THE REALISATION OF THE R.F. SYSTEM FOR THE 2 MeV ELECTRONS STORAGE RING

I. Introduction

The aim of the R.F. system is to force the electrons injected by the Van de Graaff generator into a bucket and to accelerate them toward the outer side of the vacuum chamber. One resonant cavity is foreseen for this task. Two different types of cycles have to be distinguished during the stacking process:

a) Small cycle. We assume to start the cycle when the vacuum chamber is empty of electrons. As soon as the Van de Graaff injects a charge of electrons of 2 MeV kinetic energy, a voltage at a fixed frequency $f'_0$ - nominal value $(24 - 1 \text{ o/o})$ Me - has to be available at the cavity in order to build up a stationary bucket. The trapping efficiency is optimized if the cavity voltage starts from a very low value (of the order of $1/10$ V) and reaches, in about one millisecond, the final value $V'_0$ (order of 10 -15 V) following a quasi exponential law. The stationary bucket has to be changed into a moving bucket by decreasing the frequency following a parabolic law with time. The electrons can then be accelerated by decreasing the frequency linearly. At the value $f'_f = f'_0 \simeq 1 \text{ o/o } f'_0$, the voltage $V'_0$ at the cavity has to be dropped suddenly in order to avoid the electrons hitting the outer wall of the vacuum chamber. The frequency and amplitude programmes during a small cycle are shown in fig. 1. It is required that the entire time interval $t_1$ to $t_5$ can be changed easily.

b) Big cycle. At the time $t_7$ the length of which is about 20 msec the second shot of the Van de Graaff occurs. In order to stack the electrons at a slightly lower energy than in the previous cycle, the voltage at the cavity has to drop at a time shorter than $t_5\text{max}$, thus at a frequency slightly higher than $f_{\text{max}}$. After a stack, the R.F. at the cavity is present only in the time interval $t_5$ to $t_1\text{min}$. The stacking process is then accomplished and the stacked beam has to be destroyed before a new big cycle be started again.
Since the Van de Graaff voltage is supposed to be stable to $10^{-5}$, the initial frequency $f_0$ must be reproducible within the same order of magnitude. A good reproducibility is required throughout. A great flexibility of the machine and an easy access of the control is also essential.

2. Description of the block diagram of the programmes generator machine

The amplitude and frequency programme being strictly correlated, only one machine is foreseen to deliver both amplitude and frequency programme. The block diagram is shown in fig. 3. The heart of the machine is the FFG. The purpose of the FFG is to generate a waveform (fig. 4) to frequency modulate the VO (fig. 5 and fig. 1 a). The waveform of fig. 4 is initiated by a pulse coming from the timer T, which in turn is actuated by a pulse coming from the Van de Graaff indicating that the 2 MeV electrons have been injected into the storage ring. Since the FFG consists mainly in an integrator which is reset periodically to zero in synchronism with the line, a stop pulse is delivered (fig. 1 e) from the integrating condenser which is suddenly discharged. The stop pulse resets the whole machine. The Van de Graaff can now inject again. If for some reason, the injection does not occur in an interval of 1 ms, a trigger is generated internally in the FFG which puts it again into operation and prevents the timer to be operated from excessively late Van de Graaff pulse. Thus, even in the absence of a Van de Graaff pulse, the part of the machine enclosed into the dashed lines is continuously operating at 50 Hz repetition frequency. Such a way of operation is due to technological reasons as will be discussed later.

The PG and FM boxes are foreseen for monitoring purposes. The output of VO is sent to the amplifier VA which can be divided into three parts (fig. 6). The first part of VA is a logarithmic amplifier which generates the exponential shape of fig. 1 b, the second part of VA consists of a sharp cut-off pentode for cutting abruptly the R.F. voltage at the end of each small cycle. A third part of VA consists of a power amplifier and a feedback control in order to keep the voltage at the cavity independent of
the actual frequency. The sharp cut-off pentode in the second part of VA is driven by a positive gate starting at the time $t_1$ and terminating at the time $t_2$. This gate comes from the gate generator GG which is programmed in order to accomplish the operations required in the big cycle.

