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REDUCTION OF RIPPLE VOLTAGE IN A DYNAMITRON

Alexander Langsdorf, Jr.
Physics Division, Argonne National Laboratory, Argonne, IL 60439

Abstract

We determined that a precise neutralization of the RF ripple voltage on the high-voltage terminal of a Dynamitron has previously been prevented by a nonnegligible phase shift of RF currents in the two halves of the ~100-kHz class C oscillator tank circuit, which is actually constituted of two slightly unequal high-Q coupled circuits because it has two ground points: the inescapable center-tap-ground in the capacitive legs and a center-tap-ground lead to the induction coil. The latter is needed to prevent damage by flashover transients; equivalent to its removal was the adjusting of RF ground return current to a null by aid of a current transformer on this lead and the suitable adjusting of trimmer capacitance. While the phase shift was thus held to a null, the actual ripple amplitude on the hv terminal was minimized by adjusting additional trimmer capacitances installed in the terminal of the machine. Then p/p 100-kHz ripple at 2-MV DC output was reduced to about 50V and RMS resolution by (p,γ) resonance threshold data near 1 MV was about 250 V. The limit to resolution has various causes including mechanical vibrations and unbalanced harmonics of the RF.

Introduction

A Dynamitron[1] generates dc high voltage by rectification of radiofrequency power typically at ~100 kHz. The rf voltages within the system can produce a substantial rf modulation superposed on the dc output voltage. In our 4 MV Dynamitron this has been conspicuously the largest component in the spectrum of modulation frequencies due to all causes. Therefore, when requirements for improved performance provided incentive, it was natural to concentrate attention upon reducing this 100 kHz ripple voltage which previously had a p/p amplitude of at best several kV at ~2 MV dc output. The new technique allows reducing this amplitude to ~50 V. Subsequent measurements of a sharp (p,γ) resonance have yielded an overall RMS resolution of ~250 eV, to which the 100 kHz ripple component provides only a small contribution. The technique is adaptable to other Dynamitrons and similar machines.

General Description

Figures 1 and 2 are schematic diagrams of our Dynamitron and Fig. 3 is a circuit diagram, showing principally the components that are important to the rf behavior and omitting most of the details having to do only with the dc circuitry. The rf tank circuit is composed of a large (actually toroidal) induction coil of ~5.4 mH inductance, and a network of capacitance between all pairs of six major electrically functional components, which are given identifying numbers (see Fig. 1) convenient in specifying capacitances between them: thus C_{16} is the capacitance between items 1 and 6, etc. The pressure vessel (#6) is at earth ground. The gaseous dielectric in it is SF_6. The vessel contains the high voltage terminal (HVT), item #5, which is supported by an electrically insulating column structure of Plexiglas, not shown on the figures. The column supports and is surrounded by a series of many metal hoops much the same as in an electrostatic generator except that they are split to form half-hoops as shown on Fig. 2. Several half hoops are indicated on Fig. 1 but actually there are many more. The whole set of upper half-hoops are collectively called item #3, and the lower set item #4. The two sets are driven electrically by the transverse field supplied by two large sheet-metal electrodes conventionally called "dees". The upper dee is item #1, the lower is item #2. Rectifier units (each containing ~500 diodes) connect to the half-hoops as indicated on Figs. 1 and 2. There are actually 94 units of which only 8 are shown on Fig. 1. The rf is applied in parallel to the rectifiers while their dc outputs are in series. (It is the parallel feed that gives the Dynamitron its good characteristics at large load currents despite many stages of rectification.[1]) Lumping all the half hoops into just two items, #3 and #4, is an approximation adequate for our purposes. On Fig. 3, the diodes are not shown; instead their effect is symbolized by the mainly resistive equivalent impedance Z. The value of Z depends upon the dc load current.

Between all pairs of the six numbered components there are 15 capacitances of which 11 are shown in the circuit diagram, Fig. 3. The four omitted (C_{14}, C_{23}, C_{36}, C_{46}) are small and unimportant and will not be further discussed. There are a few more details to mention: the mutual inductance M between the upper L_1 and lower L_2 halves of the inductor is shown explicitely on Fig. 3. The primary coil is also shown on Fig. 1 and 3. (Not all Dynamitrons use a separate primary. To carry through our ripple-reduction, such a separate primary is certainly convenient and probably essential. It had been installed previously because it helped to inhibit previously-experienced violent parasitics.) Grid drive by the tertiary coil rather than more usual capacitive feedback coupling is convenient but seems to be optional.

