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Electrical analysis for 15MW REBCO designed wind turbine generators

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Background

Number of offshore wind farms is still increasing all over the world. The offshore wind power is greater than that on land. In addition, there is no restriction of site and road for construction. However, the offshore wind farm is expensive. Therefore, the capacity in electricity per a wind turbine needs to be much larger than those on land and onshore. Especially, in Japan, there is so little shoal that not traditional fixed-bottom wind turbines but floating wind turbines are required. So the capacity in electricity per a single turbine for offshore wind farms should be larger than 10 MW or 15 MW.

In this study, to reduce the ac loss in REBCO superconducting tapes, we intend to adopt the ac loss reduction technique which was applied to construct a 3phase-66/6.9kV-2MVA superconducting transformer. It is the combination of scribing and special winding. Using the observed and theoretically estimated properties, we conceptually designed 15 MW fully superconducting generators with the magnetic field at the gap and the operating temperature as a parameter.

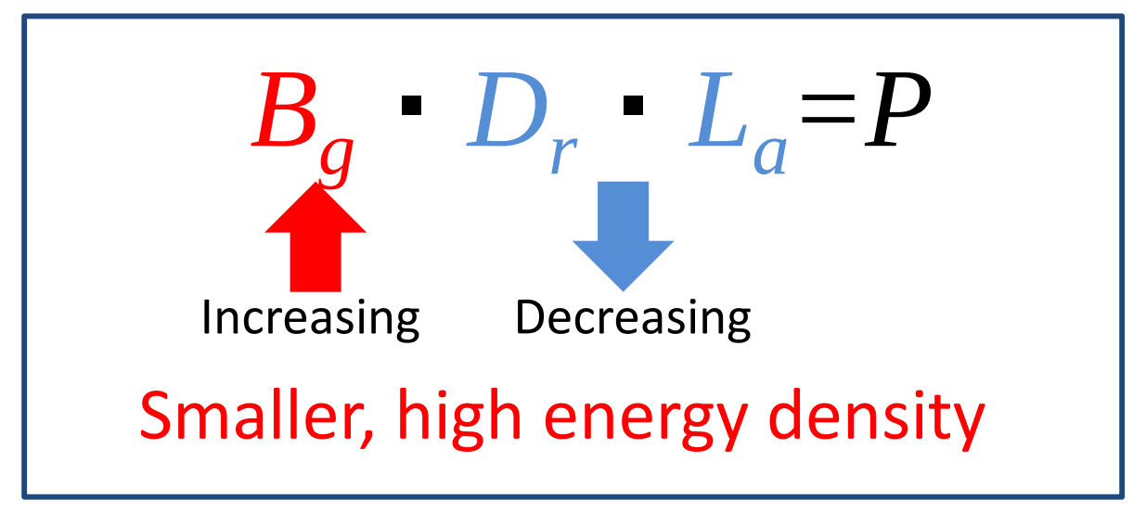
Objectives

- Development of analysis model for wind power generator, using scribing and special REBCO superconducting tapes.
- For each case, the weight of generator, the required length of REBCO superconducting tapes, ac loss of the tape, efficiency and the construction cost ware investigated by numerical simulation using the software on the market.

