HIGH-POWER RF PHASE AND AMPLITUDE CONTROL

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Abstract

This paper describes the equipment developed in order to control the phase and amplitude of the RF that is fed to the four accelerating structures of the Sao Paulo racetrack microtron. Since the RF is produced by a single 50 kW cw klystron, the control of each branch is done at high-power (~ 10 kW). We describe the hardware of the wave-guide power attenuator and phase shifter, which are driven by stepper motors. We also present a description of the logic of the control system, the algorithm used, and results for the response of the system, when subject to external amplitude and/or phase perturbations.

1 INTRODUCTION

The Physics Institute of the University of Sao Paulo (IFUSP) is building a 31 MeV cw racetrack microtron. This two-stage microtron includes a 1.9 MeV injector linac feeding a five-turn microtron booster that increases the energy to 5.0 MeV. After 28 turns, the main microtron delivers a 31 MeV cw electron beam. The complete accelerator has four RF accelerating structures, a chopper and buncher system and a single source of high power RF, a 50 kW klystron operating at 2450 MHz.

Figure 1 shows a simplified block diagram of the high-power RF distribution system.

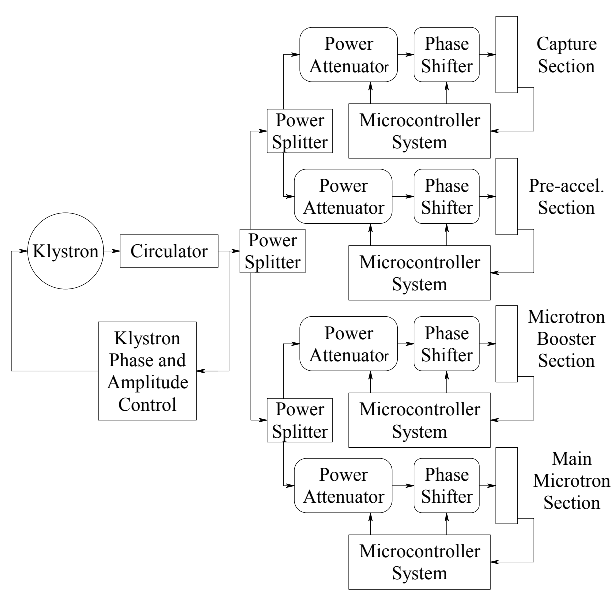

Figure 1 - Block diagram of the high-power RF distribution system

A circulator is used to protect the klystron from power reflected from the rest of the system; the power splitters are wave-guide hybrids with adjustable power division, the phase shifters and power attenuators are motor driven and allow individual control of phase and amplitude to each structure.

2 WAVE GUIDE POWER ATTENUATOR AND PHASE SHIFTER

The power attenuators and phase shifters used in the RF distribution system are built over a common basic component, a directional coupler, as shown in the diagram of Fig. 2.

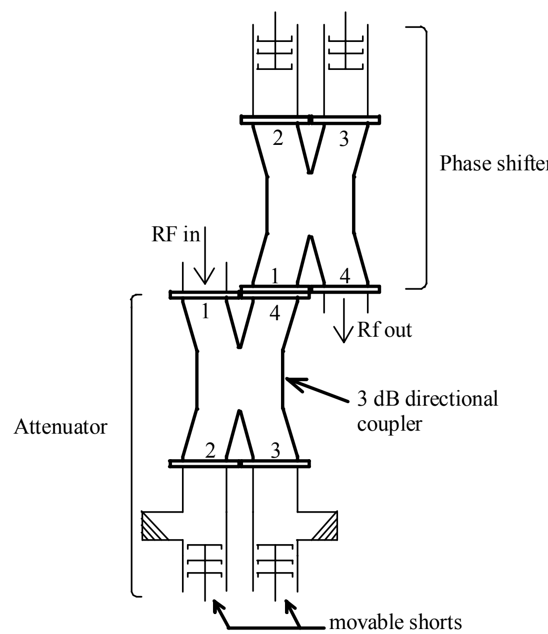

Figure 2: RF power attenuator and phase shifter. The basic component is a directional coupler. The movable shorts are motor driven and the attenuator loads are mounted in a *T*-junction.

