Development of new rotating-disk-type production target at J-PARC Hadron Experimental Facility

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KEK/J-PARC

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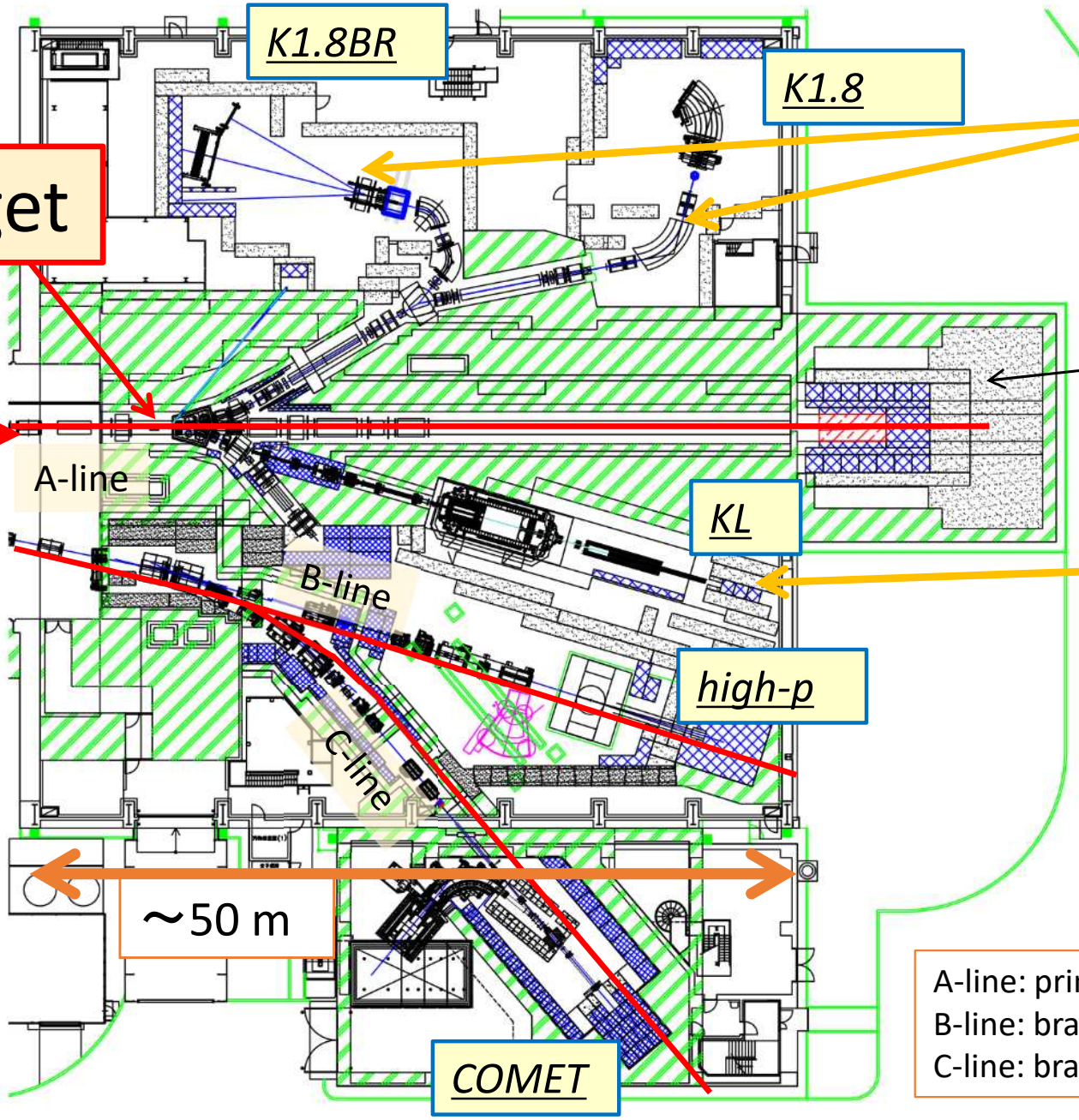
Contents

- Hadron Experimental Facility and beam condition
- Previous and Current Target
- New target development
  - Conceptual design
  - Cooling capability
  - Detail Design (plan)
  - Rotation-system development
- Summary

Hadron Experimental Facility at J-PARC



Charged Kaon beam
for nuclear-physics
experiment
(up to ~2 GeV/c)

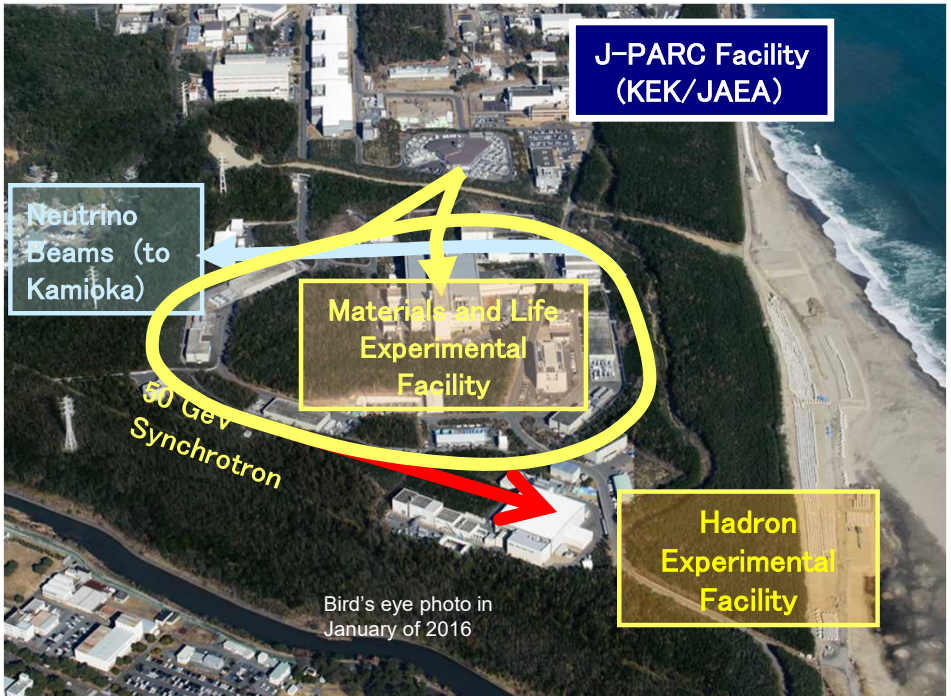
Beam
dump

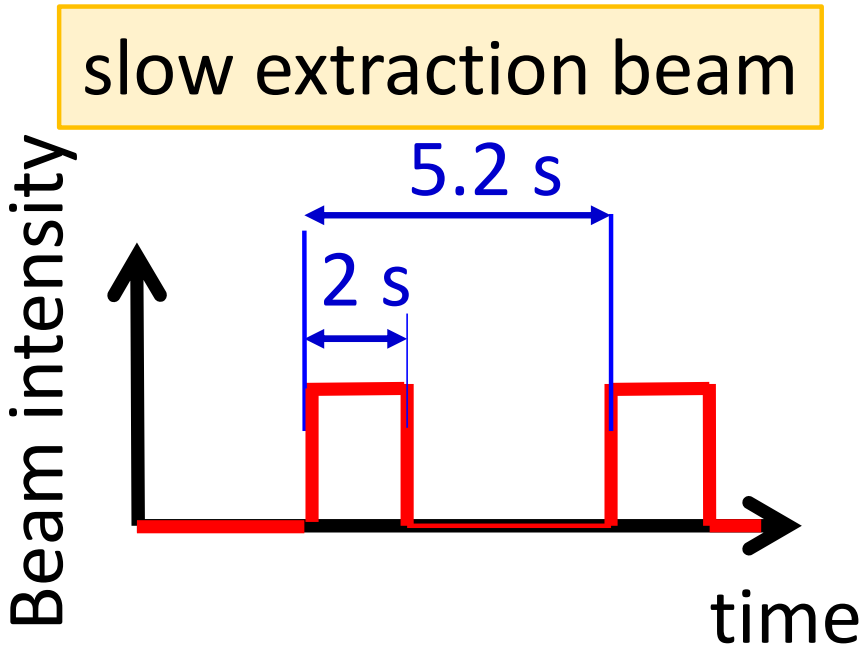
Neutral Kaon beam
for particle-physics
experiment

A-line: primary beam line to T1
B-line: branched from A-line to high-p
C-line: branched from B-line to COMET

Beam conditions for T1 target

- Primary proton beam energy: 30 GeV
- Spill structure: 2-s DC extraction and 5.2-s repetition cycle
- Beam size at T1 target: (σ_H, σ_V) = (2.5 mm, 1.0 mm)
  - Beam loss at T1 target: 50% (max.)
  - Beam-direction length of T1 : 66 mm (max.)
    (→ determined by secondary beamline optics.)
- 65 kW beam operation was archived so far.

