

Progress on high efficiency klystron

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Outline

◆ R&D status

- 1st klystron prototype high power test
- High efficiency klystron manufacture status
- High power test stand status
- Design progress

◆ Future plan

◆ Summary

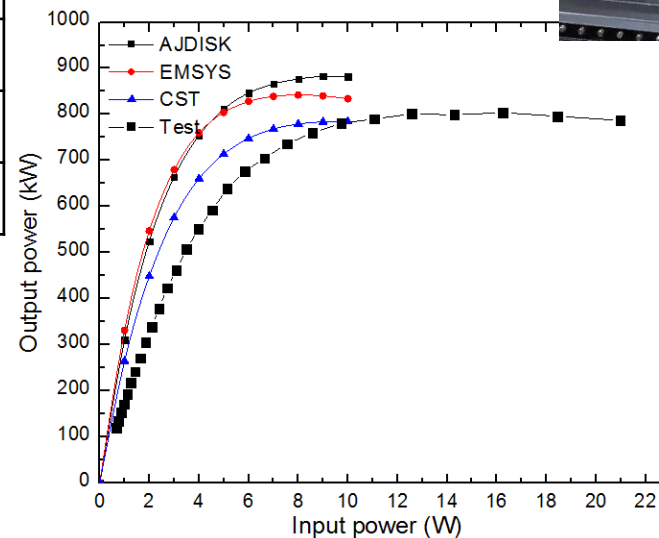
R&D Status

1st prototype high power test status

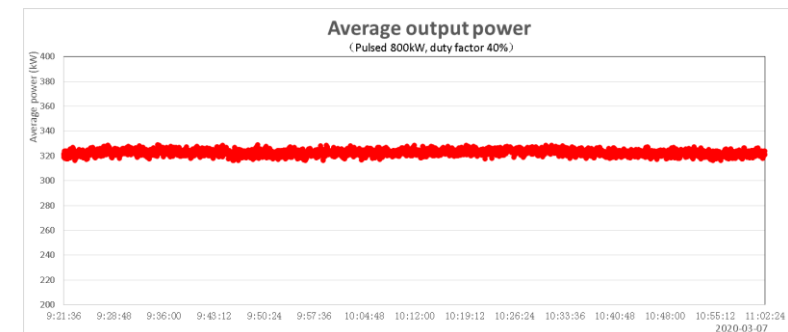
◆ Phase I:

◆ 400 kW CW test and 800kW pulsed conditioning from Jan.3-Mar.9 2020

| Parameters | Design | Test |
|---|-----------|------|
| Operating frequency (MHz) | 650 | 650 |
| Beam Voltage (kV) | 81.5 | 80 |
| Beam Perveance ($\mu\text{A}/\text{V}^{3/2}$) | 0.65 | 0.7 |
| Efficiency(%) | 65 | 62 |
| Saturation Gain(dB) | ≥ 45 | 47 |
| Output power(kW) | 800 | 800 |
| 1 dB Bandwidth(MHz) | ≥ 1 | 1.8 |



High power test stand



Pulsed 800kW⁴

1st prototype high power test status

◆ Phase II:

Phase II test is started from Aug. 24 2020, CW power is up to **490kW** on Sep.1 2020. Arc happened on load, conditioning is stopped.



Cold test for waveguide system



Test stand



800kW Load

1st prototype high power test status

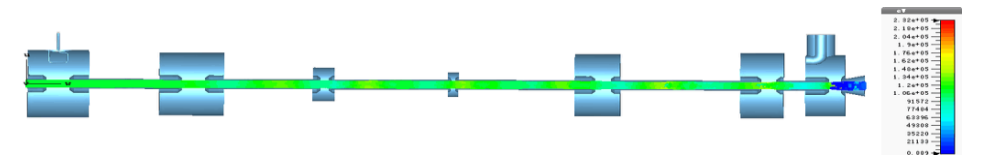
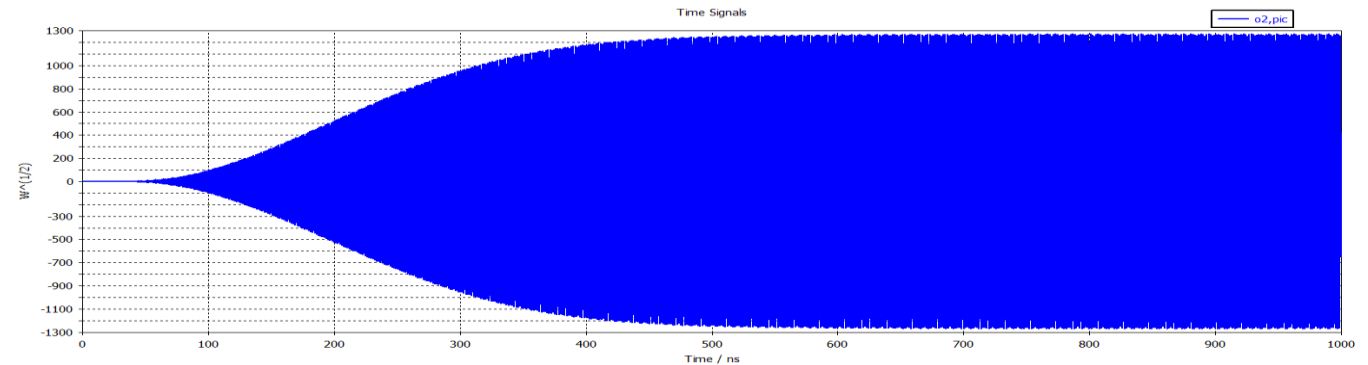
◆ Phase III:

Phase III test is started from March. 2021, CW power is up to about **700kW** on March. 31 2021 with new 800kW load. Window is cracked at 700kW power and higher power conditioning is stopped.

