CHARACTERISATION OF THE LOW LEVEL SYSTEM OF THE ELETTRA RF PLANTS

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ABSTRACT

Each of the four RF plants of the ELETTRA RF system is equipped with four low level loops. The temperature loop stabilises the reference temperature of the cavity with an accuracy better than 0.1 °C, a mechanical tuning loop and an amplitude loop are installed for beam loading compensation, whilst a phase loop is used to maintain the phase stable. All of these loops interact with each other and are coupled via the beam. Therefore an optimisation of their parameters under real operating conditions becomes necessary. During the last year, extensive measurements were performed to completely characterise the transfer functions of the loops and different configurations have been tested under various operating conditions.

1 INTRODUCTION

The ELETTRA RF system is composed of four 60 kW plants [1,2]. The system is of modular construction and each plant is connected to a single cell 500 MHz cavity. The cavity gap voltage is set to 630 kV, which means that the wasted power on the cavity surfaces is 29.2 kW. The beam current for users' operation is 250 mA at 2 GeV and the power to the beam, without taking into account the losses in the insertion devices, is 16 kW per cavity. The operation of the RF plants is strongly influenced by the loading due to the circulating beam current. At high current the system stability may be affected. Moreover, during the various phases of machine operation (injection, ramping, beam storage), which require different power levels from the amplifiers, amplitude and phase of the cavity fields must be kept stable for a proper operation of the system. To compensate these effects, three feedback loops are installed: a tuning loop, an amplitude loop and a phase loop. Besides these loops, a temperature feedback stabilises the reference temperature of the cavity.

2 TUNING LOOP

The tuning loop keeps the cavity tuned by compensating for stationary beam loading and temperature effects. A block diagram is shown in fig. 1. As already described elsewhere [3], the tuning is performed by an elastic deformation of the RF cavities in the direction of their axial length. With each of the four cavities' peak gap voltage equal to 630 kV, the calculated frequency shift for a 400 mA beam is 53 kHz. The required axial deformation is therefore about 66 μm, since the resonant frequency variation of the cavities is equal to 8 kHz for a 10 μm deformation in the axial region. The position of the mechanical tuner can be read on a meter on the rack containing the loop electronics. From this reading the resonance frequency of the detuned cavity can be calculated. Measurements performed are in very good agreement with expected values. For instance for a 200 mA beam a frequency shift of 26 kHz was calculated from the meter readings, while the theory gives a value of 26.5 kHz. The reference signal for the tuning loop is taken from a directional coupler in the RF power feeder line just before the cavity main coupler. A phase comparison is made between this signal and two others, opposite in phase, picked up from the cavity. The sensitivity of the phase detector is 10 mV/deg. The output signal of the phase detector is used to drive the tuning motor, which obviously sets the limit to the correction speed. The speed is now set to 700 Hz/sec (i.e. 3.5 deg/sec). A window detector is used to stop the motor if the error signal exceeds pre-set limits. The output of the window detector also interrupts the driving signal to the corresponding RF plant. Limiting blocks are also used as a further safeguard in case the window detector fails. In order to avoid undue wear of the tuner a further window detector is used to inhibit tuning until the error signal exceeds a pre-set threshold level. Loop operation is similarly inhibited in the absence of the RF drive. The cavities' resonant frequency is set 1 kHz below the generator frequency to prevent Robinson instabilities. Therefore the output of the phase detector is zero if this relation is satisfied. The sensitivity of the system can be set either to 100 or 500 Hz (i.e. if the difference between generator and cavity resonant frequencies exceeds this limit the motor is switched on to restore the required condition). In machine operation with stored current, if the sensitivity is set to 100 Hz the motor is almost continuously in operation alternating in direction due to the beam loading detuning the cavity. In the 500 Hz option due to the high temperature stability of the cavity, the motor needs to be switched on very rarely, except of course during injection or after beam losses. Since no differences in beam quality have been observed between these options, the sensitivity is normally left at 500 Hz. This also saves motor and tuning system operation. Depending on the plant, in the 100 Hz option the open loop 3 dB bandwidth is in the range between 200 and 230 Hz, with a dc gain from 36.5 to 38 dB. The time needed to recover a 2 kHz frequency variation has been measured on the cavities at full power and it ranges from 3 to 4 sec. A detuning due to an input power variation takes a slightly longer time to be recovered due to the interaction with the cooling system. However the measured values are from 4 to 6 sec for a 1 kW variation around 30 kW wasted power on the cavity surface. In the 500 Hz option, the open loop 3 dB bandwidth is the same, while the loop gain is decreased to a value between 22 and 24 dB depending on the plant. The time needed to recover from frequency or power variation is roughly the same as in the 100 Hz option. The operation of the mechanical tuning loop is very much influenced by the temperature loop and vice versa, since the time constants involved are comparable. The temperature loop acts to stabilise the temperature of one point on the cavity surface. This reference point is maintained at a constant temperature to better than 0.1 °C in a temperature range from 40 to 70 °C. Obviously a detuning of the cavity brings to a lower power wasted in the cavity itself and a hence a fast decrease in the reference temperature, while a temperature change requires a correction of the cavity tuner. It must be remembered that the temperature tuning is the technique used in ELETTRA to fight multi-bunch instabilities [4]. For all of these reasons the optimisation of the temperature loop operating parameters is a crucial point for the operation of the RF plants. This optimisation was done in parallel with the optimisation of the parameters of the mechanical tuning loop.