3. Description of the various components

3a. The timer $T$

During a small cycle an accurate sequence of pulses is required. The timer which will furnish this sequence of pulses will consist of two continuous variable delay units (double pulse generator available at the PS electronic workshop) which can be set up with a precision of 3 o/o with a jitter of 1 o/o plus an indefinite series (8 in the actual version of the timer) of digital delay units which can be set with a precision better than 1 μsec with a jitter of $10^{-4}$. The continuous variable delay units are foreseen for special experiments, whereas the digital delay units are preferred for their clearness and ease of operation. As fig. 6 shows, the stop pulse coming from the FFG is firstly delayed by an amount of the order of 100 μsec (in order to make sure that the machine is well at rest) and is sent to the Van de Graaff, to permit the injection. If the Van de Graaff injects, a pulse comes into the timer (fig. 1 c). In the absence of the Van de Graaff and for testing purposes, a 1 msec delayed pulse simulates the operation of the Van de Graaff. The Van de Graaff pulse, or the one coming from the Van de Graaff simulator, opens a gate, which will be closed about 20 msec later by the FFG stop trigger. When the gate opens, a 100 Kc ringing oscillator starts to oscillate which, through a pulse former, energizes a counter. The ringing oscillator is enclosed in a thermostatic box, therefore its stability reaches some $10^{-4}$. The counter consists of three decades plus a binary stage. It follows that its number capacity is 2000. Since the period of the oscillator pulses is 10 μsec, a maximum delay of 20,000 μsec is obtained in steps of 10 μsec. A continuous variable delay unit constructed by Pflumm (PS) allows to interpolate between each 10 μsec step, thus allowing the operator to obtain all values of delay between
1 and 20,000 μsec. The decades have been designed by Affaticati (DD).
They are of unconventional type and permit to select a number with a delay
ranging from 0.1 to 0.3 μsec, thus quite independent of the selected number.

3b. Description of the FPG (fig. 7)

The timer pulse coming at the time $t_3$ (fig. 1 d) opens a gate which
will be successively closed at the time $t_5$ by the FPG stop pulse. In the
absence of the Van de Graaff pulse, perhaps due to misfunctioning of the
Van de Graaff itself or to alignment purposes, the gate is opened 5 msec
after the FPG stop pulse. The gate is amplified and is sent to the grid
of a cathode follower which works as a switch. When the grid is at zero
volt, the cathode of $V_1$ is also at zero volt, due to the presence of the
$D_1$ diode. When the grid drops suddenly to -200 V, the voltage at the con-
denser $C_1$ falls exponentially toward -450 V with a time constant depending
on the resistance $R_1$ and on the setting of the potentiometer $P_1$. The
diode $D_2$ prevents the cathode voltage to fall below -150 V. Therefore one
obtains, when the gate is open, a trapezoidal waveform at the cathode of $V_1$.
The waveform is successively integrated by the condenser $C_2$ and the $R_2$
and $P_2$ resistances. Resistance $R_3$ and potentiometer $P_3$ are foreseen
to correct the nonlinearity in the characteristic of the V0 oscillator.
The $C_2$ condenser is periodically discharged by the $S_1$, $S_2$ mercury
switches. The charge of $C_2$, passing through $R_0$ produces the FPG stop
pulse. The mercury switches are operated by the mains, through a pulse
shaper PS and pentode tubes $V_2$ and $V_3$. The switch $S_2$ is normally closed
and opens $\Delta t$ μsec after switch $S_1$ closes. Therefore the mechanical short
circuit occurs as indicated in fig. 1 f. The need for the mercury switches
arises from the necessity to discharge exactly to zero the condenser $C_2$
(whereas this is not possible for the condenser $C_1$) in order to have a good
reproducibility of the initial part (between 0 and $t_3$) of the waveform d of
fig. 1. Thus the random variations of the initial frequency—nominal value
(24 Mc - 1 o/o) — are due only to the oscillator V0 and do not depend on
the driving voltage.
3c. The variable oscillator VO

The block diagram is represented in fig. 8. It consists of a biased-diodo oscillator constructed by Bricchi, (VO1), which can oscillate between 20 and 30 Mc, depending on the bias. If enclosed in a thermostatic box, the long term stability is better than $10^{-4}$. Due to the fact that the oscillator has to deliver the initial frequency (24 Mc - 1 o/o) when the output of the FG is exactly zero volt, a reference voltage is necessary for the proper bias of the diode. This can be obtained with temperature controlled mercury cells.

