Thermal analysis of a prototype cryogenic polarization modulator

for use in a space-borne CMB polarization experiment

Satellite, "LiteBIRD"

Teru. Iida

Y. Sakurai

T. Matsumura

H. Sugai, H. Imada, H. Kataza, H. Ohsaki,

M. Hazumi, N. Katayama, R. Yamamoto,

S. Utsunomiya, Y. Terao

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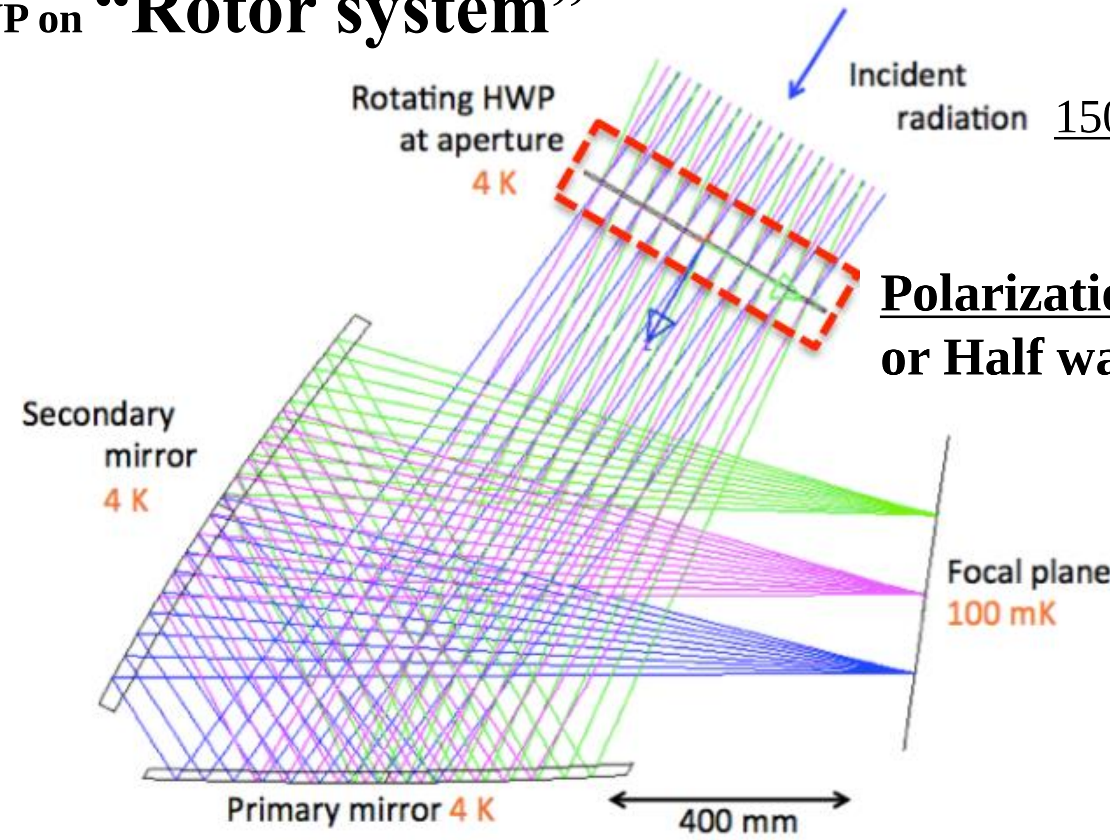
Contents

Where is Polarization modulator used?

Sketch of optical system and function of modulator

HWP on “Rotor system”



