Thin-gauge silicon steel strips and Applied products

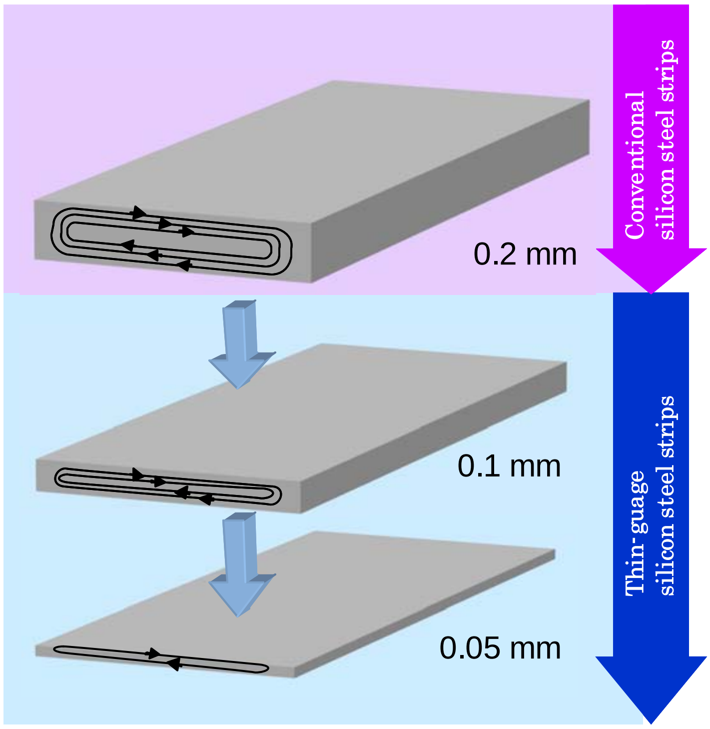
NIKKIN DENJI KOGYO Co., Ltd.

Thin-gauge silicon steel strips

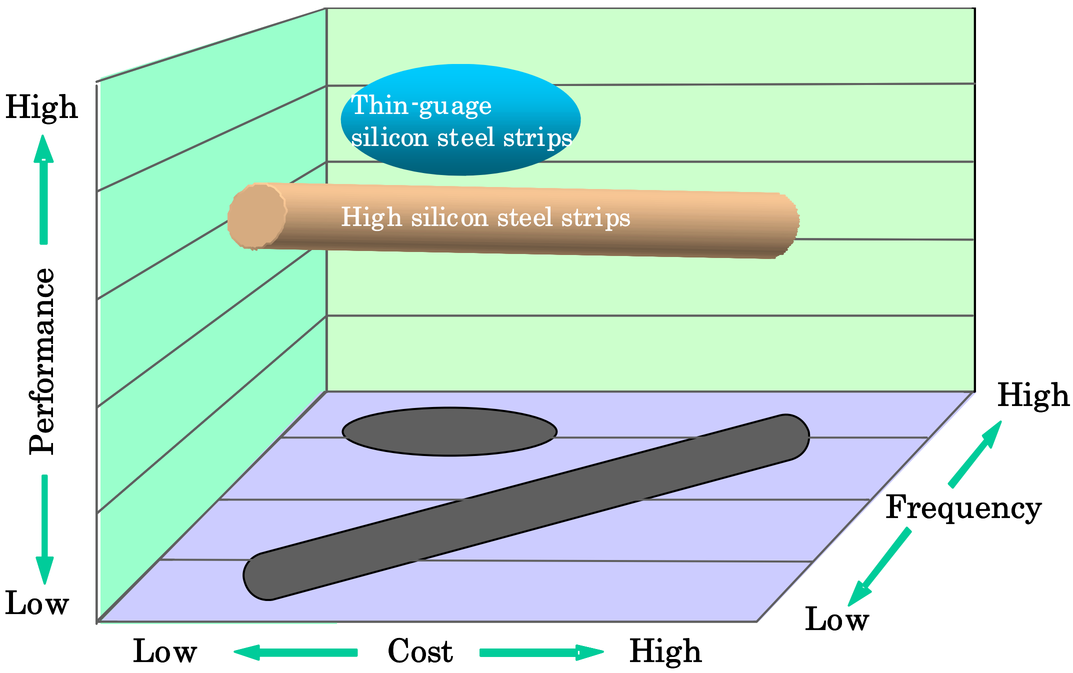
Conventional silicon steels are widely used for electrical power apparatus, electrical components in industrial products and home electronics. However, most silicon steel strips are more than 0.2mm in thickness, and applied only to apparatus operated at industrial frequencies.

