RF POWER SYSTEM FOR THE TRIESTE SYNCHROTRON LIGHT SOURCE ELETTRA

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Abstract

For Elettra a 500 MHz system using independent plants each delivering 60 kW for each cavity has been adopted. At 1.5 GeV and a beam current of 400 mA four cavities and consequently four plants will be used in order to provide the total accelerating voltage of 1.7 MV and the total power to the beam of 51 kW. Four cavities will be also sufficient to store 200 mA of beam current at 2 GeV providing the total accelerating voltage of 1.8 MV and the total power to the beam of 64 kW. The requirements of the Elettra RF power system design, the configuration of the plants and the present status are here described.

Introduction

The Elettra RF system will be working at 499.654 MHz [1]. Four cavities will be installed in the main ring, each one having its own power plant. The choice of independent plants has been done for two main reasons, i.e. the ease of implementing longitudinal feedback and the possibility of acting on each cavity with independent feedback loops even in a different way. In this way the phase and amplitude control of the gap voltages can be obtained in a simpler and more sensible way.

Moreover it was decided to use as much as possible equipments wich are derived from industrial ones in order to obtain a drastic reduction in research and development costs, in time and manpower. This lead to the choice of four power plants with an installed RF power of 60 kW each.

For Elettra at 1.5 GeV the estimated energy losses due to the bending magnets are 81.5 keV/turn, while the losses due to the insertion devices are 46.1 keV/turn. For the upgrade at 2 GeV the corresponding values are 257.5 keV/turn and 62.5 keV/turn. The total voltage requirements are 1.7 MV/turn at 1.5 GeV and 1.8 MV/turn at 2 GeV. The main parameters for the RF design are summarized in table 1.

Table 1. RF design parameters.

Beam Energy (GeV)	E	1.5	2
Revolution frequency (MHz)	f_r	1.1566	1.1566
Harmonic number	h	432	432
RF frequency (MHz)	f_0	499.654	499.654
Total losses (keV/turn)	V_{bt}	127.6	320
Total voltage (MV/turn)	V_{btp}	1.7	1.8

Operation at 1.5 GeV

With reference to table 1, the total voltage seen by the beam is 127.6 kV/turn, while the peak voltage must be 1.7 MV/turn. With four cavities this leads to a peak cavity voltage equal to 607 kV. The theoretical value of the shunt impedance is 7.85 MΩ[2]; in order to have a safety margin for the power requirements calculations an effective value of 5.5 MΩ (i.e. the 70 % of the theoretical one) has been assumed. Then the power wasted in each cavity is about 33.5 kW, while for 400 mA of beam current the power to the beam is 12.75 kW. Then the total required power per cavity is 46.3 kW. Being 60 kW the available power per plant, there is a good safety margin to account for losses external to the cavity and the amplifier and for possible upgrades. The maximum frequency shift needed to compensate the reactive component of beam loading is 58 kHz [1]: this is less than the mechanical tuning range of the cavity [2]. The equivalent impedance $R_{//}$ of the cavity (< 4 MΩ) seen by the beam into the cavity fulfills the Robinson condition to avoid instability (in this case should be $R_{//} < 10$ MΩ) [1]. The main parameters at 1.5 GeV are listed in table 2

Table 2.RF parameters (for one plant) at 1.5 GeV.

Energy (GeV)	E	1.5
Beam current (mA)	I_b	400
Power to the beam (kW)	W_b	12.75
Stable phase (degrees)	Φ	4.3
Voltage seen by the beam (kV)	V_b	31.9
Cavity shunt impedance (calculated) (MΩ)	R_{sh}	7.85
Gap factor	T	0.7
Peak cavity voltage (kV)	V_{cp}	607
Power wasted in the cavity (kW)	W_c	33.5
Total power per cavity (kW)	W_t	46.3
Power available per plant (kW)	W_a	60
Frequency shift for reactive current compensation (kHz)	Δf	58