High efficiency klystron

Design parameters

- ① CST 3D efficiency: 77%
- ② Output power: 808.3kW(Beam power 1.05MW)
- ③ Gain(3D): 48.3dB
- ④ Bandwidth(2.5D): $\geq 0.8\text{MHz}$



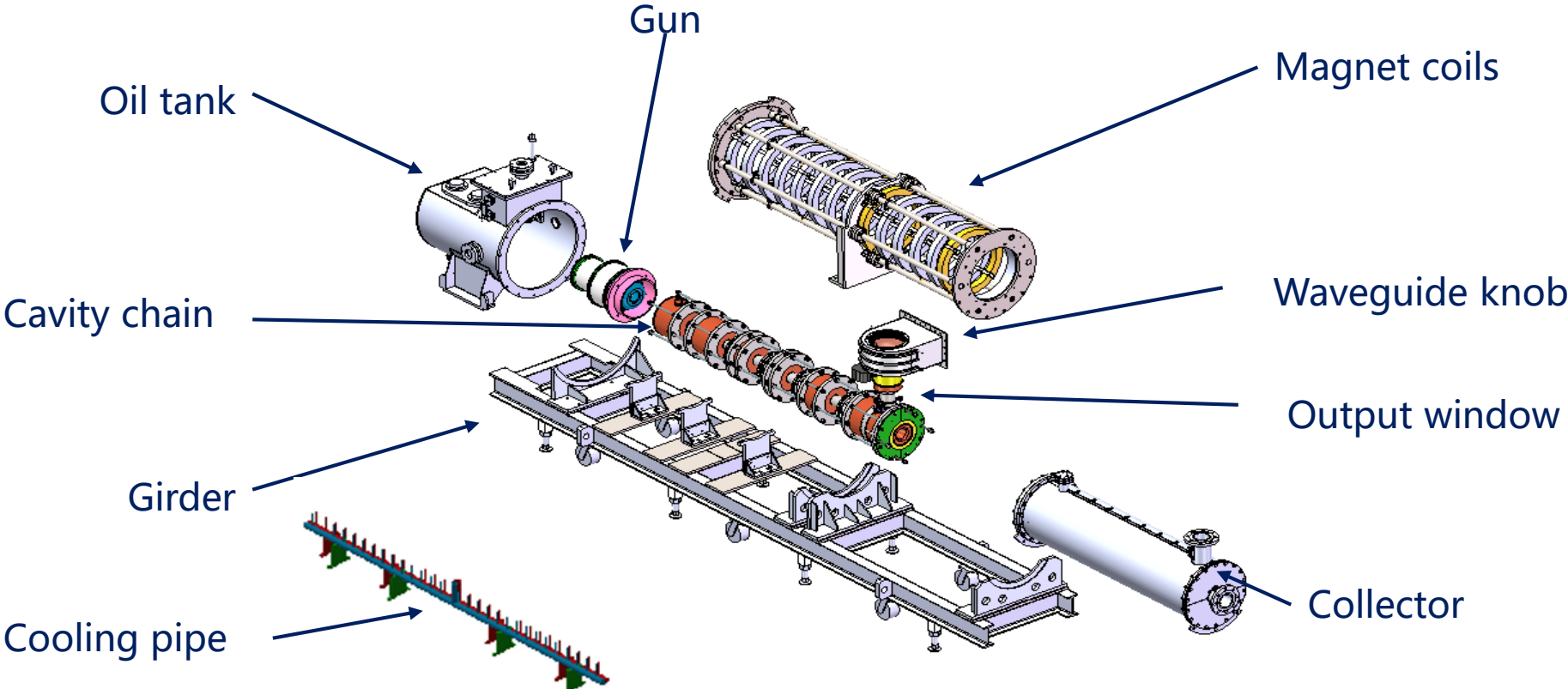
| Post-Process | |
|--------------|------------|
| Time | 1000 |
| Energy | 171.24e+09 |
| Beam | 171.24e+09 |
| Time (ns) | 1000 |
| Particles | 200000 |

Manufacture status

- ① The high efficiency klystron prototype is being fabricated in Chinese company.
- ② The klystron prototype will be completely manufactured at the end of June and then high power conditioning and test will be started in PAPS test stand.