The directional coupler, or short-slot wave-guide hybrid, divides the input RF power (port 1) in two equal parts with a 90^o phase difference. The movable shorts are driven jointly by a stepper motor and reflect the RF back to the hybrid. Because of the phase difference both signals add up in the exit port (4) and vanish in port 1. The shorts follow the design of the University of Mainz [1]. They present cylindrical geometry and three stages, with a separation of one fourth of the wavelength, in order to maximize the reflected intensity.

The shift in phase is accomplished by moving the shorts in order to change the length travelled by the wave.

The coupling in the *T*-junctions of the attenuator is changed when the shorts are moved, and thus the amount of power dissipated in the loads can be controlled.

Obviously this also causes a change in phase, so that an action of the attenuator must always be followed by an action of the phase-shifter.

3 CONTROL SYSTEM

At each accelerating structure two RF samples are taken: one is furnished to a double-balanced mixer (DBM) and the other to an amplitude diode detector. The DBM also receives a sample of the main RF oscillator (a reference common to all parts of the accelerator), as shown in Fig. 3.

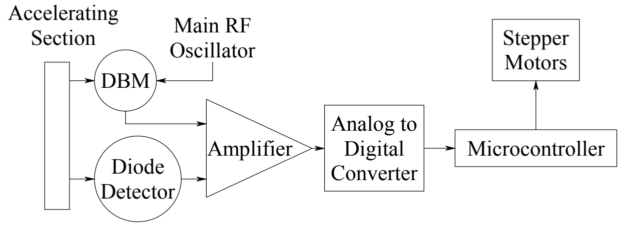

Figure 3: Block diagram of the control system

A DBM is a device that receives two signals as inputs (*R* and *L*) and delivers the product of these signals as output. When the input signals are at the same frequency the output is a dc signal proportional to the phase difference between *R* and *L*. The diode detector is a schottky diode which operates in the so called square region, where the amplitude of the output signal is proportional to the input power.

These two signals (phase and amplitude) are sent to a control board near the accelerating structure. The control board contains amplifiers to signal conditioning, an analog to digital converter, a microcontroller, a serial interface for communications and drivers to the stepper motors. The microcontroller continually acquires the phase and amplitude signals and verifies if they are compatible with a given setpoint. It runs a Proportional Integral algorithm to determine the direction and number of steps of the motor necessary to take the Power Attenuator or the Phase Shifter to the new position. Whereas the Attenuator causes a phase shift and the Phase Shifter causes some attenuation, the software limits the amount of movement of each motor to maintain stability. To avoid excessive mechanical wear of the parts, a constraint in the program allows movement of the shorts only for corrections above a certain threshold.

Setpoints are defined by the accelerator control system and sent to the control board through the serial interface.

4 RESULTS

4.1 Characterization of the components

The attenuator and the phase-shifter were tested as an assembly, like shown in Fig. 2. We measured each parameter (phase or power) as a function of the short position, and also the reflected power. The results are shown below, in Figs. 4-7.

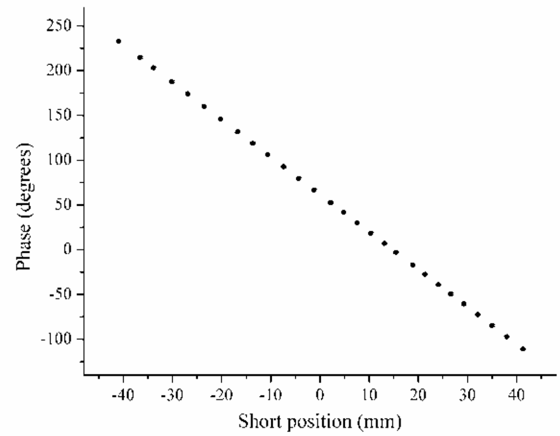

Figure 4: Phase shift as a function of the position of the shorts.