By suitable modulation of this reference voltage it becomes eventually possible to obtain a better matching between initial frequency and Van de Graaff voltage. The output of the DFG is made to drive VO1 between 30 and 25 Mc. To increase the long term stability, the output frequency of VO1 is divided 8 times by VO3 and then added to the output of a X-tal controlled oscillator. It is therefore possible to reach the long term stability of $10^{-5}$ at 24 Mc with a frequency sweep of 2 o/o. Since VO1 is not exactly linear over the whole range 30-25 Mc, it can be expected that the output of VO is also nonlinear. It is therefore necessary to monitor the output frequency in order to correct the nonlinearity with the aid of the potentiometer $P_3$ (fig. 7). This is obtained with the frequency discriminator FM (fig. 3). Moreover, in order to know the instant when the output frequency of VO reaches a certain value, the output of VO3 is mixed in FG (fig. 3) with the output of a Rhode and Schwarz oscillator. A pulse is delivered when the two frequencies are equal.

3d. Variable gain amplifier VA and cavity (fig. 9)

The output of the VO enters the first stage of the VA. This stage consists of an EP41 tube, the output of which depends well logarithmically on the bias of the first grid and quite linearly on the voltage of the screen grid. The second stage is an EL30F sharp cut-off pentode and the final stage is a 300 Watt radial beam tetrode. The plate is connected through a $\lambda/2$ 120 Ohm cable to the reentrant type accelerating cavity.
Some resistances inserted between the lips keep the $Q$ down to about 50, whereas a capacity of about 1500 pF, inserted at the same place, lower the characteristic impedance

$$Z'_n = \sqrt{\frac{L}{C}}$$

to 5 Ohm, thus allowing a great reduction of the cavity dimensions, at the expenses of the dissipated power. The voltage at the cavity gap is rectified and drives the screen grid of stage 1 through a saturating amplifier. It is possible, by this way to obtain a flat response when the R.F. cavity voltage is higher than a preselected $V_c$ voltage. The R.F. power available with the beam tetrode is enough to meet all practical requirements.

3e. The amplitude function generator

Suppose in fig. 9 the transistor is non conducting. Then the well known formula for the gain of positive feedback amplifier

$$\frac{V_{out}}{V_{in}} = \frac{A}{1 - \beta A}$$

gives

$$\frac{V_{out}}{V_{in}} = \frac{A(s + p)}{s - (A - 1)p}$$

where

$$s = \text{complex frequency} \quad f = \frac{RR}{R_l + R_o} \quad C$$

If $A < 1$ the amplifier is stable.

When the transistor is conducting, both input and output will be zero.

When the transistor opens, the output will tend toward the voltage

$$A \frac{V}{R + R_o}$$

P3/2754
with time constant

\[ \tau = \frac{1}{(1 - A)p} \]

If this asymptotic voltage is higher than the saturating voltage \( V_s \), the output waveform will be as in fig. 10 b.

When \( A = 1 \), the amplifier becomes an integrator and the output looks like fig. 10 c.

When \( A > 1 \), the output will grow exponentially as \( e^{(A - 1)pt} \) until the saturating voltage \( V_s \) is reached. (fig. 10 a).

The output of the AFG bias is the control grid of the first stage of VA, thus modulating the amplitude of the RF voltage of the cavity from near zero to \( V_c \).