Mechanical design

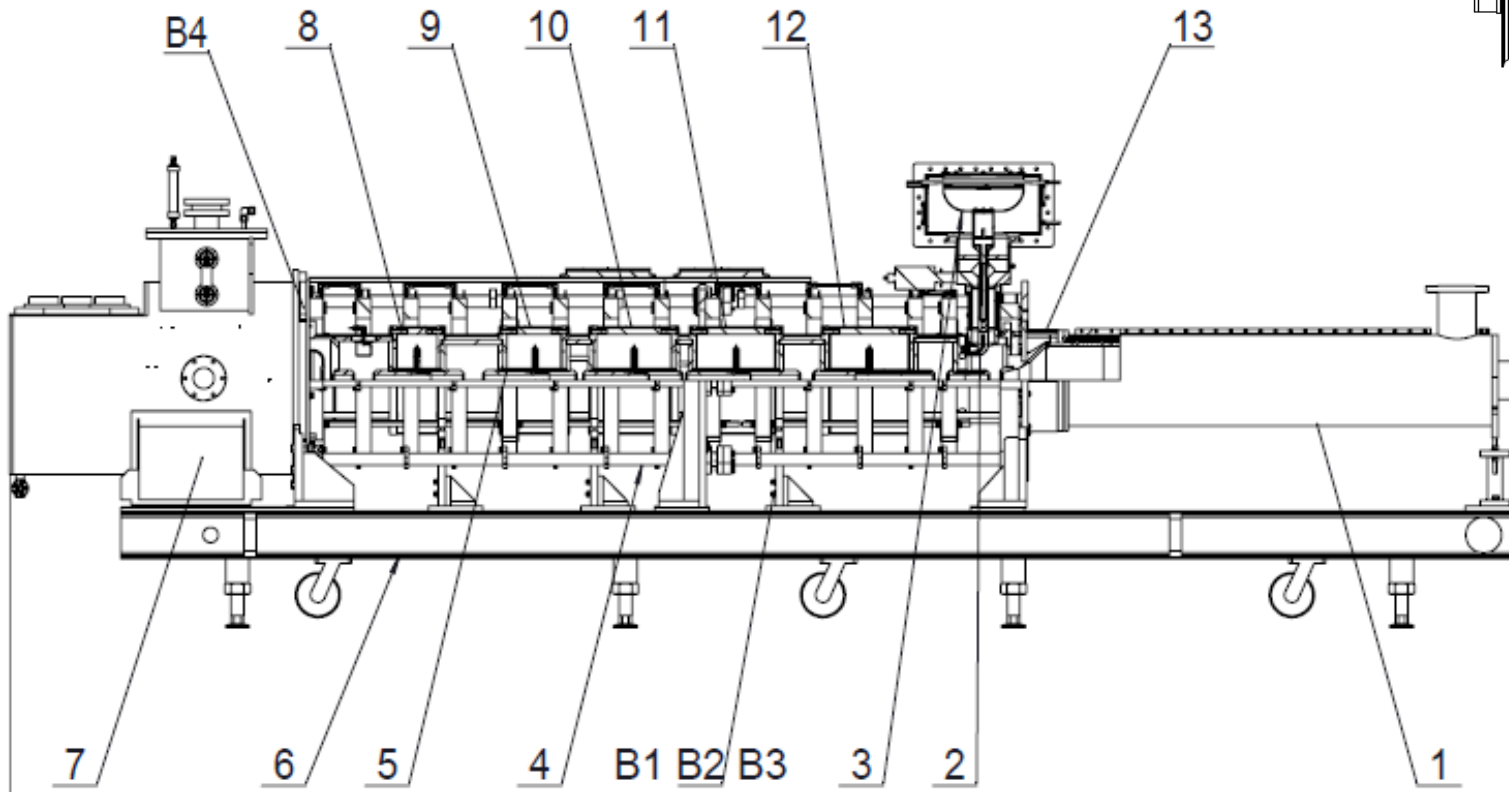
After completing mechanical design at the end of 2020, klystron prototype manufacture is collectively started.



