IMPROVEMENT OF EFFICIENCY OF KLYSTRON TO APPLY THE CPD METHOD

K. Watanabe, KEK, Tsukuba, Japan

Abstract

A high power RF system for the particle accelerators needs large electrical power in the operation. Improvement of efficiency is also always required as a technology component for the energy saving.

To improve efficiency of a high-power rf source, the CPD (Collector Potential Depression) method already was applied a Gyrotron to recovery the electrical energy form the dissipated power in the collector. The CPD is an energy-saving scheme that recovers the kinetic energy of the spent electrons after generating rf power. A proto-type klystron (E37703 CPD) was fabricated at 2013, to recycle an existing klystron of Toshiba E3786. The purpose of our study is to demonstrate the proof-of-principle of the CPD method to apply a klystron. A plane of R&D at KEK is reported in this meeting.

INTRODUCTION

Two examples to obtain the high efficiency of the klystron are shown as following, (1) more strong bunching on the output cavity to optimize rf design (increase number of cavities compare with existing model) and electron gun (chose multi-beam gun)[1], (2) dissipated power on the collector reuses to do the energy recovery by CPD (Collector Potential Depression) method. The CPD method already was applied a Gyrotron to recovery the electrical energy form the dissipated power in the collector. It was worked very well [2].

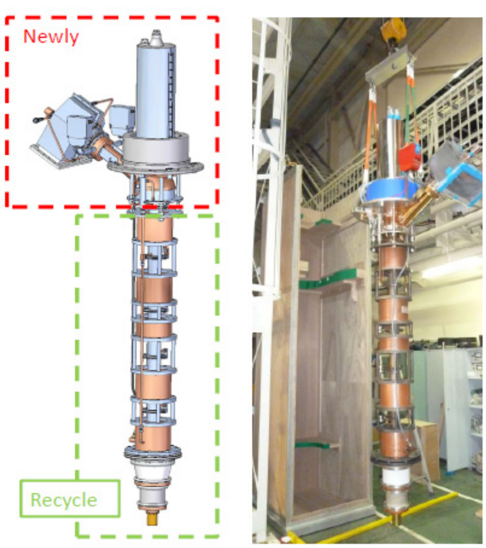

Figure 1: the proto-type CPD klystron (E37703 CPD).

At KEK, a proto-type CPD klystron (CW, 508.88 MHz) was fabricated using by existing klystron (it was used at TRISTAN and KEKB.) at 2013, to demonstrate the proof-of-principle of this method to apply a klystron (see figure 1). In the fabrication, the recycled components were the electron gun, the input cavity and the middle cavities in drift tube. Newly fabricated components were the output cavity, the output coupler and the collector with CPD gap. These parts were bonded by brazing. The parameters of the existing and newly klystrons are shown in Table 1. The range to apply CPD for a klystron is restricted to the un-saturate situation. Then, the efficiency of klystron has the possibility that 10~20 % is improved. However, at present three issues are assumed for the operation. We must design and build an experiment setup in consideration of the health hazards by exposure of the electromagnetic wave and the radiation. We are estimating the amount of field level of rf leakage from the proto-type klystron to design rf shield with some access port by the CST-studio (Particle studio). Moreover, commercial viability of CPD klystron is required development of KPS (Klystron Power Supply) to optimize it. At present, it is not the category of this examination. This is a future task.

