Simulation Study on Magnetically Insulated Line Oscillator for Efficient Operation[1]

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Abstract – The magnetically insulated line oscillator (MILO) which can generate the high-power microwave of gigawatt level draws an attention due to its compact size, high efficiency capability and light weight because of no-need of external insulation magnetic field. The effort to enhance the efficiency of MILO operated at π-mode has been made by several researchers. One of the main issues is the effective extraction of generated microwave power. A tapered structure can adjust the group velocity of the generated wave at π-mode to propagate effectively. For effective power extraction, the tapered structure should be well-matched to a transformer from slow-wave structure to coaxial transmission line and microwave mode converter from TM_{01} mode to TEM mode. The numerical study for the efficient operation is underway using various computational codes such as MAGIC PIC code and MWS (Microwave Studio). The simulation works by other groups is benchmarked by PIC code, MAGIC. Along with the circuit study, a design of a pulsed power machine of 500 kV, 30 kA in 100nsec pulse duration using Blumlein pulse forming line is being prepared for future experimental study.

1. Introduction

The magnetically insulated line oscillator (MILO) is a crossed-field microwave tube that can generate gigawatt-class high-power microwave. The MILO has dc magnetic field generated by intrinsic electron current in the circuit. Thus, there is no need for external magnetic field. Because the self magnetic field inhibits electrical breakdown of the anode-cathode gap, it (self-insulation) enables the tube to handle extremely large input power (more than tens gigawatts) at modest applied voltage (several hundred kilovolts). Consequently, the MILO draws an attention due to its compact size, light weight, and high-efficiency capability.

In the initial experiment [1], an efficient extraction of microwave power was the most significant problem in order to get a good efficiency. They extracted the microwave power to cavity top, but the coupling to the cavity top made problems of mode competition and electron flow disruption, and dropped the efficiency (less than 1%). The use of an axial extraction of microwave power through a coaxial output section gave a good performance with 7–13% peak power efficiency [2–4]. They employed a vane [2, 3] or a set of tapered vanes [4] with changing its radius in order to match with the output coaxial section.

It seems to be possible to increase peak power efficiency more than one of previous studies. Even though a part of the current for self-insulation magnetic field can hardly use to a rf conversion of electron beam, the efficiency was quite low considering that magnetron has high efficiency about 70%. It is hard to confirm that the previous designs were optimized.

A numerical study for efficient MILO design is underway by using various computational codes such as MAGIC PIC code, HFSS (high-frequency structure simulator), and MWS (microwave studio). A dispersion relation has been calculated and compared with HFSS and MWS. The simulation works by other groups is benchmarked by PIC code, MAGIC (section 3). Along with the circuit study, a design of a pulsed power machine of 500 kV, 30 kA, in 100 nano-second pulse duration using Blumlein pulse forming line (PFL) is being prepared for future experimental study (section 4).

2. Dispersion Relations of MILO

The dispersion relations of MILO can be driven by a calculation of dispersion for coaxial linear magnetron [5]. Resonant frequencies can be obtained from the condition of matching between cavity region and interaction region under slow-wave structure cavities; that is analog with continuity of electromagnetic fields. Fig. 1 shows dispersion relations for 5-cm period, 1-cm vane thickness, 3.75-cm cathode radius, 7.5-cm vane radius, and 15-cm cavity top radius. Although the calculation [5] assumes that the field is uniform on the bottom of cavity (perimeter between cavity region and interaction region), it is very well-matched (less than 1% error) with simulation results of HFSS and MWS.

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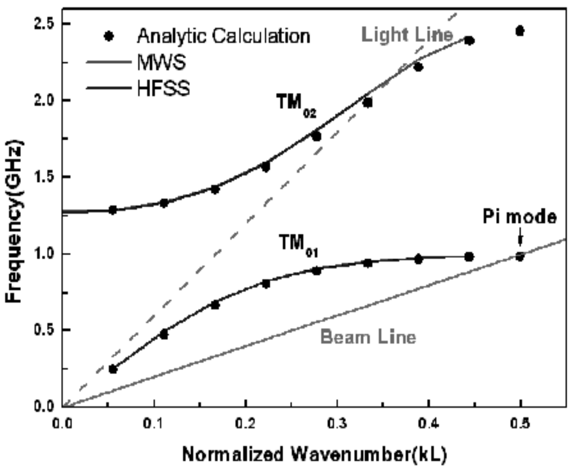

Fig. 1. A dispersion relation of MILO for 5-cm period, 1-cm vane thickness, 3.75-cm cathode radius, 7.5-cm vane radius, and 15-cm cavity top radius

3. Benchmarking for Tapered MILO

We have done benchmarking by using MAGIC PIC code for Tapered MILO [4]. The benchmarking model is in Fig. 2.

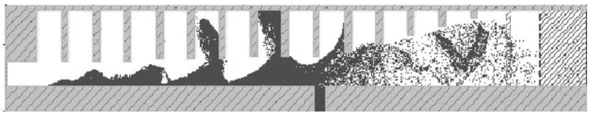

Fig. 2. A model of MAGIC PIC code for benchmarking

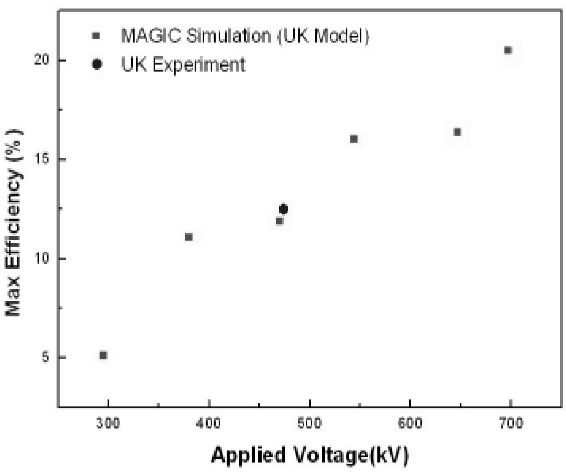

Fig. 3. A comparison of peak power efficiency with the reported result of tapered MILO

MAGIC PIC simulation results (Fig. 3) show that the reported experiment result of tapered MILO is exactly on the trend of efficiency versus applied voltage. This result tells us that the MAGIC PIC code can very well simulate the performance of MILO.

4. A Preparation of Pulsed Power

A 500-kV, 30-kA, and 100-ns pulsed power is preparing with 2-m long and water-filled Blumlein PFL [6, 7]. The matched load impedance should be about 14 Ohm. The output energy per pulse is 2-kJ. The breakdown voltage of line is 1100-kV.

5. Summary

A numerical study for efficient MILO design is underway by using various computational codes such as MAGIC PIC code, HFSS, and MWS. A dispersion relation has been calculated and compared with HFSS and MWS. The simulation works by other groups is benchmarked by PIC code, MAGIC. Along with the circuit study, a design of a pulsed power machine of 500-kV, 30-kA, in 100-ns pulse duration using water-filled Blumlein pulse forming line is being prepared for future experimental study.

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