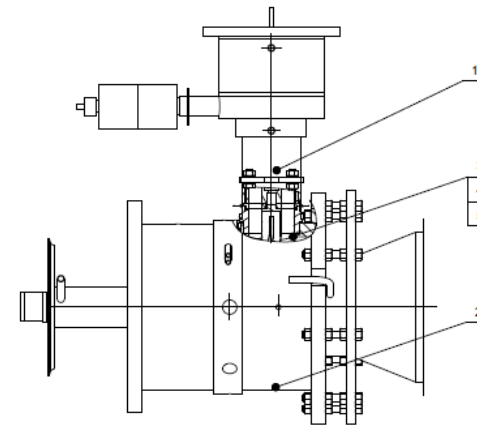
Klystron parts

Mechanical drawing

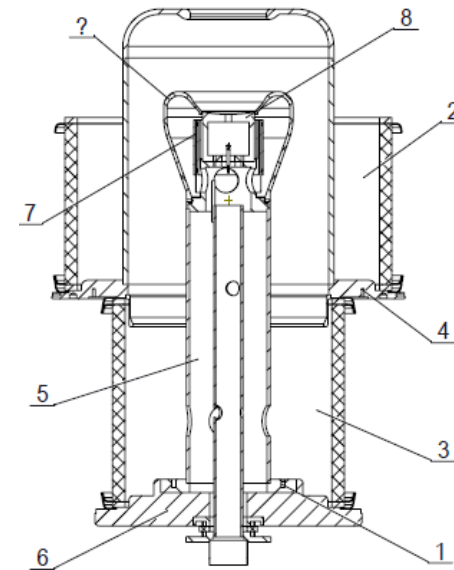
Klystron mechanical drawing



Klystron layout



Cavity



Gun

Fabrication status

Electron gun



Ceramic insulator



Focusing electrode



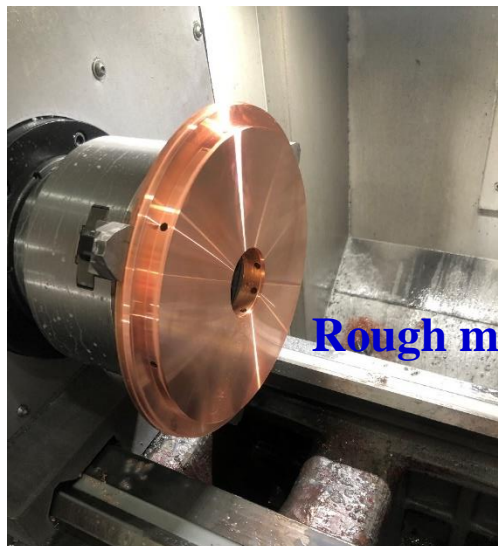
Modulator anode



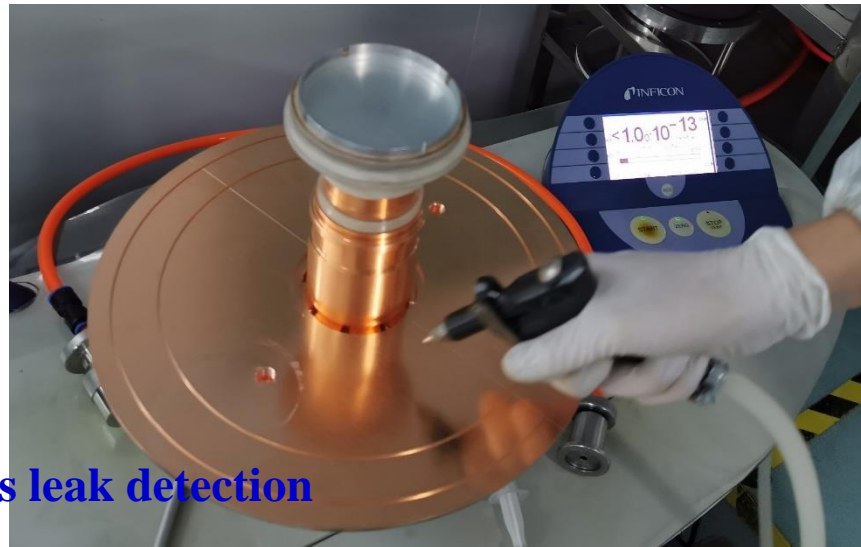
Cathode Assy.¹¹

Fabrication status

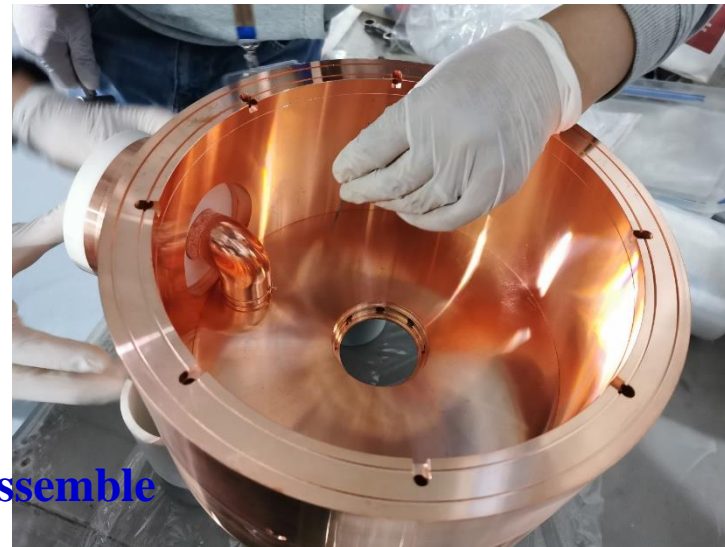
Cavity chain



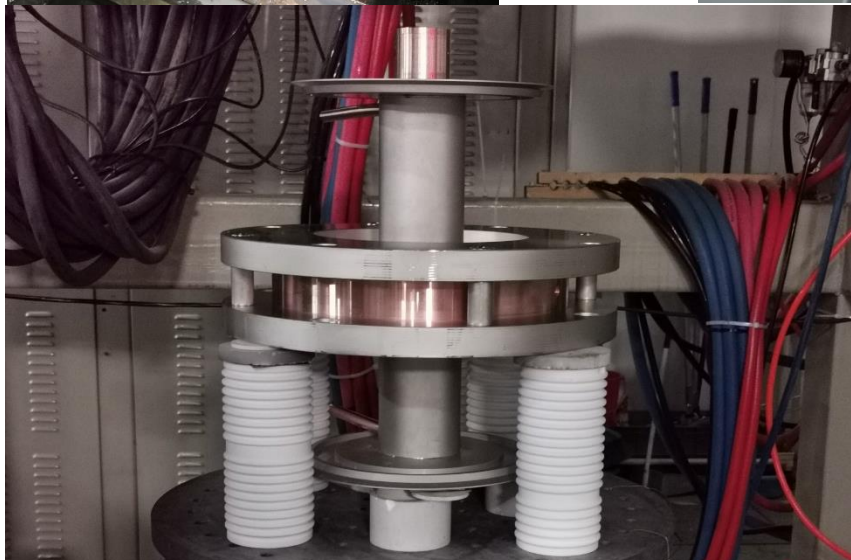
Rough machining



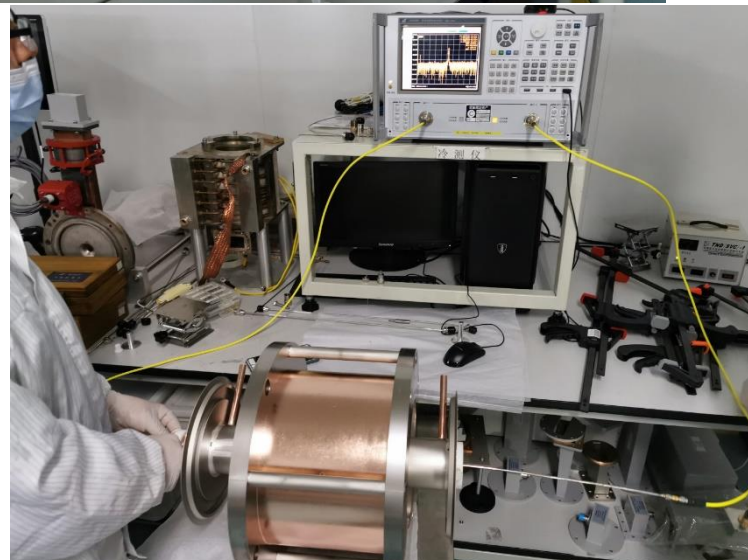
Parts leak detection



Parts assemble



Cavity brazing



Cold test



Storage with nitrogen

Fabrication status

Collector

Rough turning is finished, fine machining is started



Collector body



Water jacket

Fabrication status

Focusing magnet

Magnetic bar is ready for machining , enameled wire and copper pipe are processing.



