STABILIZATION OF MAGNETRON FREQUENCY FOR A MICROTRON-DRIVEN FEL*

B. A. Gudkov[#], S. Bae, K. H. Jang, Y. U. Jeong, H. W. Kim, K. Lee, J. Mun, S. H. Park, G. I. Shim, KAERI, Daejeon, Korea

S. V. Miginsky, N. A. Vinokurov, KAERI, Daejeon, Korea, and Budker INP, Novosibirsk, Russia

Abstract

Under KAERI WCI program we develop a compact pulsed microtron-driven FEL. Electron bunches are accelerated in the microtron and transported by the beamline to the unlulator. The RF cavity in the microtron is fed by the magnetron. Any accelerator driver for a FEL should provide an electron beam having very stable parameters such as electron energy, beam current and especially repetition rate in a train. All mentioned parameters depend on magnetron current. It means that special attention should be paid for the shape of a current pulse, supplied to the magnetron from the modulator. We developed the modulator project with a computer control that will provide an arbitrary shape of the magnetron current. A simplified prototype was fabricated and tested. The methods of controlling of the pulse shape are considered. Simulation and experimental results are presented.

INTRODUCTION

If one wants to obtain the maximum monochromatic FEL emission, the repetition rate of microbunches should be equal within a train and in all the trains. If maximum power is necessary, while monochromaticity is not so important, frequency ramp within a train can be used, as described in [1]. In this case, initially the detuning is significant, optimal for amplification. It increases the rise time, thus lengthen the emission pulse. Then the detuning comes to zero, and a FEL transits to so called spiking mode, and the spectrum broadens. Thus, in different cases, one can need absolutely stable or increasing in a certain way through a train repetition rate.

A magnetron, unlike a klystron, is an oscillator, but not an amplifier, so one cannot obtain stable frequency using a high-stable low-power master oscillator. The magnetron frequency depends on many factors: the mechanical tuning, the magnetic field, the anode current, the load impedance, and the temperature.

The magnetron is coupled to RF cavity of the microtron via a waveguide and an isolator. Isolator usually is tuned to allow some portion of reflected power to come back to the magnetron. Quality factor of the RF cavity is approximately of order higher than of magnetron.

In case of narrow band resonant load, the frequency pulling effect may take place. The presence or absence of the effect depends on waveguide length, reflected power level and on cavity and magnetron detuning.

Thus, one should provide stable flat top current pulse through a magnetron or some specific current pulse shape for a frequency ramp within a train.

Ability to form an arbitrary shape of a current pulse is a universal solution.

EQUIVALENT CIRQUIT

Volt-Ampere characteristic of a magnetron one can see in Fig. 1. Typical threshold voltage is 45-50kV depending on the magnetic field in a magnetron. There is no current for low voltage across the magnetron due to so-called magnetic isolation. Differential resistance dU/dI in the conducting area is 50-70 Ohm.

First approach for equivalent circuit of the magnetron may be series connected resistor, an ideal diode and Zener diode with a threshold voltage Vth. Another possibility is to use an ideal voltage source instead of Zener diode.
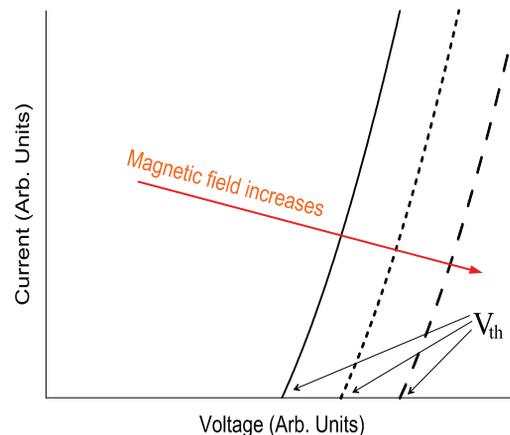

Figure 1: Volt –Ampere characteristic of a magnetron.

Simplified equivalent circuit of the modulator and the magnetron is shown in Fig. 2, where:

L_s is a leakage inductance of the HV transformer, referenced to the secondary side of the transformer,

C_s - the sum of the stray capacitances of the W2 and of a high voltage cable,

R_d - differential resistance of the magnetron,

D – ideal diode (magnetron conducts current only one direction)

V_{th} -Zener diode with threshold voltage V_{th}.

