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DEVELOPMENT OF THE RF ACCELERATING SYSTEM FOR THE GSI HEAVY ION SYNCHROTRON

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Summary

An extended program has been started to investigate critical components of the RF accelerating system for the planned GSI Heavy Ion Synchrotron. A ferrite test-cavity has been developed to measure the properties of ferrite rings under the final operating conditions. An HP 9835 A computer performs on-line control and evaluation of the measurements. The data of the 78 FXC 8C12 ferrite rings delivered for the prototype studies are given. The test-cavity has also been used to develop the closed loop amplitude and phase control circuits for the final accelerating cavities. The prototype accelerating station, comprising the cavity, the RF power system, and all control equipment is expected to come into operation before the end of 1981.

Introduction

During the last years various heavy ion synchrotron scenarios have been discussed at GSI to extend the end energy of the UNILAC accelerator from about 10 MeV/u into the several GeV/u region (1). In each alternative the accelerating frequency must be varied by the same factor of about 7.6 and can be moved into the range of about 1.0 to 7.6 MHz without serious problems. In each case a maximum of RF voltage has to be generated in the cavities. The data expected for the GSI cavities are given in Table 1. Between 4 and 12 cavities of this size will be needed in the machines discussed.

Frequency tuning range	(MHz)	1.00-7.60
Peak RF voltage per cavity	(KVp)	16
Peak RF power per cavity	(KWp)	40
Total length of the cavity	(mm)	2980
Ferrite material used	Philips	FXC8C12
Ferrite ring dimensions	(mm)	498x270x25
Number of ferrite rings		2x32
Mean RF induction in ferrite	(mTxMHz)	15
Mean RF power density	(W /cm3)	0.24
number of magnetic bias turns		6
Magnetic bias current	(A)	6-600

Table 1: Data of the GSI prototype accelerating cavity

The main difficulties in the design of the accelerating system arise from the ferrite material with which the cavities are tuned over the required frequency range. The development of the necessary measuring techniques and of a complete prototype accelerating station has already been started by GSI at a very early phase.

Investigation of different ferrite materials

The first cavities covering a frequency tuning ratio of 8 were built at Saclay/France, a short time before GSI started the discussion about heavy ion synchrotrons. All existing earlier cavities do not exceed a frequency ratio of 4. Measurements showed that the ferrites used at Saclay (Philips FXC 8C12) can be run at considerably higher RF levels as well. So, the GSI studies could be based for a great part on the Saclay experiences.

Nevertheless, about 10 different ferrite qualities from 4 manufacturers have been measured at GSI, all having remanent permeabilities μr of about 600 to 800 to allow tuning over the given range. When measured statically, that is at fixed frequencies, all useable materials revealed a strong Q-loss effect.

When a square RF pulse is applied to a ferrite-tuned cavity, the RF voltage and current fed to the cavity usually show the same square envelopes. When the voltage exceeds a certain level, about 2 to 20 milliseconds after the beginning of the RF pulse, either the voltage drops to a lower value, or the current jumps to a higher level, indicating that a sudden drop of the ferrite Q-value has occured. From this moment, stable operation seems no longer possible. The effect, known as "Q-loss effect", is little understood. Probably, it is caused by excessive non-linearities in the ferrite. As observed by (2), the level at which Q-loss occurs can be raised considerably by slight frequency modulation of the operating frequency. So, the Q-loss effect observed at a fixed frequency can disappear with the continuously growing frequency used in synchrotron operation.

In the ferrite samples tested the Q-loss effect appears only for medium DC bias fields. When the operating frequency of the cavity is changed by means of capacitors, the effect appears at another frequency but in the same DC bias range as before. The maximum RF flux-density reached without Q-loss was about BRFxF=15 mTxMHz, and was obtained with the Saclay ferrites. The design values for the prototype cavity given in Table 1 refer to FXC 8C12 and an RF level just below the onset of the Q-loss effect. One of the main aims of the prototype measurements is to find out if higher RF levels than those in Tab.1 can be run in the cavities as well.

Test-cavitiy for measurements on single ferrite rings

For the design of the cavities, the incremental permeability μ_Δ, the magnetic quality factor Q, and the product $\mu_\Delta Qf$ of the ferrite material must be known, all being functions of the frequency F, the DC bias field HDC, and the temperature T. As these data can vary considerably among ferrite rings of the same material, it is usual to measure or at least check each ferrite ring used. A cross-section of the ferrite test-cavity built for this task is shown in Fig.1. The principle of the measurements and more details are described in (3).