Magnetic bar



Copper pipe

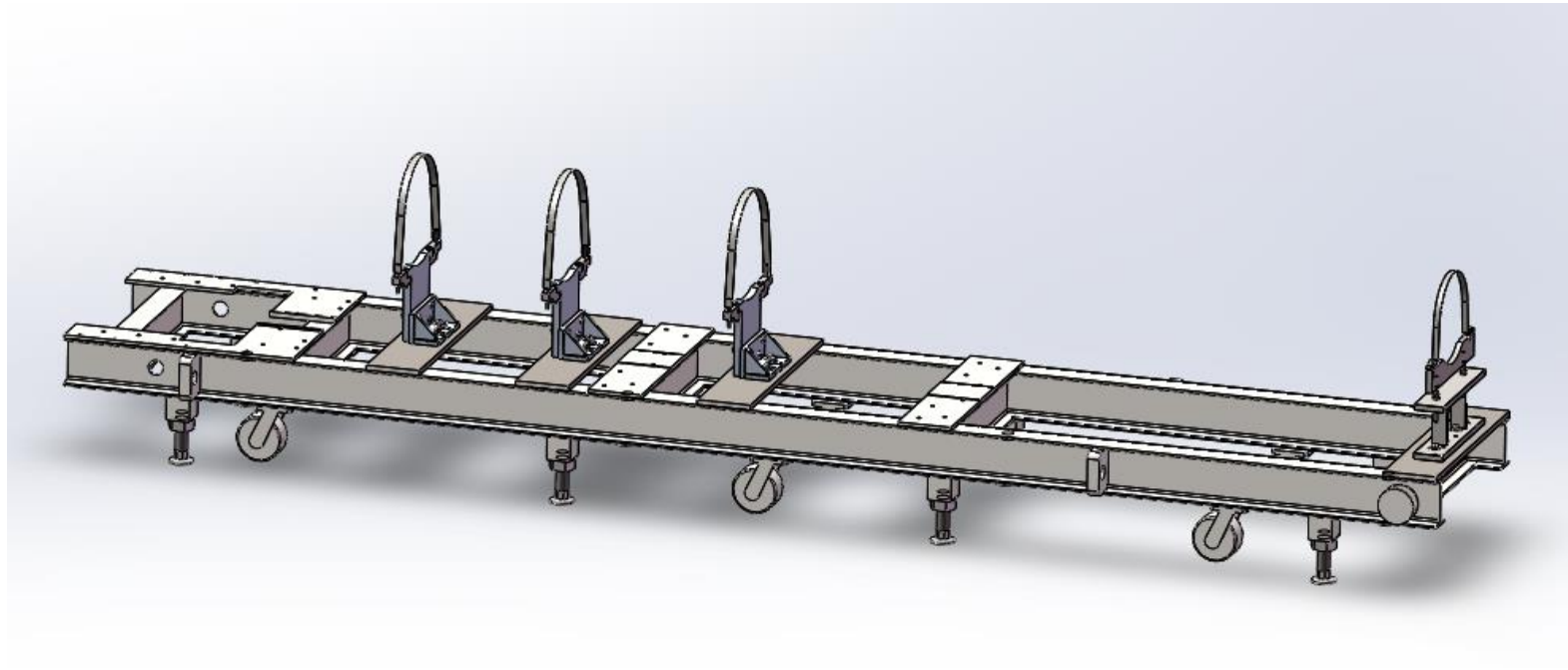


Enameled wire

Fabrication status

Klystron girder

Klystron girder is processing in collaboration company.



