Experimental Investigation of Giga-watts Magnetically Insulated Transmission Line Oscillator (MILO)[1]

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Abstract – Experimental works on L-band magnetically insulated transmission line oscillator (MILO) have been carried out for generation of microwave with the GW power level. As a first experiment, a MILO composed of 6-uniform cavities and single coupling cavity with improved axial power extraction and choke cavity is chosen. The measured output power of 1.82GW shows a reasonable agreement with the simulated one of 2.1GW. In this experiment, 500kV-36kA pulsed electron beam with the pulse duration of 130nsec is generated by SEBA (Seoul National University's Electron Beam Accelerator). In addition, we observed the axial mode competition using RF B-dot proves at each cavity.

1. Introduction

The magnetically insulated transmission line oscillator (MILO) [1, 2] is a crossed-field microwave tube that can generate gigawatt-level high-power microwaves (HPM). The physical structure resembles the coaxial linear magnetron without a magnet. In the early stage of researches on MILO [1, 2], the generated power at interaction cavities was extracted via top of the cavities like conventional magnetrons. However, the radial power extraction breaks the axial symmetry and causes mode competition between TM and TE mode resulting in poor efficiency. In subsequent studies [3-5], the power was axially extracted via matched section or tapered vanes without a detailed design description of the coupling structure. And they employed central anode for uniform and stable self-magnet field.

The schemes of axial power extraction and central anode are also adopted in our model. In addition, an optimized axial power extracting structure is introduced for an efficient operation of MILO. And improved choke cavities for preventing backward leakage of generated wave is used. As a first design, uniform vanes are used to study basic mechanisms in MILO.

2. Numerical Studies and Design

Fig. 1 shows the structure of MILO and dimension parameters. The ratio of cathode radius (r_c) and anode radius (r_v) is fixed at 1.82 so that the diode impedance given by saturated para-potential flow [6] is 13.6Ω matched with one of pulsed power. The electron's axial drift velocity for MILO was driven by Lemke [3]. The period of vanes should be 4.36cm for synchronization of π-mode with electron beam at applied voltage of 500kV. Because the cathode radius determines the electric field strength on the cathode surface, it has to be smaller than velvet's explosive emission threshold (~20kV/cm) and larger than stainless steel's one (~300kV/cm). The resonant frequency of MILO is found by dispersion relation driven from the dispersion of concentric-line guide with radial delay-type slots by Hutter [7]. Fig. 2 shows the dispersion relation for TM modes. The axial drift velocity line of insulated electron beam at 500keV meets the structure's dispersion at 1GHz and π-mode.

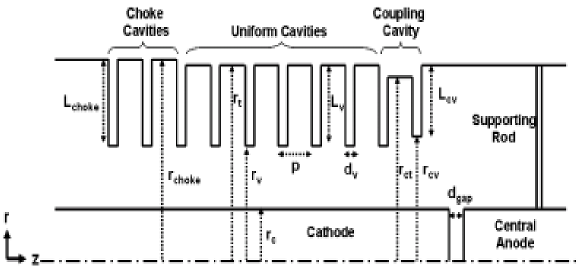

Fig. 1. Schematic of design

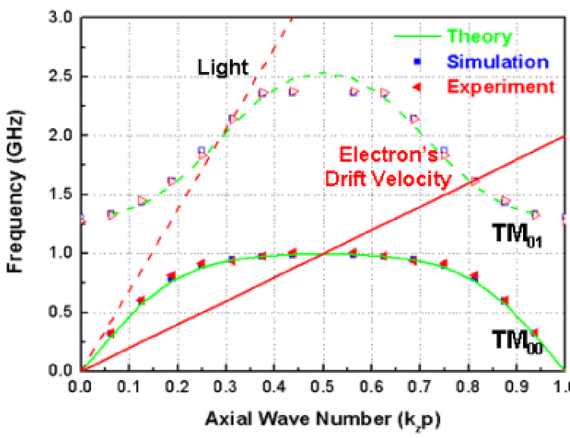

Fig. 2. Dispersion relation of MILO by theory, simulation and experiment

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The amount of coupling out of generated power in cavity determines the efficiency of MILO. It's not only the problem of the amount of coupling out, but also one of the beam-wave interaction strength due to electro-magnetic field intensity inside of cavities.

Numerical studies by particle-in-cell (PIC) code, MAGIC have been done. Fig. 3 shows the model and electron particles forming spoke current. The RF output power of 2.1GW (12.3% efficiency) at 1GHz is observed at optimized conditions for the number of cavities, axial power extraction, central gap distance, and so on. The applied voltage and current of electron beam are 500kV and 34kA, respectively. As shown in Fig. 4, the power extraction efficiency is optimized at 84% for efficiency.