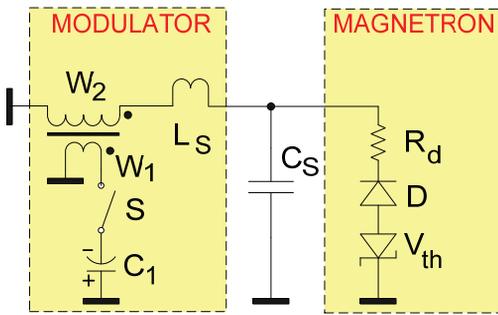Capacitor C_1 is charged from power supply (not shown) before the pulse is triggered.

Figure 2: Modulator and magnetron equivalent circuit.

After closing the switch "S", the magnetron is still non-conducting; current comes to "C_s" through "L_s" and charges it cosine-like in time. When the voltage across "C_s" reaches threshold voltage of the magnetron V_{th}, the whole current through "L_s" is switched to magnetron, and the magnetron voltage V_m is stabilized at the level according to formula [1]

$$V_m = V_{th} + I_0 * R_d , \qquad (1)$$

where I_0 is an amplitude current through "Ls" and may be estimated using formula [2]:

$$I_0 \cong V_1 \frac{W_2}{W_1} \sqrt{C_s/L_s} . \qquad (2)$$

Further current behaviour depends on the initial secondary voltage, induced to W_2, which, in turn, depends on voltage, stored by C_1 and also on C_1 value, because the capacitor is partially discharged during the pulse. Typical current shape one can see in Fig. 7, trace "0".

Fine tuning of initial current I(0) is possible by means of the short (some tens of nanosecond) "preliminary pulse" which may be generated about 1 microsecond before the main pulse with duration about some tens of nanoseconds. In this case initial conditions for main pulse will be: zero current through L_s, but not zero voltage across C_s. As a result, initial magnetron current will be changed.

SIMPLE CORRECTOR

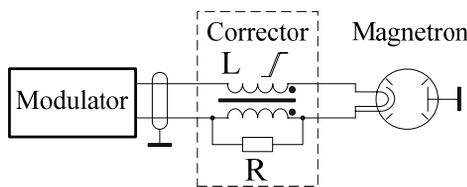The main idea was to make the top of the current pulse as flat as possible.

Figure 3. Simple corrector circuit.

We tested a simple corrector, which contains one switch as shown in Fig. 3. Inductor "L" with a saturable core acts like a switch and the corrector impedance is changed from

R to almost zero approximately at the middle of the pulse. The magnetron operates with a dummy load. This corrector changes magnetron current as shown in Fig. 4. Black trace is the voltage across the magnetron, red solid trace is the magnetron current without corrector and red dashed trace – with corrector.
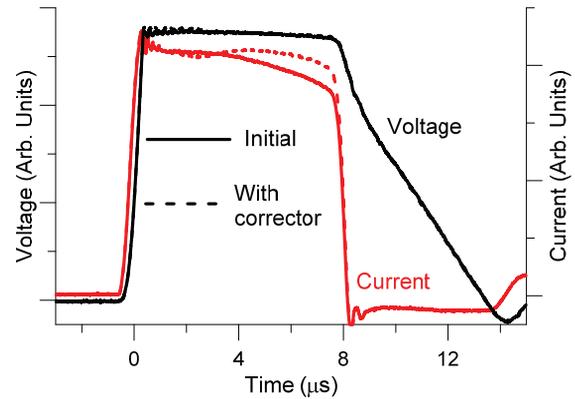

Figure 4. Current pulse shape modification.