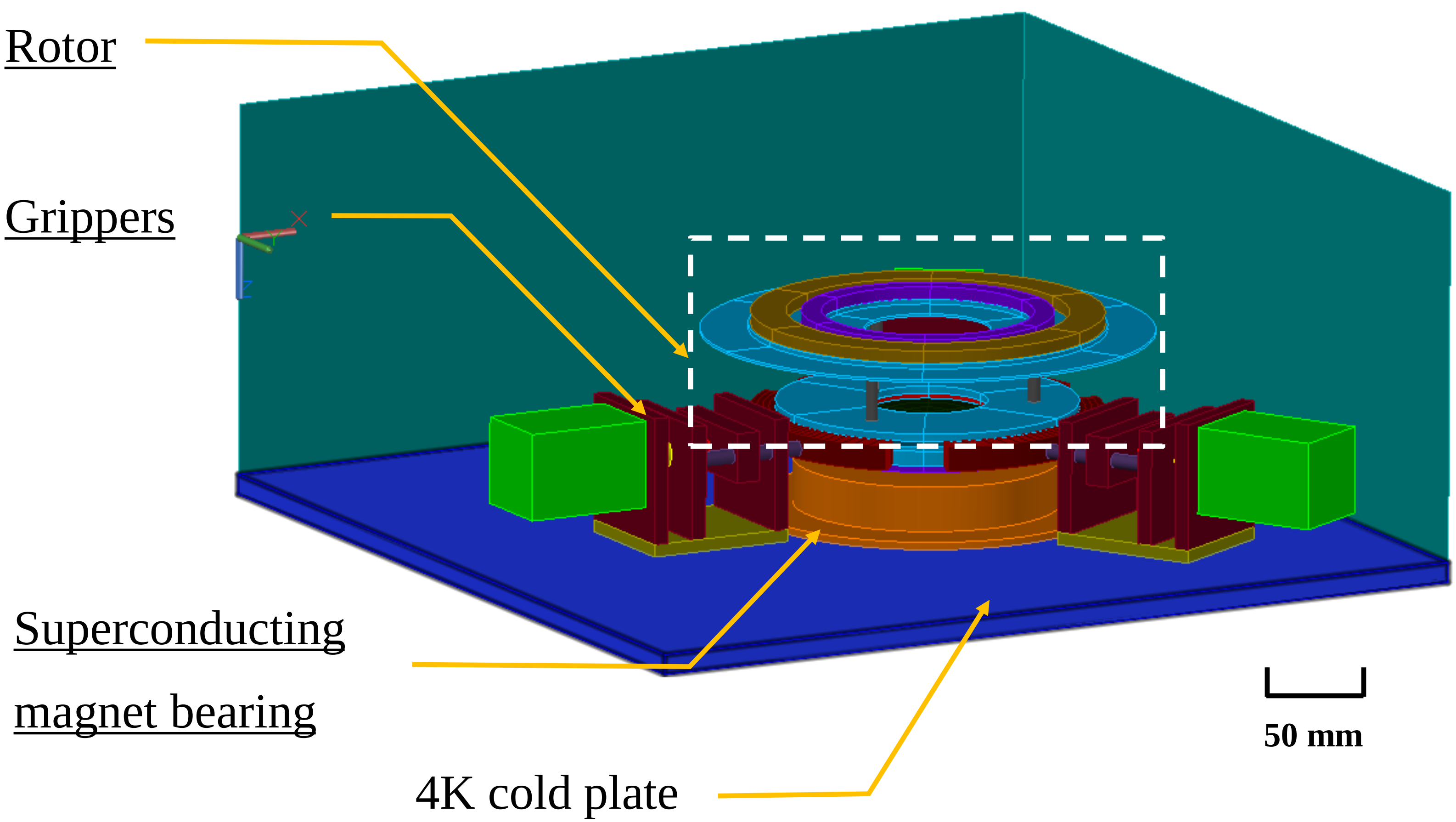
150GHz

Polarization modulator
or Half wave plate (HWP)

Detector

What does “Rotor system” look like?