A trimmer capacitor C_{16A} is shown explicitly on Fig. 1. It consists of a stator and a rotor plate, the latter precisely controlled remotely by a motor drive. This not unusual device had been installed earlier. It had conventionally been set to minimize the observed rf signal V_R from a pickup plate facing the HVT as shown on Fig. 1. When calibrated, V_R measures the rf ripple amplitude. If C_{16A} could not be set to find a minimum of V_R within its range, a sheet-metal plate was adjusted to trim (roughly) either C_{16} or C_{26} until C_{16A} did allow going through a minimum of V_R.

The small pickup plate labelled "synch. signal" on Fig. 1 allowed one to synchronize the sweep of the oscilloscope used to observe V_R. The key observation was that at the minimum of V_R its phase was shifted 90° from its value for large V_R. It was concluded and later confirmed, that the upper and lower halves of the tank circuit must have slightly different natural frequencies, and being coupled oscillators driven at one intermediate frequency, there must be a phase difference in the currents in them; because they are high-Q circuits (Q ~ 600) a small natural-frequency difference causes a significant shift. As may be seen in Fig. 3, points #1 and #2 are input points for a capacitive bridge whose output points are #5 and #6. This bridge can only be perfectly balanced by capacitive trimming, as is required to remove rf ripple from the HVT, #5, if the input currents are in phase.

The first step toward the objective of ripple elimination had therefore to be elimination of the phase shift. This would be accomplished if the

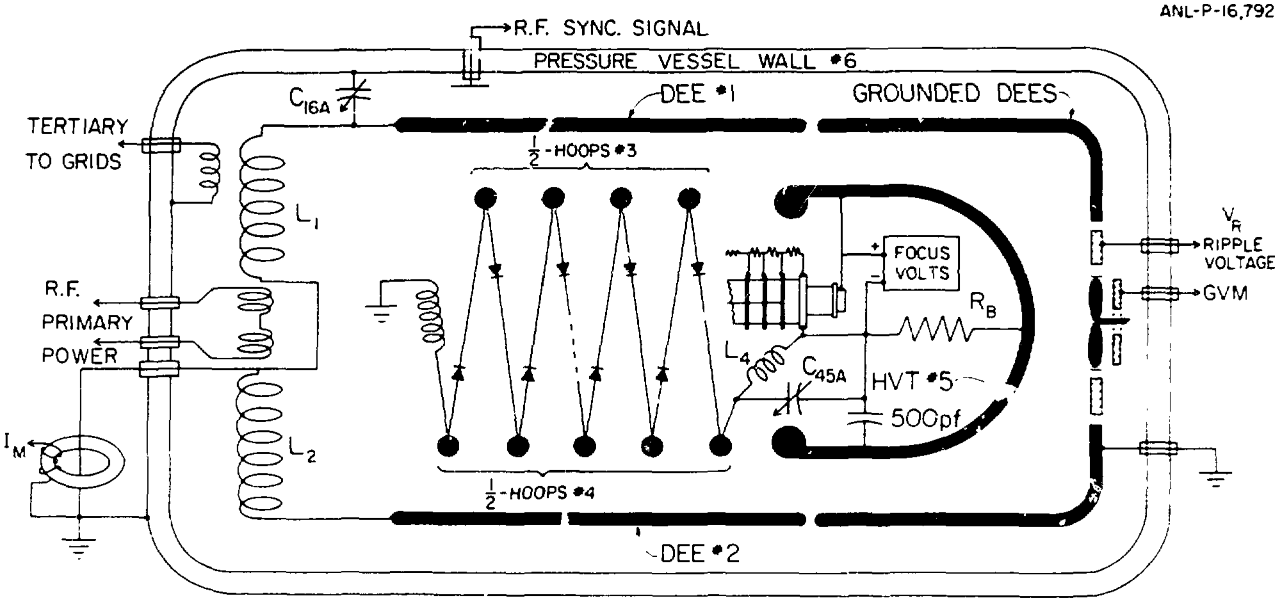
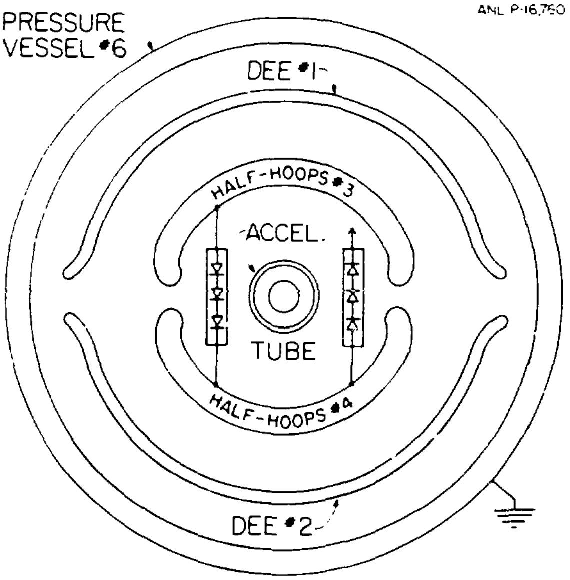
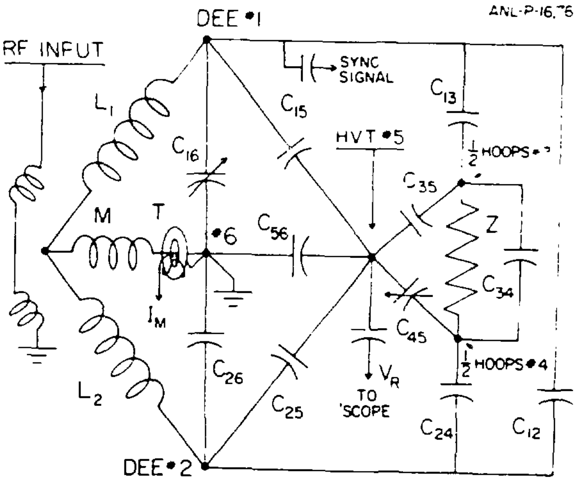


