RESULTS OF MEASUREMENTS ON A 50 MHz CAVITY DRIVEN BY A 250 kW POWER AMPLIFIER AND THE PRESENT STATUS OF THE RF SYSTEM OF THE SIN CYCLOTRON

P. Lanz
SIN-Schweizerisches Institut für Nuklearforschung
(Swiss Institute for Nuclear Research) Zürich,
Switzerland

ABSTRACT

The latest developments on the rf system of the SIN ring cyclotron will be described. With a power input of 250 kW in one accelerating cavity (Q_0=32 000) more than 700 kV peak voltage was measured. At a cavity voltage of 500 kV the phase and amplitude stability are 0,4° and 1 in 10^3 respectively. The following subjects are discussed in detail:

- Automatic tuning system
- Multipactoring
- X-rays at high cavity voltage
- Development of a flat-topping cavity
- The future rf test program

RF SYSTEMS OF THE SIN ACCELERATOR

The SIN 2-stage accelerator has three different rf systems (Fig. 1).

The first stage which is designed and constructed by Philips uses two of them:

- the first one, a self-excited rf system for low energy operation, is tunable in the frequency range 4,7-17 MHz and operates with 70 kV dee voltage
- the second one is a M.O.P.A. system for operation as an injector.

For adjustment of the operating frequency to 50,7 MHz (3. harm. of the orbital frequency) a shorting plate is pushed in between the liner and dee stem at a distance of approximately $\lambda/4$ from the gap. The required dee voltage is 90 kV. The corresponding power is delivered by a 250 kW power amplifier.

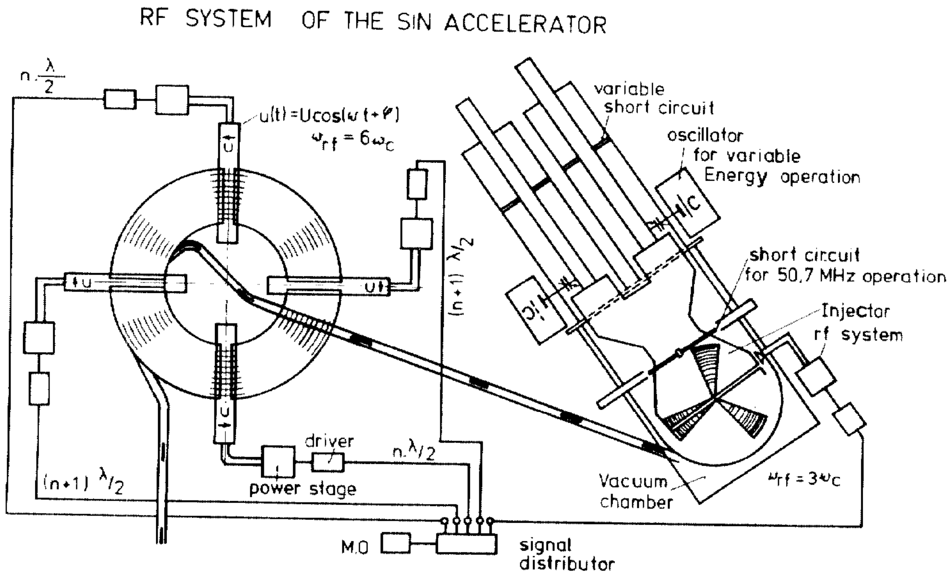
RF SYSTEM OF THE SIN ACCELERATOR
n.λ/2
u(t) = Ucos(ωt+φ)
ωrf = 6ωc
variable
short circuit
oscillator
for variable
Energy operation
short circuit
for 50,7 MHz operation
Injector
rf system
(n+1) λ/2
driver
n.λ/2
power stage
(n+1) λ/2
Vacuum
chamber
ωrf = 3ωc
M.O
signal
distributor