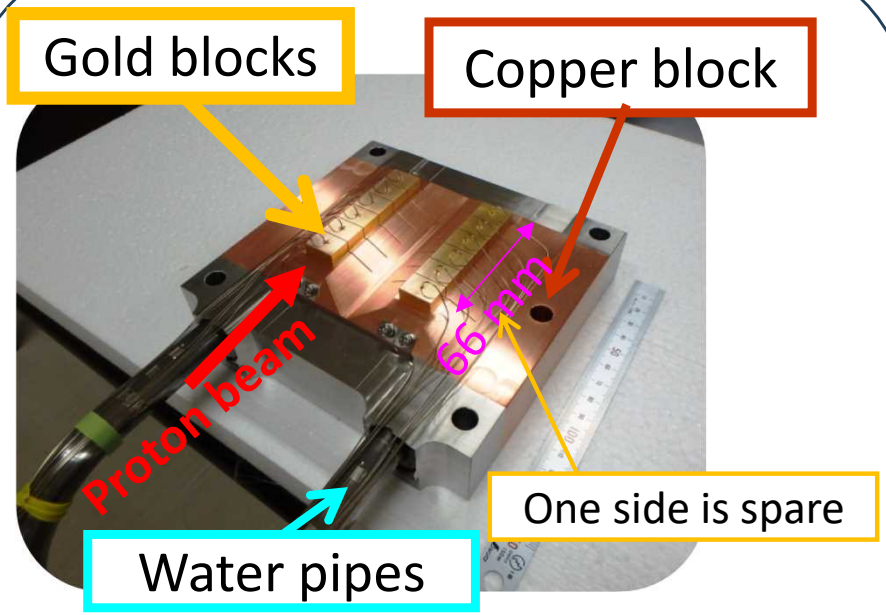


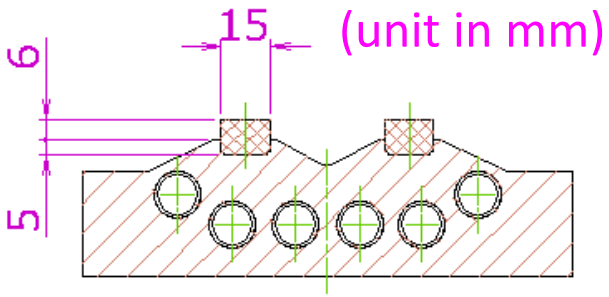


Previous and current production target

→Indirectly Water-cooled Fixed type

Previous target

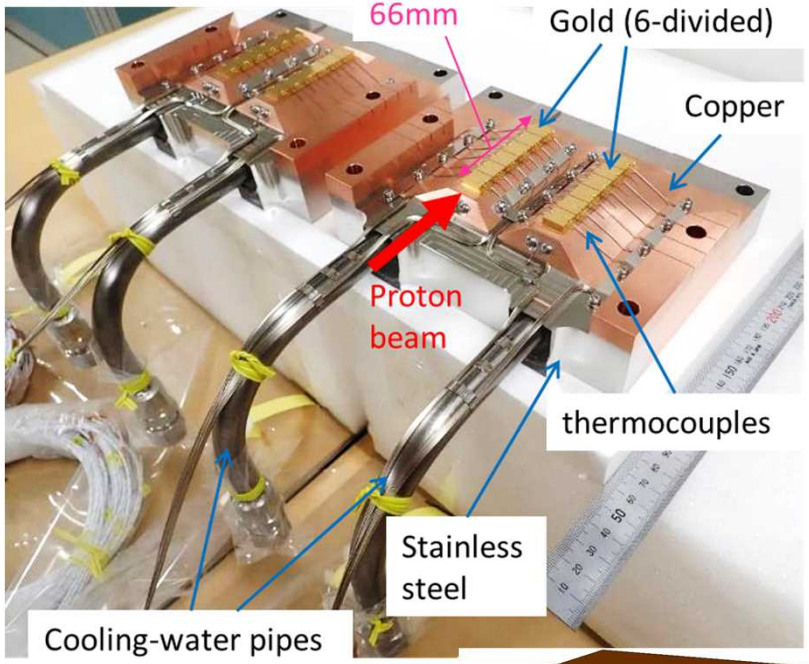


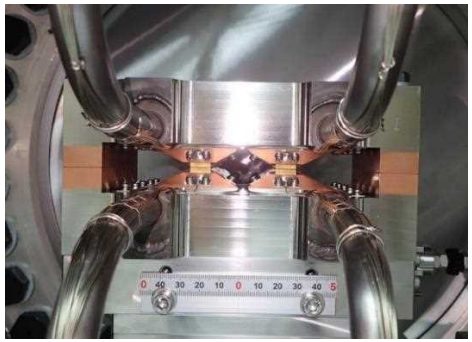


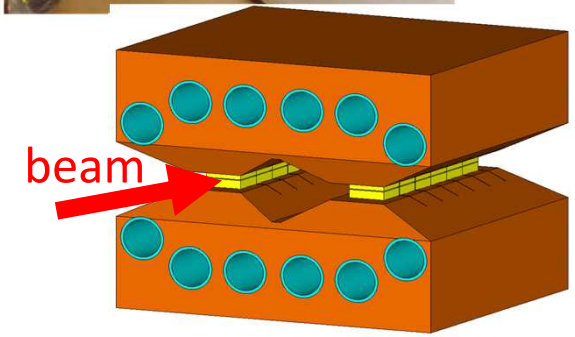
Up to 53 kW beam power.
Operated during 2014～2019.
In total, 1.5E+20 protons on target.
, 7.4 DPA estimated by PHITS (arc-dpa model). No damage was observed.

Current target (in service)

Phys. Rev. Accel. Beams 25, 063001



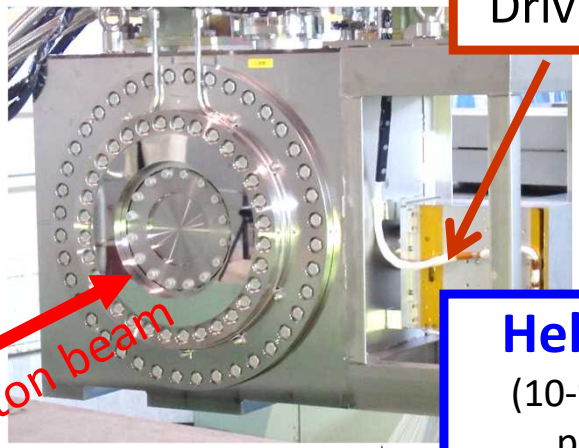


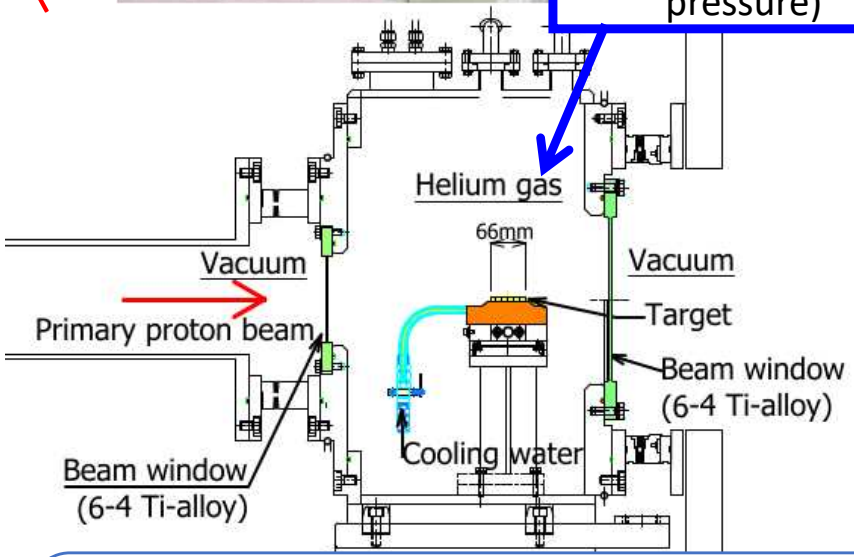


Up to 95 kW beam power (design),
65 kW stable operation was archived.
As of now, 0.7E+20 protons on target.