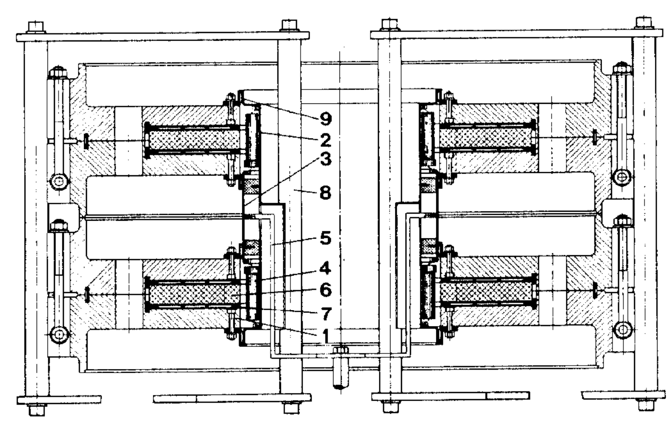

Fig.1: Cross section of the ferrite test-cavity
(1) Aluminum resonator body
(2) connection ground potential
(3) connection RF potential
(4) ceramic capacitors
(5) RF power input-lines
(6) ferrite ring
(7) cooling plates
(8) DC bias conductor
(9) spring contacts

In the SIS 100 synchrotron discussed at GSI, about 800 ferrite rings have to be measured. An HP 9835A tabletop computer and IEC-Bus controlled equipment have been

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installed and perform on-line control of the routine measurements (4). A BASIC program has been developed for this purpose. It raises the frequency from 1.0 to 8.0 MHz in increments of 0.5 MHz, tunes the test-cavity to resonance by means of the DC bias, and measures the ferrite parameters of interest for three RF amplitudes (BRFxF=5,10,15 mTxMHz). All is done within 15 minutes.

Ferrite material used in the prototype-cavity

In the second half of 1980, 78 FXC 8C12 ferrite rings were delivered. 70 rings have 25 mm thickness, 64 will be installed in the cavity, 6 are for reserve. The remaining 8 rings have 30 mm thickness and will be used to find out if the 25 mm rings can be replaced by 30 mm ones, without running into cooling-problems. With 30 mm instead of 25 mm rings, the costs of ferrites and cooling-plates might be reduced by nearly 20 %.

For the material a remanent permeability of μr=600, at F=1.0 MHz and BRFxF=15 mTxMHz, has been specified. The rather small μr value was chosen with the intention to minimize possible non-linear effects. The μ_ΔQF-product has been specified to 3000 MHz, possibly more, for the above flux-density and the whole frequency range.

All rings have been measured in the test-cavity as described above. The characteristic data of the ferrite material are presented in Fig. 2. At low DC bias, the RF magnetic field in the ferrite is in the order of the DC bias field applied. This seems to partly demagnetise the material. The μ_Δ-value measured at low bias is very sensitive to both the RF level used and to the maximum RF level applied before the measurement. The spread of the μ_Δ-values measured on the 78 rings is about ± 10%. The u_ΔQF- and the HDC-values measured at higher DC bias show a spread of only ± 5% for all rings measured (5).

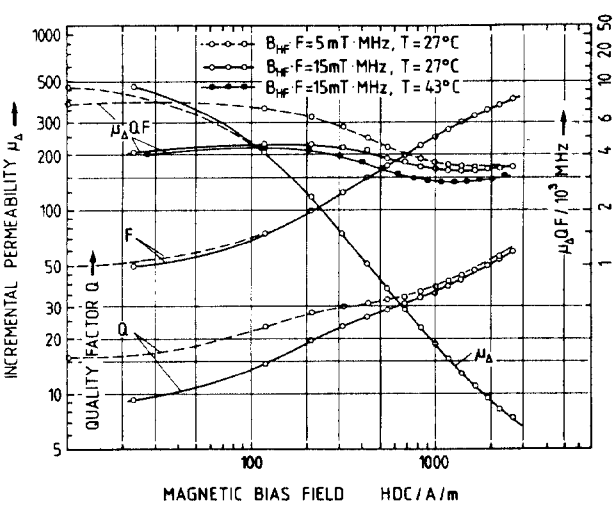

Fig.2: Data measured on FXC 8C12 rings (No.10/12)

The ferrite rings show the Q-loss effect at flux-densities of about 18 mTxMHz. First measurements with continously increased operating frequency were very promising. The Q-loss effect seems to disappear already at lower frequency tuning rates than needed in the GSI machines. Further studies have to be carried out to obtain precise and reliable results.