Fig. 1

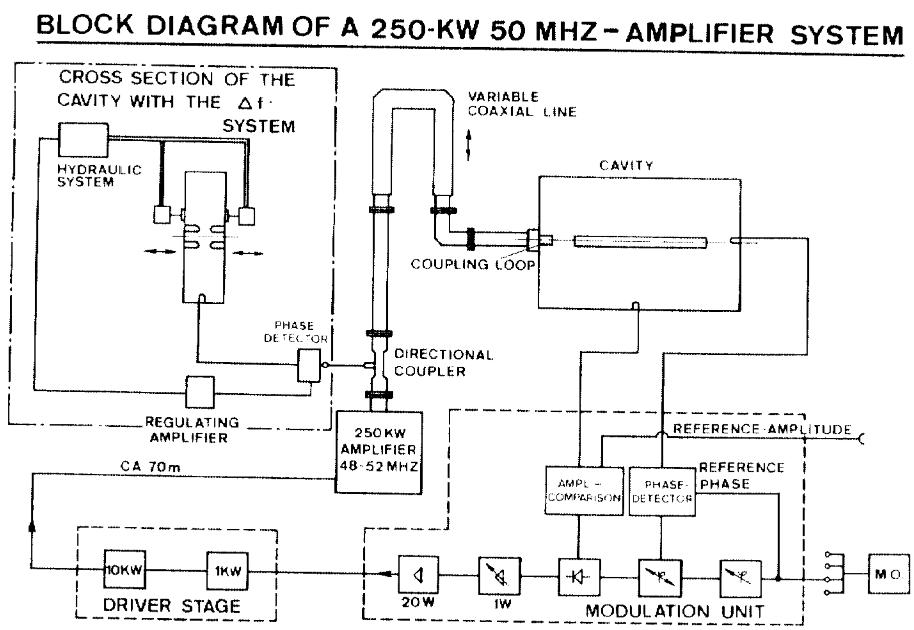
BLOCK DIAGRAM OF A 250-KW 50 MHZ-AMPLIFIER SYSTEM
CROSS SECTION OF THE
CAVITY WITH THE Δf-
SYSTEM
HYDRAULIC
SYSTEM
PHASE
DETECTOR
REGULATING
AMPLIFIER
VARIABLE
COAXIAL LINE
CAVITY
COUPLING LOOP
DIRECTIONAL
COUPLER
250KW
AMPLIFIER
48-52 MHZ
CA 70m
REFERENCE AMPLITUDE
REFERENCE
PHASE
AMPL -
COMPARISON
PHASE-
DETECTOR
10KW
1KW
DRIVER STAGE
20W
1W
MODULATION UNIT
M.O.

Fig. 2

In the ring cyclotron an rf system which was developed by SIN in co-operation with industry is used. Protons are accelerated in four cavities which are tuned to 50.7 MHz (6. harm. of the orbital frequency). All cavities are driven by the same master oscillator through four independent power-amplifier chains, each capable of delivering 250 kW rf power. The operating voltage for each cavity will be 600 kV corresponding to an energy increase of approximately 2 MeV per revolution. The desired voltage and phase stability are 10^{-3} and 1^{0} respectively.

Fig. 2 shows the block diagram of one of the four identical amplifier systems.

Apart from the amplitude and phase stabilizing units a slow hydraulic system is used for automatic resonance frequency control. This system prevents drift from the frequency of the M.O. due to temperature and air pressure variations.

Fig. 3 shows the block diagram of the amplitude and phase stabilizers. In the measuring unit error signals for the phase and amplitude regulators are generated and amplified. Each of these signals is further amplified by a P (proportinal) and an I (integral) amplifier. In both the amplitude and phase channels the output signals of these amplifiers are added together and fed to limiting amplifiers. The outputs of the limiting amplifiers control the phase and amplitude modulators in the rf unit. In the phase and amplitude stabilizer the possibility of adjustment of various parameters, indicating instruments and check points as well as space for correction networks (which may eventually be needed in order to shape the frequency response of the system) is available. In order to measure the response of the phase and amplitude stabilizers step-function disturbances were introduced in the closed loop regulating systems. At 500 kV cavity voltage an amplitude step of 6.9% leads to a resultant change in the cavity voltage of 1 in 10^{3} after 20 μsec while a 9.1^{0} phase disturbance results in 0.4^{0} phase shift between the M.O. and cavity voltage after 20 μsec.

Further measurements were carried out at 600 kV. By means of correcting networks, the frequency response and stability conditions of the stabilizer will be improved in the future.[1]

AUTOMATIC TUNING SYSTEM

During operation the cavity is automatically tuned to a fixed frequency by means of a control signal from a