Methods

Design of Fully Superconducting Generators

$$P \propto AT \cdot \Phi \propto AT \cdot (B_g \cdot D_r \cdot L_a)$$



AT : Electric loading

B_g : Magnetic flux density at the gap

D_r : Rotor diameter

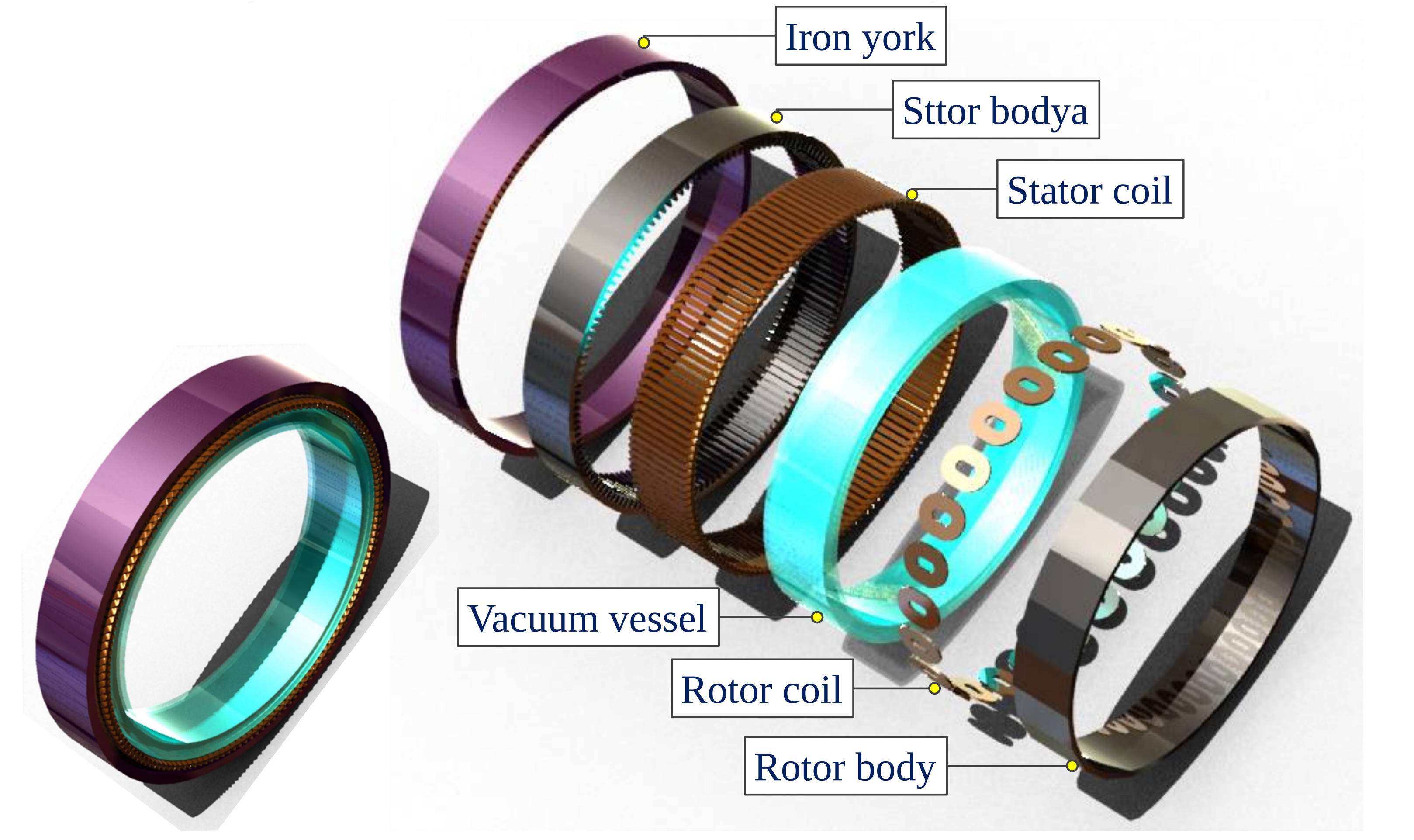
L_a : Length of the straight part of the armature

TABLE I PARAMETERS OF FULLY SUPERCONDUCTING GENERATORS

Property	Value
Power	15 MW
Rotating speed	10 rpm
Voltage	6900 V
Current	1255 A
Number of pole, *p*	32
Frequency	2.7 Hz
Diameter of stator	4.5 m
Direct axial length	1.5 m
Volume	10.7 liter
B_g	1.5, 2, 3 T
Electric loading, *AT*	161 A·Turn/mm
Magnetic loading, ϕ	0.0163 Wb
Magnetic flux density of yoke	1.7 T
Operating temperature, *T*	40, 50, 64 K
Ratio of the rated peak current to Ic Armature winding	0.8
Current density	200 A/ mm^2
Thickness of shield yoke	0.5 m
Air gap	20 mm
Thickness of walls of cryostat and 80K shield	30 mm

