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RF SYSTEM FOR THE PEP STORAGE RING‡

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Klystron and Cavities

The main parameters of the RF system for the PEP storage ring are given in Table I. A total of 6 MW will be

TABLE I

RF System Parameters

15 GeV	
Harmonic number	2592
Frequency	353.210 MHz
Number of klystrons	12
Power per klystron	500 kW
Number of five-cell cavities (aluminum)	24
Shunt impedance per unit length	21 MΩ/m
Total shunt impedance R_S †	1070 MΩ
Natural bunch length (σ_z)	2.0 cm
Momentum compaction factor	2.98×10^{-3}
Current per beam	55 mA
Luminosity	$10^{32} cm^{-2} s^{-1}$
Synchrotron radiation loss per turn	27.06 MeV
Parasitic mode energy loss per turn*	7.0 MeV
Peak cavity voltage V_p**	49 MeV
Total RF power	6.0 MW
Fundamental mode cavity dissipation P_c	2.2 MW
Synchrotron radiation loss	3.0 MW
Power loss to parasitic modes	0.8 MW
Cavity coupling coefficient for match at full beam	2.7
Synchrotron frequency	7.3 kHz
18 GeV††	
Peak cavity voltage	72 MV
Current	10 mA
Luminosity	$1.5 \times 10^{31} cm^{-2} s^{-1}$

† $R_S = \frac{V_p^2}{P_c}$.

* Assumes natural bunch length and loss impedance of 127 MΩ (84 MΩ in RF cavities).

**For 50-hour quantum lifetime.

††Momentum compaction factor $\alpha = 1.36 \times 10^{-3}$.

provided by twelve klystrons, each capable of delivering 500 kW of continuous RF power. An experimental model of this klystron has been built and is described elsewhere in these proceedings.[1] Each klystron feeds two accelerating cavity sections, each 2.1 meters in length. The general layout is shown in Fig. 1. The klystrons are housed in shelters above ground. The wave guides run through vertical penetrations

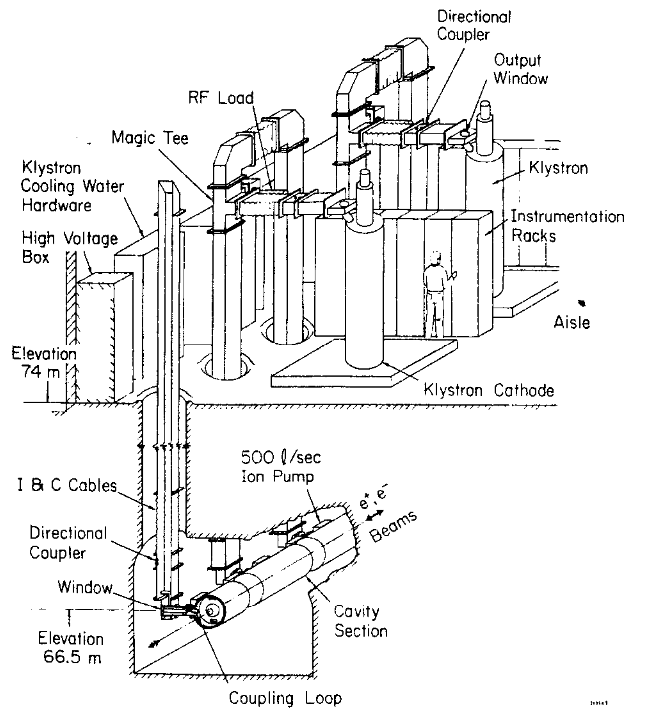

Fig. 1. Layout of RF station in klystron shelter.

to connect the klystrons to the accelerating cavities in the tunnel. The shelters are placed at three symmetrical regions around the ring. At each of regions 4, 8, and 12 there will be four klystrons and their eight cavities with the eight cavities all being grouped together in the long straight section on one side of an interaction region. The klystron power supplies are on pads outside the shelters. They are unregulated but their voltage may be slowly varied over a 40 percent range by means of variable voltage transformers in the 12 kV input line to each power supply. The output of each power supply passes into the shelter to a high voltage cabinet which contains filter capacitors, crowbars, interlock circuits, and control and metering circuits.

