, PS, SPS ; injection time in LEP shall be about 20 minutes. Time between two injections shall be several hours. Injection time is divided into 15.2 second periods. During each period LIL injects positrons and electrons according to the time diagram of fig. 1. Operating parameters of LIL must be changed between electron and positron operation in less than .12 s.

This paper describes a system which enables the automatic resetting of the phase of the RF before each injection with a reproducibility of a few degrees with respect to nominal parameters, and the commutation from electron to positron phasing in less than .12 s, during injection.

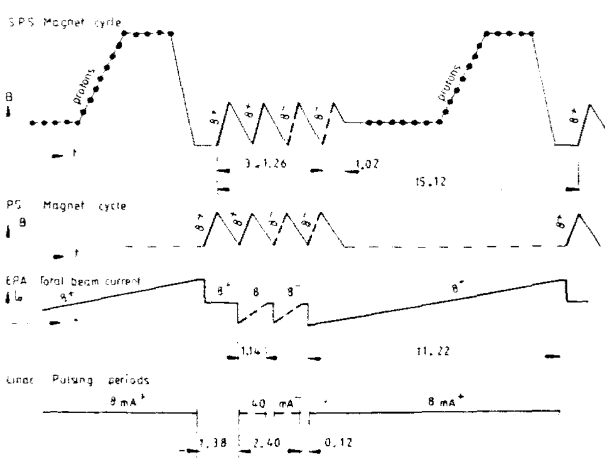


Fig. 1. Schematic diagram of the SPS and the PS magnet cycle, the EPA total beam current, and the linac pulsing periods versus time for the basic scheme. The numbers on the lines refer to the number of bunches used, and the sign of bunch charge is indicated.

The RF system of LIL

The bloc diagram of the RF system is given on fig. 2.

The RF power sources are the six 35 MW pulsed power klystrons K_1 to K_6.

Three klystrons are operated with a pulse compression system called LIPS similar to SLED [1].

Amplitude and phase of the RF at the output of LIPS during klystron operation and pulse compression are given on fig. 3.

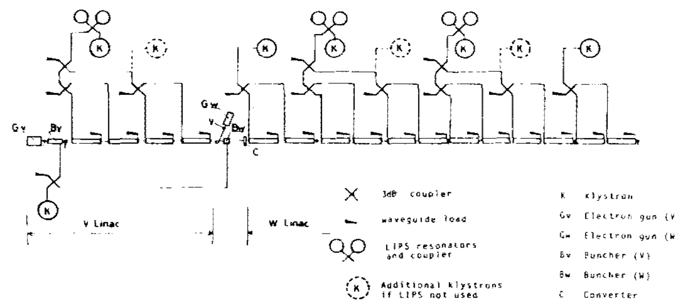


Fig. 2. Schematic layout of the LIL RF power distribution.

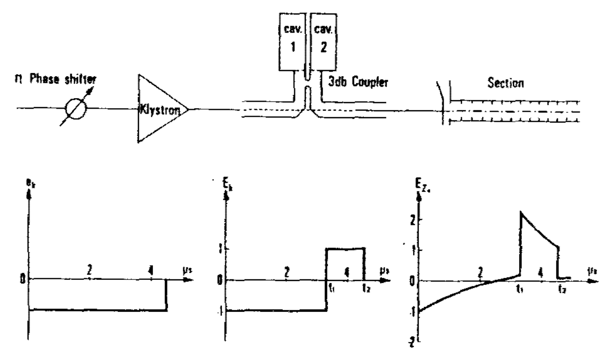


Fig. 3. Pulse compression scheme

Principle of phase lock

Power klystrons are driven through a rigid 13/30 coaxial line running along the accelerating sections in the tunnel (see fig. 4). That line is driven by a 24 KW pulsed klystron.

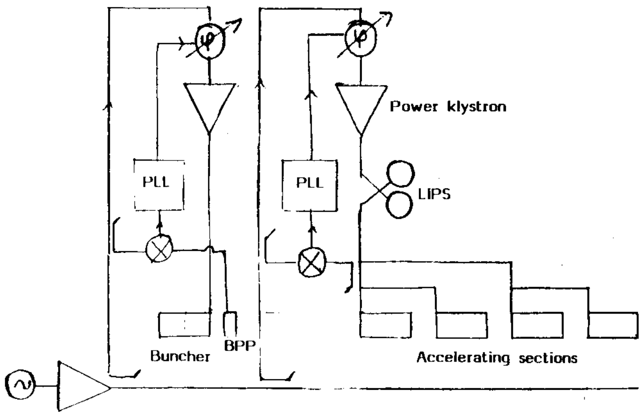
The phase of the signal at the output of the couplers driving the klystrons is kept constant with respect to the input phase by a proper temperature and pressure stabilisation.

So, if the phase of the signal at the output of Co can be kept constant with respect to the phase of the microbunches of the beam, the drive line will be as well a phase reference line for phase measurement and control of the RF of the linacs.