Model

Design of Field and Armature Windings and Iron York



Results

Numerical Simulation of Properties of Fully Superconducting Generators

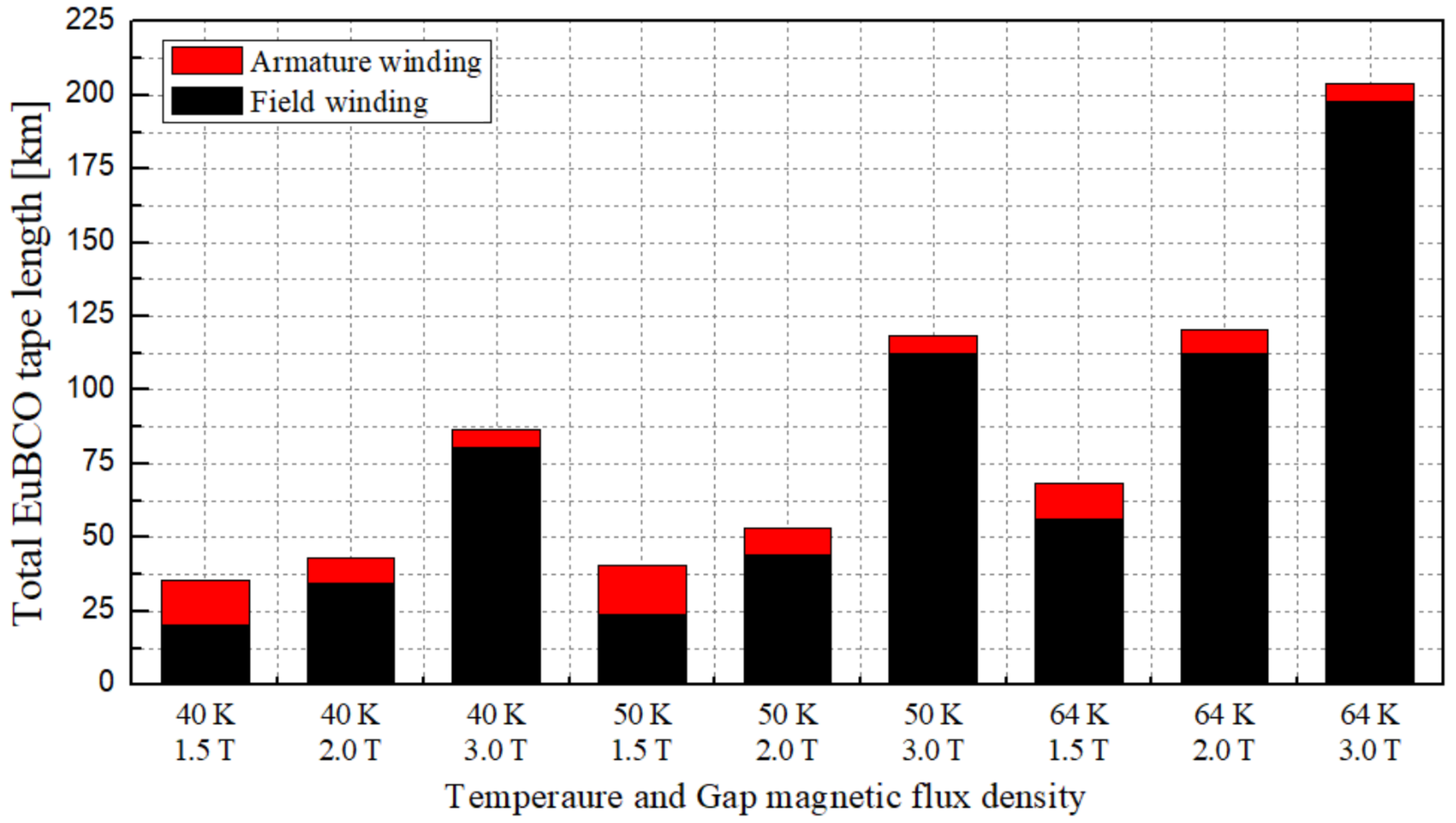


TABLE 2 RESULT OF NUMERICAL SIMULATION FOR TOTAL EUBCO TAPE LENGTH

Case	Coil$_r$ nunber	Coil$_r$ turn	Coil$_s$ turn	Armature winding [km]	Field winding [km]	total [km]	Cost [$]
40 K 1.5 T	1	180	46	20.29925	15.21315	35.5124	976,591
40 K 2.0 T	1	300	27	34.37494	8.952665	43.32761	1,191,509
40 K 3.0 T	2	350	18	80.73599	5.975772	86.71176	2,384,573
50 K 1.5 T	1	210	51	23.77746	16.85522	40.63267	1,117,398
50 K 2.0 T	1	380	28	44.00002	9.282978	53.283	1,465,283
50 K 3.0 T	2	480	18	112.5485	5.975772	118.5243	3,259,418
64 K 1.5 T	1	480	37	56.27427	12.25173	68.526	1,884,465
64 K 2.0 T	2	480	24	112.5485	7.961181	120.5097	3,314,017
64 K 3.0 T	4	425	18	197.9958	5.975772	203.9715	5,609,216