On the other hand, thin-gauge silicon steel strips have advantage for use at higher frequencies. The thickness of our silicon steel strips have been reduced to the world's thinnest level so that the core loss caused by eddy currents is compressed to the lowest level and combined with our insulation coating technology, the lamination factor has been improved. Our thin-gauge silicon steel strips assist saving energy and down-sizing high-frequency reactors, transformers, and motors.

Our thin-gauge silicon steel strips allow superior cost saving as well as performance at high frequencies.



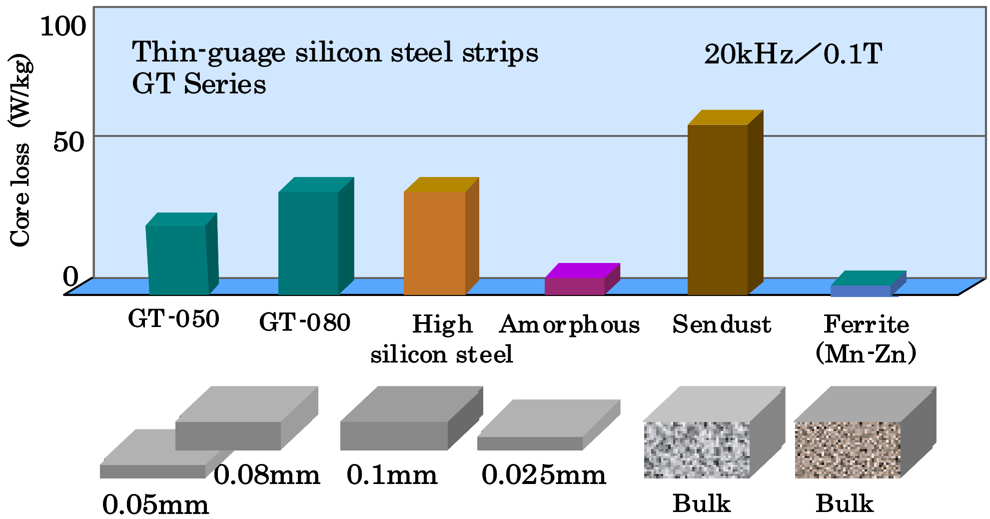
Very low core loss can be achieved by using thin-gauge strips due to its small eddy currents.



◆ Thin-gauge silicon steel strips provide superior cost performance at high frequencies.

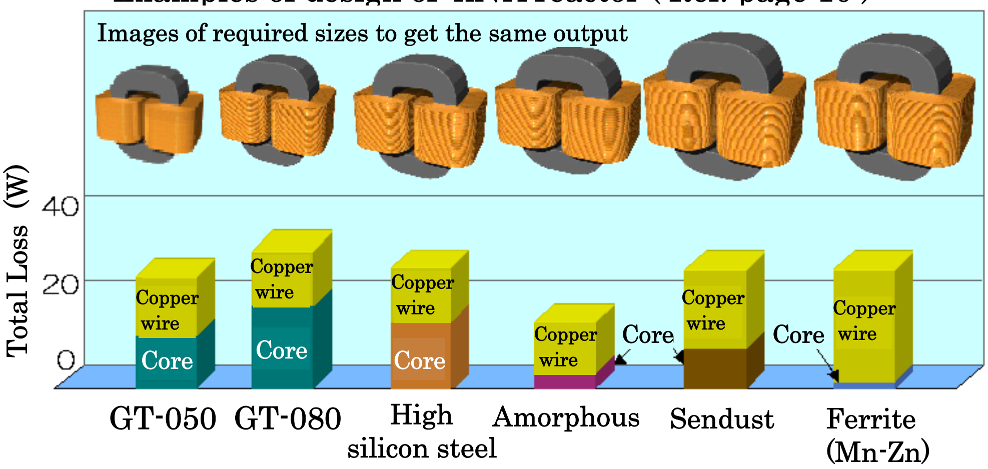
Cost performances of thin-guage silicon steel strips

Have materials been chosen for their characteristics ?