As it is shown in Fig. 5, fluctuation of the instant frequency, generated by the magnetron, was reduced from 0.7 MHz p-p (red solid line) down to 0.2 MHz p-p (red dashed line).
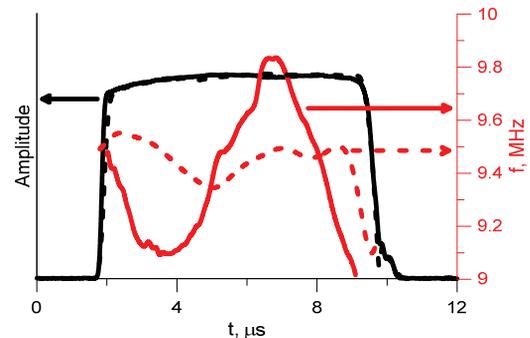

Figure 5. Instant frequency deviation modification.

It is clear that even such a simple corrector improved the situation drastically, so next evident step is to construct a corrector with a number of cells, in purpose to get a more fine control of a current pulse shape.

MULTI-CELL CORRECTOR

Corrector may be placed in series with the magnetron as it is shown in the Fig. 3, or in series with the secondary winding of the HV transformer at the low voltage terminal of W2, as shown in Fig. 6.
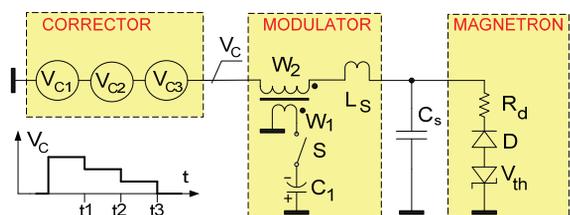

Figure 6. Modulator with a multi-cell corrector.

The minimal value of current deviation depends on the number of cells. Here three cells are shown. Each cell in the simplest case contains a resistor and a solid state switch (IGBT), connected in parallel. Also high efficiency voltage pulse sources may be used. Note that modulator instant output power is about 5MW (50kV, 100A), required corrector power is about 200kW (2kV peak voltage, 100A).

Current shapes for different circuits were simulated and are shown in Fig. 7:

• Trace "0" –modulator without corrector,
• Trace "1" –modulator with 1-cell corrector,
• Trace "3" –modulator with 3-cell corrector,

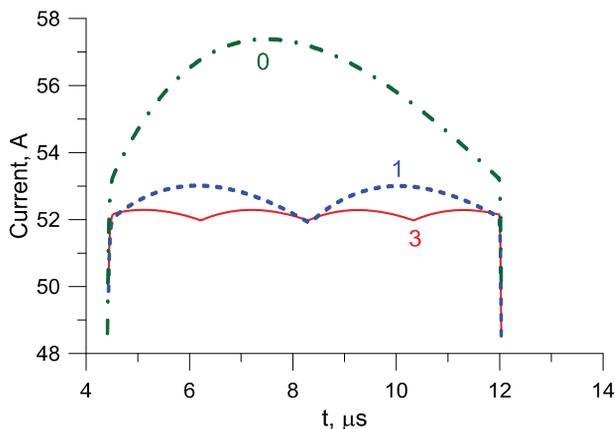Current deviations are 4, 1, and 0.3A p-p, respectively.

Figure 7. Current shape with different correctors.

For corrector composed from 2-state cells current deviation during the top of the pulse is decreased approximately as $1/(n+1)^2$, where n is the number of cells in a corrector.

PULSE SHAPE CONTROL

Now we can summarize methods of current shape control:

• magnetron voltage – by magnetic field tuning
• initial current value – by adjusting of Cs.
• average value of the first derivation dI/dt – by computer control of the primary voltage.
• shape details – by control of time diagram for the corrector, forming desirable shape of corrector voltage.
• initial current fine tuning – by control of the preliminary pulse duration

CONCLUSION

Methods of current shape control and the project of the modulator with corrector were developed. Simple corrector was tested. Multi-cell corrector now is fabricated.

REFERENCES

[1] R.J. Bakker, G.M.H. Knippels, A.F.G. van der Meer, et al. "Dynamic desynchronization of a free-electron laser", Phys. Rev. E, 48 (1993), R3256-R3258.

[2] G. M. Kazakevitch, V. M. Pavlov, Y. U. Jeong, B. C. Lee, "Intrapulse frequency stability of a magnetron frequency-locked through a wave reflected from an accelerating cavity", Nucl. Instr. and Meth. A647, 2011, pp. 10-16.