MT25

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Degradation of Critical Current in an HTS Tape with Combined Bending and Torsion Considering Curvature of Elliptical Shape

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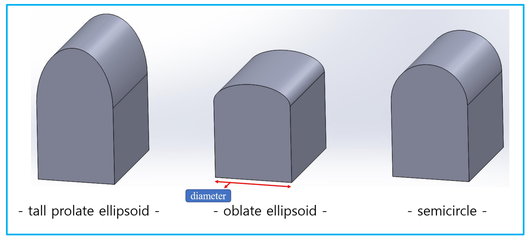
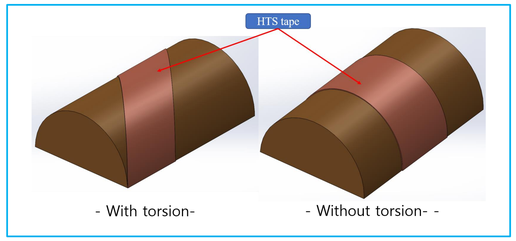
1. Introduction

- The rotating HTS flux pump is a suitable device for charging the excitation coil of an HTS synchronous motor while reducing heat loss.
- An HTS tape must be connected in series to reduce joint resistance and increase charging speed.
- Therefore, the HTS tape is wound in a shape in which bending and torsion are applied together.
- The strain that occurs when the HTS tape is wound causes a degradation of critical current.
- Therefore, this paper investigated the degradation of critical current according to the winding shape and strain of HTS tape.
  - ✓ Strain depends on the size of the beading diameter : 20, 30 and 40 mm.
  - ✓ Winding shape considered an elliptical shape : tall prolate ellipsoid, oblate ellipsoid and semicircle.
  - ✓ Winding pitch is applied to realize the shape combined bending and torsion : 0, 20 and 40 mm.

2. Experimental Procedures

1) Winding shape and bending diameter

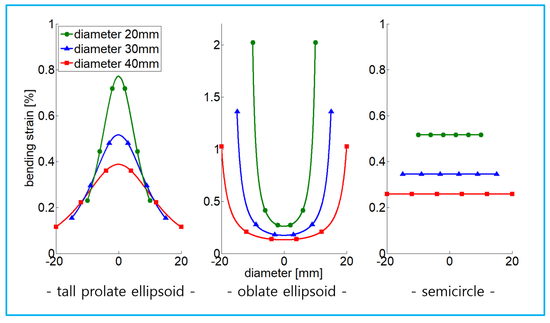




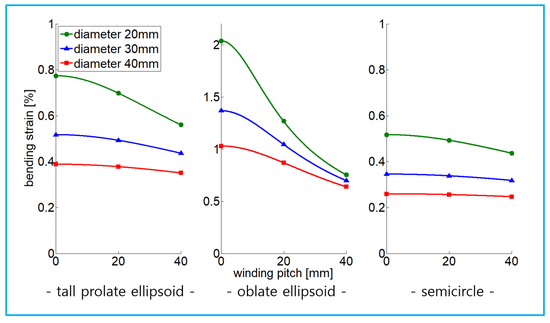
Parameters		Values
Diameter		20 mm
		30 mm
		40 mm
Ellipticity	Tall prolate ellipsoid	0.745
	Oblate ellipsoid	0.866
	Semicircle	0
Winding pitch		0 mm
		20 mm
		40 mm

Figures show the bending shapes and presence or absence of torsion
- ✓ **The bending shapes are divided into 3 kinds : tall prolate ellipsoid, oblate ellipsoid and semicircle.**
- ✓ **The tall prolate ellipsoid has the smallest diameter at the center of the curve.**
- ✓ **The oblate ellipsoid has the smallest diameter at both ends of the curve.**
- ✓ **The semicircle has the same diameter at all locations.**
- ✓ **The size of torsion is applied through the winding pitch.**

2) Bending strain without torsion



3) Maximum bending strain with torsion

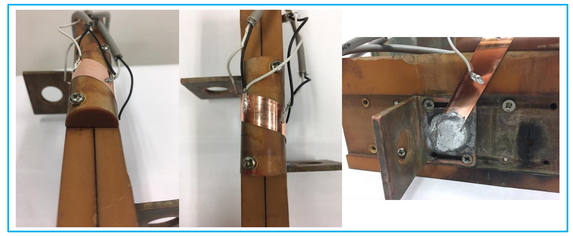


Winding shape	Winding pitch [mm]	Maximum bending strain [%]	Average bending strain [%]	Standard deviation
Tall prolate ellipsoid	0	0.7718	0.5156	0.1785
	20	0.6972	0.4843	0.1541
	40	0.5598	0.4199	0.1096
Oblate ellipsoid	0	2.0226	0.5160	0.3682
	20	1.2626	0.4595	0.2538
	40	0.7525	0.3860	0.1484
Semicircle	0	0.5163	0.5163	0
	20	0.4922	0.4922	0
	40	0.4360	0.4360	0

