RESONANCE FREQUENCY STABILIZATION OF A SIDE-COUPLED ACCELERATING STRUCTURE

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Abstract

This paper describes an automatic process of controlling the resonance frequency of a side-coupled accelerating structure, by the use of moving plungers. Brief descriptions of the frequency monitoring system and of the plungers are presented. Hardware and software of the control system are described. Results for the performance of this system operating with a 17-cavity accelerating structure are presented.

1 INTRODUCTION

The Physics Institute of the University of São Paulo (IFUSP) is building a 31 MeV continuous wave (cw) racetrack microtron [1,2]. This two-stage microtron includes a 1.9 MeV injector linac feeding a five-turn microtron booster that increases the energy to 5.1 MeV. After 28 turns, the main microtron delivers a 31 MeV cw electron beam. The injector has a capture section and a pre-accelerating section; therefore the complete accelerator has four RF accelerating sections, operating at 2450 MHz.

Like in every recirculated accelerator, in this microtron the accelerating field amplitudes must be kept very stable to avoid phase slip and beam loss. Moreover, requirements for the energy resolution impose that the accelerating field fluctuations must be kept within 0.5%.

The resonance frequency of the structure (2450 MHz @ 42^{o} C) is achieved by accurate processes of machining and brazing, followed by a careful fine-tuning. Nevertheless, during operation changes in the structure temperature can alter its geometry and consequently the resonance frequency, which affects the accelerating field. There are two ways to compensate the changes in the resonance frequency: by controlling the temperature of the structure or by de-tuning the frequency of some of the cavities. The last method is faster and simpler and can be accomplished by the use of moving plungers.

This paper describes an automatic process of controlling the resonance frequency of a 17-cavity side-coupled accelerating structure, using movable plungers, located at the two extreme cavities.

2 RESONANCE FREQUENCY MONITORING

When the exciting RF frequency coincides with the resonance frequency of the structure, there is a 90^{o} phase difference between the input signal and an RF sample from the structure. This phase difference can be measured by a double-balanced-mixer (DBM), thus establishing a parameter to monitor if the structure resonance frequency agrees with the RF input.

The DBM is a device that receives two input signals (*R* and *L*) and delivers a product of these signals as output. This product has the following form:

$$V_{out} = V_R V_L \cos(\omega_R t + \varphi_R)\cos(\omega_L t + \varphi_L)$$

V_{out} can also be expressed as a sum of two cosine-waves:

$$V_{out} = \frac{V_R V_L}{2}\left\{\cos\left[(\omega_R - \omega_L)t + (\varphi_L - \varphi_L)\right] - \cos\left[(\omega_R + \omega_L)t + (\varphi_R + \varphi_L)\right]\right\}$$

The output signal presents two frequencies: the difference and the sum of the frequencies of the input signals. Since the sum is very high (about 5 GHz), it can be easily removed with any piece of circuit working as a low-pass filter. Besides, the input signals have the same frequency, therefore we have:

$$V_{out} = \frac{V_R V_L}{2}\cos(\varphi_R - \varphi_L)$$

This is a dc signal that provides the information about the phase difference. The derivative of V_{out} presents a maximum when the phase difference is 90^{o} (zero volts). So the best working range is around 0 V, where the sensitivity is maximized. To assure that the output signal is proportional only to the phase difference, the input signals must have sufficient magnitude to put the mixer in the saturated mode [3].

3 THE SYSTEM

To change the resonance frequency of the structure, two moving plungers were coupled to the two extreme accelerating cavities. These plungers change the geometry of the cavities and thus alter the resonance frequency of the whole structure.

The design of the plungers was based on the one developed by the Accelerator Development Group of the Johannes Gutenberg Universität, Mainz, Germany [4,5], with only minor changes due to the difference in the cavity geometry. The system is water-cooled, vacuum tight and uses a two-stage RF short circuit. The separation between the stages and the gap between the piston and the walls were optimized empirically by the Mainz group [4].

Figure 1 shows a block diagram of the plunger control system. The phase shifter (adjusted manually) is used to compensate for the cables, and to set a phase difference of 90°. A low-pass filter and an amplifier make the signal conditioning. Using a 12-bit ADC, this system provides a resolution of about 0.07°.