3f. The gate generator

Due to the logarithmic characteristic of the control grid of the EF41 tube, it appears necessary to make use of the second stage of VA in order to cut abruptly the RF voltage. A gate can drive the E186F tube on-off. This gate is also necessary when a small stop (S) on the R.F. voltage has to be produced in order to investigate the trapping process. As shown in fig. 11 and 12, the GG consists of a multivibrator which is brought into operation by a timer trigger occurring at time \( t_1 \) (fig. 1 b) and is set at rest by the HFG stop trigger. The basic period of the multivibrator is 100 \( \mu \)sec, but means are provided to multiply the period by a factor 1, 2, 3, \( \ldots \) up to 31. The pulses coming from the multivibrator are counted by a binary counter (the "A" counter). When the configuration of the "A" counter is equal to the configuration of a second reference counter (the "B" counter) a flip-flop is closed, which was previously opened by the timer trigger at time \( t_1 \). The output of the flip-flop is the R.F. gate. At the beginning of each block cycle the "B" counter is set at the "maximum number" \( n_{\text{max}} \), i.e., the length of the R.F. gate is \( p n_{\text{max}} \), \( p \) being the period of the multivibrator. The following HFG stop trigger sets to zero the "A" counter and sets the "B" counter to \( n_{\text{max}} - 1 \); the R.F. gate will therefore be
(n_{\text{max}} - 1) \mu\text{sec long. Each successive stop pulse scales by one the "B" counter. When the "minimum number" } n_{\text{min}} \text{ is reached the big cycle is accomplished and the whole machine stops. The big cycle will therefore consist of } n_{\text{max}} - n_{\text{min}} \text{ small cycles. Means are provided in order to stop the "B" counter in his "minimum number" position in order to observe the equal energy-multiple stack effects. This can be obtained when stopping the input of the "B" counter by means of a gate actuated by a third counter, the "C" counter. The number capacity of the "C" counter is 16, therefore the effect of 1, 2, 3, ... 16 stack at the same energy can be observed. More details are shown in fig. 12. It is also possible to let the "B" counter count in the forward direction, thus starting the big cycle with a gate } n_{\text{min}} \cdot p \mu\text{sec long and increase successively up to } n_{\text{max}} \cdot p \mu\text{sec.}

4. Status of work

In July 1961 the machine works without GG and Timer. The former has been constructed and little work is required for the adaptation to VA, the latter requires still some wiring work.

5. Collaboration

The machine was designed to meet the specification outlined by D. A. Swenson. The work was approximately executed as follows:

T - S. Hansen, J. Leroux, R. Nettleton
FPG - S. Hansen, M. Zanada
VO, PG, FM - S. Hansen
C, AFG, GG - M. Zanada

The help of G. Affaticati in the design of T and GG was considerable.
S. Hansen is responsible for the general set-up.

pd A. Susini

Distribution:
AR division and Library.
References:

D. A. Swenson:  PS/Int/AR/60-25, August 31st, 1960
PS/1641, June 27th, 1960
Fig. 1. TIMING CYCLE.
Fig. 2. RF GATE.
**Symbols**

- **T**: Timer
- **FFG**:Freq. funct. gen.
- **VO**: Variab. freg. gen.
- **VA**: Variab. amp.
- **C**: Cavity
- **GG**: Gate gen.
- **AFG**: Amplif. fun. gen.
- **PG**: Peep gen.
- **FM**: Freq. meter
- **V.d.G.**: Van de Graaf gen.

**Thick trace**: signal PATH.
**1, 2, 3 etc**: Trigger number.

**Fig. 3.**

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**Table:**

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**CERN ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE - GENÈVE**
fig. 4

fig. 5
STOP PULSE FROM F.F.G.

Delay \( \Delta t \)

TO THE V.d.G. preparing trigger

Delay 1m sec

FROM THE V.d.G.

V.d.G. SIMULATOR

OR

var. continuous delay
1-20000 \( \mu s \)

var. continuous delay
1-20000 \( \mu s \)

stop

FF

5\( \mu \)s

5\( \mu \)s

PF

THERMOSTATIC BOX

ringing oscill. 100 kHz

FF 3\(^{rd}\) decade 2\(^{nd}\) decade 1\(^{st}\) decade

0.10 msec 0.1-9.9 msec 0.1, 100-900 \( \mu s \) 0.1, 10-90 \( \mu s \)

AND

continuous variable delay
1-10 \( \mu s \)

\( \Lambda \)

\( \Lambda \)

Fig. 6. MASTER TRIGGER.
Fig. 7. F.F.G. BLOCK DIAGRAM.
**Fig. 9. AMPLITUDE GENERATOR BLOCK DIAGRAM.**

**Fig. 10. A.G. WAVEFORM.**
Fig 11 GATE GENERATOR BLOCK DIAGRAM.
PROVISIONAL
GATE GENERATOR
BLOCK DIAGRAM