Over view of Rotor system: scaled model



Overview of rotor system components

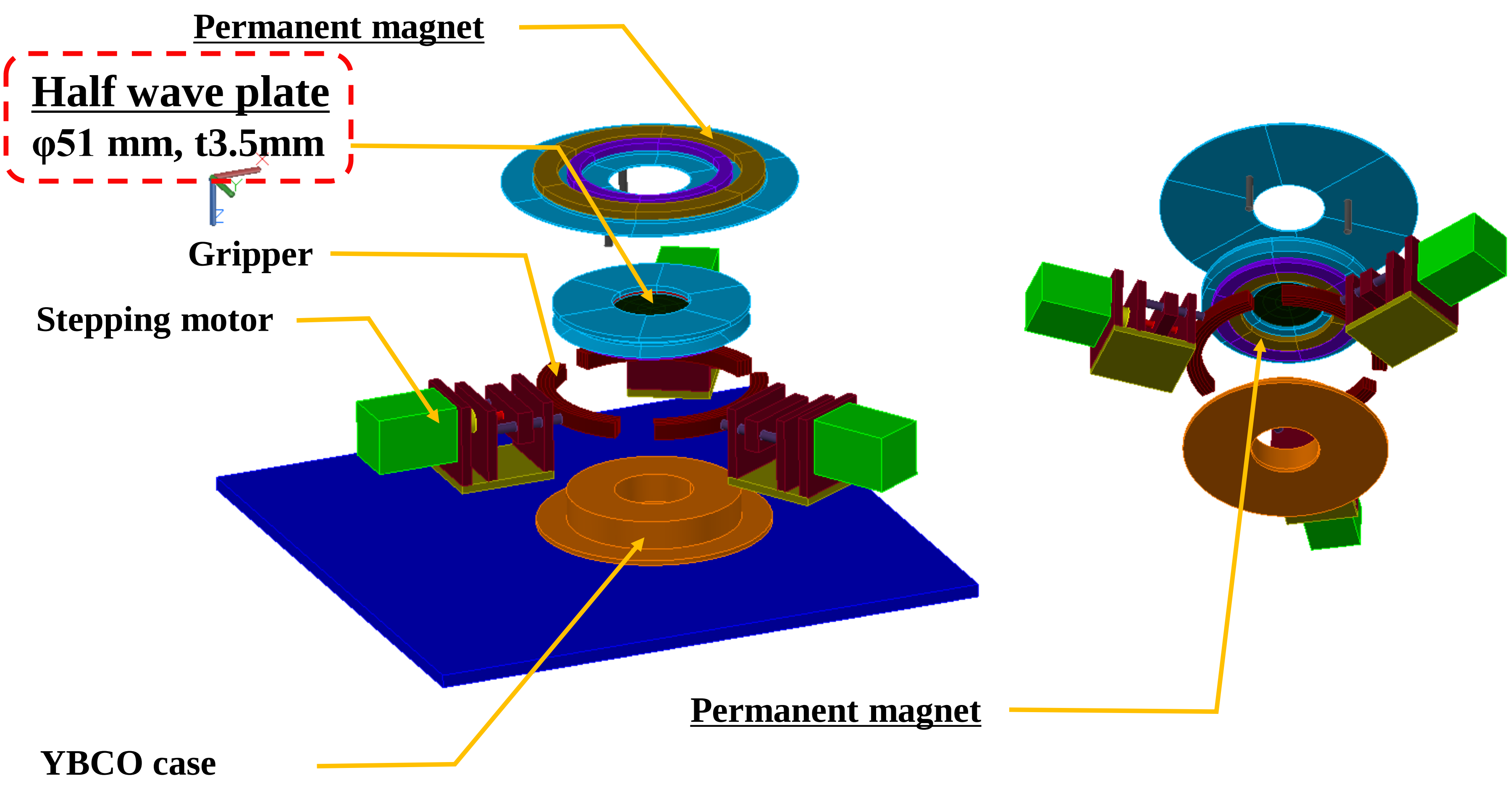
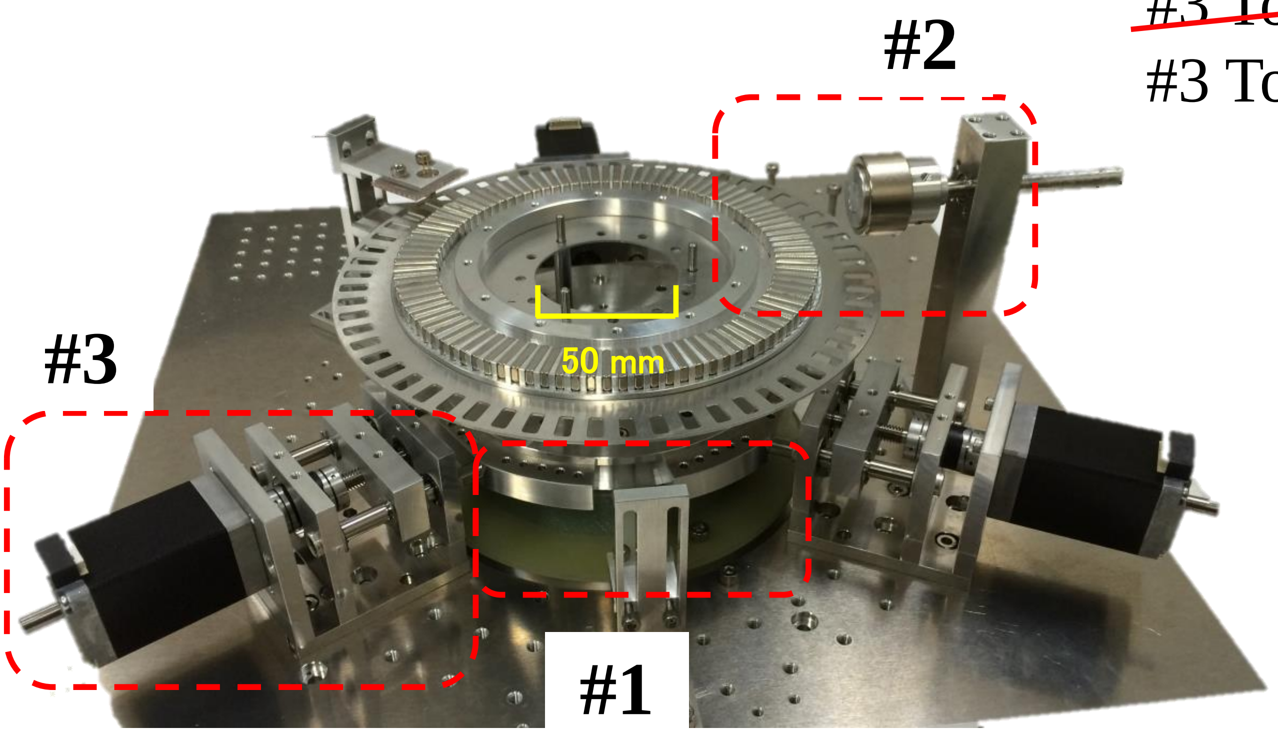
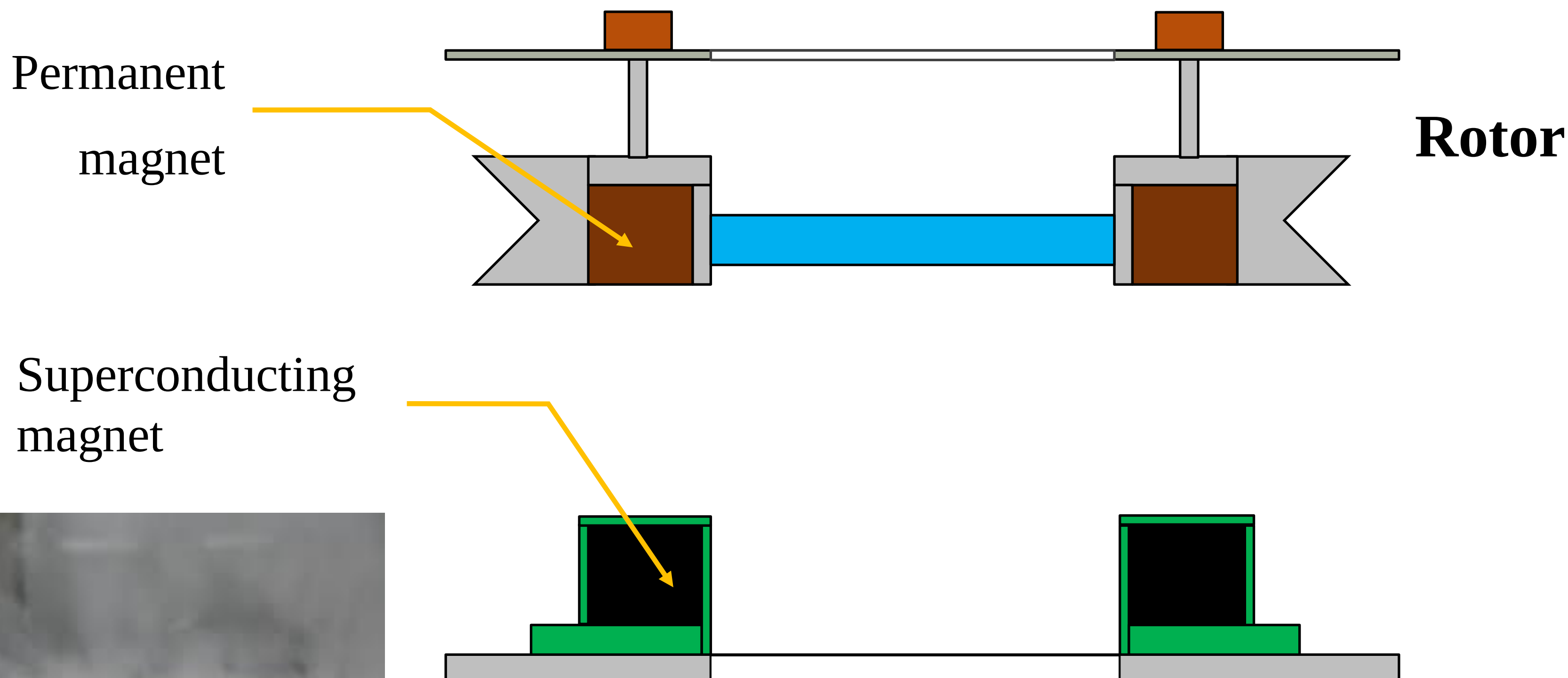