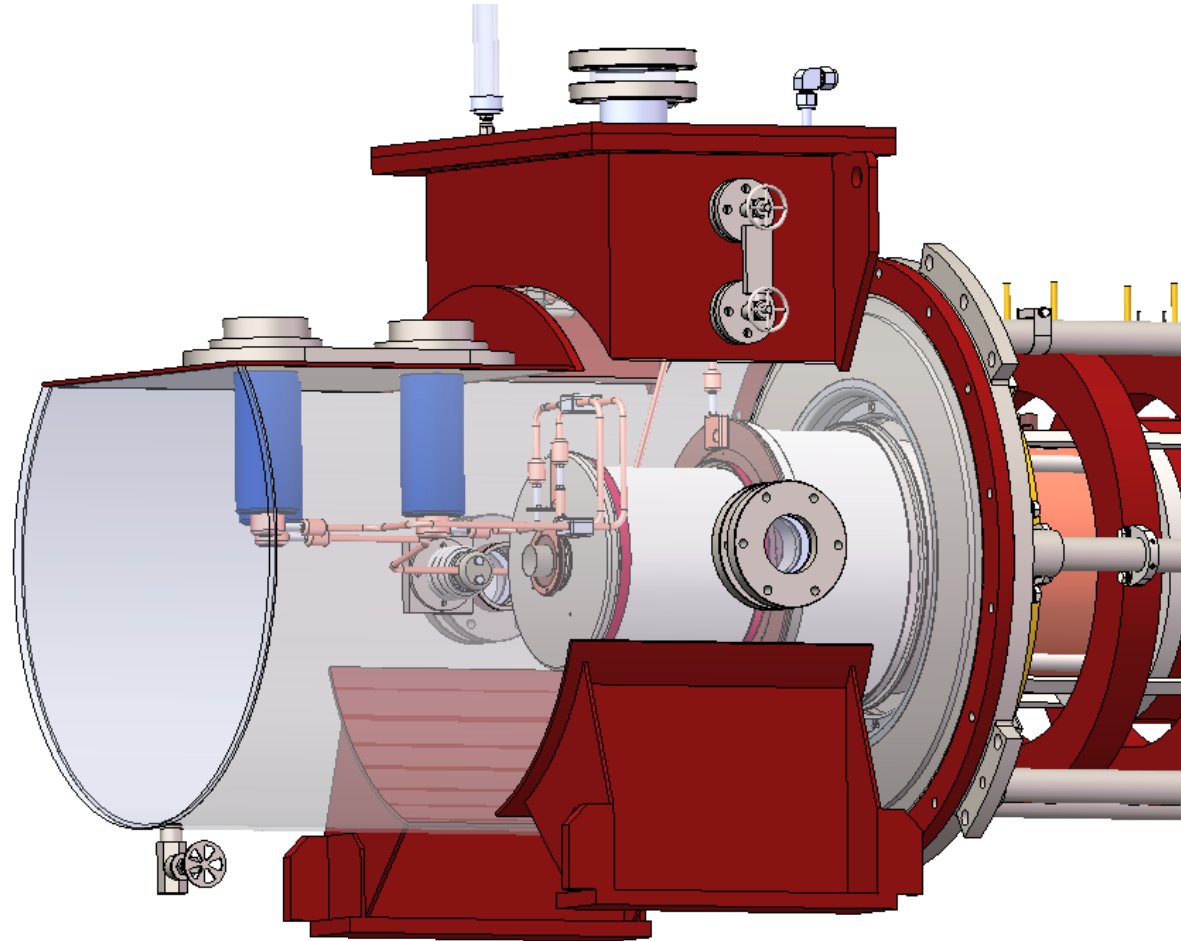
Fabrication status

Oil tank

Ceramic connector is ready and other parts are also processing in collaboration company.



Ceramic connector



Oil tank 3d drawing

High power test stand

130kV/16A PSM power supply is under adjusting and testing in PAPS site.



PSM Power supply

Multi-beam klystron

1) Design Parameters

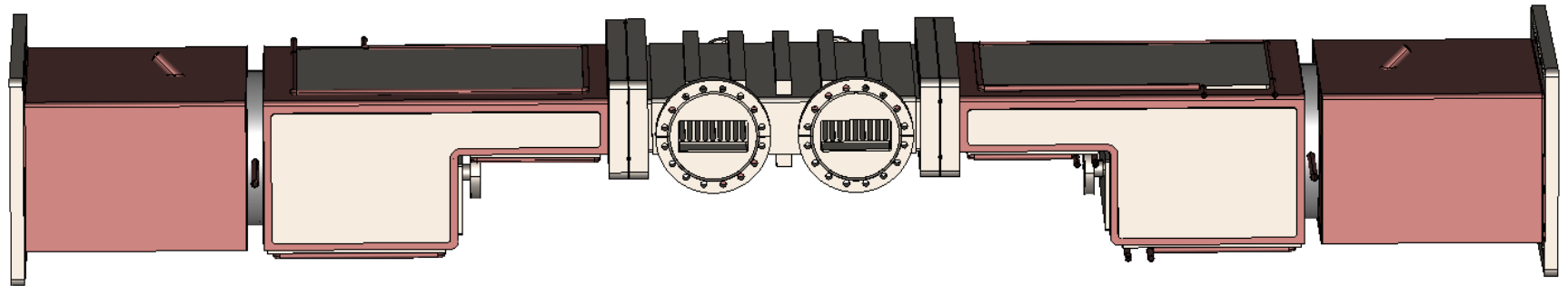
| Parameters | Unit | Value |
|--------------------------------|---------------|------------|
| Gun Voltage | kV | 54 |
| Beam number | | 8 |
| Beam perveance | μP | 0.2 |
| Output power | kW | 800 |
| 1dB bandwidth (3-D simulation) | MHz | ± 0.75 |
| Efficiency(3-D simulation) | % | 80.5 |

The MBK physical design is finished, including the interactive cavity, electron gun, focusing solenoid, window and collector. The final efficiency is about 80.5% with 3d simulation code.

Multi-beam klystron

2) Current status

- ◆ The mechanical design of MBK is in progress.
- ◆ The mechanical design of output-window prototype is finished.
- ◆ The output-window prototypes and the test bench is under manufacturing.