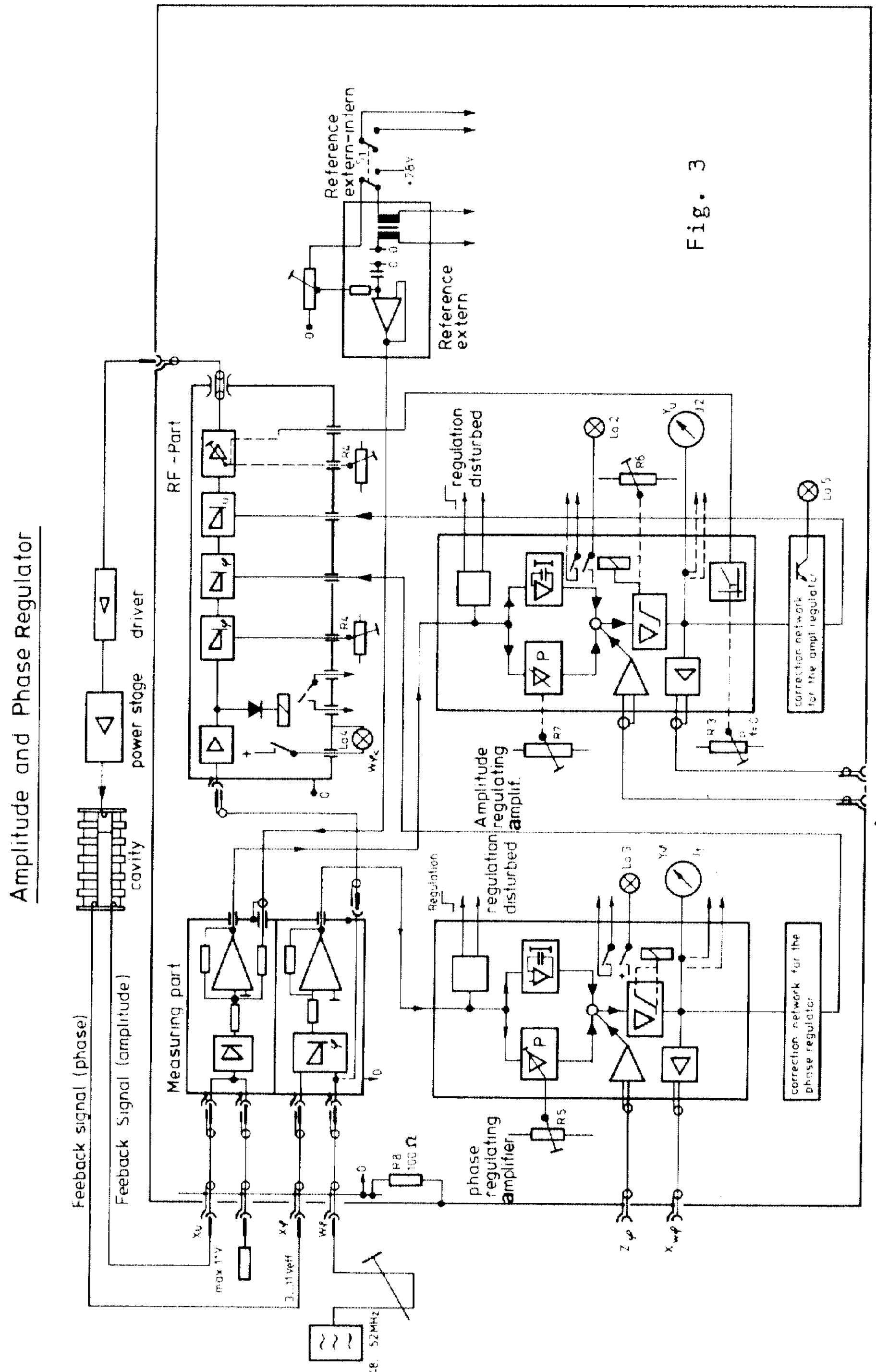
Amplitude and Phase Regulator
cavity
power stage
driver
Feeback signal (phase)
Feeback Signal (amplitude)
Measuring part
RF - Part
Reference extern
Reference extern-intern
regulation disturbed
Amplitude regulating amplif.
phase regulating amplifier
Regulation
regulation disturbed
correction network for the ampl regulator
correction network for the phase regulator
R8 100 Ω
R5
R7
R3
R6
R4
La 2
La 3
La 5
La 4
max 1 V
52 MHz

Fig. 3

phase detector. The phase detector measures the phase between the incident wave and the cavity voltage (Fig. 4).