Table 1: Parameters compared with E3732 and E37703 CPD

Item	E3732 (E3786)	E37703 CPD
Frequency	508.89 MHz	508.89 MHz
Maximum rf output power	1.2 MW (saturation)	500 kW (un-saturation)
Efficiency	20~65%	w/o CPD 20~60% w/ CPD 40~80%
Collector	1 MW	500 kW
Cooling method of collector	Vapor cooling (130 l/min ＋ AFC)	Water cooling (360 l/min)
Cooling items	Klystron body Output coupler Focusing coil	Klystron body Output coupler Focusing coil Ceramics insulator Microwave absorber
KPS	B-type x 1	B-type x 1 PS for CPD
Vk	47~90 kV	47~90 kV
Va	25~60 kV Ib max = 20 Adc	25~60 kV Ib max = 20 Adc
Vc (CPD)	none	0 ~ -50 kV

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HOW TO APPLY THE CPD METHOD TO KLYSTRON

Figure 2 shows a schematic diagram of conventional design and one for CPD to apply klystron. An insulator needs to insert between the body and the collector to isolate the collector from body (ground). High voltage (Vc) is applied to the gap between collector and body to recovery as electrical energy form spent electron beam after generating rf power.

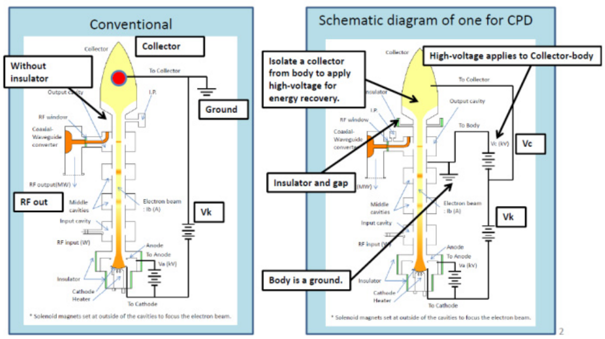

Figure 2: Schematic diagram of the conventional and one of CPD to apply klystron.

In case of the klystron, the spent electron beam has large energy spread through electromagnetic interaction in the cavities at the saturated operation. Therefore, the collector potential cannot be increased beyond the lower limit of distribution of the spent electron beam, otherwise backward electrons hit the cavities. To apply the potential which can obtain satisfactory effect, the operation mode of klystron is restricted to the un-saturate situation with high cathode voltage (Vk = 90 kV).

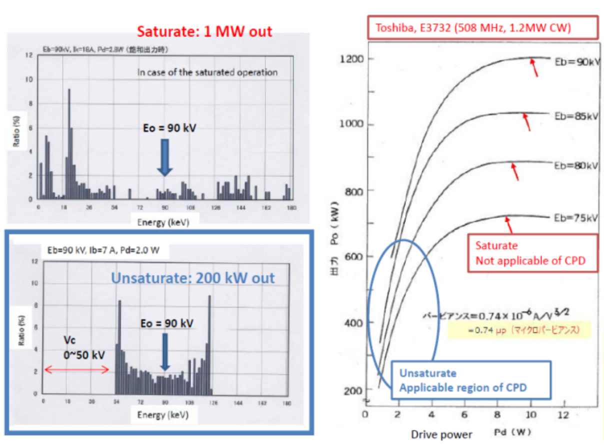

Figure 3: Energy distribution of the spent electron beams after pass through the output cavity of the klystron.

Figure 3 shows the energy distribution of the spent electron beams after pass through the output cavity of the klystron. The improved efficiency is defined by ratio of Vk and Vc. The amplitude of Vc is depend on the energy distribution of the spent electron beam, then the amplitude of Vc must be controlled to keep the maximum efficiency for all power range.

ISSUES MUST BE ADDRESSED FOR CPD KLYSTRON

The structure around CPD gap is used only dielectric materials to isolate between the collector and the body. In the operation, the high voltage of Vc is applied to physical gap. In this case, three issues must be addressed for the operation. That is; (a) the corona discharge and breakdown around ceramics insulator and the outside of klystron, (b) the rf leakage from the physical gap include the dielectric materials and (c) the structure of the radiation shield to cover top of klystron. Figure 4 shows the cross-section drawing at the gap.