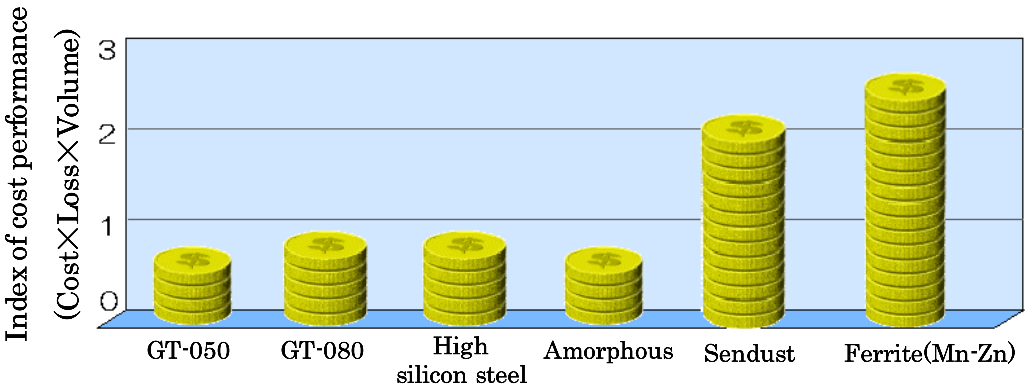


Amorphous and ferrite exhibit excellent performance in a evaluation of the core loss.

Examples of design of 4kVA reactor (Ref. page 10)



Evaluation of performance will change according to the total loss including losses from the size and copper wires.



Additionally, considering cost performance, the advantages of thin-gauge silicon steel strips is apparent.

- Thin-gauge silicon steel strips demonstrate their true abilities only after application.
- Thin-gauge silicon steel strips contribute to down sizing , saving energy and lower costs.

Types and applications of thin-gauge silicon steel strips

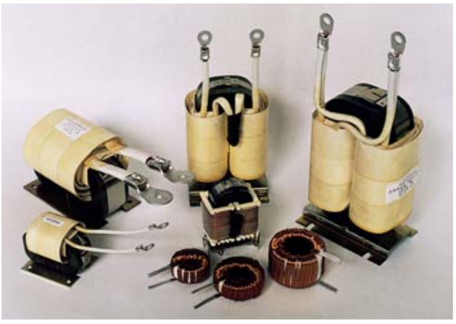
Table 1 Types of thin-gauge silicon steel strips

Classification	Grade	Thickness	Characteristics
GT series Oriented thin-gauge silicon steel strips	GT-100	0.10mm	＊Similar oriented magnetic properties relative to the rolling direction ＊Very low core loss at high frequencies and high saturation flux density ＊Most suitable for reactors, transformers, and shields
	※GT-080	0.08mm	
	GT-050	0.05mm	
	※GT-040	0.04mm	
ST series Non-oriented thin-gauge silicon steel strips	ST-150	0.15mm	＊The same as magnetic properties of GT series ＊No orientation in magnetic properties ＊Most suitable for motors, shields and also for high frequency reactors
	ST-100	0.10mm	
	ST-050	0.05mm	

Notes) Grade(※) shows newly developed products.

