RESULTS OF A NEW PASSIVE RF STABILIZING SYSTEM

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Abstract

The method developed at the Milan AVF Cyclotron for stabilizing the RF accelerating voltage is a passive network where the desired stabilization is achieved by a dummy resistive load connected to the Dee and driven by the RF voltage amplitude. A small amount of the power is extracted from the Dee through a capacitive coupling and feeds the plates of two tubes operating in push-pull mode.

The tests made so far show a ripple on the accelerating voltage around $3 \cdot 10^{-4}$, meaning that a reduction of a factor ≈ 45 has been achieved with respect to the previous unregulated system.

1. Introduction

It has been widely reckoned, since quite a few years, that RF voltage stability is one of the key parameters to better cyclotron performance. This is particularly true whenever good energy spread and good beam quality are desired. For some rather special applications, like the development of beams with very short pulse duration, good RF stability is practically mandatory.

Since at the Milan AVF Cyclotron an analysing magnet has been installed, to provide energy analysed beams, and, furthermore, experiments with time of flight technique are being set-up, it was decided to build a stabilizing network in order to reduce the actual ripple, of more than 1%, to something of the order of a few 10^{-4}.

The new system, built in order to reach this goal, is of very general design. In fact it could be conceivably applied to a number of RF installations either for accelerators or other uses.

In our opinion its main advantage is to offer a very good voltage amplitude stability whenever it is difficult, or practically impossible as in our case, to use a conventional negative feed-back on the RF power generator.

2. Principle of Operation

Let us consider an RF installation formed by a generator, with a different from zero internal impedance, connected to a load of impedance Z_L.

In order to stabilize the voltage amplitude on the load, it is conceptually sufficient to put in Parallel with the latter a variable impedance which can compensate the voltage variations.

This can be obtained with a suitable network which transfers to the load the impedance of a tube controlled by the ripple of the output voltage.

The design principle is sketched in fig. 1.

This system has two main characteristics:

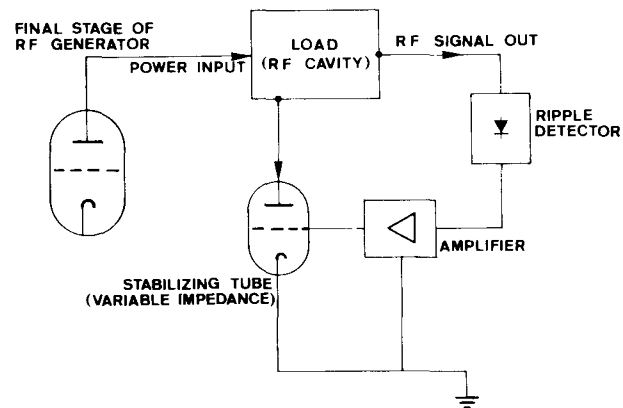

Fig. 1 - Scheme of operation.

- It is completely passive. No d.c. power is supplied to the tube, which can only absorb power from the load.

- It is basically non linear. For this reason the development of an adequate scheme which would allow a simple mathematical treatment while still leading to an effective design, has been a rather complex task.

Details are given in ref. 1).

3. Network Analysis

The system has been built according to the scheme shown in fig. 2.

The variable load, producing the required stability of the accelerating voltage amplitude, is obtained with two tubes in push-pull, directly connected with the Dee via a 6 pF capacity and a $\lambda/8$, 50 Ω coaxial cable. The stabilizing loop is closed with a chain composed by a little capacitive probe, AM detector, a.c. amplifier, d.c. generator and RF filter.

Some details of the main components of this network are given in the following.

3.1 Coupling of the Variable Load to the Dee

The choise of the type of coupling depends upon the location in the cavity resonator where the connection of the variable load is made. In our case it was decided to make the connection near the Dee end.