Photo of Rotor system: Three mechanical functions

#1 To levitate a rotor
#2 To spin a rotor
~~#3 To throw a white ball~~
#3 To grip a rotor



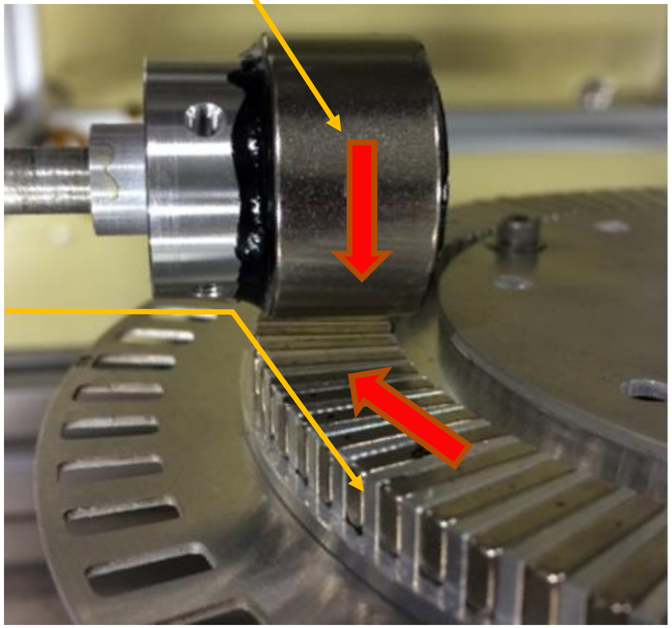
#1 To levitate a rotor, HOW?