The beam induces a 12 ns long signal at the RF frequency in the phase pick-up BPP. The phase difference between this signal and the RF signal at output of Co is sampled and measured with a circuit described in this paper. This phase difference is kept constant by a feedback loop controlling the input phase shifter of the klystron K_1 feeding the bunchers.

Then the phase difference between the RF signal at the input of the first accelerating section fed by each klystron and the reference RF signal at the output of the couplers C_1 to C_5 is measured and a feedback loop keep that difference equal to the proper value.

The phase lock of the drive line signal with respect to the beam induced signal and of the RF signal at the input of the accelerating sections with respect to the drive line signal is used before each injection to automaticaly reset the input phase shifters of the klystrons.



Phase comparator

Phase lock loop

PLL controlled phase shifter beam phase pick-up.

RF coupler

Fig. 4. LIL phasing system.

The setting for electron and positron are digitized and memorized.

The commutation between electron to positron and positron to electron during injection is done by changing the programmation of the input phase shifters of the power klystrons.

These phase shifters are Fox ferrite phase shifters electrically controlled which can commute the phases in less than 0.12 s.

Design of the components

Drive line :

Since we want to use the drive line as a reference line, both attenuation and phase characteristics must be be good. We use a coaxial rigid line with air dielectric. Temperature and pressure of the air inside the line are stabilized. The drive signals are picked up through directionnal couplers. These couplers are rigidly fixed to the building and flexible sections are inserted between them to keep the line length equal to the beam path.

The main characteristics of the line are given below :

Length : 100 m
Attenuation : 4 db
Diameter : 13 mm/30 mm
Temperature stability : ± 2°C
Pressure stability : ± 5 Torr
Couplers directivity : 40 db

Drive line RF source :

Master oscillator is a solid state cavity oscillator phase locked on a high stability quartz reference.

The input signal of the phase locked source is amplified up to a peak level of 24 KW by a pulsed amplifier. That amplifier is a THOMSON TH 2452 klystron. The power supply is a 25 KV, 5 A hard tube modulator.

The block diagram of the master oscillator and amplifier and the characteristics of the signal generated are given on fig. 5 and tables below.

Master oscillator :
Frequency : 2998.55 MHz $\pm$ 10^{-6}
Frequency stability : 1.10^{-7}/month
Spurious FM : < 1 KHz in 1 MHz BW

Modulator :
Output voltage and current : 24 KV/5 A
Pulse duration : 5 µs
Repetition rate : 100 Hz
Rise time and fall time
(0/90%, 100%/10%) : < 200 ns
Level stability : 2.10^{-3}
of linear decay during the pulse.

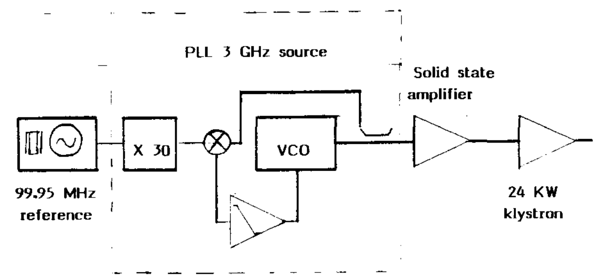


Fig. 5. Block diagram of the drive line RF source.

Variable phase shifters

We shall use Fox phase shifters made by MAG in wich the rotation of the polarization plane is achieved by the polarization of a ferrite material [2]. The settling time is less than 1 ms allowing the use of the same phase shifters for positron and electron operations.

Beam phase pick-up (Fig. 6) :

The beam goes through a piece of WR 284 waveguide terminated at one end by a short circuit at a distance $\lambda/4$ of the beam axis and matched at the other end where the signal induced is output coupled through a waveguide to coaxial transition.

The signal at the output is the sum of the signal reflected on the short circuit and of the direct signal so that phase errors caused by change of the transverse beam position are cancelled.

The sensitivity of the circuit is about 200 W/A²

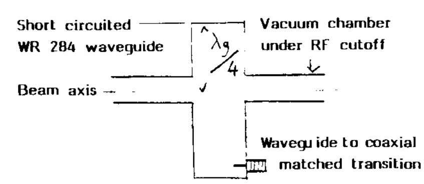


Fig. 6. Side view of beam phase pick-up (small side of the waveguide).

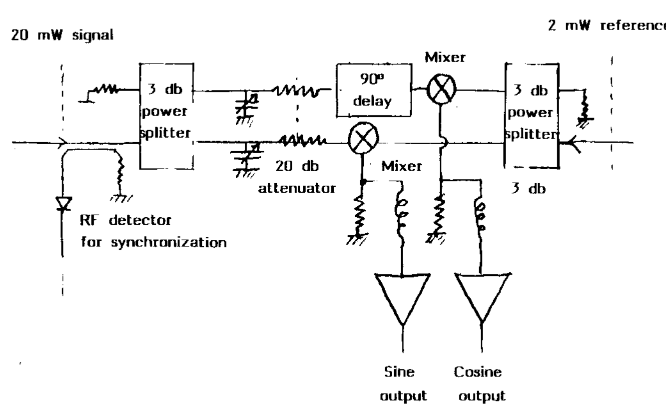


Fig. 7. RF head block diagram

RF phase detectors :

As usually for that application ([3], [4]) we use a double balanced mixer as phase detector.