Previous and current target chamber (gas-tight chamber)

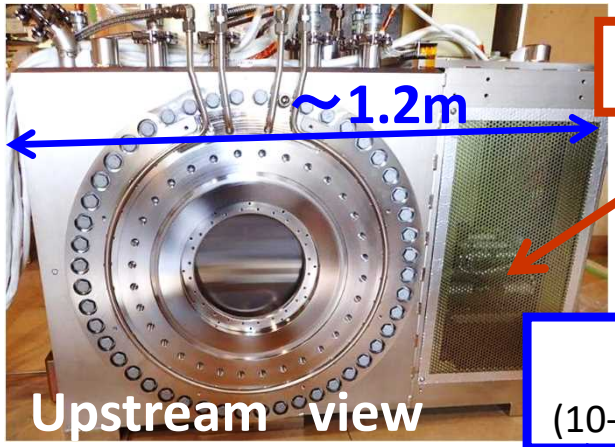
Previous target chamber





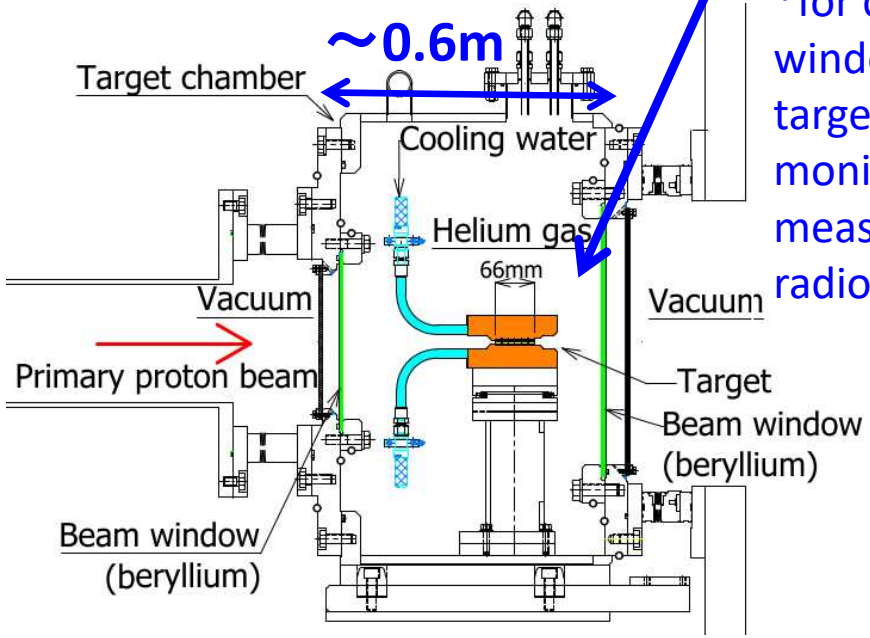
In total, 1.5E+20 protons on target.
Before replacing, the driving system was confirmed to work properly .

Current target (in service)



Helium gas
(10-% negative pressure)

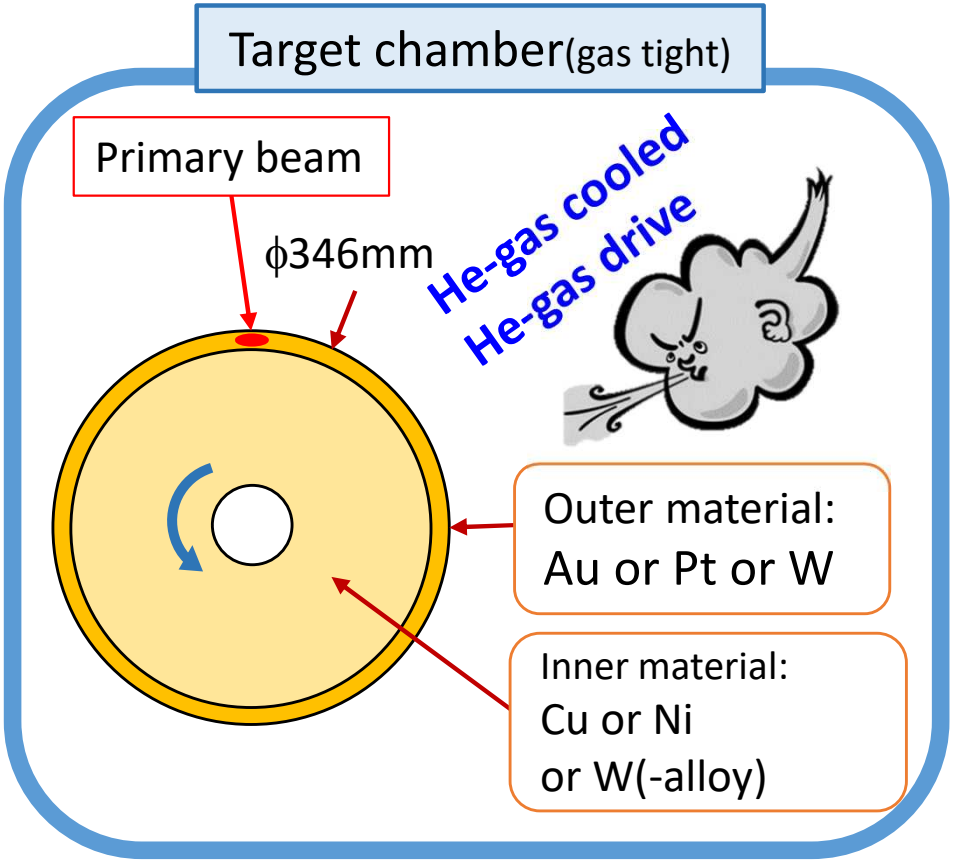
*for cooling beam windows and target-soundness monitoring by measuring radioactivity level.



Up to 95 kW beam power.
As of now, 0.7E+20 protons on target.

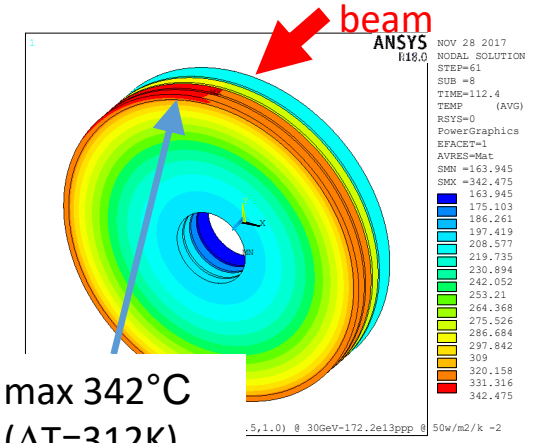
Next Production Target ～Conceptual Design～

→ Directly He-gas-cooled Rotating-disk type



- Rotating disk : heat load and radiation damage can be distributed in larger area.
- Max. beam power: 150 kW (plan)

Thermal calculation (Au, 150-kW) *Preliminarily



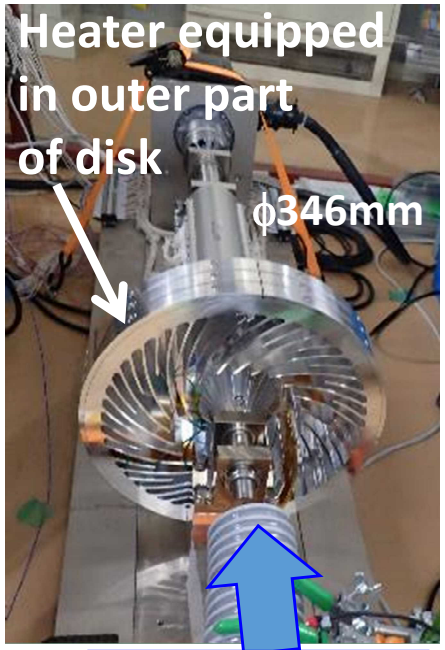
max 342°C
(ΔT=312K)

Assuming 50 W/m²/K .
(Geom.: 4 separate flat disks)

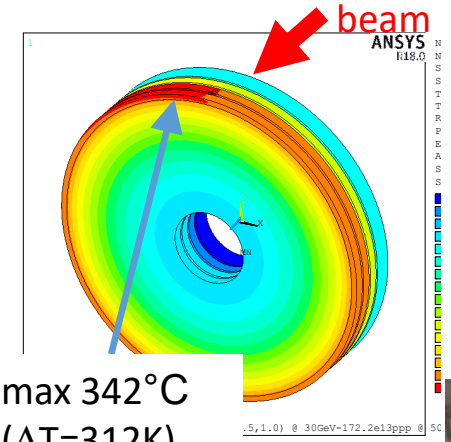
He-gas rotation drive like wind turbine is planned for rotation.
→ Hermetic rotation feedthrough is unnecessary (→better reliability)