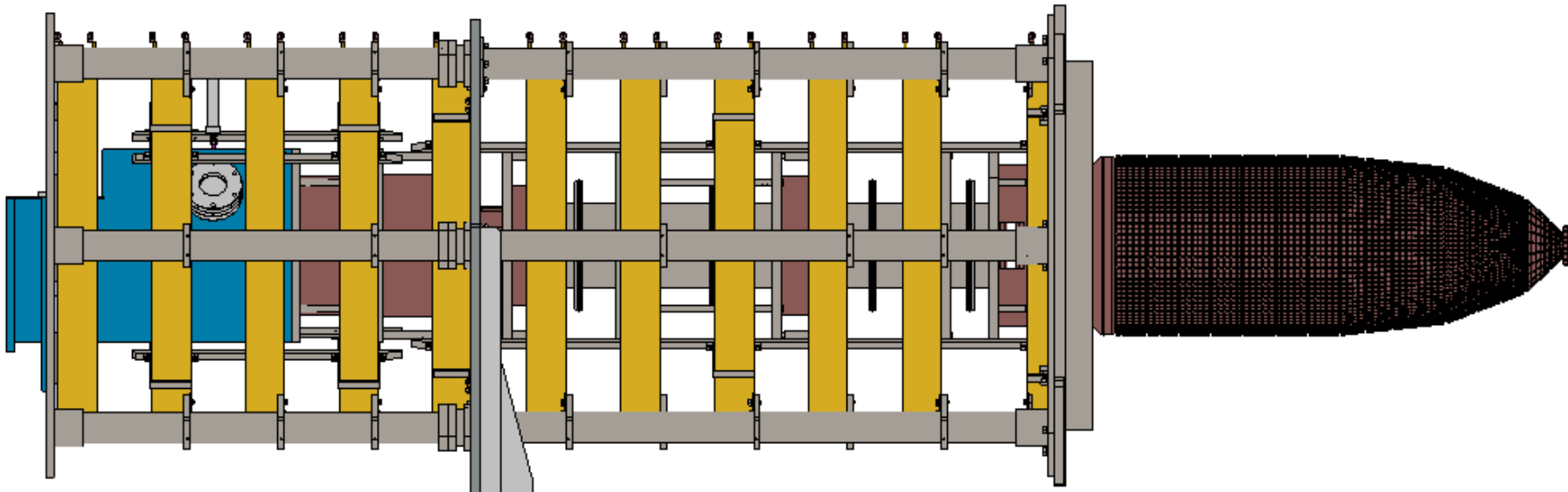
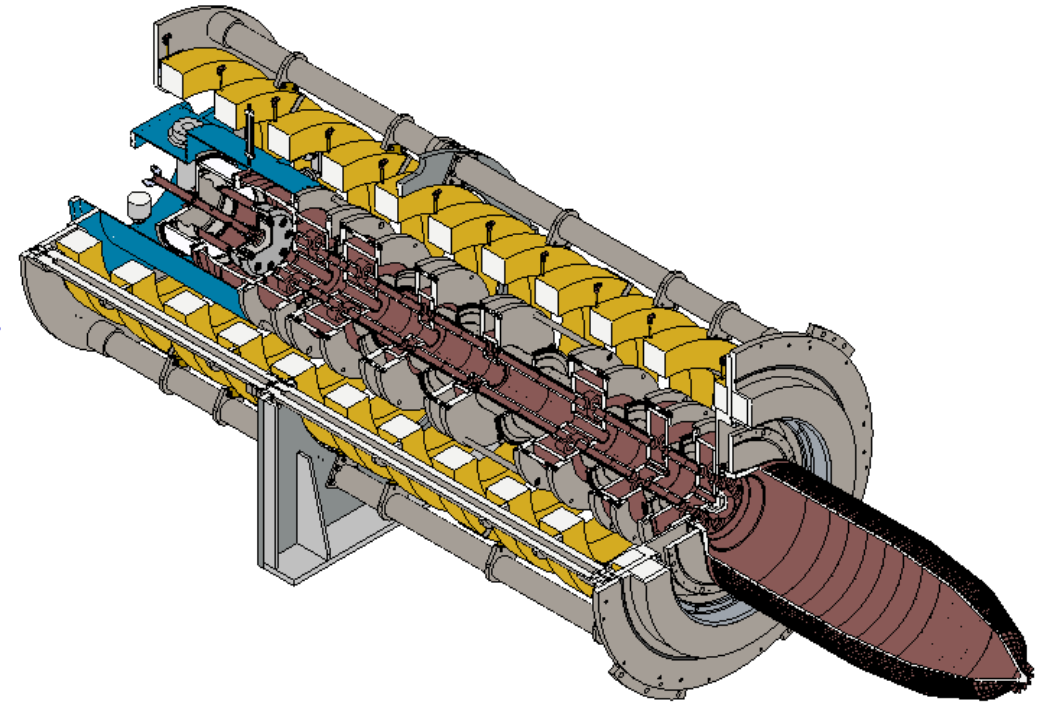


Test bench of the output-window prototype

Multi-beam klystron

3) 3d mechanical drawing

- ◆ The preliminary 3d mechanical drawing is finished.
- ◆ Design review will be done in the near future.



Future plan

Future plan

The klystron with RF power conversion efficiency:

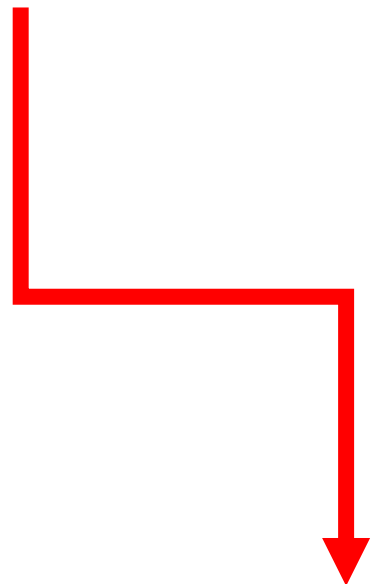
Main methods:

- ① **Smaller perveance and the weaker space charge effect.**
- ② **Multi-beam klystron.**

