SOME THOUGHTS ABOUT TUNING NARROW BAND CAVITIES WITH REACTANCE VALVES.

For very high energy proton accelerators (in the 100 to 1000 GeV range) the necessary frequency modulation becomes very small due to the highly relativistic velocity of the particles. The relative frequency band width then depends on the injection energy chosen but possible relative band width \( \frac{\Delta f}{f} \) would be in the \( \frac{\Delta f}{f} = 0.8 \) to 10 o/o region\(^1\).

Then the question arises how this frequency swing is most economically brought about especially at frequencies in the range of 70 to 100 MHz. So far very intense studies have been carried out concerning the possibility of using rotating condensers or tuning with ferrites. The first method has to rely upon very precise mechanical and electrical adjustments and synchronisation whilst the second asks for driving an inductive load of varying size.

There also exists the purely electronic solution of the problem which would be the radio valve connected such as to give either a positive or negative reactance with which one could tune the acceleration cavity.

This note proposes to outline the advantages and inconveniences of the system.

The behaviour of a reactance valve.

\[
i_a = S u_g
\]

\[
u_g = \frac{R}{R + 1/j\omega C} \quad u_a
\]

\[
\frac{i_a}{u_a} = \varepsilon_a = \frac{SR}{R + 1/j\omega C} = \frac{1}{\tau_a}
\]

with \( R \ll \frac{1}{j\omega C} \) or \( \omega RC \ll 1 \)

\[
\frac{i_a}{u_a} \approx j\omega S R C. \quad C_{eq} = SRC
\]

The above formula shows how we can produce a capacity which is equivalent to \( C_{eq} = SRC \) where \( C_{eq} \) is a function of the transconductance \( S \) of the valve. \( S \) in turn can, however, be influenced by the working point of the valve. We recall the characteristics of a valve in the \( i_a, U_g \) plane.
By modulating $U_G$ we can vary $S$ from $S_{\text{max}}$ to $S_{\text{min}}$ which allows us to determine the capacity swing $\Delta C_{\text{eq}}$.

$$\Delta C_{\text{eq}} = RC (S_{\text{max}} - S_{\text{min}}).$$

Assuming the case that we want to work at relatively high accelerating frequency bands, for instance $f_0 = 70$ MHz, we would like to make $\frac{1}{\omega C} \gg R$ which means $C$ must be as small as possible. This fact permits at the same time to decrease the current through $R$ (which would be a lossy current) and safe RF-power. In order to have a minimum capacity from plate to grid we can make use of the plate-grid stray capacitance of a good tetrode valve. As a representative example we would cite the Eimac 4 x 500 A power tetrode that has a capacity $C_{\text{PG}} = 0.05$ pF.

With $\omega = 2\pi \cdot 70$ MHz, we then find $R \ll 50$ kΩ.

With $R \approx 8$ kΩ, $S_{\text{max}} = 10.0$ mA/V, $S_{\text{min}} = 0.4$ mA/V, we find $\Delta C_{\text{eq}} = 4$ pF.

Estimating the capacity of an accelerating cavity at $f_0 = 70$ MHz to be $C_{\text{cavity}} \approx 50$ pF we could expect to modulate the cavity by a band width

$$\left| \frac{\Delta \omega}{\omega_0} \right| = \frac{1}{2} \left| \frac{\Delta C}{C_0} \right| \approx 4 \, \text{o/o}.$$  

The disadvantage of the system is represented by the power consumed by the valve itself and the power dissipated in the resistance $R$. If we consider the project described in 1) we could accommodate $\sim 550$ accelerating stations with a total gain of 7.7 MeV/turn. This means that our accelerating voltage per station is $V \sim 14$ KV.
Then the current flowing through \( C \) and \( R \) is

\[
i = \frac{14 \text{ KV}}{50.5 \text{ K}} = 0.28 \text{ A}.
\]

or \( N \approx \frac{I^2}{R} \cdot R \approx 600 \text{ W} \). (making the assumption of \( V \approx \frac{Vo}{\sqrt{2}} \)).

To this value will have to be added the losses of the valve \( N = \approx 400 \text{ W} \).
These two values depend strongly on the valve and working point chosen, but they are meant to be representative values.

The total power consumed by one reactance valve would be \( N_{\text{total}} \approx 1.4 \text{ KW} \).
Together the power consumed by 550 station would accordingly be 770 KW.

Conclusion

This note tries to recall the possibility of electronic tuning of the accelerating cavities. This way of tuning would have the advantage of being practically without time-constant (being favorable for any repetition-cycle) and easily controllable by means of nearly powerless electronic circuits. However, the circuit itself has non-negligible power losses and it must be more closely studied how these losses could be minimized by still improving on the capacity and the voltage values.

F. A. Ferger

Distribution: (open)
AR Division
Library