#2 To spin a rotor, HOW?

Drive gear

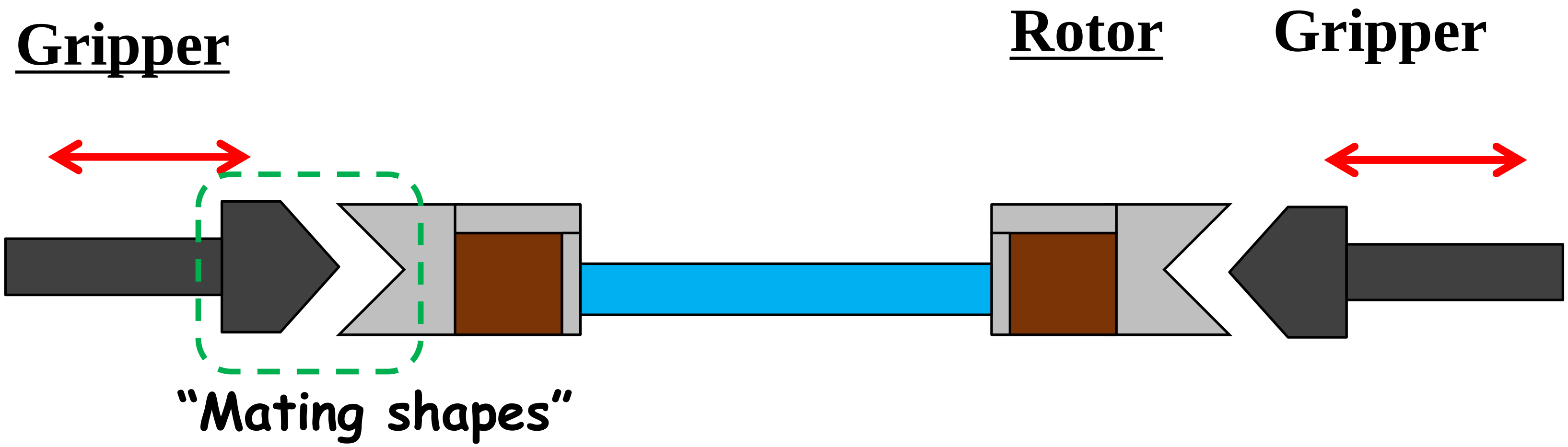
Rotor gear

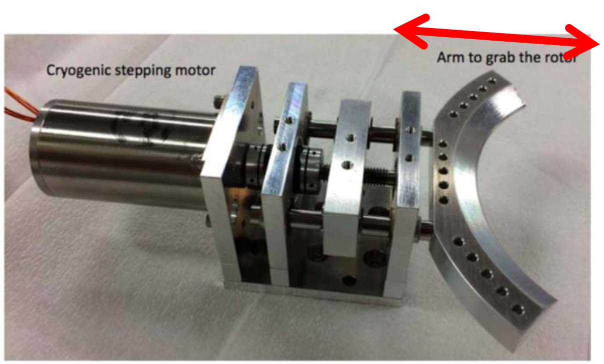


The drive gear consists of 20 magnets with an alternating pole along the circumference as teeth.

The magnetic gear on rotor side consists of 96 rectangular shaped magnets and their poles are alternated in every next magnet.

#3 To grip a rotor, HOW?





Thermal requirements for HWP on the rotor

#1 Temperature of a half wave plate（HWP）should be 10K or lower in an observation period of 24 hrs. to reduce noises entering onto the detector. The period is the hold time of an adiabatic demagnetization refrigerator (ADR).

#2 If a temperature of the plate goes beyond 10K, the temperature should get back to below 4K within 4hrs., which is the recycle time of ADR.