Operation at 2 GeV

Referring to table 1, for 2 GeV the total beam losses are 320 keV/turn. With four cavities the peak cavity voltage must be about 643 kV. This leads to a total power wasted in the cavity of about 37.7 kW. Then, installing four 60 kW plants and taking care of a safety margin of 6 kW for the external losses, there are 16 kW of available power to the beam. This is sufficient to store a maximum beam current of 200 mA. The maximum frequency shift for the compensation of the beam loading is in this case about 28 kHz. The increase of the installed power to achieve 400 mA of beam current is foreseen in a second stage. The main parameters at 2 GeV are summarized in table 3.

Table 3.RF parameters (for one plant) at 2 GeV.

Energy (GeV)	E	2
Beam current (mA)	I_b	200
Power to the beam (kW)	W_b	16
Stable phase (degrees)	Φ	10.2
Voltage seen by the beam (kv)	V_b	80
Cavity shunt impedance (calculated) (MΩ)	R_{sh}	7.85
Gap factor	T	0.7
Peak cavity voltage (kV)	V_{cp}	643
Power wasted in the cavity (kW)	W_c	37.6
Total power per cavity (kW)	W_t	53.6
Power available per plant (kW)	W_a	60
Frequency shift for reactive current compensation (kHz)	Δf	28

Power Plant - Brief Description

The block diagram of the RF system is shown in figure 1. The main oscillator is a very stable synthesized signal generator. The regulation of the relative phases of each RF chain is obtained by means of a phase shifter. The output of the phase shifter drives the preamplifier whose output drives the power amplifier. Between the klystron and the cavity a circulator is placed. In this way the possible reflected wave from the cavity always sees a resistive matched load. The klystron - cavity coupling is calculated in order to obtain the matching when the power absorbed by the beam is the largest. Then the shunt impedance seen by the beam is always the parallel of the equivalent shunt impedance of the cavity with the transferred impedance of the amplifier that is kept constant by the circulator. The circulator will also protect the power amplifier against reflected power.