First tests with the 30 mm rings have also been successful. A flux-density of 15 mTxMHz has been run over more than 20 minutes in CW operation which means that about two times more power was dissipated in the rings. No problems have been observed.

Amplitude and phase control of the prototype station

The SIS accelerating cavities need precise amplitude, frequency and phase control. These controls are developed in parallel with the cavity prototype program. In a first step amplitude and phase control for the test cavity were built (Fig. 3).

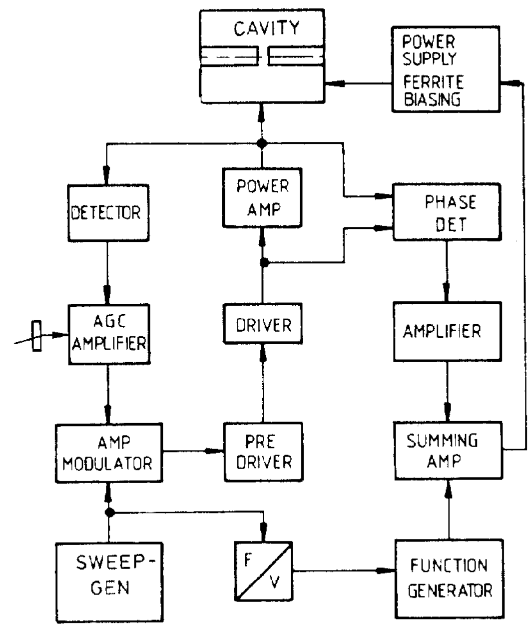

Fig.3 Block diagram of the amplitude and phase control

The amplitude control system makes use of a linear peak-type rectifier connected to the cavity gap by means of a broad band capacitive voltage divider in order to measure the amplitude independently of frequency. The rectified RF signal is compared to the reference signal in an AGC amplifier. The error signal is amplified, and adjusted to the frequency response of the regulation loop.

In the amplitude module - a balanced mixer followed by a broadband-amplifier-chip - the amplitude of the RF-signal is controlled.

The sweep generator also delivers the RF signal for the frequency and phase control loop. This signal passes via a buffer amplifier to a TTL 8:1 divider and a frequency to voltage converter where it is measured. This analog signal feeds a 5 step diode function generator that delivers the reference signal for the ferrite bias power supply. Without control loop only coarse control of the ferrite bias current is possible. For precise control the phase difference between the grid of the power amplifier and the gap has to be controlled to 180°.

The phase detector, a flip-flop set and reset by the two input signals was built using fast emitter-coupled logic (MECC 10000). Two electronically controlled variable low-pass filters at its inputs prevent disturbations due to harmonics. The signal from the phase detector is used to correct the reference signal of the diode function generator.

The amplitude and phase control loops need further improvement for the final synchrotron accelerating cavities where a higher precision will be required and cable lengths of more than 100 m have to be taken into account.