Engineering points:
- ✓ Sufficient cooling capability by He gas
- ✓ Fabrication of the complicated disk
- ✓ Rotating system :
  - ✓ Bearing lifetime (>5-years)
  - ✓ Sufficient rotation torque by He gas

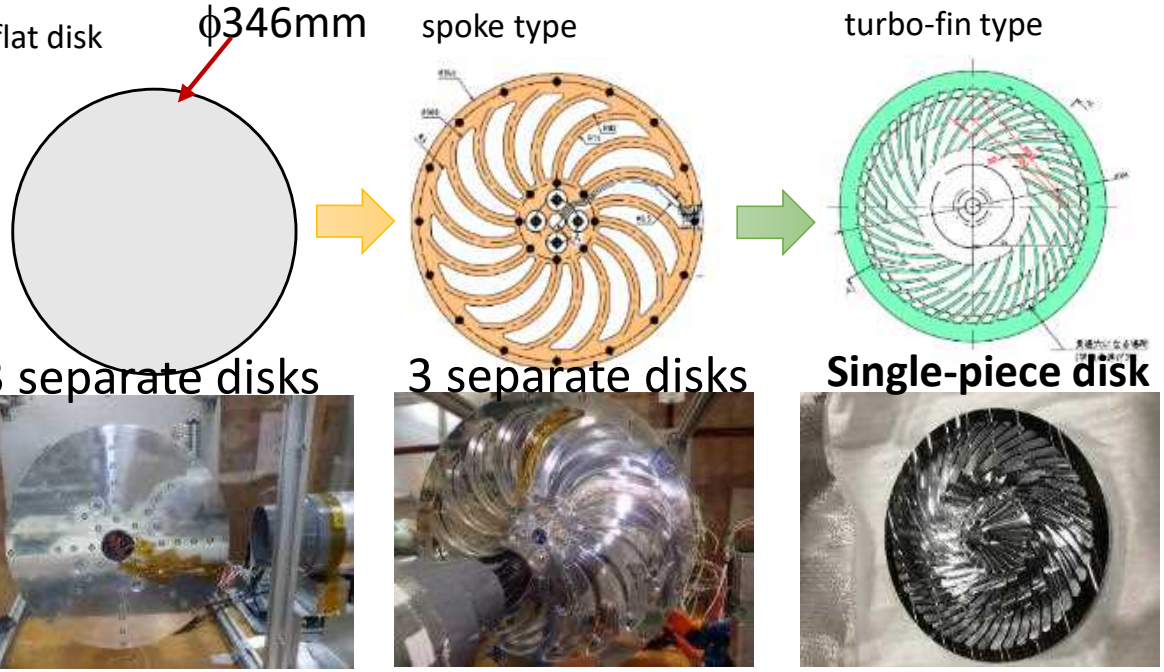
Measuring cooling capability by test bench (in air)

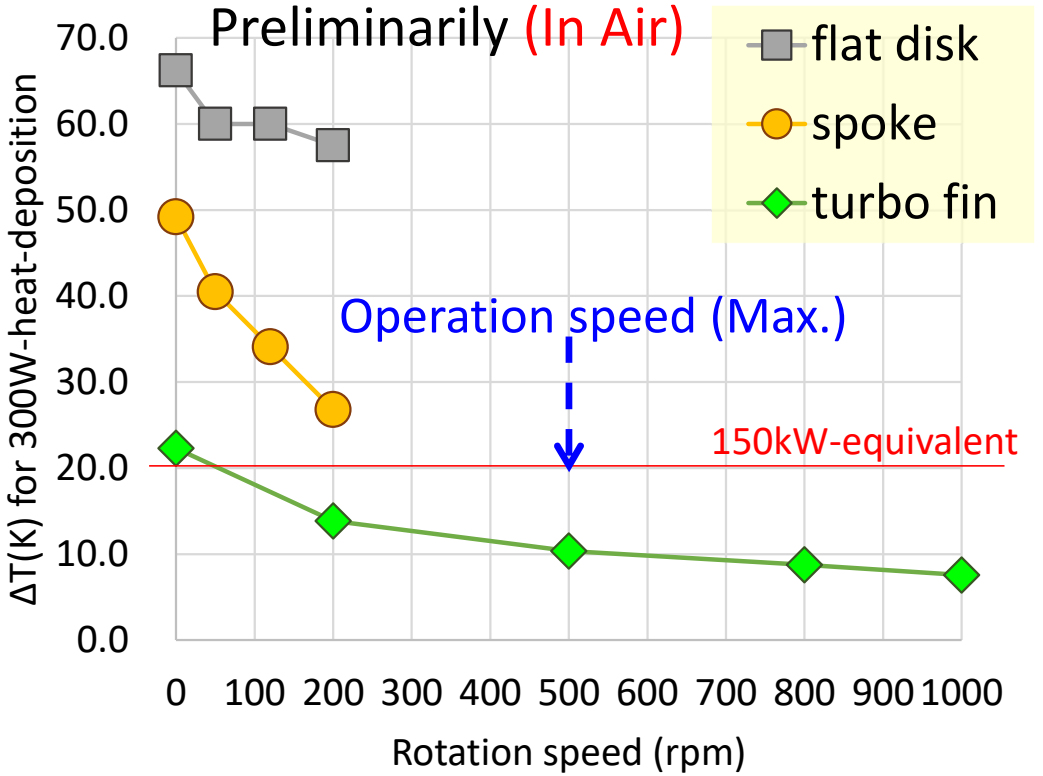


Temperature-controlled air



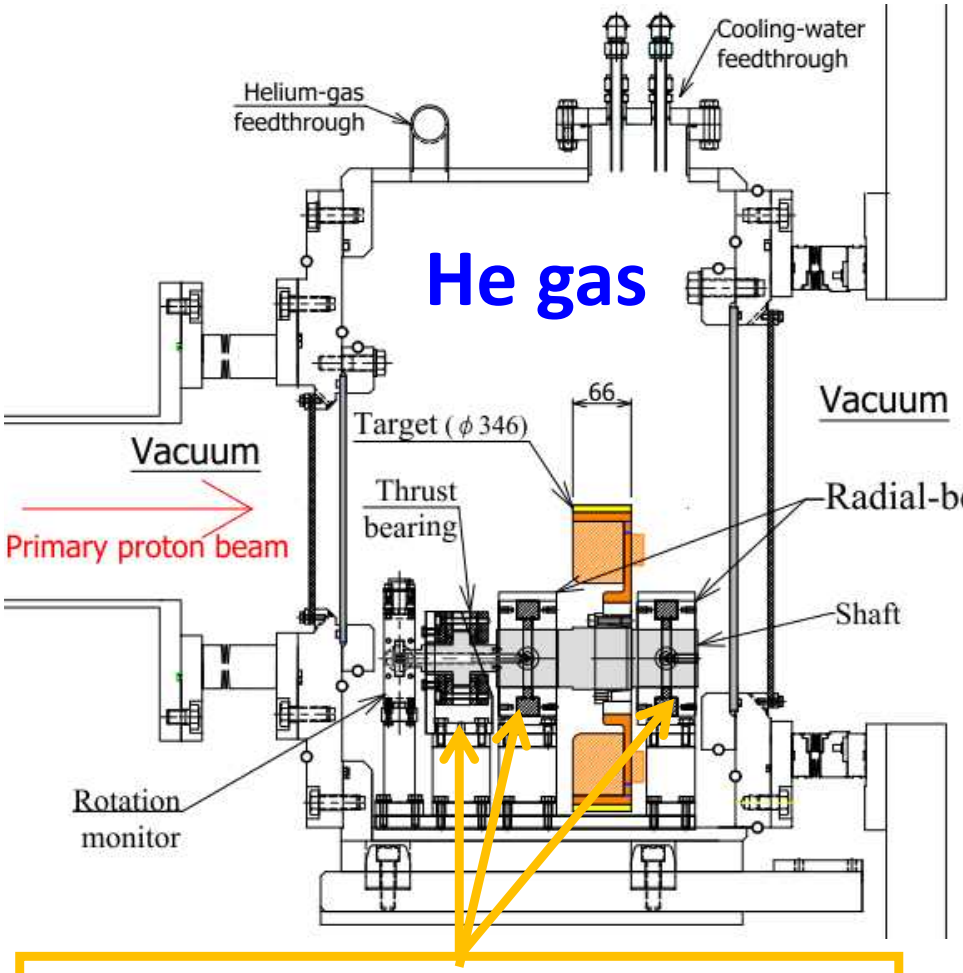
equivalent to ΔT=20K in test bench from the difference of coolant (He/air) and heat deposition