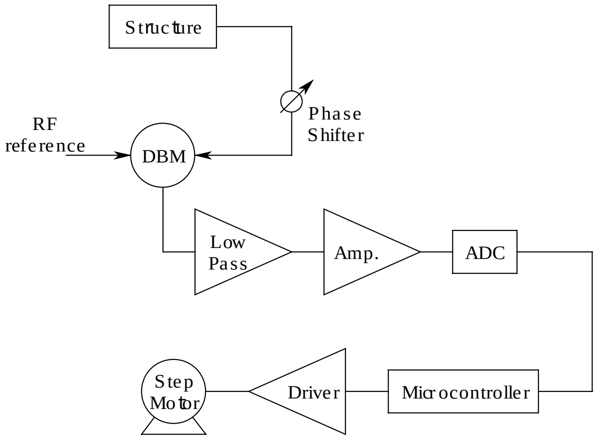

Figure 1: Block diagram of the automatic control system of the plungers.

The microcontroller is a 8751, an industry standard, and runs a program written in C language. The microcontroller itself drives each coil of the step motors, by software, thus avoiding the need of a hardware sequencer. The step motor has a maximum torque of 48 N.cm and a resolution of 200 steps per revolution. A 3:1 belt reduction increases the resolution to 600 steps per revolution.

The program verifies if the signal is different from zero. If the difference is larger than a given threshold, the CPU drives two step motors (wired in parallel) that move the two plungers inside the extreme cavities of the structure. The direction of movement is determined by the polarity of the signal. When the signal is different from zero and above the threshold, the CPU executes a Proportional-Integral (PI) algorithm. The PI drives the step motors according to the signal, as long as the difference from zero is enough to be corrected by at least one step.

The whole process of measuring the phase and moving the plungers is very quick (fraction of a second). To avoid excessive mechanical wear of the plunger, a constraint in the program allows the movement of the plunger only for corrections of 15 or more steps.

4 RESULTS

A de-tuning of the two end cavities by 425 kHz produces a change of 50 kHz in the resonance frequency of the structure. Figure 2 shows how the resonance frequency of the structure depends on the position of the plungers. One can see that a displacement of a few millimeters is enough to correct for a couple of hundreds of kHz in the frequency. These changes are small enough to be made without altering the properties of the cavity, or jeopardizing the field distribution along the structure.

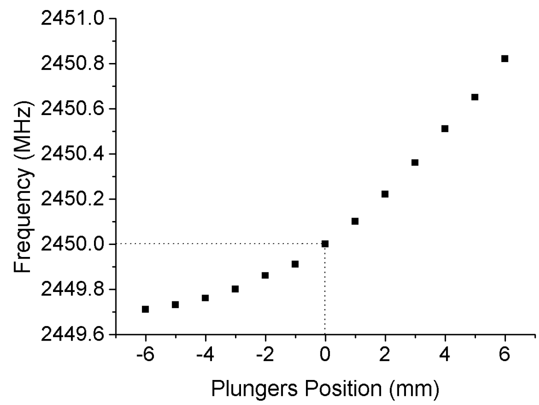

Figure 2: Resonance frequency of the structure as a function of plungers position (both acting in parallel). The dotted lines indicate the optimum operating frequency.

Figure 3 shows the accelerating field amplitude as a function of the structure temperature, with and without the tuning plungers in operation. The results with the plungers in operation present a slight decrease in the accelerating field around the optimum temperature. The results obtained keeping the plungers fixed (at their position for the optimum temperature), presents a much faster drop in the accelerating field.

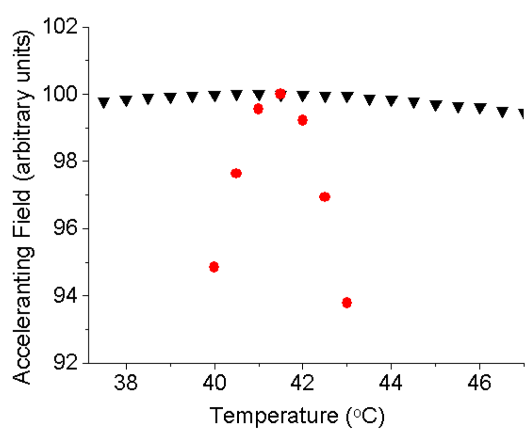

Figure 3: Accelerating field strength as a function of the structure temperature, with the plungers operating (triangles) and fixed (circles).

The decrease in the accelerating field with the plungers operating is caused by the different tuning of the cavities, even though the structure as a whole is kept tuned.

Operation of the system at temperatures far from the optimum value worsens its efficiency, transferring part of the energy to other modes. The drop in the accelerating field is slow enough to allow a comfortable operation of the system if the temperature of the structure is kept within $\pm 2.5\ ^{o}C$. In this range the resonance frequency was kept tuned and the accelerating field stable within 0.1%.

ACKNOWLEDGMENTS

The authors would like to thank FAPESP, CNPq and FINEP for financial support.

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