An issue to be considered: heat dissipations

No heat load, but some heat dissipations on the rotor in operation:

#1 A loss due to magnet hysteresis or magnetization response of superconducting magnet to a variation of an external magnetic field

$$P_h = k_h \cdot f \cdot B_m^{1.6}$$

f: frequency

Bm: maximum magnetic flux density

kh: proportional constant

#2 A loss due to eddy currents in a time variation of an external magnetic field

$$P_e = k_e \cdot \frac{(t \cdot f \cdot B_m)^2}{\rho}$$

t: metal thickness

ρ: specific resistance of magnet

ke: proportional constant

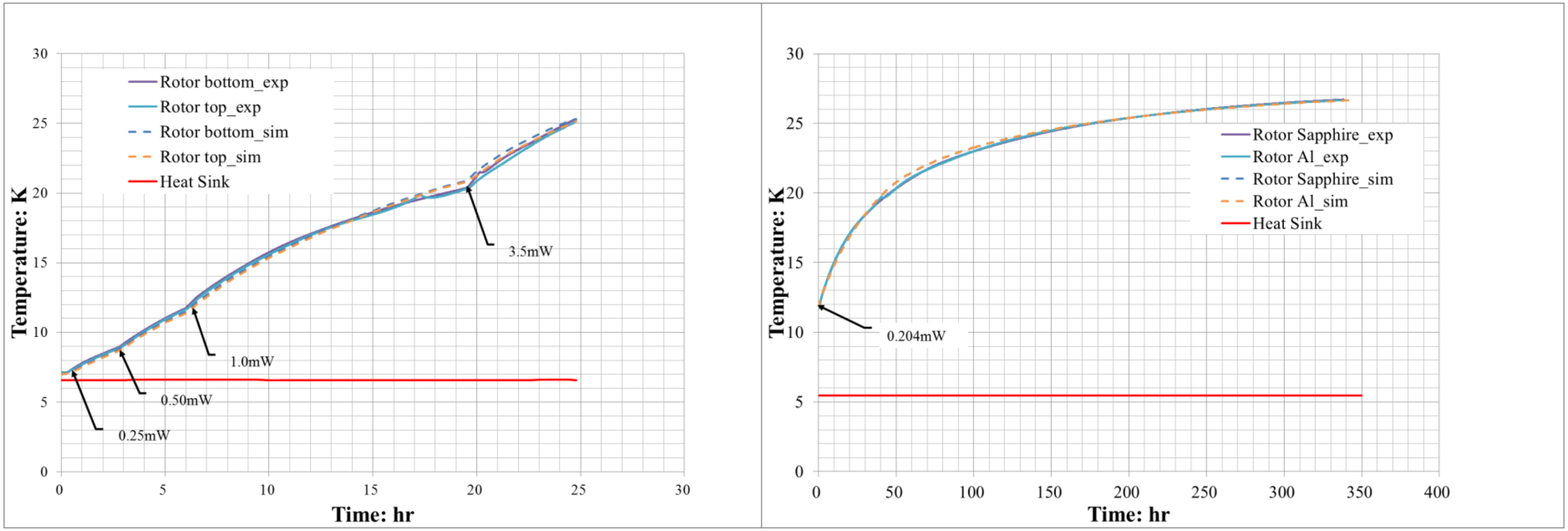
Simulation targets

#1 To predict the maximum heat dissipation is allowed to keep the HWP temperature below 10K in a period of 24 hrs.

#2 To estimate the cool-down time from 10K to 4K.