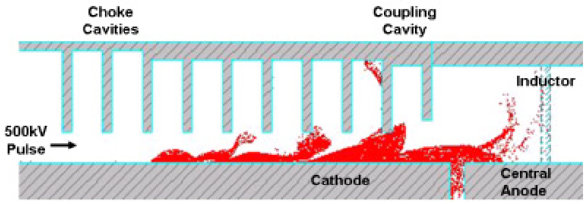

Fig. 3. Model of particle-in-cell code and electron particles forming spoke current

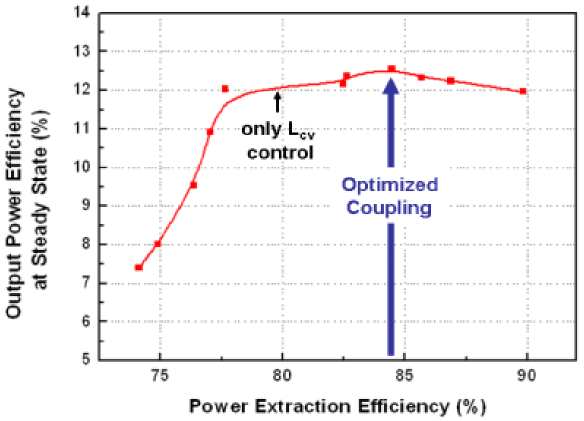

Fig. 4. Optimized power extraction efficiency for output power efficiency

3. Experimental Investigation

Pulsed power system, SEBA (Seoul National University's Electron Beam Accelerator) composes of 8-stage Marx generator and 2-meter water-filled Blumlein pulse forming line with water spark-gap switch. This can operate a range of 250kV ~ 700kV with single-shot. The matching impedance is 13.6Ω. A preliminary hot test has been carried out with microwave termination shown in Fig. 5. The RF power is measured through RF B-dot probe made of vacuum feed-through. The measured power is 1.82GW (11.5% efficiency) with 50ns duration shown in Fig. 6. This result using a simple uniform cavities with optimized coupling and choke cavity approaches closely to the best efficiency obtained by other group [5]. The electron beam voltage and current used in this experiment are 466kV and 34kA, respectively. The voltage pulse has a rise time of 20ns and a flat top of about 80ns.

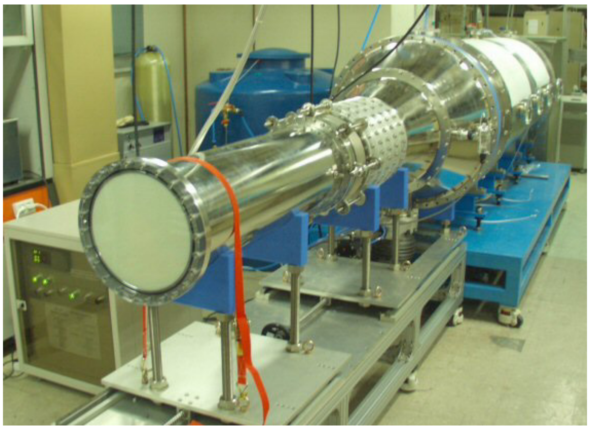

Fig. 5. Experimental setup for MILO; Marx generator, Blumlein pulse forming line, MILO circuit, SEBA (Seoul National University's Electron Beam Accelerator)

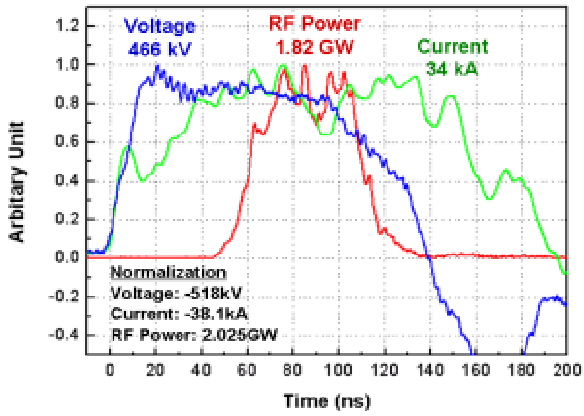

Fig. 6. Experimental result; applied voltage, current, and RF output power

The experimental results for different applied voltages are compared with MAGIC PIC code as shown in Fig. 7.