With a careful design the desired impedance

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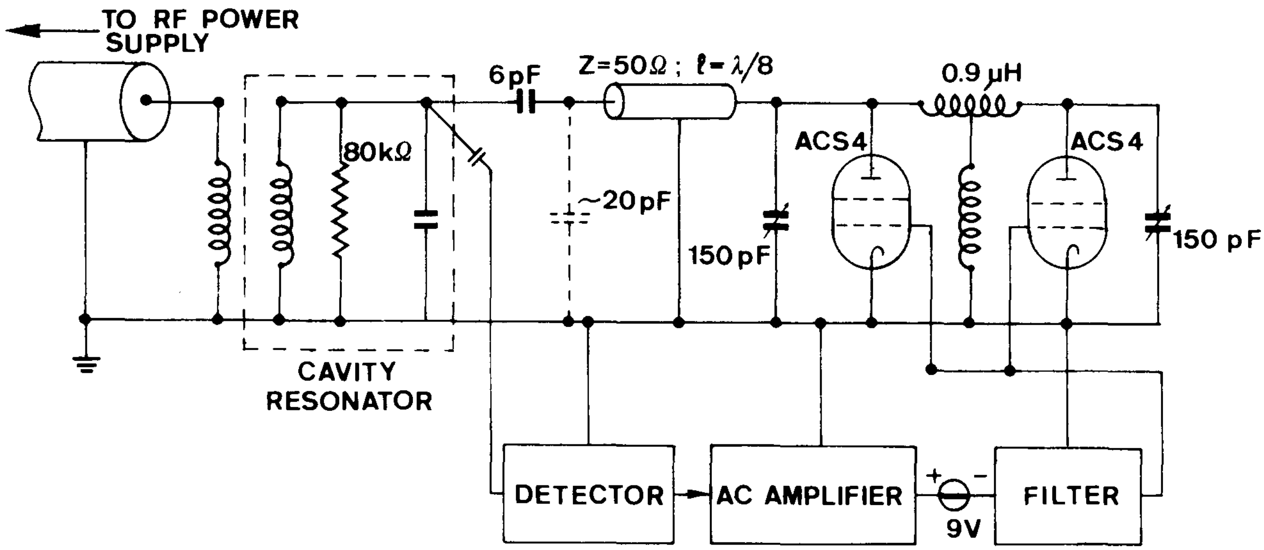

Fig. 2 - Network diagram

transfer was obtained with only a negligible perturbation of the cavity tuning. In fact, in our case, the capacitance variation induced by the variable load is of the order of 10^{-3} pF around a central value determined by the coupling capacity. Therefore, after one compensates for this fixed detuning, no further troubles arise due to the capacitance variation mentioned above.

3.2 Push-pull

The push-pull operation is not strictly necessary. We chose this option because it allows an easier design of the plate circuit, mainly due to the strong reduction of the harmonic content in the plate current.

3.3 Tuning Network

The tuning network consists of a π circuit with a fixed inductance and two variable capacitors. It transfers to the coaxial cable a load which behaves like a resistive load for all practical purposes.

3.4 Ripple Detector

In order to insure the stability of the control loop, the ripple detector must have a time constant negligible with respect to the value of the dominant time constant determined by the cavity resonator. Moreover the detector must give an RF signal attenuation of at least 80 dB to allow the correct operation of the a.c. amplifier. This has been obtained mainly with a series resonant circuit tuned at the working frequency. Finally, to obtain a good signal to noise ratio, the capacitive probe provides, at the detector input, an RF signal of about 50 volt amplitude.

3.5 a.c. Amplifier

We selected an alternating current amplifier because the slow drifts of the RF accelerating voltage around the nominal value had been already compensated for with a conventional negative feed-back which controls the plate voltage of the generator power stage. Nevertheless we extended the amplifier band down to 0.2 Hz to compensate voltage variations produced by the trimming capacitors and movable tuning panels.

Moreover the amplifier has an output impedance of 50 Ω and must be able to absorb current.

4. Operating Conditions and Experimental Results

4.1 Operating Conditions

4.1.1 Cavity Resonator

- Working Frequency: 20.531 MHz
- Peak Dee Voltage: 50 KV
- Power Loss in the Cavity: 15 KW

4.1.2 Stabilizing Tubes

- Plate RF Voltage: 2.9 KV
- Average Power Absorption: 1 KW
- Grid Bias: -9 V

4.1.3 Ripple Detector

- Input RF Voltage: 48 V
- Output RF Noise: 3 mV

4.1.4 a.c. Amplifier

- Voltage Gain: 2500
- Band Width: 0.2 Hz - 3 MHz
- Output Dynamic Range: ± 40 V

4.1.5 Grid Filter

- RF Insertion Loss: 50 dB

4.2 Experimental Results

In the above mentioned conditions, we measured a ripple of $1.4\cdot10^{-2}$ with the stabilizing loop left open, while, when the loop was closed, the ripple was down to $3\cdot10^{-4}$. Therefore the reduction factor is about 45. The ripple measurements were performed in a conventional way, picking up the RF signal from a suitable capacitive probe on the Dee. This probe is different from the one used for the stabilizing loop.