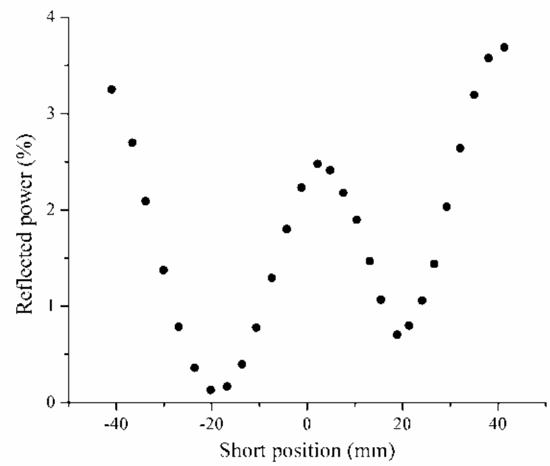

Figure 5: Reflected power as a function of the position of the phase-shifter shorts.

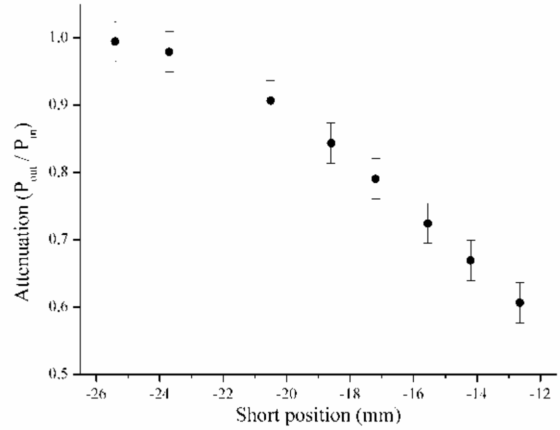

Figure 6: Attenuation as a function of the position of the shorts.

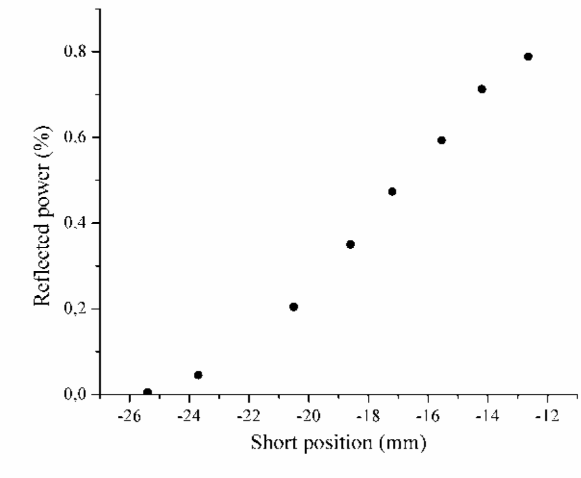

Figure 7: Reflected power as a function of the position of the attenuator shorts.

We expect to be able to work with the phase-shifters around the region of minimum reflected power. The attenuators, on the other hand, should operate in the 1.0 to 0.9 range of attenuation, since they must compensate for the beam loading and other small power losses. In this case the reflected power due to the attenuator is less than 0.3 %.

4.2 Dynamic control

The control system was tested initially on a bench, with low power RF, but using the same hardware. In this situation we were able to keep the phase stable within 0.1 degree and the power within 0.2 %. Phase perturbations are corrected faster than power perturbations, because shifts in phase introduce little change in power. On the other hand an attenuator action causes phase shifts that must be corrected. The system takes less than 5 s to correct 5 % perturbations in amplitude, which are much higher than expected to happen during operation.

Tests at high power showed that the system supports well the RF, without excessive heating or electrical discharges.

5 ACKNOWLEDGMENTS

This work was supported by Brazilian agencies FAPESP and CNPq.

6 REFERENCES

[1] H. Herminghaus, private communication.