THE RF SCANNING SYSTEM FOR THE 2 MeV ELECTRON STORAGE RING

1. Introduction

Among the experiments that can be carried out with the 2 MeV Electron Storage Ring (hereafter called CESAR) we find the interesting problem of how to obtain information about the phase-space density of the particles in the stack as a function of energy. Of course the stack should not be destroyed whilst measuring.

2. Principles

As a good means of "plotting" phase space density against energy appears the possibility of sweeping a constant phase space area containing no particles through the stack. (We have adopted the expression "hole" for the particle-free phase space area.) Observing the stacked beam (where the RF structure is washed out) with an electrostatic pick-up electrode, the hole which is displaced across the stacked beam will induce a signal in the pick-up electrode, proportional to the number of particles displaced at each particular instant and radius, in other words at each particular particle energy. Therefore if the motion of the hole and the signal or the pick-up electrode are synchronized a good information should be obtained concerning the phase space density versus energy.

The constant phase space area that can be swept over a certain distance is materialized by a constant RF voltage of variable frequency and applied to a cavity. It must be possible to turn on the RF phase space area (bucket) well outside the stack, that is at a frequency well above the injection or well below the stacking energy. This empty bucket is then swept across the stack by modulating the RF frequency.
At the same time when sweeping the empty bucket across the stack a
certain energy spread is produced and the entire stack will be displaced by
an amount proportional to the constant phase space area of the probing bucket.
Care must therefore be taken when choosing the repetition rate of the sweeping
and the RF voltage which determines the scanning bucket area.

It might, of course, also be of interest to examine the possibility of
displacing the entire stack by sweeping an empty bucket at high repetition
rate. Therefore repetition rate, RF voltage and sweeping time are made
quite flexible in the RF scanning system.

3. General Parameters

For CESAR it is of interest to show the order of magnitude of the RF
voltage involved. For instance if we inject a beam of momentum \( p_i \) and an
energy spread \( \Delta p_i \) it will occupy a certain area in phase space. If we
now choose the area of the RF bucket such that the maximum energy width of the
stable phase area is equal to the energy width of the injected beam one can
define a peak RF voltage determined by

\[
\hat{V} = \frac{\pi \hbar E_i}{8} \left( \frac{\beta_1}{\gamma_{tr}} \right)^2 \left( 1 - \frac{(\gamma_{tr})^2}{(\gamma_1)^2} \right) \left( \frac{\Delta p_i}{p_i} \right)^2
\]

\( h = \) harmonic number of RF frequency = 2
\( E_i = \) energy at injection = 1.75 MeV
\( \gamma_{tr} = \gamma \) at transition = 6.71
\( \Delta p_i \)

\[ \frac{\Delta p_i}{p_i} = \frac{\Delta E_i}{E_i} = \frac{10^3 \text{ eV}}{1.75 \cdot 10^6 \text{ eV}} \approx 6 \cdot 10^{-4} \]
\( \Delta E_i = 1 \text{ keV} \)

Then \( \hat{V} \) becomes \( \hat{V} = 0.045 \text{ V} \).
The frequency swing corresponding to an energy variation of the beam of 0.255 KeV can be approximately determined by

\[
\frac{\Delta f}{f_1} \approx \frac{\Delta \beta}{\beta_1} (1 - \alpha) - \alpha \frac{\Delta E}{E_1} \quad \frac{\Delta f}{f_1} \approx 1.5 \% \]

where \( \alpha \) stands for momentum compaction factor near central orbit. A more precise calculation of \( \frac{\Delta f}{f_1} \) taking into account the variation of orbit length as a function of momentum \( p \) can be found in AR/Int. SR/62-6.

In order to turn on the probing bucket well outside the stack we have chosen the starting frequency of the scanning system as \( f_{\text{start}} = f_{\text{inj}} (1 + 0,0075) \). The total frequency swing will be \( \left( \frac{\Delta f}{f} \right)_{\text{probe}} = 3 \% \). The sweep rate of the RF scanning system is variable between:

\[
\frac{3 \%}{10 \text{ ms}} \leq \left( \frac{\Delta f/f}{\Delta t} \right)_{\text{probe}} \leq \frac{3 \%}{0.2 \text{ ms}} .
\]

This allows to scan the stack up to about 80 times within the repetition rate of the Van de Graaff injector (repetition rate 50 Hz).

The period of one phase oscillation of a particle in a stationary bucket is about 4 ms and in a moving bucket with \( \sin \phi_s = T \approx 0.5 \) ms.

4. The Electronic Conception of the RF Scanning System

Since the construction of the RF scanning system is now finished, it might be useful at this stage to give a short introduction to how it works, and what are its operational possibilities. The system has been constructed as flexible as possible, and the parameters chosen in such a way as to satisfy a wide range of the parameters involved.
The following parameters are variable:

(a) The RF voltage across the cavity gap.
(b) The starting frequency of the sweep.
(c) The time it takes to sweep across the vacuum chamber.
(d) The frequency of the scan.
(e) The number of scans with a certain frequency.

Fig. 1 shows the different voltage and frequency functions.

The RF voltage across the cavity gap can be varied between 0.9 V R.M.S. and 12 V R.M.S.

The RF voltage is held constant during the sweep. The setting of the gap voltage is done manually from a potentiometer on the front panel. A loop has been put into the cavity, so the voltage across the cavity gap can be monitored from the control room.