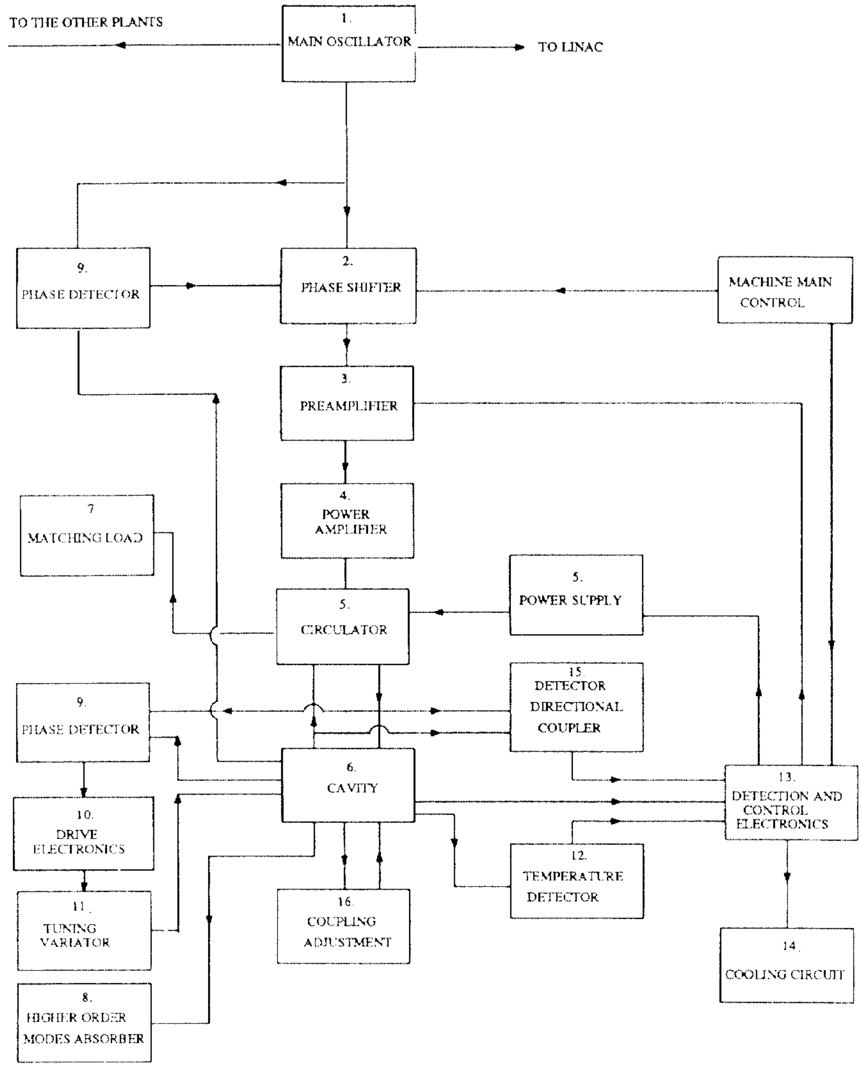

Figure 1. Block Diagram of Main Ring RF System

In order to compensate the reactive component of the beam loading effect, as it is well known, the cavity should be properly detuned in such a way that the amplifier is matched to the cavity loaded by the beam. The phase and amplitude of the gap voltage will be controlled by the low level electronic system.

Power Amplifier

The power amplifier will be supplied by Varian TVT Cambridge UK. The final stage is a water cooled mod. VKP-7983 klystron amplifier [3]. The output RF power is 60 kW and the central working frequency is 499.654 MHz with a - 3 dB bandwidth of ± 2 MHz. The harmonic level is lower than - 60 dB. The driver stage is constituted by a chain of broadband solid state linear amplifiers operating in class A. The output power stability is ± 1 % and the input-output phase stability is less than ± 0.5 degrees with mains stabilized at ± 1 %. The maximum admissible reflected power of the klystron amplifier is 4 % at each rated output. The protection of the amplifier against excessive reflected power is assured by a circulator supplied by ANT Backnang West Germany which can substain up to 75 kW of forward and reflected power simultaneously.

Amplitude and Phase Stabilization

As for the amplitude control of the gap voltage, a small fraction of the cavity RF voltage on the axis is sent via a coaxial cable to an amplitude comparator. The cavity signal is compared with a reference level provided by the machine main control. The error signal is then used to modify the gain of the preamplifier which controls the level of the RF driving signal of the amplifier.The reference level of the cavity voltage is also compared with a signal proportional to the reflected power and in case of too high reflection the reference level can be reduced in order to proportionally reduce the forward and associated reflected power.
The functional diagram of the phase control system is shown in figure 2. Two kinds of phase control are foreseen: a slow mechanical tuning and a fast phase control loop. A phase detector compares the relative phases between the cavity gap voltage and the input signal of the cavity. The output signal of the phase detector directly commands the variations of the mechanical tuning of the cavity, in such a way that the amplifier always sees a real load. The frequency shift needed to compensate the reactive current (58 kHz at 1.5 GeV and 28 kHz at 2 GeV) is lower than the mechanical tuning range of the cavity (around 100 kHz). The response time of the mechanical tuner is of the order of the second. For a prompt

compensation of the phases, the phase of the gap cavity voltage is compared with the reference phase of the plant via the fast phase control system. The difference signal acts on the phase shifter in order to obtain a dynamic phase variation during the time necessary for the operation of the mechanical tuner. This delay time could be estimated to be of the order of few microseconds. The fast phase control system assures the correctness of the relative phases between the cavities.

Present Status

The first amplifier (tested at the factory) has been installed in the RF laboratory of Sincrotrone Trieste for the power tests. Two circulators and other main components of the power plant (such as dummy loads, directional couplers, etc) has already been delivered.