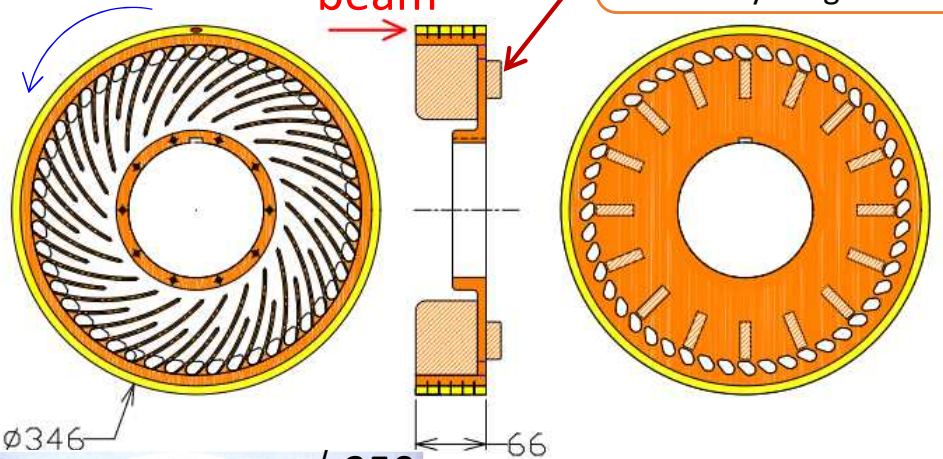
- ✓ The cooling capability of turbo-fin shape (> 200 rpm) seems to be high enough for 150-kW beam operation.
- → Measurements in helium gas are in progress.

Design of the rotating target (plan)

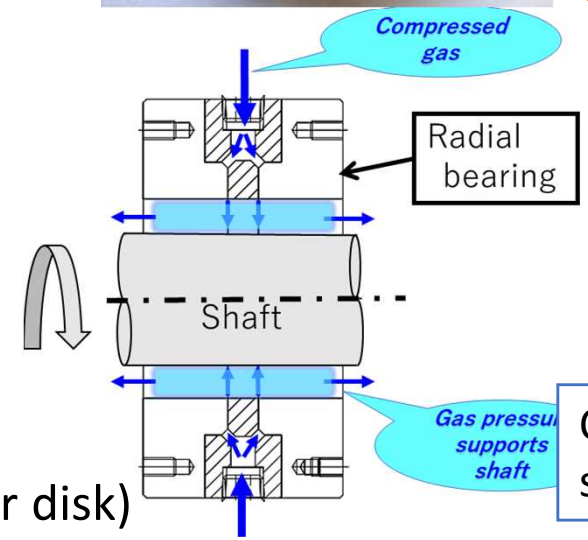


He-gas-lubricated bearing

- ✓ Higher rotation speed is acceptable.
  (cf. rad-hard ball bearing max. 330 rpm)
- ✓ No life time for stable operation.
  (cf. rad-hard ball bearing:
  5600 hours at 330rpm for Gold+Copper disk)



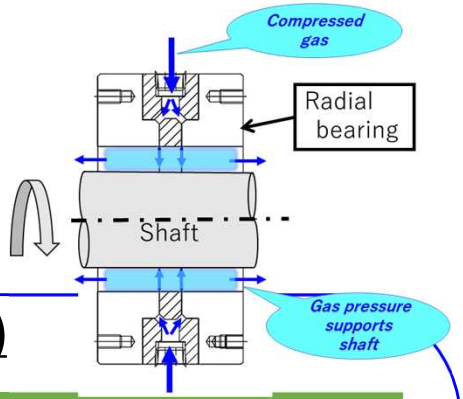
For rotation test:
Inner : pure copper
Outer: tungsten alloy
(W-95%, Ni-2%, Cu-1%)
instead of gold.
(with shrinkage fit for this test).



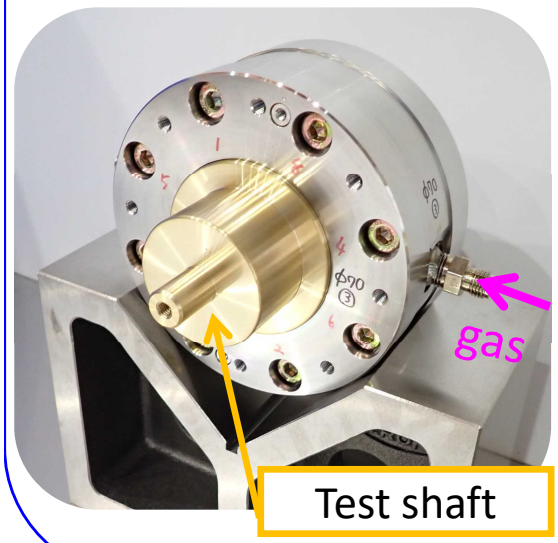
Max. Disk weight
(including shaft):
～40 kg (Au+Cu disk)
～60 kg (All W disk)

Can the gas bearing support such a heavy disk?

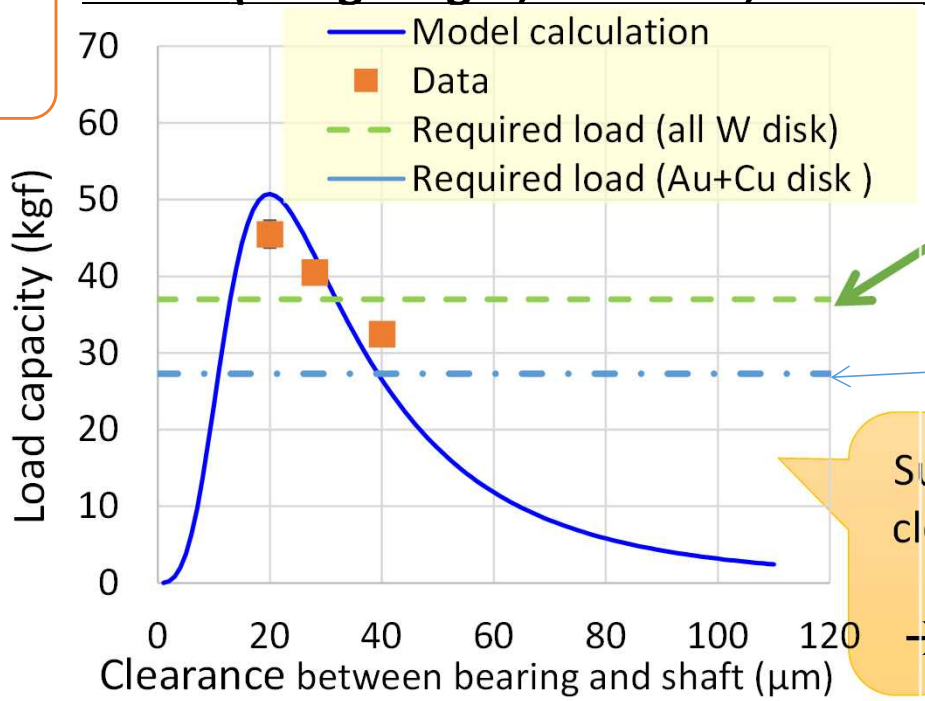
Measuring performances of the Gas-lubricated Bearing



Radial bearing
(double slot restriction)



Result (using He gas, 0.5MPaG,～30liter/min)

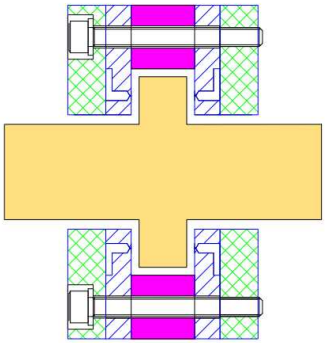


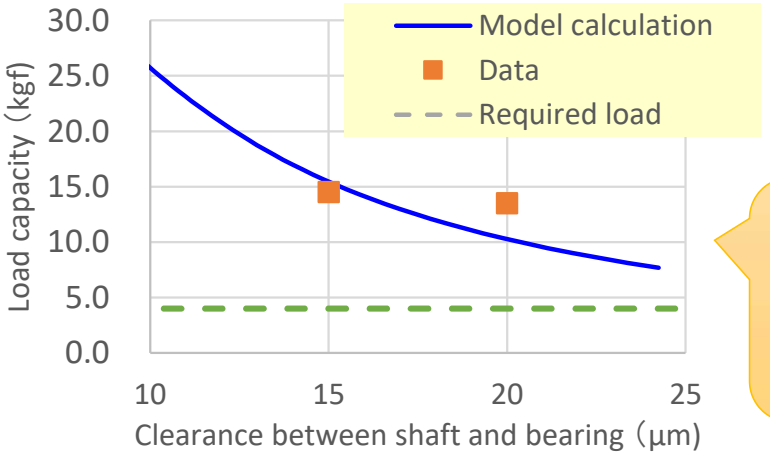
Required-load level: Disk weight x 1.3 (1.3 is a safety factor) *for all W design

Required-load level: for Au+Cu design

Sufficient load capacity at the clearances of 20 ～ 30 μm for all tungsten-disk design !!
→ 20～30 μm was adopted.