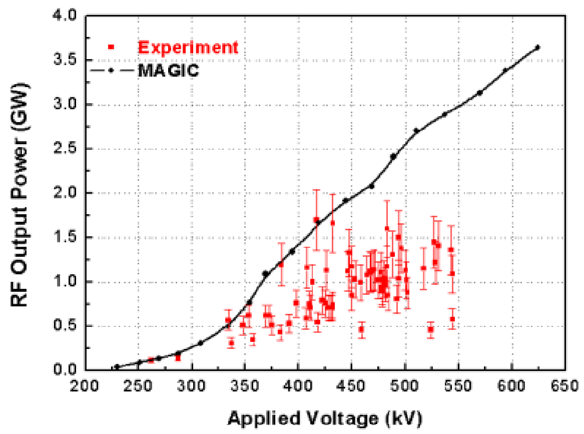

Fig. 7. Output power versus applied voltage

Here, a axial mode competition between π-mode and its neighboring mode(5π/6) has been observed both in MAGIC PIC code and in experiment. An experimental result of frequency variation and axial field pattern as time is shown in Fig. 8 and Fig. 9. In initial stage of RF generation from 0ns to 30ns, the 5π/6-mode of 1.00GHz starts to grow first, but the π-mode of 1.15GHz suppresses the neighboring mode and becomes dominant mode later as shown in Fig. 8. Fig. 9 shows the axial field pattern versus time. Initially, the pattern has two peaks corresponding to the pattern of 5π/6-mode, but one peak is disappeared after 40ns and the pattern has only single peak of π-mode.

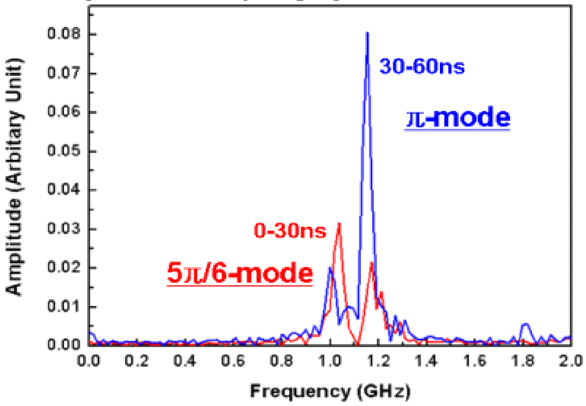

Fig. 8. Change of dominant mode as time

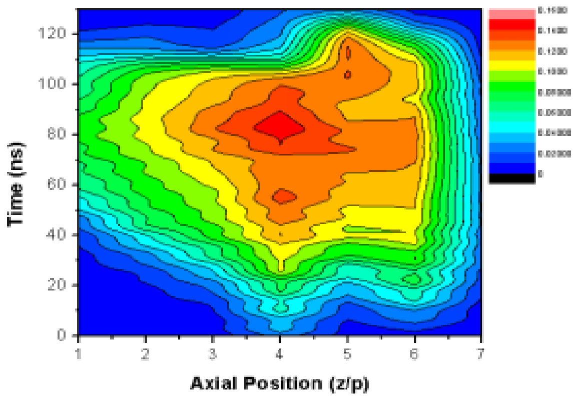

Fig. 9. Contour plot of magnetic field amplitude measured in axial direction and time.

The axial mode competition is attributed to the variation of electron's drift velocity during the stabilization period of the beam and beam-induced magnetic field.

A Vlasov antenna and an anechoic chamber have been prepared for radiated power and pattern measurement. The hot test is underway.

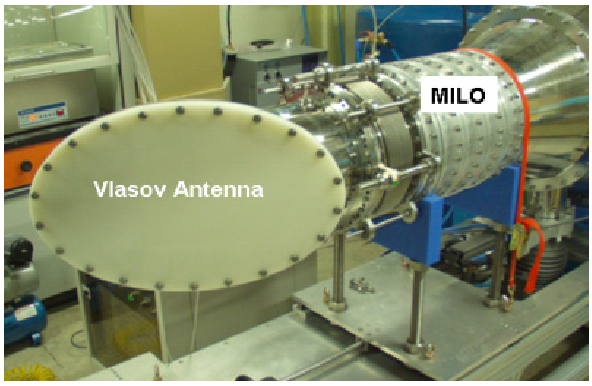

Fig. 10. Vlasov antenna

4. Summary

A simple MILO with an uniform cavities is fabricated and tested. Output power of 1.82GW corresponding to an efficiency of 11.5% is obtained. The axial mode competition is also observed using RF B-dot proves located at each cavities and is attributed to the variation of the drift velocity.

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