Result #1

Simulation results compared with experimental results for the scaled rotor



Solid lines SHOW Experimental results; Dotted lines SHOW Simulation results

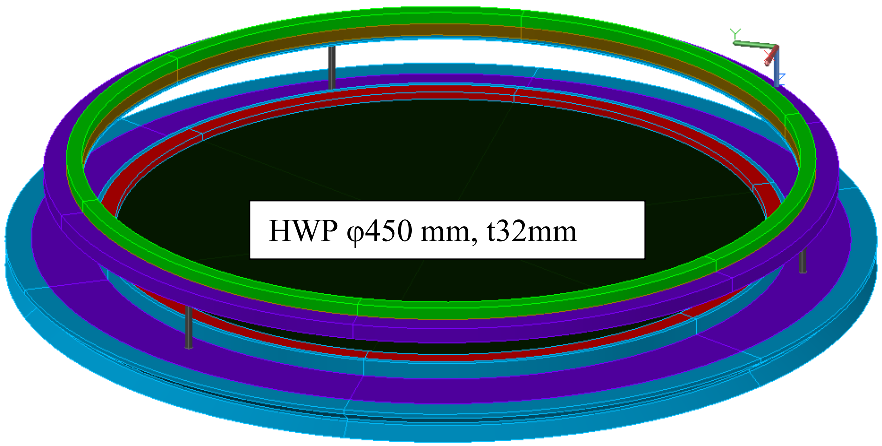
$Cp(T)_{NdFeB}$ → 0.61*$Cp(T)_{SUS304}$

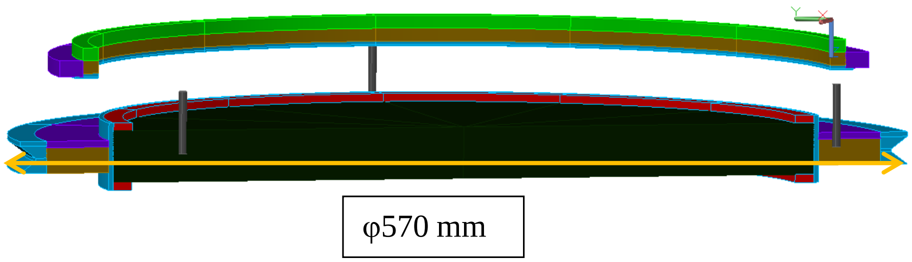
The temperature difference between simulation and experimental results is <u>within 3%</u>.

Thermal model is acceptable.

Simulation results for <u>full-scale rotor</u>

Differences between the scaled and full-size rotors



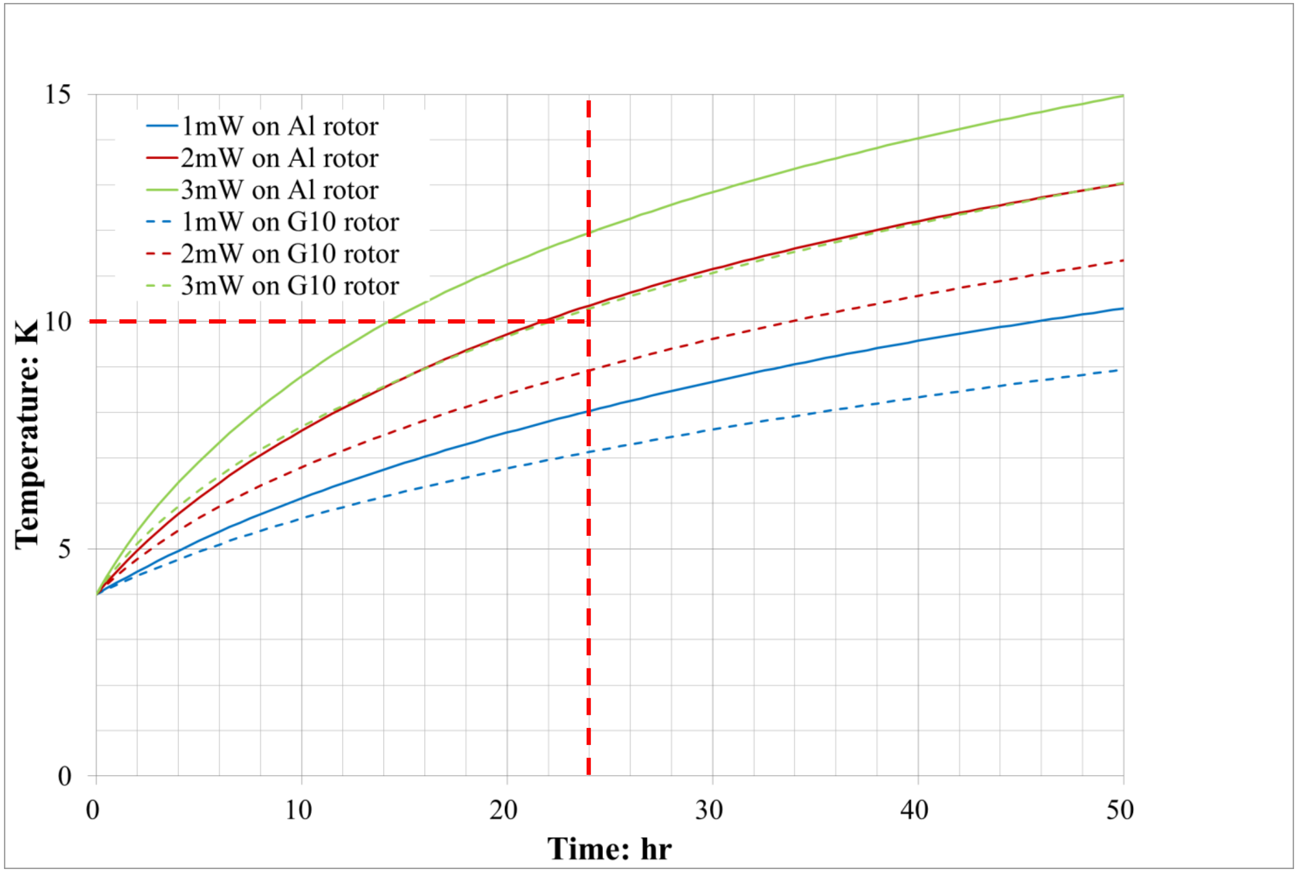


	Scale-down	Full-size	Remarks
Dimensions # Outer diameter on Rotor bottom # Height	 120 mm 53.3 mm	 570 mm 81.0 mm	
Weight	0.759 kg	28.721 kg	
Gripper contact area ratio	1	9.5	

The full-size rotor is about 5 times larger in diameter !