A double balanced mixer is a three ports diode network giving at the output port a response function of the two input signals S_{OL} and S_{RF} given by the relation :

$$V_{OUT} = G\, V_{RF} \sin(\phi_{RF} - \phi_{OL}) + V_{OFF} \quad (1)$$

with
$$S_{OL} = V_{OL} \cdot \sin(\omega t + \phi_{OL})$$
$$S_{RF} = V_{RF} \cdot \sin(\omega t + \phi_{RF})$$
$$G \simeq -6 \text{ db.}$$

V_{OUT} is independant of V_{OL} within a range of about 10 db. V_{OFF} is function of input levels, temperature and is produced by diode mismatching in the mixer. Automatic measurements of G and V_{OFF} will be made before injection to calibrate each RF head. We use a model M 63 mixer made by Watkins Johnson. In our system we do not use the mixer only as a nulling detector but for phase measurement so two mixers are used for cosine and sine measurements in order to keep the same accuracy on a 2 π range. The block diagram of the RF head is given in fig. 7. It is designed in stripline. We make an amplitude detection for self synchronization of the track-and-hold circuit when operating on beam induced RF. Variable capacitors are used for fine tuning of phase difference between the two mixers inputs. 10 db attenuators isolate the mixer ports from the capacitors. Inductances isolate the track-and-hold circuits mismatched at the RF frequency.

Track-and-hold circuit

Since RF signal induced in the beam phase pick-up portion of the LIPS pulse usable for phase measurement are very short (see fig. 3), the signals at the outputs of the mixers must be sampled in order to allow processing for phase calculation and control.

We designed a track-and-hold circuit with a tracking 3 db bandwidth of 30 MHz and a switching time of less than five nanosecond.

A block diagram of the circuit is given on fig. 8.

Principle of operation of the circuit has been described by various authors [5].

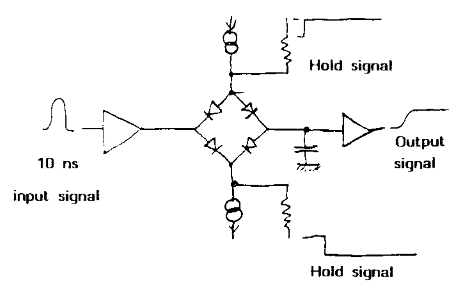


Fig. 8. Track-and-hold circuit

Test of the sampling RF head

Phase measurements on a bunched beam have been made using the circuits described above, and a 16 bits A/D converter controlled by an HP 85 computer.

The block diagram of the test set up is given on fig. 9. The variable phase shifter is a Fox, mechanical rotary vane type, actuated by an electrical motor ; position of the vane was given by a rotary potentiometer coupled to the vane. The computer calculated the offset and the gain of the sine and cosine output of the sampling RF head. After normalization it uses the measurement of the voltage at the sine and cosine output of the circuit to calculate the phase difference between the signals at the RF and OL inputs and compares this results to the value measured at the monitoring output of the phase shifter.

Typical plot of the output signals (after normalization and offset suppression) are given on fig. 10 and phase measurement error with respect to the position of the vane are given on fig. 11.

Measurement of the mixer sensitivity to OL level and temperature has been made. Phase error caused by change in S_{OL} level is less than 2°, 5 mW < S_{OL} < 20 mW and less than 6° for ΔT = 60°C.

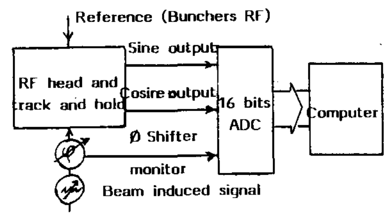


Fig. 9. Phase measurement circuit test set up.

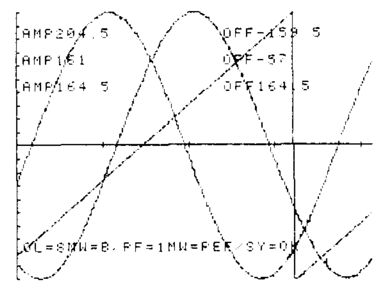


Fig. 10. Cosine, sine and phase shifter monitor output signals.

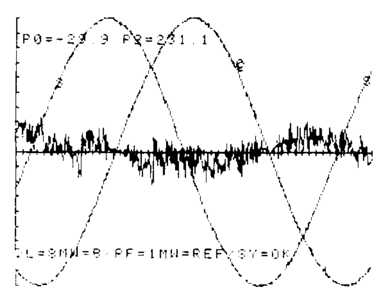


Fig. 11. Difference between monitored and calculated phase (+9°, -9° full scale).

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