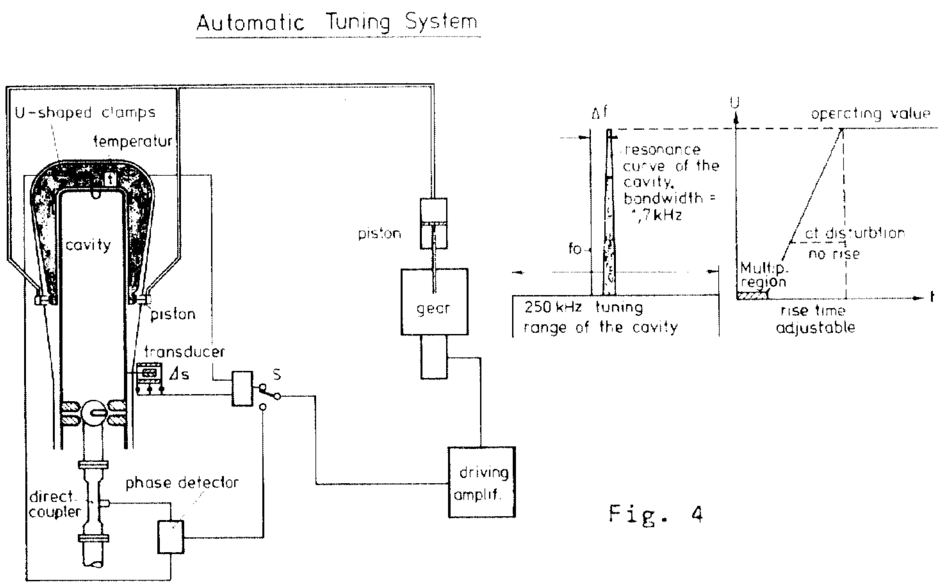

Fig. 4

As soon as the rf is switched off (due to a disturbance for instance) this signal is no longer available and special precautions must be taken because the resonance frequency of the cavity changes very fast when the temperature drops. Switch-on is no longer possible after 1 sec of interruption because too much power is reflected due to the detuning of the cavity which has a bandwith of only 1,7 kHz.

With the rf power turned off the hydraulic tuning system is controlled by two other parameters i. e. the temperature change Δt of the cavity walls and the expansion and compression Δs of the cavity which is measured by means of a transducer. With these parameters the resonance frequency is kept close to the frequency of the M.O. thereby permitting automatic switch-on at low power levels after which the control of the hydraulic tuning system is taken over by the phase detector. As soon as the cavity is tuned to resonance the voltage is increased to a predetermined value. The voltage increase is stopped as soon as a disturbance appears. With this control system it is possible to pass automatically through the multipactoring region.[2]

MULTIPACTORING

When energy is fed into a new cavity for the first time multipactoring exists and must be overcome.

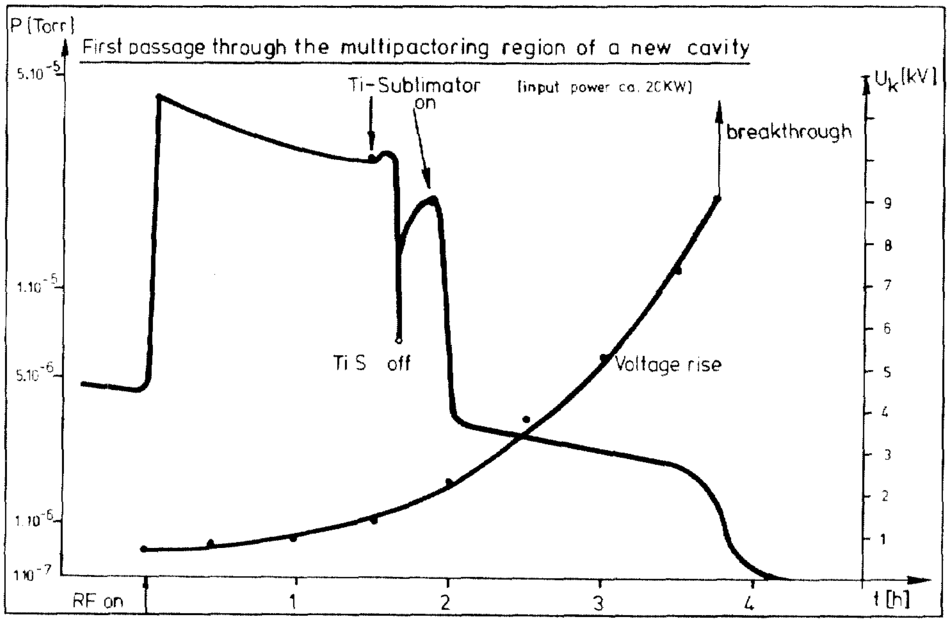

Fig. 5

Fig. 5 shows the voltage increase and pressure variation in the cavity against time with a constant input power of approximately 20 kW which is the maximum allowable reflected power. After about 4 hours the cavity voltage rises suddenly.