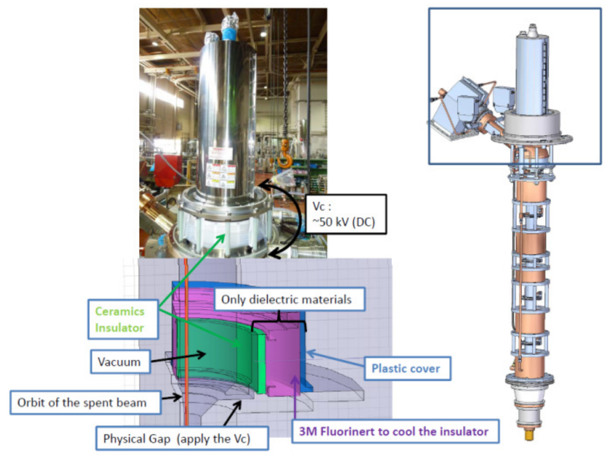

Figure 4: The structure around CPD gap.

RF Leakage from CPD Gap

The amount of field level of rf leakage exciting by spent electron beam is under estimating by HFSS and CST-studio (PCI solver) to design the rf shield for the health hazards by exposure of the electromagnetic wave. Figure 5 shows an example of the calculation result using by HFSS. This result shows the rf leakage to pass through drift tube and CPD gap at 1 MW rf output power form output cavity to check the cut-off frequency of drift tube. The leakage field level of fundamental mode (500 MHz) and 2nd order mode (1000 MHz) are very small, it fills the regulation value of the low (28 V/m at UHF).

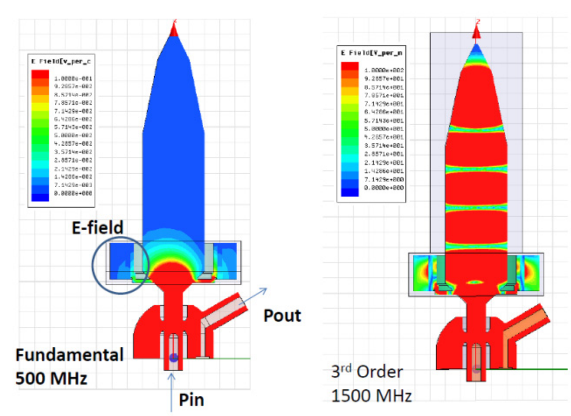

Figure 5: Calculation result to check the performance of cut-off frequency of drift tube for each mode.

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The 3rd order mode (1500 MHz) must be care because of the field level of rf leakage has possibility over the regulation value.

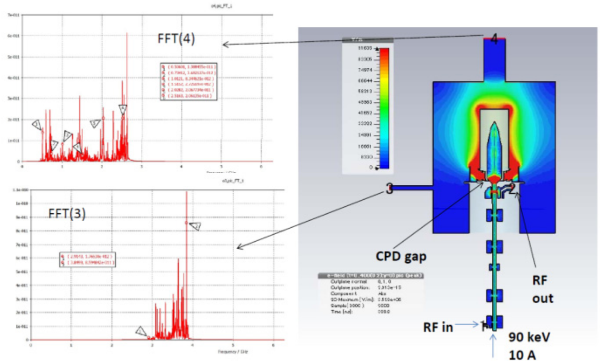

Figure 6: The amount of wake field level excited by modulated electron beam.

Figure 6 shows the calculation result using by CST-studio. This result shows that when the modulated electron beam passes through at CPD gap, the strong leakage field excites from klystron. The rf shield and some access ports must be built around the klystron in consideration of the cut-off frequency. In the DC aging of the klystron, the rf leakage does not generate from the gap.