The noise signal is detected with a detector having a 10 μs time constant (5 times less than the time constant of the cavity resonator) and an RF signal attenuation larger than 90 dB.

The measurement are affected by an intrinsic error of the order of 10%, which is much larger than that due to the oscilloscope itself. This depends upon the kind of ripple signal, which is not completely periodic. Moreover the two measurements, i.e. with open and closed loop, are carried out in two different time instants, although they are as close in time as possible. The two ripple photos obtained on the oscilloscope, without and with stabilizing loop insertion, are shown in fig. 3.

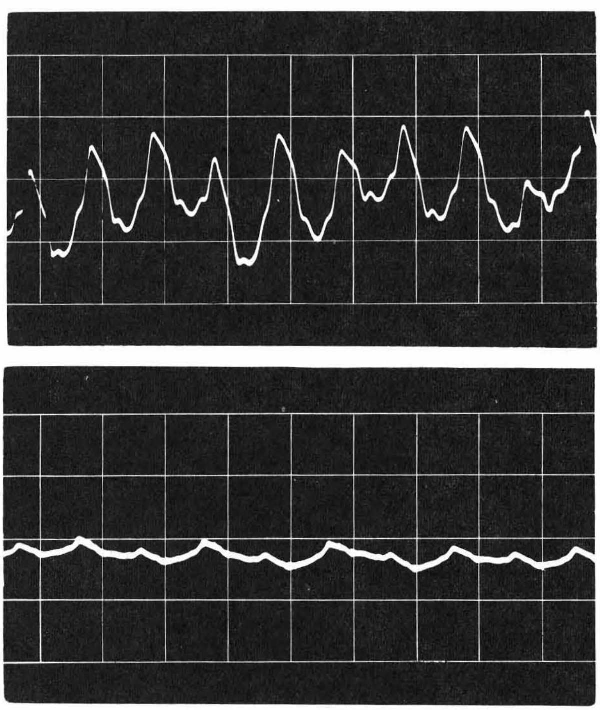

Fig. 3 - Operating Results. Top: RF ripple without stabilization (100 mV/div. - 20 ms/div.); bottom: RF ripple with stabilizing network (10 mV/div. - 20 ms/div.).

5. Concluding Remarks

The ripple reduction factor so far obtained is, in our opinion, satisfactory and in agreement with theoretical predictions. It is indeed one half the calculated value, but this discrepancy was foreseen and depends upon a precise choice made during the construction. In fact, since a larger ripple reduction was not really necessary, we limited the plate voltage of the tubes to a lower value than the calculated one. This was decided merely as a caution against possible breakdowns and oscillations being the apparatus a prototype.

Another effect of the lower plate voltage is the limited dynamic range of the system. As a consequence when the instantaneous ripple amplitude is greater than the nominal anticipated value of 1.4 %, the stabilizing system gets out of its dynamic range. This happens for just brief instants, when the cavity is not yet in stationary operating conditions (thermal or otherwise), and therefore one has frequent intervention of the trimming capacitors and movable tuning panels. In these conditions, and for time periods of the order of a few seconds, the ripple wave form shows some spikes, with a frequency equal to the fundamental frequency of the ripple signal (50 Hz).

The observed spike amplitude is about $1\cdot10^{-3}$ of the peak RF voltage and therefore for these spikes the reduction factor is around 15.

We expect that these spikes will be eliminated by an increase of the plate voltage and therefore by the consequent extension of the system dynamic range.

Since during the present tests nothing happened which would prevent a plate voltage increase, we intend to carry out this modification in the near future.

Reference

1) - G. Marinone, C. Pagani, M. Puglisi and G. Volpi (Presented at the 11th E.C.P.M. - Louvain), INFN/TC-74/9, 6/8/1974.

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DISCUSSION

K. ERDMAN: Why is this method superior to a direct modulation of the power amplifier tube?

C. PAGANI: In principle the two methods are almost equivalent. Nevertheless, in our case to use a conventional negative feed-back on the RF power amplifier was practically impossible or extremely expensive. In fact the generator -- a rather old broadcasting transmitter -- works in class C_2, contains only automatically biased amplifiers, and no modulation equipment is provided. The cost of our system was about 4'000 $.