The further increase in the cavity voltage is accompanied by an outgassing process Fig. 6.

The cavity voltage is at first adjusted to a value just below the voltage at which switch-off due to reflection occurs. The pressure in the cavity rises slowly due to outgassing of the inside surfaces which is a consequence of the increasing cavity temperature. At a certain pressure a sudden increase in the reflected power from the cavity occurs and the rf is automatically switched off.

Thereafter multipactoring in the cavity starts again and is maintained for as long as possible in order to clean the cavity surfaces.

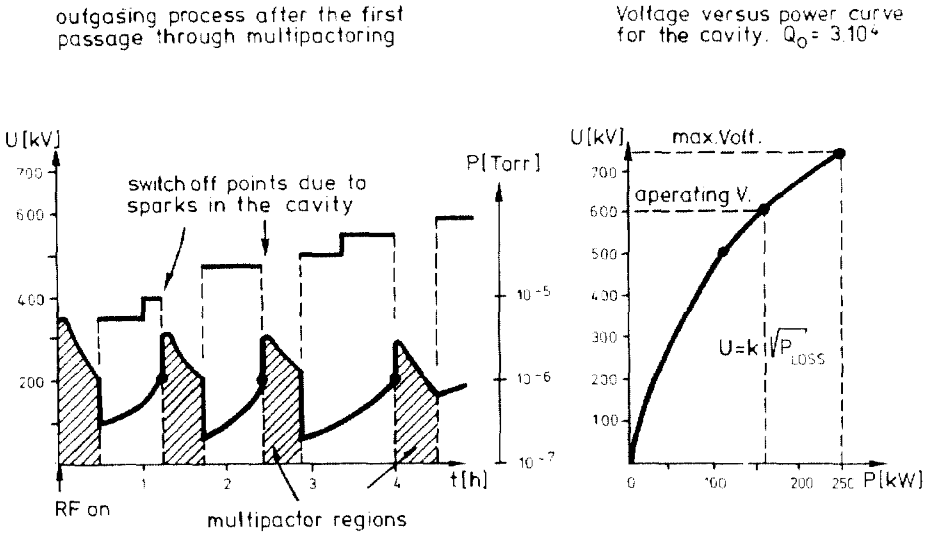

Fig. 6

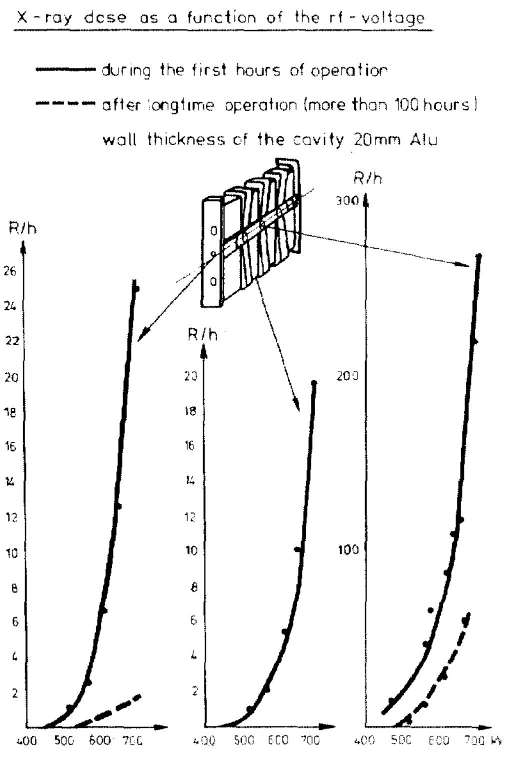

Fig. 7

This cycle, multipactoring - voltage increase - multipactoring is repeated as described above until the total power of 250 kW (730 kV cavity voltage) can be fed into the cavity. Operation at a high power level for a long time decreases the possibility of voltage breakdown in the cavity further. Also the influence of multipactoring becomes smaller and smaller until it is barely noticable after a long time.

X-RAYS

Fig. 7 shows the results of measurements of the x-ray intensity at three different positions around the cavity.

It is to be noted that the intensity decreases with the time that rf was switched on. It appears as if the x-ray intensity depends on the degree of cleanliness of the cavity surfaces.