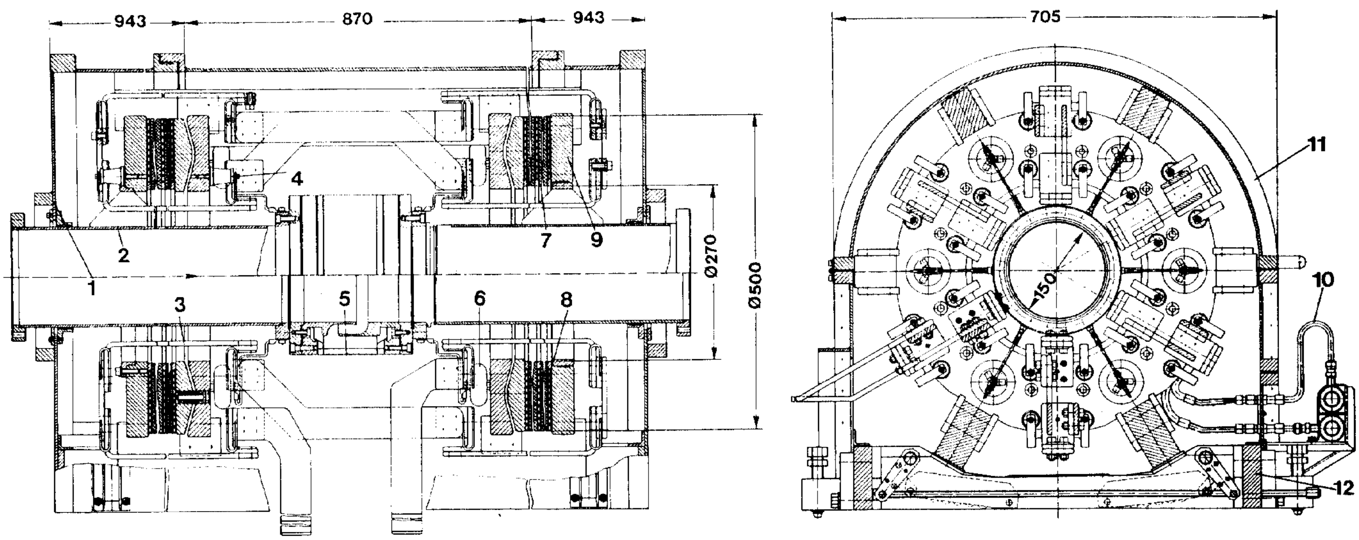

Fig.4: Cross-section of the prototype accelerating cavity built at GSI
(1) RF-tight enclosure of the cavity, (2) inner conductor, (3) DC magnetic bias winding, (4) ceramic insulator, (5) accelerating gap, (6) ceramic tuning capacitor, (7) ferrite ring, (8) water-cooling plate, (9) aluminum end plate.

Design studies for the frequency control system for the SIS and development of other critical components have begun.

Power system for the prototype accelerating station

The cavity will be mounted on a base unit with the dimensions 2.80 m x 1.10 m x 1.10 m. The base unit comprises three RF-tight compartments. The larger compartment in the middle serves to house the RF power amplifier installed in an easy-to-roll-out box. The two compartments left and right are used for distribution and control of the cooling-water for the cavity and the power stage, electrical connections etc. If necessary, additional filtering of RF from the bias lines can be installed here too.

The RF power stage is based on an RS 2052 tetrode able to provide 120 kW of RF power, which means that about three times the value given in Table 1 is available to test the cavity at higher levels. The driver stage, delivering about 2 kW, is also installed in the power amplifier unit. For the final cavities, the driver stage will be taken out of the cavity base unit, most probably.

The prototype accelerating cavity

The cross-section of the cavity is shown in Fig.4. It combines two quarterwave-resonator sections operated in push-pull mode upon a common accelerating gap. Each quarterwave-section consists of a stack of 32 ferrite rings with inserted cooling-plates. Ferrite rings and cooling-plates are pressed together between two rigid aluminum end-plates. Six figure-of-eight heavy current windings are distributed circumferrentially around the two ferrite stacks to produce the DC bias field. The cross-section of the windings is large enough to reduce their number to 4, if needed. The remaining two could then be used for fine tuning, or simply omitted. The windings are supported on 35 mm ceramic insulators; the gap between the windings and other parts of the cavity is at least 22 mm.

The whole cavity is enclosed in an RF-tight cover. All joints in the cover are bridged by spring contacts and the top covers can be easily opened. The weight of the cavity will be more than 2 tons. Most Probably, there will be no crane in the sychrotron tunnel, but with a mechanism installed in the ground frame the cavity can be lifted on four roller-tracks and rolled from the base unit onto a transport carriage in front. The mechanical construction of the cavity is rigid enough that transportion in a pre-adjusted state is possible.

It is expected that the prototype-cavity will be under RF power before the end of 1981.

References

(1) K. Blasche et al., SIS - A Two Stage Synchrotron Facility for Heavy Ions, Proceedings of the 1981 Washington Particle Accelerators Conference

(2) James E. Griffin, Private Communication, Aug. 1977, Fermi Nat. Accelerator Laboratory

(3) K. Kaspar, G. Stubenrauch, Test-Cavity for Single SIS 100 Ferrite Rings GSI, Annual Report 1979

(4) K. Kaspar, J. Ahrens, On-Line Control of Ferrite Measurements Performed by a Desktop Computer, GSI, Annual Report 1980

(5) K. Kaspar, M. Emmerling, A. Gasper, Measurements on the Ferrite Rings for the SIS Prototype Cavity GSI, Annual Report 1980