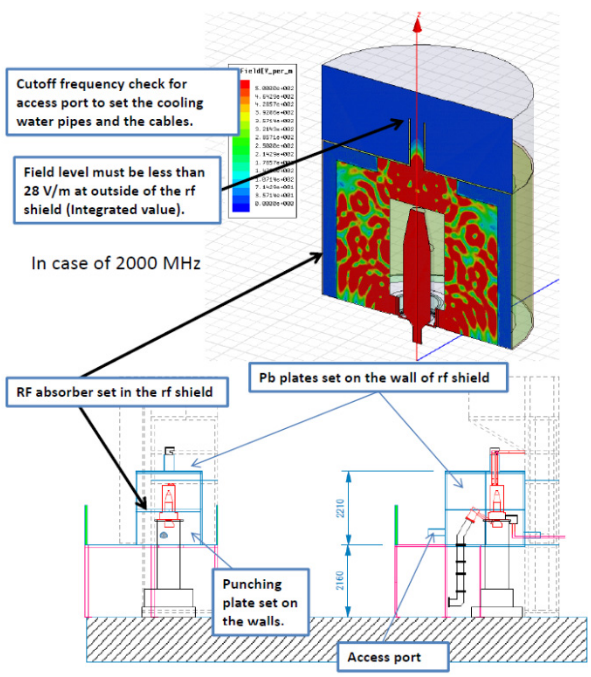

Figure 7: Structure of the rf and radiation shield.

Structure of RF and Radiation Shield

Figure 7 shows a drawing of rf and radiation shield. The klystron will be installed in metal box. The high power type microwave absorber is put in the rf shield to reduce the field level of rf leakage. And some components in the shield are also protected using by microwave absorber from exposure to rf leakage.

FUTURE PLANS

We are planning three stages to demonstrate the proof-of-principle of the CPD method for klystron after Phase 2 of SuperKEKB. First stage is to check whether to drive as normal klystron include DC aging and RF output. And the amount of field level of rf leakage and the radiation level are also measured in this stage. Second stage is the measurement of the output signal from collector without Vc under the condition of small collector loss. The output signal from collector will be terminated to the water cooling type high-power dummy load. Third stage is the measurement of recovery power from the collector with Vc. Another klystron with Marx-circuit will be used as the high-power dummy load to terminate recovery power.

We must be considered that how to design the KPS to optimize the CPD klystron. Figure 8 shows a schematic diagram of KPS.

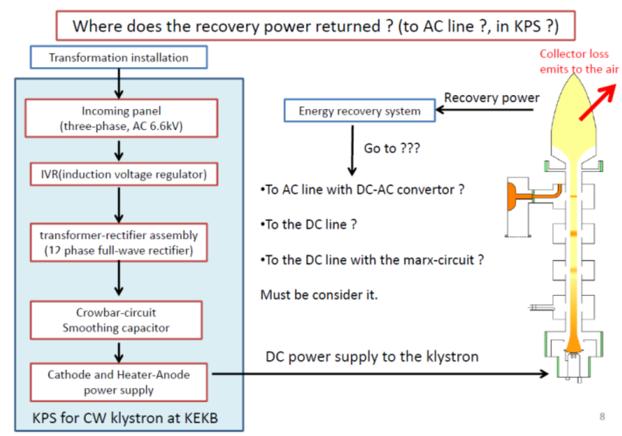

Figure 8: Schematic diagram of KPS.

CONCLUSION

A proto-type CPD klystron was fabricated at 2013 to recycle an existing klystron of Toshiba E3786. (It was used to TRISTAN and KEKB.) Target is a proof-of-principle of CPD to apply CW klystron in the unsaturated region. Now, we are doing the design of rf and radiation shield to optimize the CPD klystron. The test to demonstrate the proof-of-principle of the CPD method for klystron is planning to after Phase2 of SuperKEKB. This CPD klystron will not be installed in SuperKEKB in the future. Commercial viability of it is required development of KPS (Klystron Power Supply) to optimize it. At present, this is a future task.

REFERENCES

[1] D. Constable, "High Efficiency Klystron Development for Particle Accelerators", presented at eeFACT2016, Daresbury, UK, October 2016, paper WET3AH2.

[2] K. Sakamoto *et al.*, "Major Improvement of Gyrotron Efficiency with Beam Energy Recovery", *Phys. Rev. Lett.*, vol. 73, no. 26, p. 3532, Dec. 1994.

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