FLAT-TOPPING SYSTEM

For a high extraction efficiency a larger orbit separation at the extraction radius as well as equal energy increments per revolution for all particels are desirable. Except for the large energy gain per revolution which is obtained with the 4 cavities a flat-topping system with which the second requirement is fulfilled is planned for the future. The flat-topping system will probably consist of a fifth cavity operating at the 3rd harmonic (150 MHz). Fig. 8 shows the basic system and the required voltage and phase stability.

Flat-Topping System

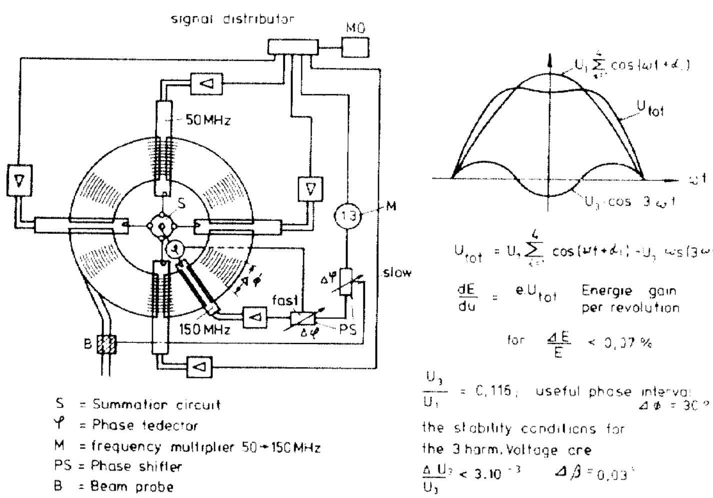

Fig. 8

For experimental study of the flat-topping system a 1:1 model of a cavity was built and coupled to a 3 kW, 150 MHz amplifier. In the future a fast phase stabilizer will be built and tested. In the meantime the most critical components of such a phase stabilizer, i. e. the phase detector, the summation circuit an the connecting cables were studied theoretically and experimentally. This study is not completed yet.

The design of a 150 MHz cavity will be very similar to that of the 50 MHz cavities. The required 380 kV third harmonic voltage can be obtained with a power input of 70 kW in the fifth cavity which has a Q value of approximately 25 000.[3,4]

In Fig. 9 the further rf program until completion of the ring (1 July 73) is shown.

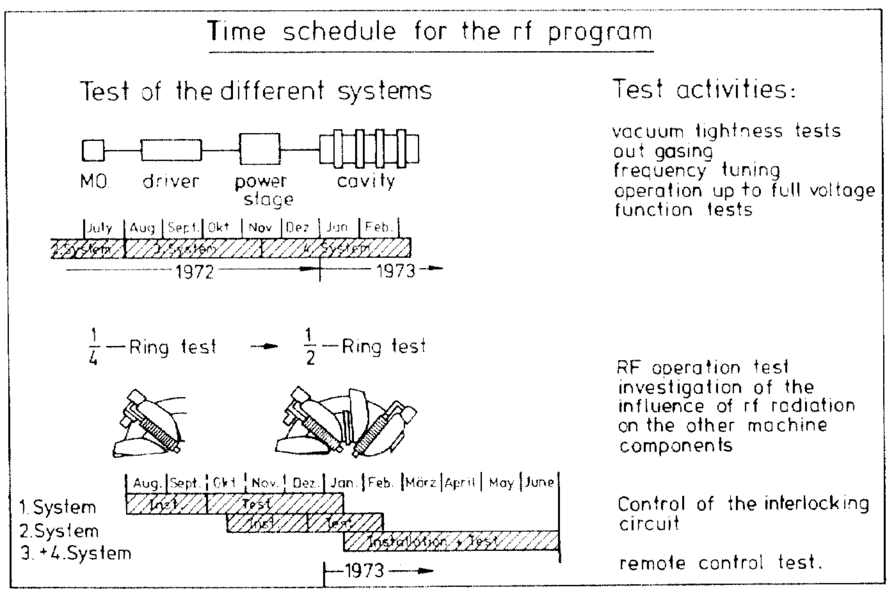

Fig. 9

REFERENCES

1. R. Häussler, SIN Tätigkeitsbericht 1971
2. M. Märki, SIN Tätigkeitsbericht 1971
3. B. Bischof, A.H. Botha, SIN Tätigkeitsbericht 1971
4. W. Joho, Tolerances for the SIN ring cyclotron SIN TM-11-06 (1968)