So is the HWP !!

Result #2-1: Maximum heat dissipation to be allowed in operation



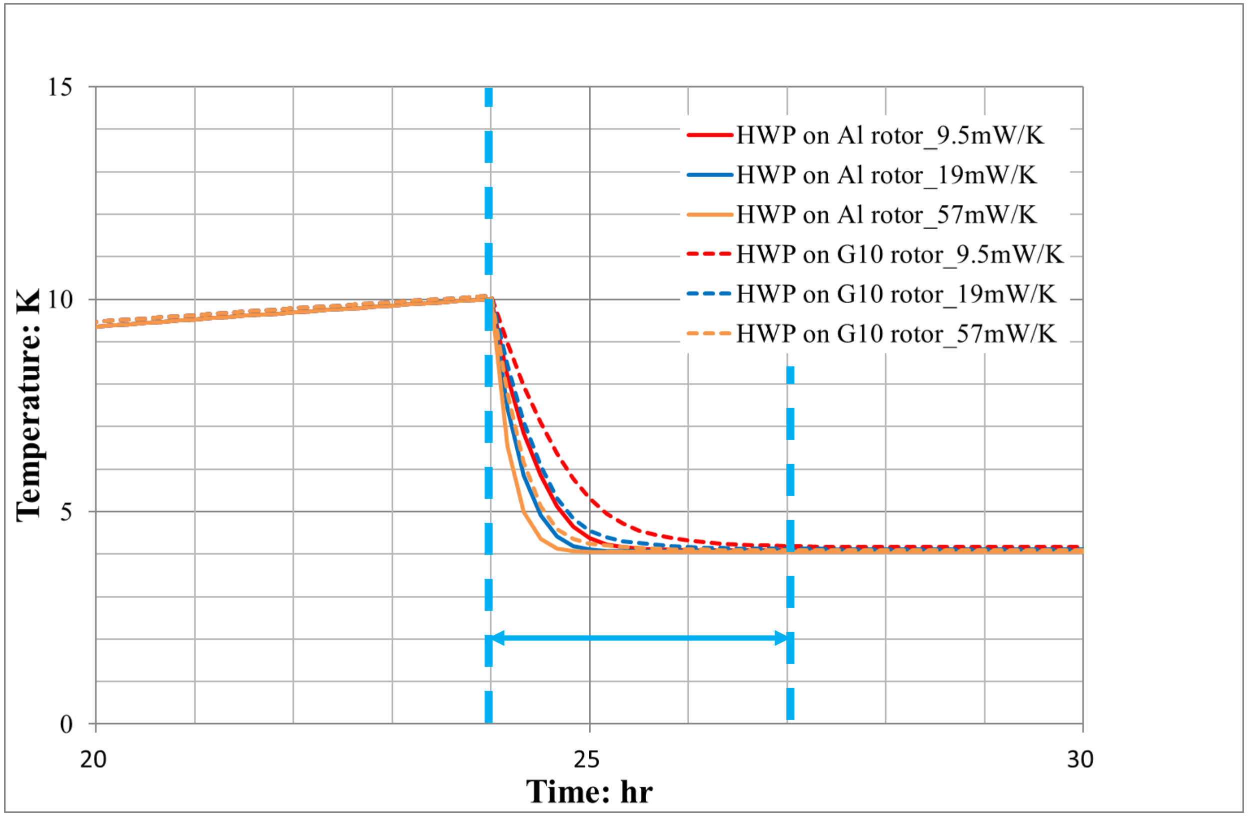
Result #2-1: Maximum heat dissipation to be allowed in operation (cont.)

At Time 24 hr,

	1mW	2mW	3mW
Rotor material: Aluminium 6061	8.03 K	10.35 K	11.96 K
Rotor material: G10	7.13 K	8.93 K	10.28 K

The heat dissipation of 1.82mW for Al rotor and that of 2.76mW for G10 rotor are allowed from the result above.

#2-2 Cool-down time to recover 4K on the Rotor



The cool-down time is about 3 hrs. in the worst case, as in the graph.
It is still within our ADR recycle time, which is 4 hrs.

Concluding remarks

#1 *Maximum heat dissipation to be allowed in operation:*

The heat dissipation allowed on the rotor is <u>1.82mW</u> for Al rotor and <u>2.76mW</u> for G10

#2 *Cool-down time prediction to recover 4K on HWP:*

Any cases are within the ADR recycle time, which is 4 hrs.

#3 Thus, the thermal design of the full-size rotor is acceptable.

<u>Summer vacation project</u>

To measure the thermal properties of NdFeB, still unknown!