Figures show the maximum bending strain according to diameter and winding pitch
- ✓ **The bending strain is inversely proportional to the diameter.**
- ✓ **Oblate ellipsoid has the largest maximum bending strain.**
- ✓ **The maximum bending strain becomes smaller as the winding pitch becomes larger, and the change is largest in the oblate ellipsoid.**
- ✓ **The smaller diameter, the greater effect of the torsion.**

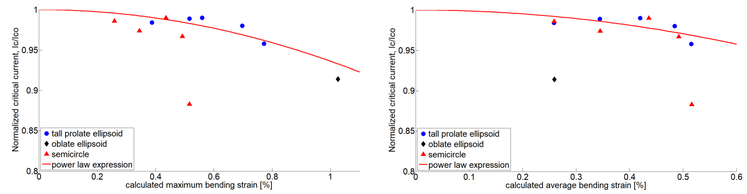
3. Experimental Results

1) HTS tape with winding pitch



Parameter	Value
Fabrication process	RDE-DR
HTS film thickness	1 ~ 1.5 [μm]
Critical current	624 ~ 677 [A]
Dimension	
Thickness	0.142 [mm]
width	12 [mm]
Substrate	Stainless steel
Thickness	104 [μm]
Stabilizer	Copper
Technique	Electroplating
Thickness	~ 20 [μm] (both side)
Manufacturer	SuNAM

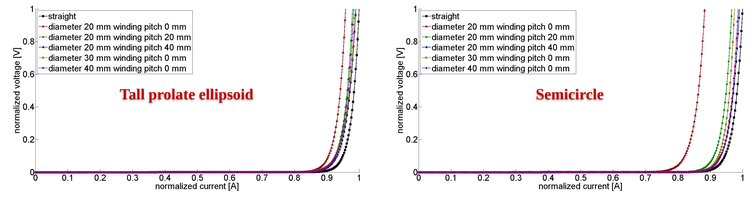
2) Normalized critical current



Figures show the normalized critical current according to maximum and average bending strain of tall prolate ellipsoid, oblate ellipsoid and semicircle.

Figures show degradation of critical current.
- ✓ **The degradation of critical current tends to decrease symmetrically because the substrate is stainless steel.**
- ✓ **Even though there is a winding pitch, the degradation of critical current according to the bending strain appears linear in the reversible strain region.**
- ✓ **The degradation of critical current due to the reversible strain occurs within the 95 % critical current retention, but the critical current decreases sharply in the irreversible strain region.**

3) N value



Figures show the normalized voltage according to normalized current of tall prolate ellipsoid and semicircle.

Figures show n-value.
- ✓ **Flux creep creates a pseudo-resistance on the HTS tape and decreased both critical current density and critical field.**
- ✓ **The flux creep depends on n-value.**
- ✓ **The larger n-value, the greater pseudo-resistance caused by the flux creep, which in turn causes resistance in the superconducting circuit.**

Winding shape	Diameter (Winding pitch) [mm]	N-value of straight state	N-value of bending state	Degradation of critical current [%]
Tall prolate ellipsoid	20 (0)	45	41	95.8
	20 (20)	42	41	98
	20 (40)	38	38	99
	30 (0)	38	36	98.9
	40 (0)	41	39	98.4
Semicircle	20 (0)	41	32	88.3
	20 (20)	40	39	96.7
	20 (40)	39	38	99
	30 (0)	45	43	97.5
	40 (0)	41	40	98.6
Oblate ellipsoid	40 (0)	40	35	91.4

Figures show degradation of critical current and n value.
- ✓ **The normalized critical current decrease in proportion to the strain in reversible region.**
- ✓ **If the strain exceeds the irreversible strain limit, the normalized critical current decreases sharply**
- ✓ **The irreversible strain limit of semicircle is lower than that of tall prolate ellipsoid, resulting in a sharp degradation of normalized critical current in smaller strain.**

4. Conclusion

- The average strain of tall prolate ellipsoid, oblate ellipsoid and semicircle is similar, but the difference of bending strain according to position is large.
- In the reversible strain region, there is little change in I_c and *n*-value degradation. However, in the irreversible strain region, abrupt I_c and *n*-value degradation were observed.
- At the same winding diameter, the semicircle has the smallest maximum bending strain but a low irreversible strain limit. Thus, when winding at the same winding diameter, winding with tall prolate ellipsoid results in less I_c and *n*-value degradation..

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