NOW WORK @IHEP



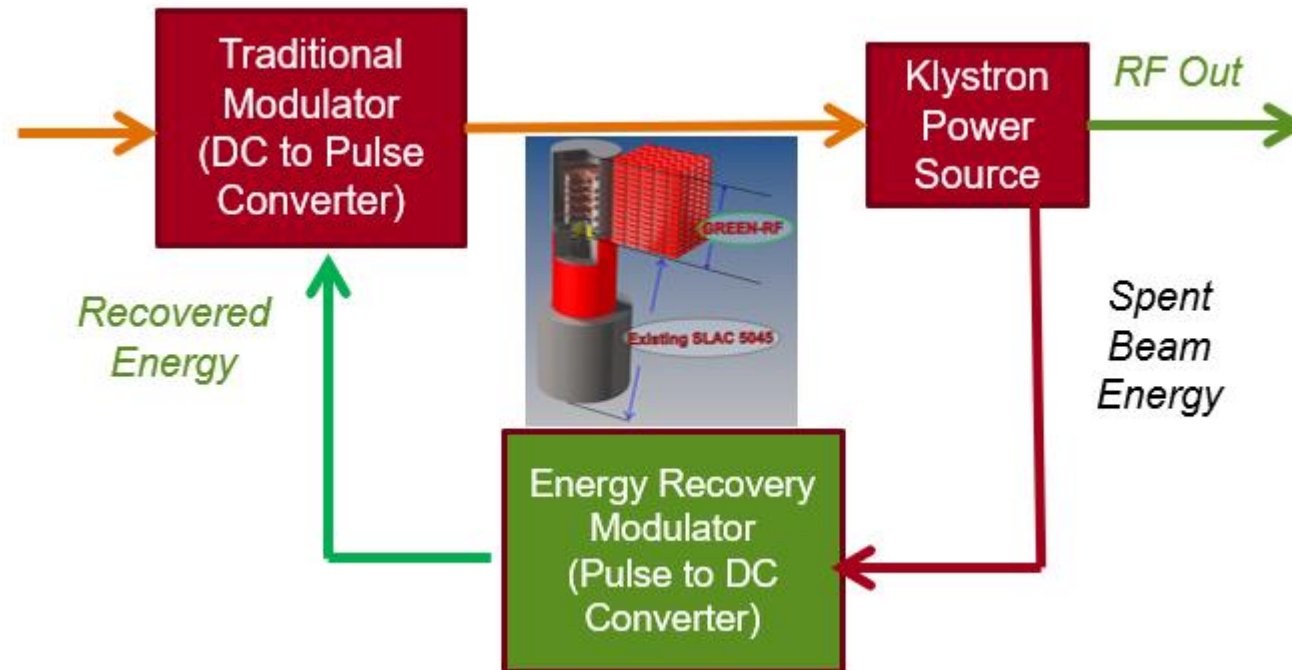
Efficiency goal: 77%



Efficiency goal: 80%

Future plan

- ① In order to **further** improve the efficiency of klystron, on the basis of improving the efficiency of high-speed modulator, the power dissipated in the collection stage is recovered to the high-voltage power supply / modulator.
- ② The waste energy collected can be reused.



Future plan

For klystron

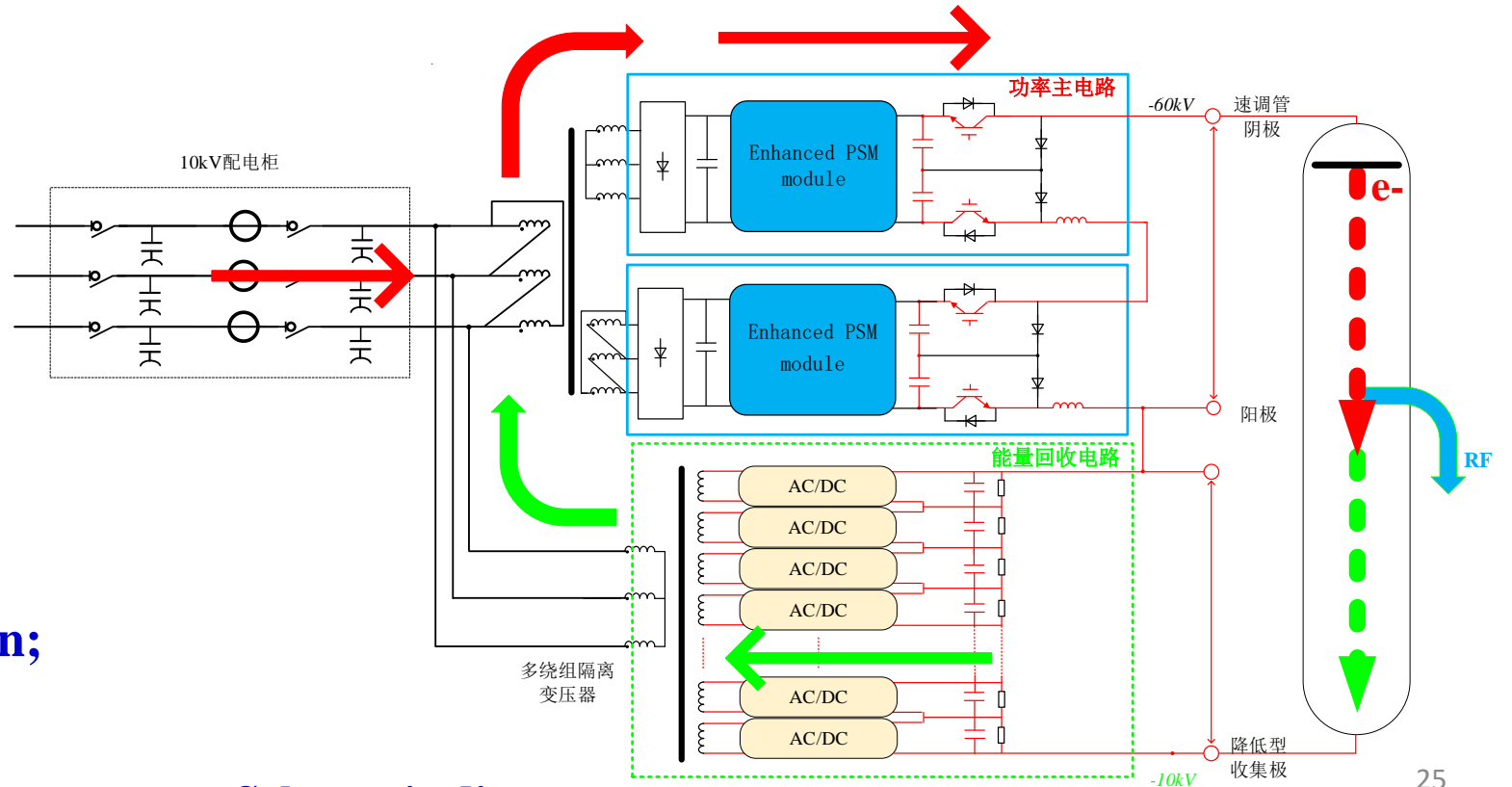
- ① So called MSD (Multi-stage Depressed Collector) klystron was developed to improve the efficiency.
- ② Our target is to improve klystron efficiency with MSD method in the **unsaturated region.**

Future plan

For power supply

① Depressed collector/potential depression technology is the way that dissipated power in the collector is back to PS by depressed collector potential.

- No recycling mode;
- Start up initial mode;
- Recycling mode;
- Recovery mode of pulse operation;



Schematic diagram

Summary

- ① The manufacture of high efficiency klystron prototype will be completed at the end of next month.
- ② MBK will be immediately manufactured after design review.
- ③ The scheme of energy recovery power supply is proposed and a small prototype module is developing in IHEP.
- ④ Depressed collector method will be used for klystron improvement based on high efficiency klystron design in the near future.

Thanks for your attention!