Thrust bearing
(hole restriction)



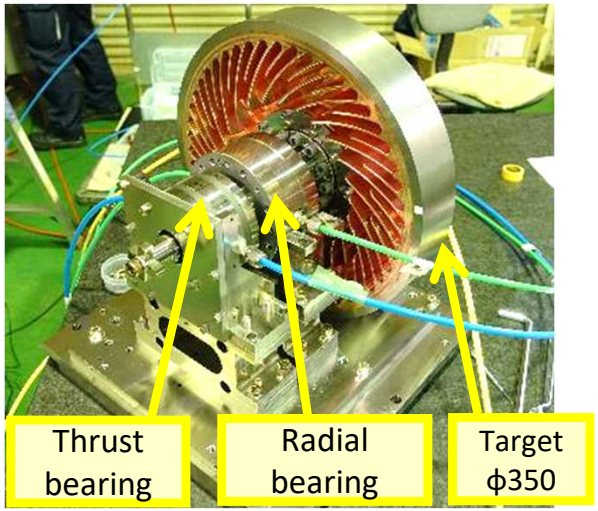


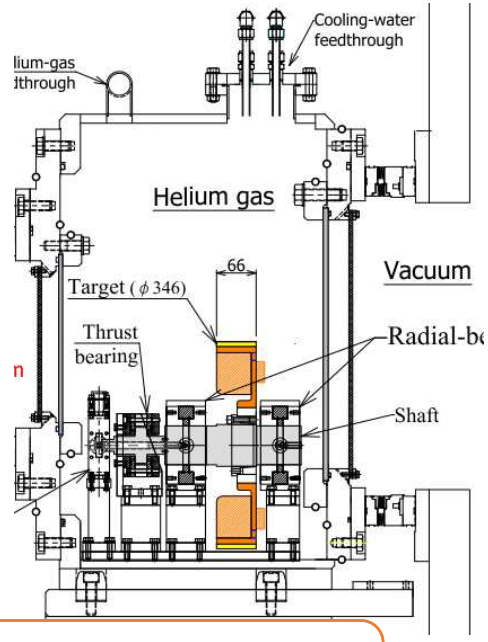
The thrust bearing shows sufficient load capacity.

Assembling a test unit → Rotation tests

Realistic size and shape

36 kg including a shaft

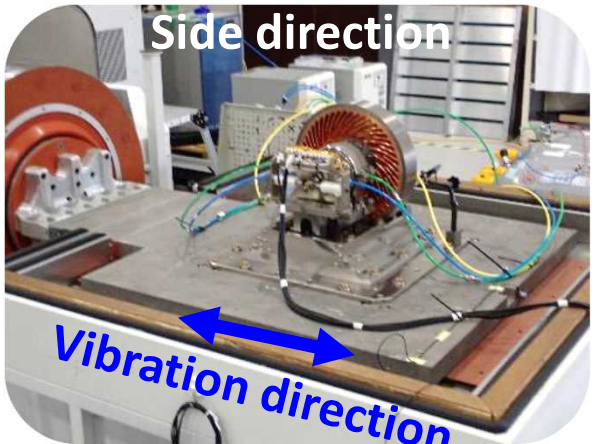




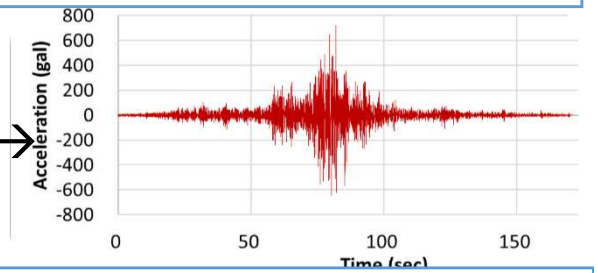
Rotation test with the gas bearings was succeeded.
Rotation drive with wind-turbine method (> 600-rpm) was worked properly.

Major concern is **robustness of the gas bearing**, especially for emergency case such as earthquake because of lower bearing stiffness (measured stiffness: ～1.7 kgf/μm).
→ Shaking test (with 1-axis vibration tester) was carried out.

Real earthquake data was used: seismic intensity 6+, in Hitachi city (2011)



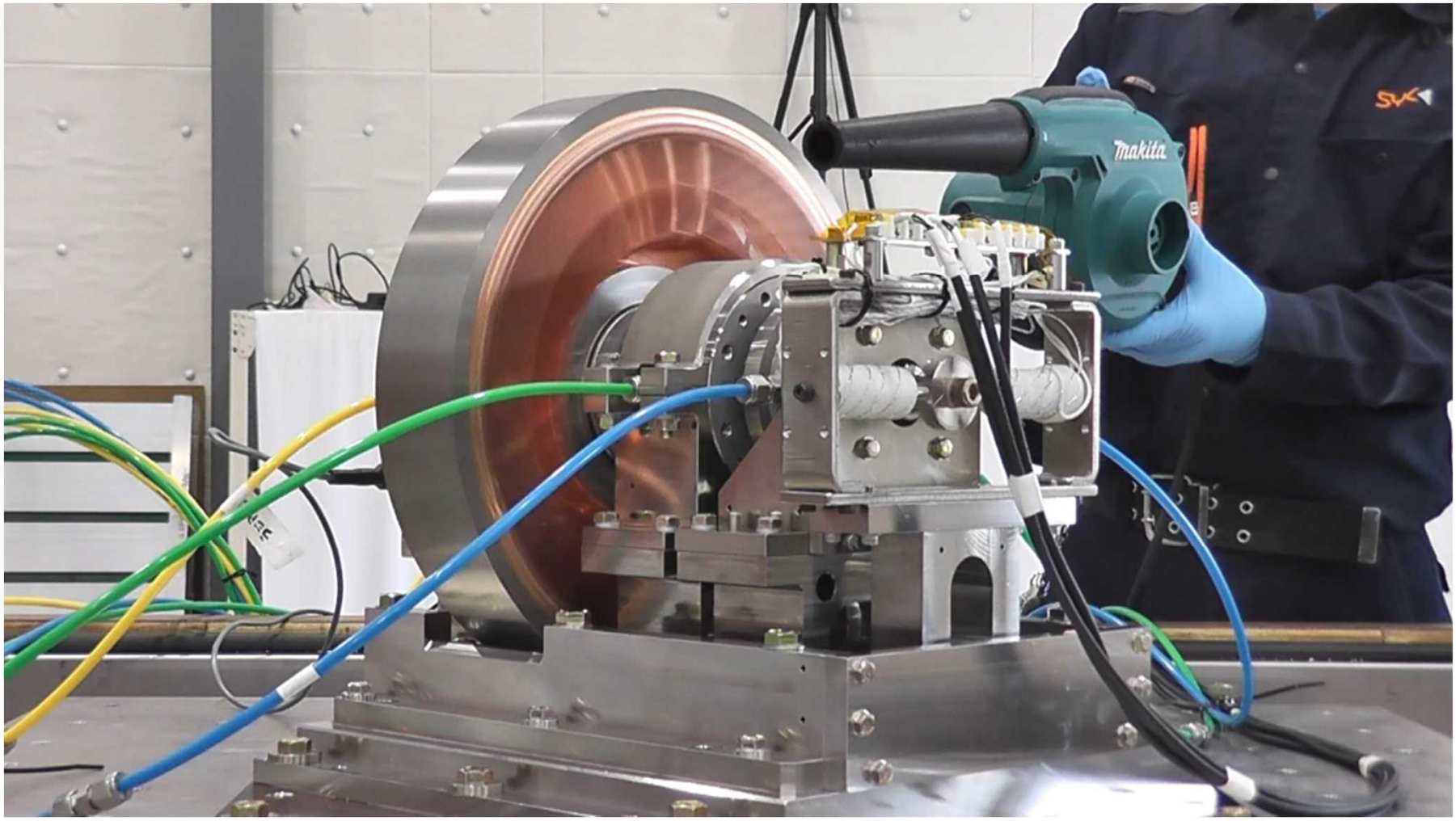
Horizontal input→
max 725 gal.



For all cases of horizontal(side, 45-deg, thrust) and vertical direction,
→All shaking tests were passed.
(No trouble for rotation was found.)