Fig. 1 Diagram of Dynamitron



SECTION THROUGH SYSTEM
NEAR MIDDLE

Fig. 2



RF CIRCUIT SCHEMATIC

Fig. 3

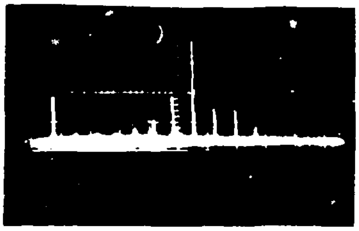


Fig. 4A Frequency Spectrum, Unbalanced

Fig.4B Spectrum, Balanced

ground-bus to the center-tap on the inductor were disconnected but this was impractical: transients during flashover would damage the coils. The primary and secondary were too close to prevent flashover between them during a severe transient. As an alternative, tests showed that the ground-return current I_M at the 100 kHz frequency could be set to zero by a suitable adjustment of C_{16A}. When $I_M = 0$, the phase shift was eliminated just as if the bus were disconnected. I_m was measured by aid of a current transformer labelled T on Figs. 1 and 3. It was a small ferrite ring with a ten-turn secondary. When surge currents occur in a flashover, the ferrite will saturate and a low impedance path to ground is assured.

Conclusion

Having determined how to control the phases of the input currents to the previously mentioned bridge circuit, it remained to adjust capacitances so it would be balanced while correct phasing was maintained. This might be done, in principle, by varying any one or more of C_{13}, C_{15}, C_{35}, C_{24}, C_{25}, or C_{45}. A practical choice was to vary C_{45} by adding a trimmer C_{45A} shown on Fig. 1. It was mounted in the HVT in a relatively low-field region, and could be accurately set by a motor drive. When C_{45A} was adjusted to reduce V_R, C_{16A} was readjusted to maintain $I_M = 0$. The minimum of V_R thus achieved was much less than ever previously attainable, i.e., only ~50 V p/p at 100 kHz and 2MV dc.