Each accelerating cavity consists of five cells coupled together in the π mode by two slots in the common wall between the cavities. A cutaway drawing of the cavities is shown in Fig. 2. The construction material is 1100-F aluminum plate which is a high-conductivity (60% of copper) alloy. The shells are rolled from 1½" plate. The dividers are machined from 2" plate with the nose cones machined from 3" plate which is welded to the dividers. Cooling is provided by radial cooling passages bored through the dividers and passing close to the nose cones and by circumferential water channels with externally welded covers on the shells. The coupling of RF power is by means of a water-cooled loop in the center cell. A layer of titanium nitride deposited on the surface of the cavities serves to inhibit multipactor. The cavities are designed to have adequate cooling to allow 250 kW to be dissipated. A two-cell experimental model has been built and tests have been carried out in which up to 100 kW was dissipated in each cavity cell. Calorimetric data were taken on all water-cooling channels and direct measurements were taken of the nose cone tip temperatures using thermocouples embedded directly in the nose cones. The results of these tests[2] showed that the cavity design is adequate for the PEP design power level of 50 kW per cell. Each of the five cells

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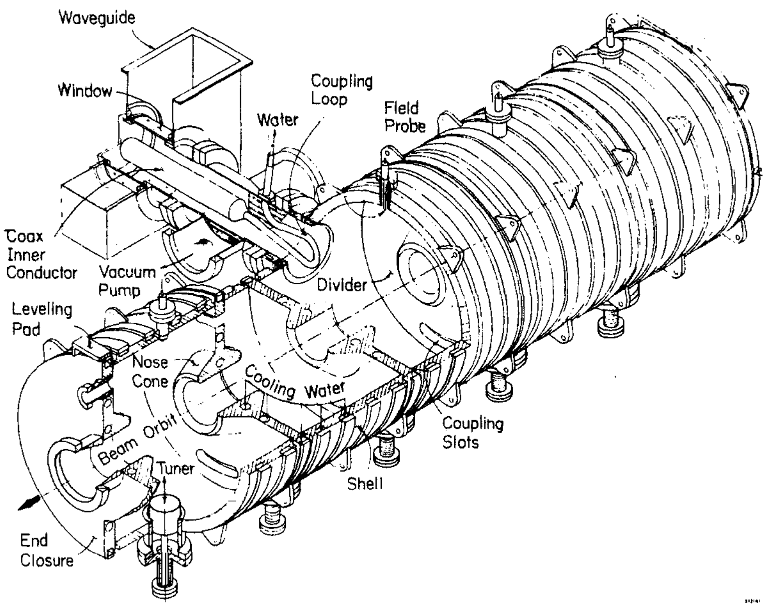

Fig. 2. Isometric drawing of 5-cell accelerating cavity.

has a water-cooled tuning plunger; however, only two of them will be movable during operation. Reducing the number of movable tuners from five to two gives a considerable cost saving. Because of adequate coupling between cells it is anticipated that having tuners in only two of the five cells will be sufficient to accommodate both thermal detuning and beam loading. Furthermore, experiments carried out at SPEAR indicate that operation with only two tuners per cavity will be feasible for PEP.

No isolation in the wave guides between the klystron and the cavities is presently planned. It is known from SPEAR operation that the klystron is quite sensitive to load changes and under certain operating conditions may put out spurious signals which can lead to beam loss. The ideal solution would be to isolate the klystron with a nonreciprocal device such as a circulator with low insertion loss. However, this would be very costly and also very cumbersome at the PEP RF frequency. Without isolation the klystron will see a VSWR of over 2 to 1, which will reduce to a match as the current is increased in the ring. Match is reached at the full current of 55 mA per beam at 15 GeV. If the klystron does not perform well under conditions when the load is not matched, an E-H tuner could be inserted into the line between the klystron and the magic-T power splitter. The positions of the shorting plungers could be remotely controlled to maintain match as current is fed into the ring. The stability of the experimental klystron looking into various types of loads is now being examined, and a decision on whether or not to use the tuners in PEP will be based on the outcome of these tests.

Low Level Circuits

The low level circuits deal with the control and stabilization of the amplitude and phase of cavity fields. These functions are achieved by the following four servo loops (see Fig. 3): the klystron phase lock loop, the gap voltage automatic leveling circuit, the cavity phase control, and the intercell power balance loop.

Phase stability of the RF amplifiers and klystron is obtained by means of a voltage controlled oscillator (VCO), a phase detector, and a filter amplifier (Fig. 4). The VCO output is locked onto the master oscillator frequency (353.210 MHz), but its phase is varied in proportion to the phase detector output. Phase detection is made at an intermediate frequency of 100 kHz, generated from the RF frequency by a sampling technique (time stretcher). The detection method is independent of the input level over a range larger than 50 dB and has a long-term stability of ±1°. The 100 kHz is then filtered, although a lag-lead filter must be used for stability reasons because of the orthogonal response of the VCO when it is used as a phase shifter. By introducing a dc error in the klystron loop, the station phase can be adjusted. Likewise, by modulating this error, a phase modulation can be produced for diagnostic purposes or for stabilization of longitudinal beam oscillations by feedback.

Reactive beam loading of the cavity and thermal detuning effects are compensated by the common motion of the two tuners. A phase detector similar to the one described above measures the phase variation between the input of the "magic T" and the field from a pickup loop in the center cell. The output of the detector causes the two tuners to move in or out together to adjust the cavity tuning angle. The 100 kHz intermediate frequency of the phase detector provides a linear sample of the RF fields in the center cell, and is used for gap voltage leveling via the AGC loop.