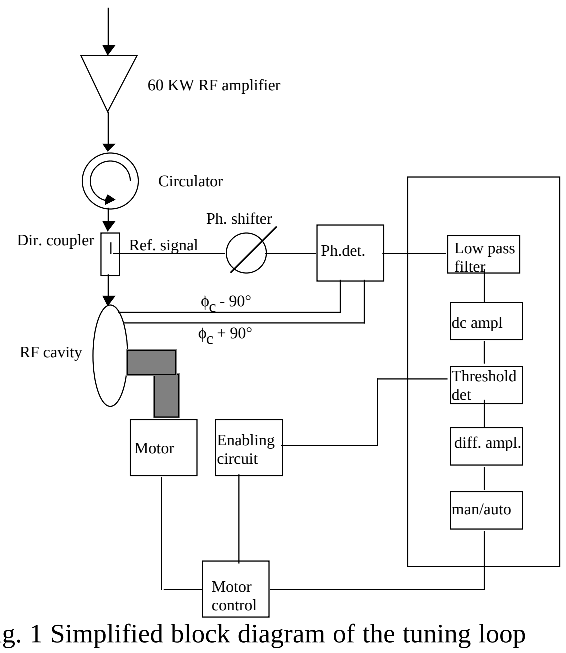

Fig. 1 Simplified block diagram of the tuning loop

3 AMPLITUDE LOOP

The amplitude loop keeps the gap voltage constant in a 1 % range, counteracting the beam loading effect. The power wasted on the cavity surface should remain constant through the entire operating range of beam current and energy. The amplitude loop controls the driving signal of the plants and regulates it so to provide more power for the beam while keeping constant the gap voltage. It is worthwhile to mention that an amplitude stabilisation is performed on the amplifier itself. The incoming mains in fact are stabilised at ±1 % and a body to cathode regulator has been implemented on the klystrons to improve amplitude and phase stability against transients.