The starting frequency of the sweep is chosen to a minimum of 24.0 Mc/s, with possibilities for small changes if one wants to conserve the total frequency sweep of 0.7 Mc/s. The starting frequency can be set to frequencies higher than 24.0 Mc/s, then one has to suffer a reduction in the total sweep. The frequency variation is a linear function of time.

The frequency corresponding to a stack sitting 4 cm outside central orbit, is given by Pentz to be 24.25 Mc/s, so with a starting frequency of the scanning sweep of 24.0 Mc/s, one starts with a frequency corresponding to a stack sitting approximately 11.4 cm outside central orbit. With a total frequency sweep of 700 kc/s, one will sweep through the total cross-section of the vacuum chamber, and end up ≈ 9.0 cm inside the central orbit. See Fig. 3.
The rate of change of frequency $\frac{\Delta f}{\Delta t}$ is variable. The total frequency sweep is fixed to 700 kc/s, and the time is variable in 10 steps between 0.2 ms and 10 ms. The fastest rate of change is thus

$$\frac{\Delta f}{\Delta t} = \frac{7 \times 10^5 \text{ c/s}}{2 \times 10^{-4} \text{ s}} = 3.5 \times 10^9 \text{ c/s}^2$$

and the slowest

$$\frac{\Delta f}{\Delta t} = \frac{7 \times 10^5 \text{ c/s}}{10^{-2} \text{ s}} = 7 \times 10^7 \text{ c/s}^2$$

The frequency of the scanning sweep can also be selected in several steps. The lowest frequency is 60 c/s, the highest 2000 c/s. The sweep length and the scanning rate are related in such a way, that one can not select a scanning frequency whose one period corresponds to a time shorter than the selected sweep time. However, one can select a sweep time that is shorter than one period of the selected scanning frequency. If one for example wants to scan with a rate of 200 c/s, one can select any sweep time shorter than 5 ms.

The number of scans for any selected frequency, which one might want to apply to any particular stack, can be selected by a counting unit. One can select from 1 to 99 scans for any frequency selected within one scanning cycle.

If one for example selects a sweep time of 0.2 ms, a scanning frequency of 2000 c/s, and the number of scans to 99, the total scanning time would be 49.5 ms.

One other possibility is to select the same sweep speed of 0.2 ms, but change the scanning frequency to 50 c/s, and maintain the number of scans to 99. Then we would scan for 1.98 sec.

This means that the scanning bucket will sweep through the stack in 0.2 ms, once every 20 ms and this for 99 times.
Another interesting possibility of the system is that one can try to accelerate the whole stack by displacement. The RF voltage across the cavity gap is gated on, and the starting frequency can be selected to correspond to a stack sitting anywhere in the vacuum chamber.

With an outside gate generator, one can also gate on a fixed frequency for any selected time.

Fig. 2 shows the block diagram of the system.

An outside timing pulse starts the ringing oscillator, which is stopped by the counting unit, when the number of oscillations corresponds to the selected number on the counting unit. The frequency of oscillations can be selected from a switch on the front panel.

The ringing oscillator drives the function generator, which produces the modulation voltage for the variable oscillator. The sweep length can be selected by a knob on the front panel.

In the function generator is also incorporated a gating unit. The gate opens when the frequency of the variable oscillator starts changing, and closes when the oscillator has reached the end of its sweep, stays closed until the next period of the ringing oscillator, and so on.

The modulation of the frequency in the variable oscillator is done by a variable capacitor diode. In its test position, the frequency is determined by the reference voltage. The frequency at rest position is the starting frequency, and by varying the reference voltage, one varies the starting frequency.

The oscillator gives out a frequency sweep with a constant amplitude, which drives the power amplifier. The amplifier has an amplitude control,
taken out on the front panel. A built-in gate is driven from the function
generator gating unit.

The same type of cavity as on the main RF system is used. A constant
amplitude across the cavity gap during the sweep is obtained by matching the
output of the amplifier to the cavity by a 120 Ω, λ 3/4 coaxial cable. The
Q of the cavity is damped down to 5.6 by resistive loading. The cavity is
tuned to 24.4 Mc/s, and the resonance impedance is roughly 50 Ω.

The characteristic performance data of the RF scanning system are
summarized in Table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability of starting frequency (short term)</td>
<td>better than 10⁻⁴.</td>
</tr>
<tr>
<td>Total frequency sweep AF/f</td>
<td>~ 3 o/o</td>
</tr>
<tr>
<td>Minimum RF voltages on cavity</td>
<td>0.9 V R.M.S.</td>
</tr>
<tr>
<td>Maximum RF voltage on cavity</td>
<td>12 V R.M.S.</td>
</tr>
<tr>
<td>Sweep time variable between</td>
<td>0.2 - 10 ms</td>
</tr>
<tr>
<td>Sweep rate variable between</td>
<td>50 c/s - 2000 c/s</td>
</tr>
<tr>
<td>Number of scans per scanning cycle</td>
<td>1 - 99.</td>
</tr>
</tbody>
</table>

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Distribution (open):
Scientific Staff AR Division.
R.F scanning system

Fig. 1

![Diagram of R.F scanning system]

Fig. 2

![Waveforms for R.F scanning system]

- **R.F on cavity**
- **Gate**
- **Function gen.**
- **Ringing osc.**
- **Trigger**

**Time Scale:**
- 5 ms
- 20 ms