Movie : Shaking test (assuming earthquake) at 500rpm (horizontal 45-deg direction for rotation system)

Input acceleration: 725 gal → Recorded : 940 gal (equivalent to seismic intensity of 7).



No rotation trouble occurred. → Bearing stiffness was confirmed to be high enough.

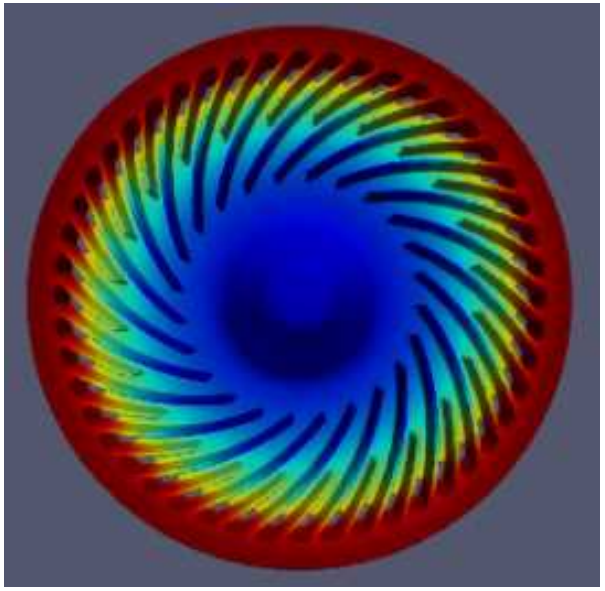
Summary and Plan

- A fixed-type target is in service, and acceptable up to 95 kW.
- For 150-kW beam, new rotating target is under development.
- Cooling capability of the turbo-fin-shape disk seems to be high enough.
  - Measurement in He gas is in progress.
- To obtain longer lifetime and higher rotation speed, He-gas-lubricated bearing is planned, and some tests are in progress.
  - In addition to basic rotation test, shaking tests assuming big earthquake were passed. → Big progress for rotation-system design.
- Next tests for rotation system:
  - Sudden power shutdown test is planned.
    - Test of emergency-stop control (reverse gas blowing) and a UPS system (should keep the compressor driving until stopping the rotation).
  - Tests with a heavier disk (for all tungsten-disk design) .
  - Long-term rotation test (with heat cycle).
- Remaining major issues (under development):
  - Fabrication of all tungsten disk.
  - Monitoring the disk (→ F. Muto presented in the Poster Session.)
- Design of the new target will be determined in FY2024 (hopefully).

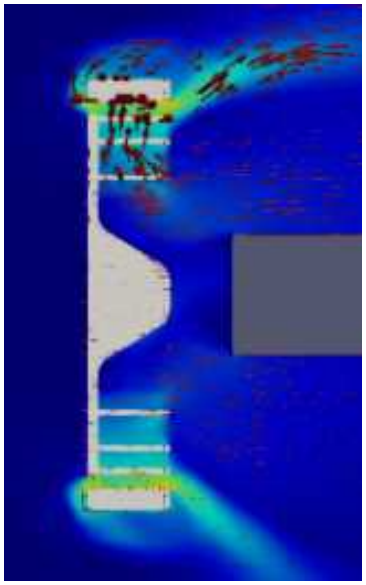
Backup pages

CFD calculation (with OpenFOAM)

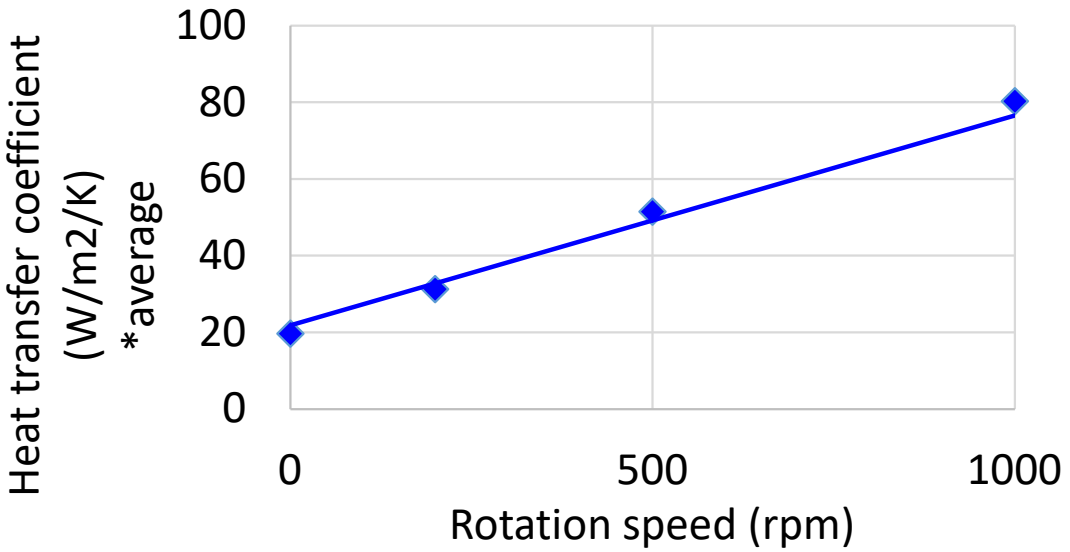
Temperature at 500rpm



Gas speed at 500rpm



CFD simulation for turbo-fin type

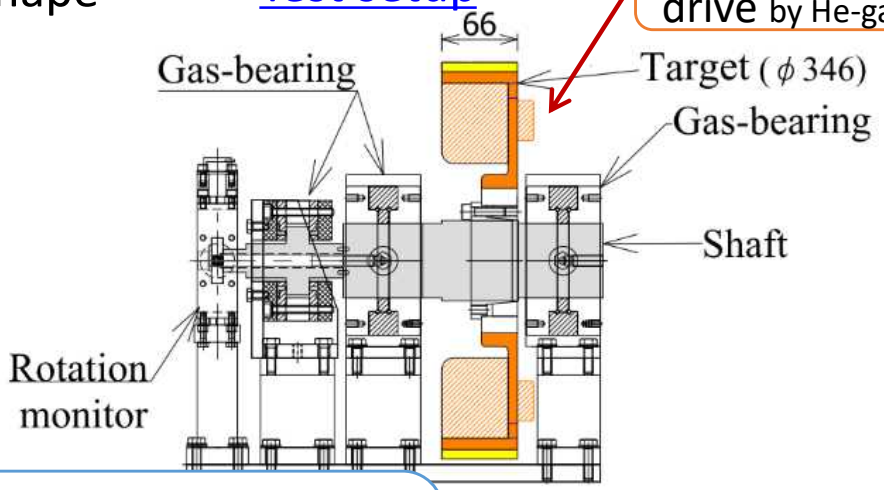


A better cooling capability is expected at higher rotating speed.
However, a ball-bearing life becomes shorter.
→ Development of a gas bearing.

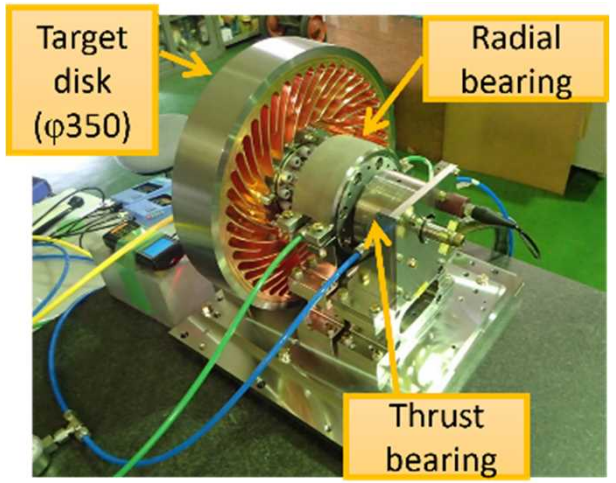
Test of the rotation driver (wind-turbine method) with De-Laval nozzle (sonic nozzle).