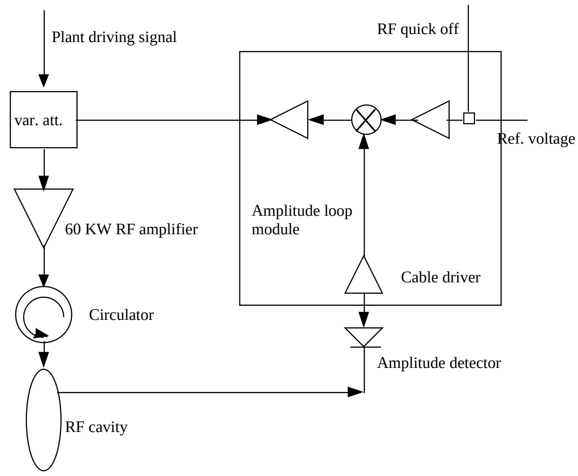

Fig. 2 Simplified block diagram of the amplitude loop

A block diagram of the loop is shown in fig. 2. A sample of the cavity field is picked up with a loop in the cavity and it is compared to the reference voltage provided by the control system. A variable attenuator in the RF plant driving signal is accordingly adjusted. The amplitude detector is a full wave rectifier. The DC amplifier for the reference voltage can be synchronised by an external signal to inhibit operation of the loop. This is used particularly during short interruptions (4 msec) of the RF common driving signal which are used to dump the beam. The variable attenuator is a voltage controlled phase-free attenuator which allows a minimum attenuation step of 0.032 dB. The range of the equipment is 32 dB and the speed is about 10 µsec. The open loop gain is 26 dB, while the loop bandwidth is now set very narrow (10 Hz). The bandwidth of the loop is limited by the cable driver bandwidth. However the time needed to recover a 30 % gap voltage variation in the cavity is approximately 4 msec. The operation of the amplitude loop has been very satisfying. An extensive study has been done on the amplitude loop varying the loop bandwidth in machine operation with beam. It is well known that a the bandwidth of this loop is limited by the synchrotron frequency. In ELETTRA the synchrotron frequency is 16.1 kHz at 1 GeV and 11.3 kHz at 2 GeV with four cavities operating at 630 kV peak gap voltage. In the tests performed the loop bandwidth could be varied in steps up to 4 kHz. At the injection energy, operation was smooth up to 800 Hz, but when the bandwidth was set to 2.5 kHz beam losses took place. These occurred together with an increase of synchrotron sidebands, the whole spectrum becoming very disturbed. As for accumulation, no saturation was observed up to this bandwidth, afterwards beam current saturated around 300 mA. Higher bandwidth should lead to a lower saturation level. At 2 GeV no beam losses occurred when switching to higher frequencies, however the spectrum was becoming very disturbed, showing the appearance and growing up of many synchrotron sidebands. From these tests, the best situation at both energies should be setting the loop bandwidth in the range between 350 and 800 Hz. The tests during ramping have still to be completed, however in this range we do not expect any problems. Afterwards we will decide whether to modify the standard bandwidth of the loops.

4 PHASE LOOP

The phase stability of the cavity field has to be within ± 0.5 deg. at any power level. The phase variation may have some effects during beam stacking. Therefore the phase loop has to compensate for phase changes on the RF plant due to the power amplifier, the circulator and the driving electronics. Since the main contribution comes from the klystrons, a phase stabilisation is performed on the amplifier itself in a similar manner to amplitude stabilisation. The output power of the klystron depends only on the driving power, since the klystron accelerating voltage remains constant. This decreases the phase shift induced by the power amplifier to few degrees over the whole power range, however a phase loop is needed as well. The loop must be designed to have an open loop bandwidth sufficient to damp the ripple coming from the klystron power supply (600 Hz), but it must be insensitive to the minimum synchrotron frequency. A block diagram of the loop is shown in fig. 3. A sample of the plant driving signal is taken with a directional coupler and after being amplitude regulated is sent to a phase detector as the reference signal. A directional coupler on the coaxial line just before the cavity picks up a sample of the RF forward power, which after being amplitude regulated is sent to the phase detector. A phase shifter in this path is provided for fine regulation. The phase detector is a mixer device with a rather constant sensitivity against large power variation. The output of the phase detector drives an electronic phase shifter, developed with minimised insertion loss. The 3 dB open loop bandwidth is 1.4 kHz and the gain is 33 dB. With the loop closed the phase variation is less than 0.2 deg for an artificially induced phase variation of 20 deg. The phase loop is closed during all the operations of the machine, causing no problem either in injection or ramping or beam accumulation. We tested also a faster phase loop (20 kHz bandwidth) and a phase loop taking as the return signal a cavity voltage sample, in order to include also the cavity in the correction scheme, even if its contribution to phase variation is negligible. With these configurations we always encountered beam losses when closing the loops or saturation during injection. These were due to the interaction between the loop and the synchrotron oscillations when working at the higher bandwidth. When using the cavity voltage signal, the loop should be revised taking account of the total delay in the feedback path to avoid anti damping effects.

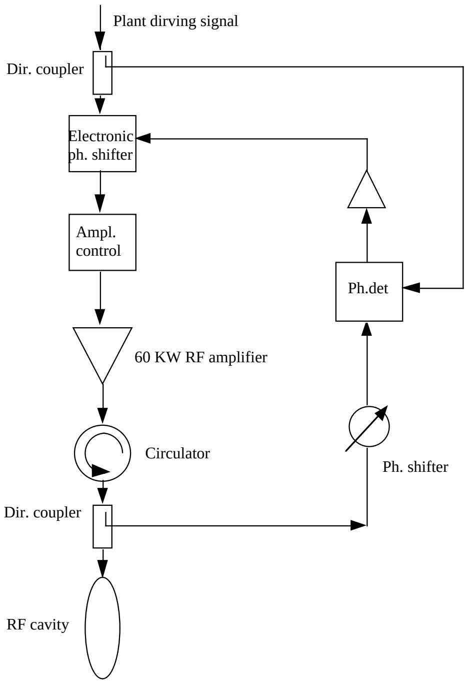

Fig. 3 Simplified block diagram of the phase loop

5 CONCLUSION

All of the foreseen low level loops have been operating successfully in the ELETTRA RF system. After almost three years of operation of the machine no faults have been reported. The tuning loop, the phase loop and the temperature regulation are in the definitive layout. Although present operation is satisfactory, we are considering enlarging the very narrow 3 dB bandwidth used up to now for the amplitude loop . A decision will be taken after the completion of the planned tests.

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