Addenda and Comments

1. The variation of C_{16} by aid of trimmer C_{16A}, Fig. 1, is indicated on Fig. 3 by a pointer through the capacitor symbol, and similarly for C_{45}. On Fig. 1, C_{45A} is shown as it was actually connected, i.e, to a 500 pf fixed capacitor. Since C_{45A} is only ~10 pf and the 500 pf is much greater, the effect is essentially the same as if C_{45A} were connected directly to the HVT as drawn on Fig. 3. The 500 pf capacitor was already installed earlier and hence it was advantageous to connect C_{45A} to it because then C_{45A} only has to withstand up to ~25 kV of rf while the 500 pf fixed capacitor withstands up to ~80 kV of dc. This allows making C_{45A} smaller (than if it had to withstand ~105 kV total), so it better fits into the restricted space conveniently available. The main purpose of the 500 pf capacitor was and remains to allow dc connections in the HVT such that changes in ion beam current do not affect the operation of the "focus volts" supply. In the original circuitry the dc current from the main Dynamitron power supply had to flow through the "focus volts" supply. The present circuit divorces the roles of the main Dynamitron power supply from the "focus volts" supply; there is no longer interplay between them; the value of R_B can be as high as one wishes without complications that depend upon beam current load.

When the dc connection from choke coil L_4 was moved from the HVT to the end of the main acceleration tube (as shown on Fig 1) the 500 pf capacitor was added because without it there would have been only be a few picofarads capacitance from the Dynamitron power supply output to the HVT, so that the charging-current pulses would cause a very excessive voltage modulation. With the 500 pf capacitor present, the load dependent ripple voltage across this capacitor due to charging-current pulses is at most ~20 volts for 1mA of average dc. The similar ripple across C_{56} is ~40 V for $C_{56} \simeq 250$ pf at ~1 mA dc load current. These load dependent ripples would only become important for dc currents considerably larger than 1mA.

The 500 pf capacitor was specially designed for the environment in which it is used, and likewise C_{16A} and C_{45A}. The transformer T is very simple and introduced no problems at all in construction or use.

2. As was the case for C_{16A}, if C_{45A} did not at first attain a setting that minimized V_R, a suitably placed metal plate allowed adjusting C_{35} until one did attain the minimum of V_R for an achievable value of C_{45A}.

3. The GVM unit indicated on Fig. 1 is a commercial generating voltmeter calibrated to read the dc voltage on the HVT. Sometimes it is also used to control this voltage.

4. Figures 4a and 4b display the frequency spectrum of the currents measured by aid of the current transformer T, and a spectrum analyzer and oscilloscope. At the left end is the fundamental rf, 100 kHz signal, and progressing to the right, every harmonic up to the eleventh, with the eighth being the largest.

Since the oscillator is class C type, one expects to excite many harmonics. (Probably there are more than eleven but the analyzer did not cover the range above ~1.1 MHz.) Figure 4a was obtained with the settings of C_{16A} and C_{45A} purposely a bit off balance; Fig. 4b when it was carefully balanced so the current at the fundamental frequency was nearly a null. None of the harmonics were affected by the balancing. Possibly further studies of the circuitry could disclose asymmetries in the structure responsible for the unbalance of the harmonics. If the structures in the system were suitably adjusted, very likely the harmonic content in I_M could be much reduced. The effects of these harmonics in I_M on the rf voltage on the HVT are not as great as Fig. 4 naively suggests, because the shunt capacitance C_{56} attenuates higher frequencies. An n^{th} harmonic current I_{Mn} produces a ripple voltage V_{Rn} on the HVT proportional to I_{Mn}/n, so that even the largest (8^{th}) harmonic voltage V_{R8} should be little greater than the fundamental component at its minimum.

Acknowledgement

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References:

1. M. R. Cleland, P. R. Hanley, C. C. Thompson, IEEE Transactions on Nuclear Science NS-16 No. 3, p. 113-116, 1969 Particle Accel. Conf. March 5-7, 1969. (Also C. C. Thompson and M. R. Cleland, p. 124-129);
   M. R. Cleland and P. Farrell, IEEE Trans. Nucl. Sci. NS-12 No. 3, p. 227-234 First Nat'l. Particle Accel. Conf. Mar. 10-12, 1965.

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