One prototype of the RF power plant has been assembled using a dummy load instead of a cavity and power tests on the various components have been performed. The starting of the power tests on the first complete prototype of the cavity is planned at the end of this summer.

As for the low level electronics, a prototype of the phase comparator has been built and preliminary tests have been performed.

Conclusions

The RF power system for ELETTRA is completely designed, most of the components ordered and the modelling work on the cavity will be completed at the end of this year.

The choice of independent channels, besides having advantages on the operational side has been attested to be cheaper compared to the choice of having one single amplifier feeding all the cavities.

Moreover an important advantage of this solution is that the modular construction of the system allows an easy and direct upgrade of it. For example at 2 GeV, the increase of the current to 400 mA could be obtained by simple adding two more identical plants (obviously the effect of the increase of the effective total impedance on the beam needs further studies). A further advantage of this solution is that the operation of the machine would be possible even if one plant would fail, the others being sufficient to operate even if not in an optimal condition.

References

[1] Sincrotrone Trieste, "ELETTRA Conceptual Design Report", 1989, ch. II-6, pp. II-80-99.

[2] A. Massarotti, G. D'Auria, A. Fabris, C. Rossi, M. Svandrlik., "500 MHz Cavities for the Trieste Synchrotron Light Source ELETTRA", this Conference.

[3] A. Fabris and A. Massarotti, "The 60 kW Amplifiers for the Storage Ring: Description and Acceptance Test Results", ST/M-TN-90/11, to be published.

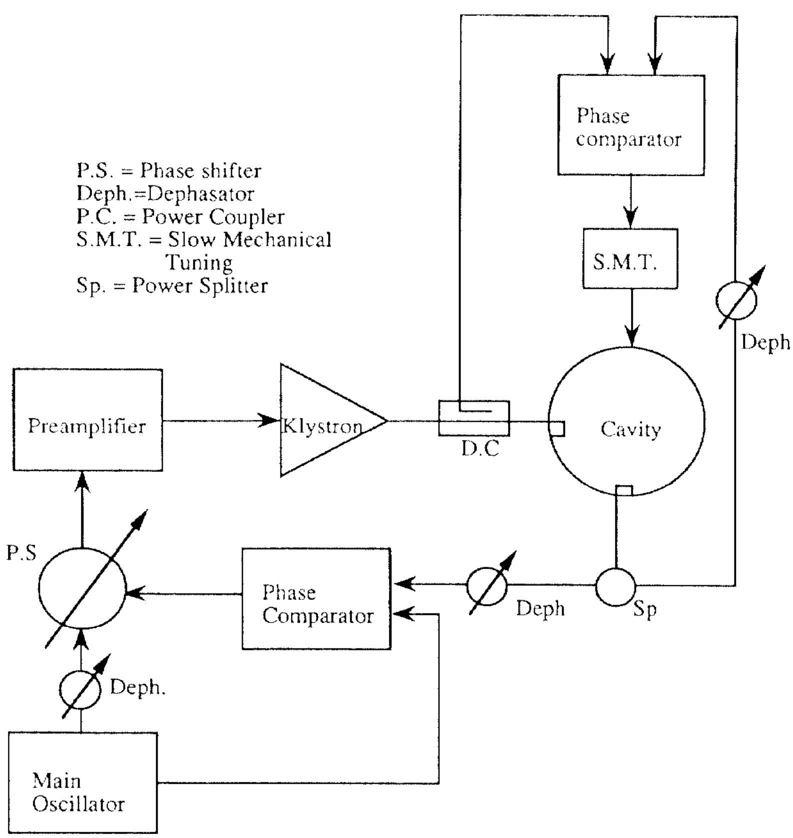

Figure 2. Functional Diagram of the Phase Control System.
(N.B. the circulator and other components of the plant are not shown).