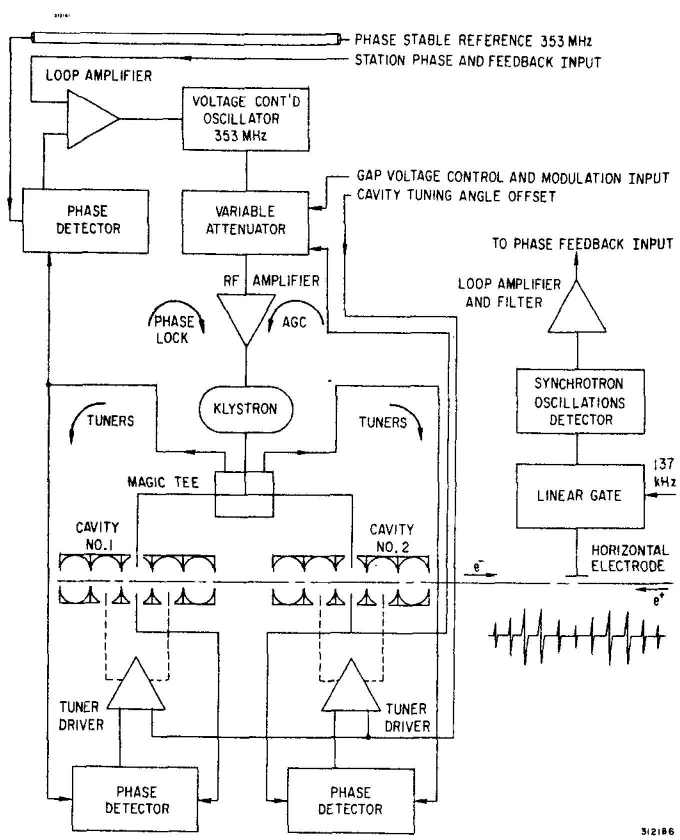

Fig. 3. Typical RF station control loops.

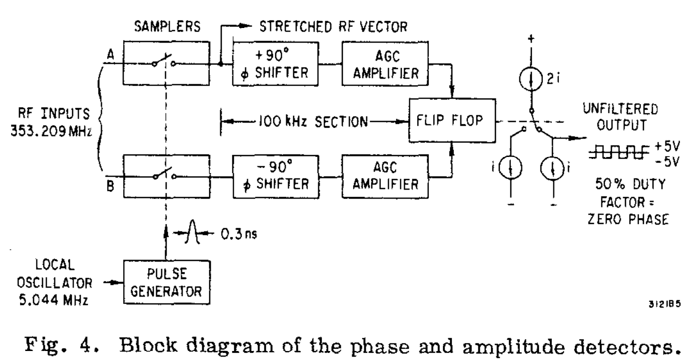

Fig. 4. Block diagram of the phase and amplitude detectors.

Two similar linear detectors sample the fields of cells 1 and 5 and generate a differential motion of the tuners. In this fashion it is expected to compensate for any uneven thermal detuning and to maintain an even power balance in the five cells.

The phasing of the four klystrons of each region will be achieved by maximizing the vector sum of all cavity fields; this operation can be conveniently done at the intermediate frequency of the phase detectors. The overall phasing of the ring will then be completed by adjusting the respective phase reference of the three regions in such a way as to obtain a maximum of the synchrotron frequency of the stored beams.

Parasitic Mode Losses

In the past several years storage ring designers have become increasingly aware[3] that the very short bunches in a ring with a high frequency RF system can excite parasitic modes in beam-line vacuum chamber components. In the SPEAR II ring, for example, heating due to these parasitic losses sets the limit on beam current under some operating conditions. Parasitic mode losses (or, looked at otherwise, the vacuum chamber coupling impedance) can also lead to instabilities.

In the construction of PEP it is expected that the parasitic loss per unit length of vacuum chamber will be reduced to 10% of the loss for SPEAR II, by improvements in component design. There are in addition higher order mode losses (excluding the fundamental mode) which are excited by the beam in the RF structure itself. For the proposed 24 cavity PEP RF system, these losses will dominate by a factor of two over the parasitic losses in the remainder of the vacuum chamber components, adding an additional 0.5 MW to the 2.2 MW dissipated in the fundamental mode for 15 GeV operation. Since the cavities are designed to take the full 6.0 MW klystron output, this additional loss will pose no problem. However, some of the excited cavity modes can couple to possible resonances in the tuner bellows. Such a resonance produced a tuner bellows failure in SPEAR II, and this possibility must be carefully guarded against in the design of the PEP tuner. Losses in the vacuum chamber components outside the RF structure are expected to be about 0.3 MW for two 55 mA beams.

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