Results

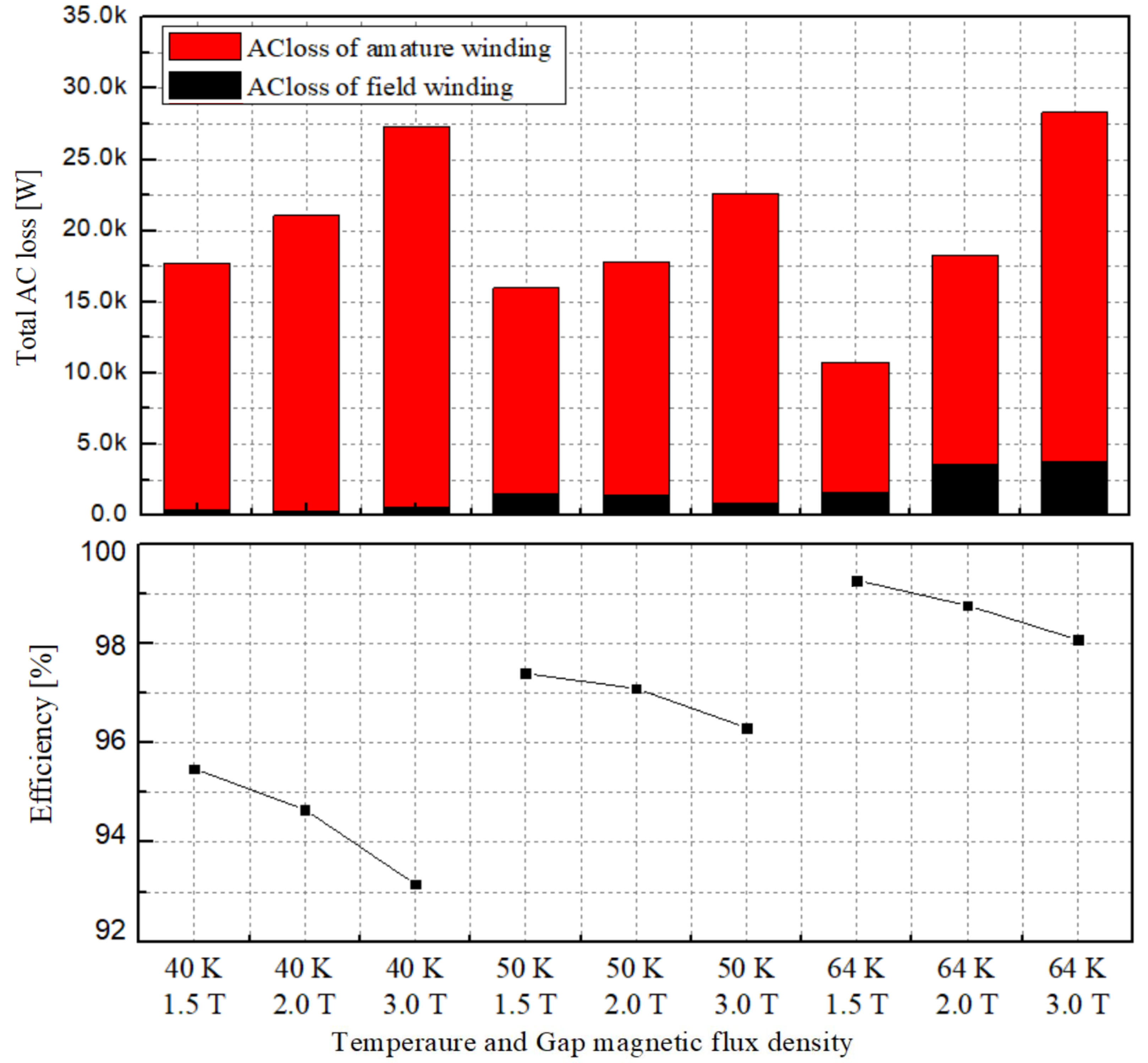


TABLE 3 PARAMETERS OF FULLY SUPERCONDUCTING GENERATORS

Power	Case	Coil$_r$ AC loss [W]	Coil$_s$ AC loss [W]	Iron loss [W]	cop	Total loss [W]	efficiency
15 MW	40 K 1.5 T	404.0515	17315.37	1111.55783	40	709888.3	95.48126
	40 K 2.0 T	293.122	20783.8	3062.87107		846139.7	94.66028
	40 K 3.0 T	546.3965	26777.07	7716.78335		1100655	93.16391
	50 K 1.5 T	1500.403	14483.26	908.231904	25	400499.9	97.39944
	50 K 2.0 T	1418.608	16405.21	3008.83638		448604.3	97.09615
	50 K 3.0 T	887.1097	21701.16	10109.2898		574815.9	96.30932
	64 K 1.5 T	1563.673	9198.716	2075.46946	10	109699.4	99.27398
	64 K 2.0 T	3583.887	14689.99	4309.55435		187048.4	98.76837
	64 K 3.0 T	3791.728	24534.28	10068.4962		293328.6	98.08198

Conclusion

- The loss of the fully superconducting generators is mostly the ac loss at armature winding. And a generator maximum efficiency of 99.2% are obtained.
- The weight of fully superconducting generators is smaller compared with conventional generators. And the superconducting tape cost is only 1 to 2 % of the total construction cost.
- The efficiency of the generator was higher as the operating temperature was higher and the gap magnetic flux density was smaller.

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