Realistic size and shape

Test setup

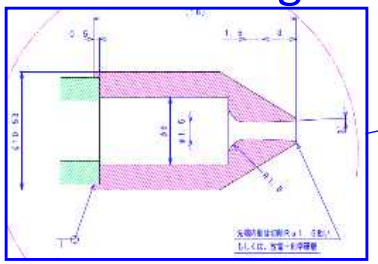


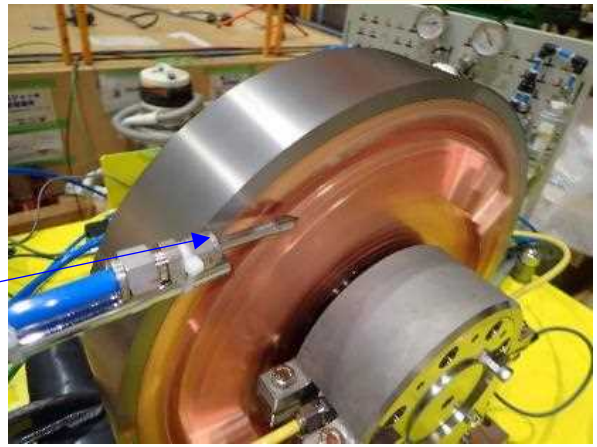
fins for rotation drive by He-gas blow



Tests of the realistic rotation system by wind-turbine method with De-Laval nozzle were carried out.

Nozzle design.



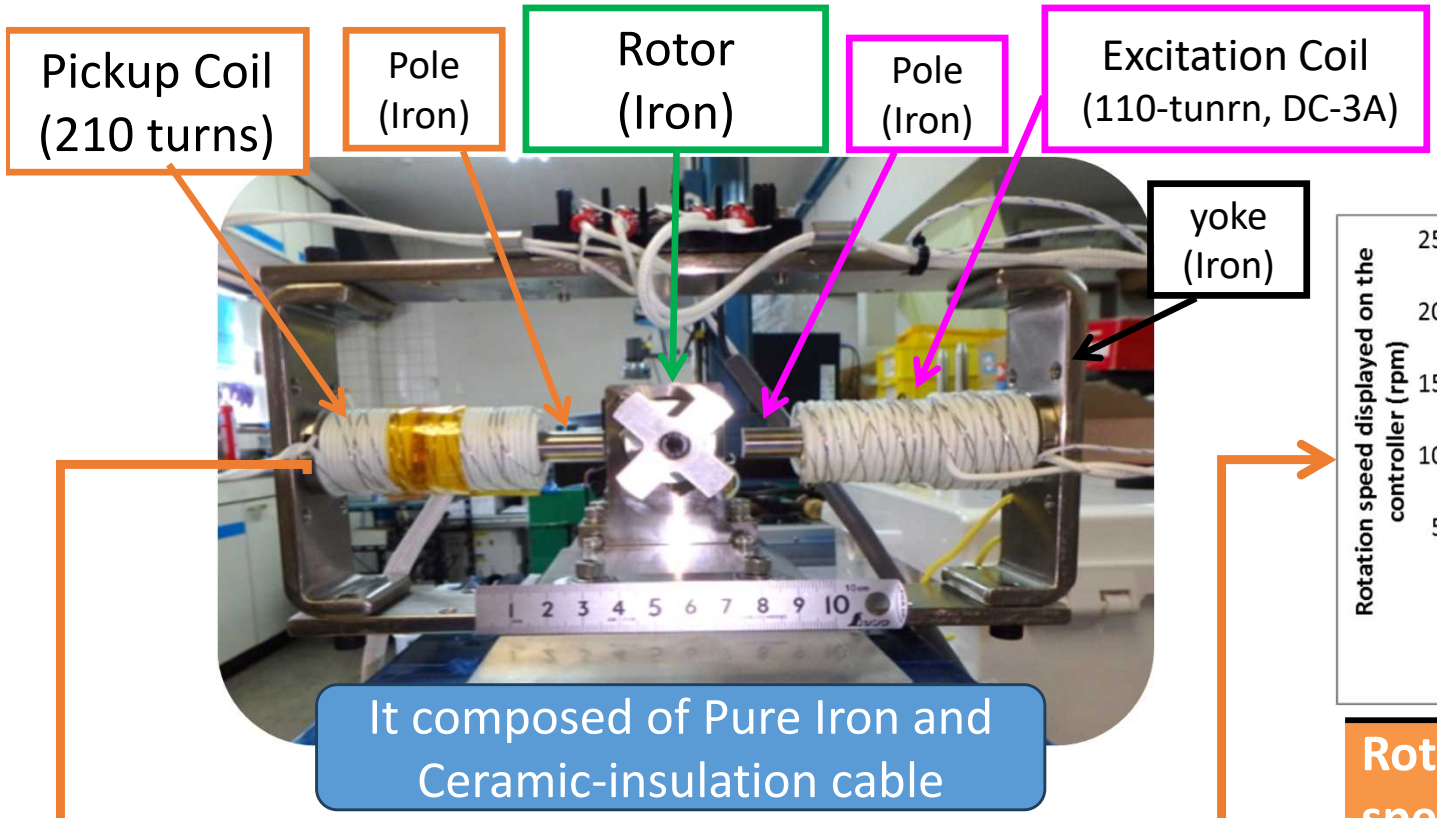


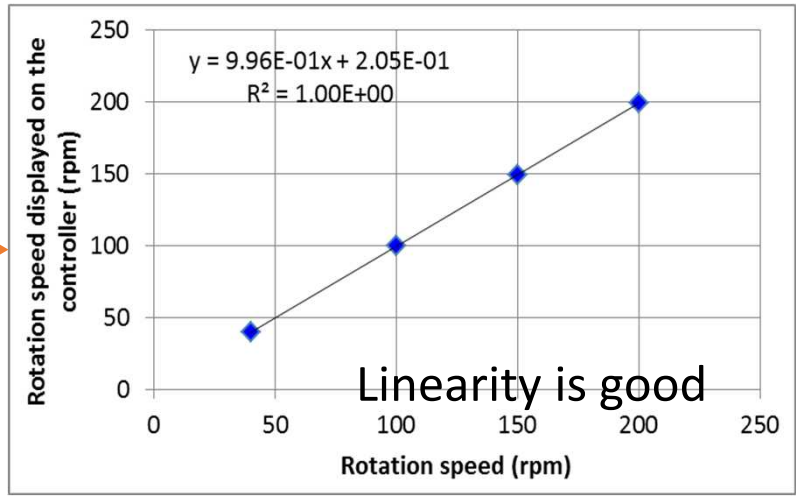
Restriction diameter of the nozzle	Max. rotation speed	Supply gas pressure	Gas flow rate
No nozzle (tube end)	～100 rpm	—	—
Φ0.5 mm	225 rpm	0.70 MPa	20.1 l/min
Φ1.0 mm	421 rpm	0.60 MPa	65 l/min
Φ1.5 mm	**542 rpm**	0.45 MPa	122 l/min

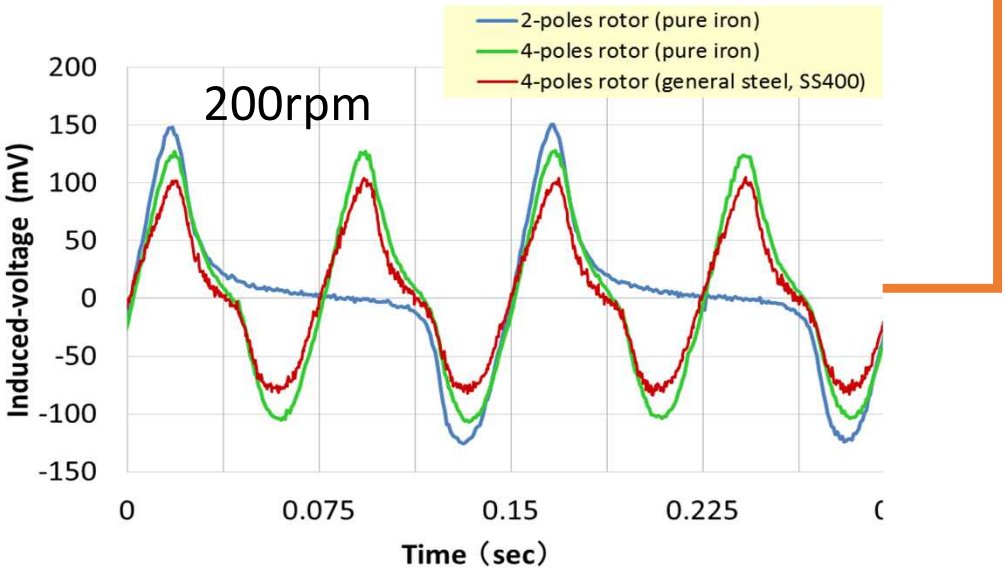
*500 rpm is planned maximum operation speed.

From this result, the nozzle with a restriction diameter of 1.5mm was adopted. → Input for helium-compressor specification.

Radiation-hard rotation-speed meter







Rotation speed	90% response period (in seconds)
40 rpm	1.2 sec.
100 rpm	1.5 sec.
150 rpm	1.7 sec.
200 rpm	1.9 sec.

Required response time : < 3.5 sec.
(to stop next spill after detecting a rotation trouble)