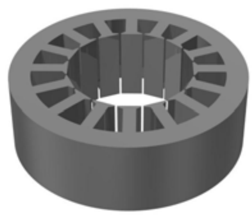
Thin-guage silicon steel strips

Applications of the GT series



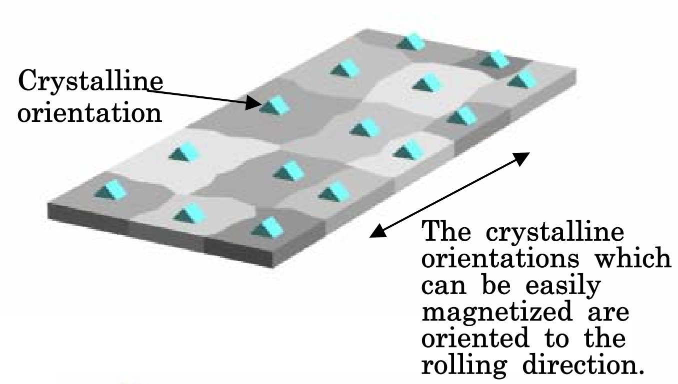
High-frequency reactors

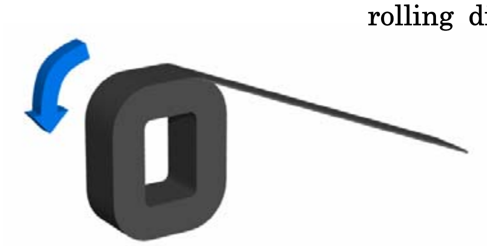
Applications of the ST series



Motor cores

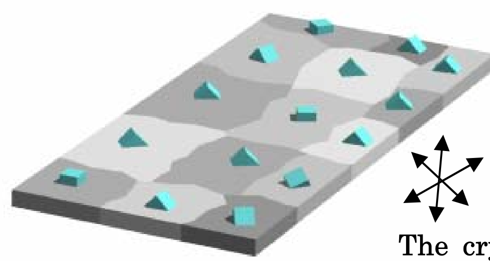
◆ Oriented thin-guage silicon steel strips

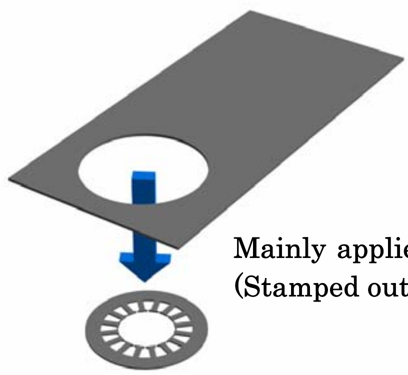




Mainly applied to wound cores
(Wound for use)

◆ Non-oriented thin-guage silicon steel strip





Mainly applied to motor cores
(Stamped out for use)

Characteristics of thin-guage silicon steel strips

Thin-guage silicon steel strips

<u>Low core loss</u>
They have low core loss at high frequencies and allow improvements in efficiency, and saves energy of reactors and transformers.

<u>High saturation flux density</u>
They contribute to down-sizing of high frequency reactors and transformers due to high saturation flux density.

<u>High permeability</u>
High permeability allows use for shields. (Ref. figure on page 6)

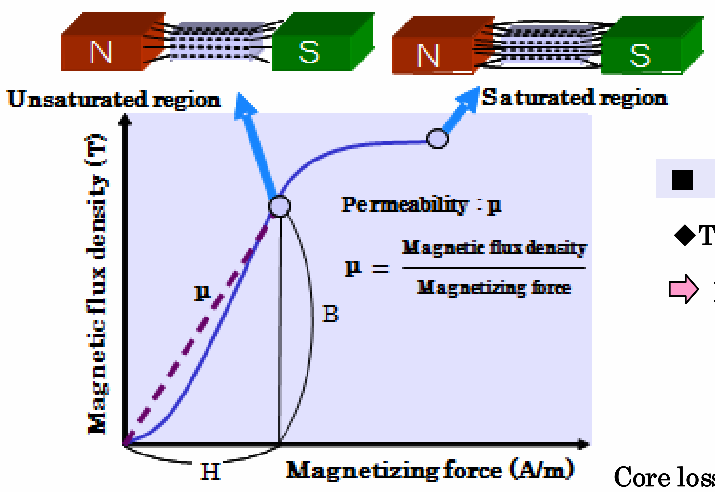
<u>Excellent insulation coating</u>
The inorganic coating allows excellent insulation, which enables the best stress relief annealing (results).

<Reference > Required properties for magnetic materials

■ High flux density、High permeability

◆**Magnetic force becomes stronger as the magnetic flux density B and the permeability μ increases.**

⇨ **Down-sizing and weight-saving becomes possible.**



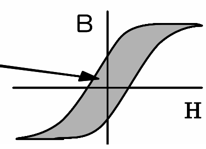
Magnetizing curve

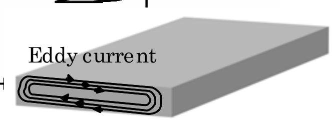
■ Low core loss

◆The lower the core loss, the smaller the energy loss.

⇨ Energy saving and high efficiency are achieved.

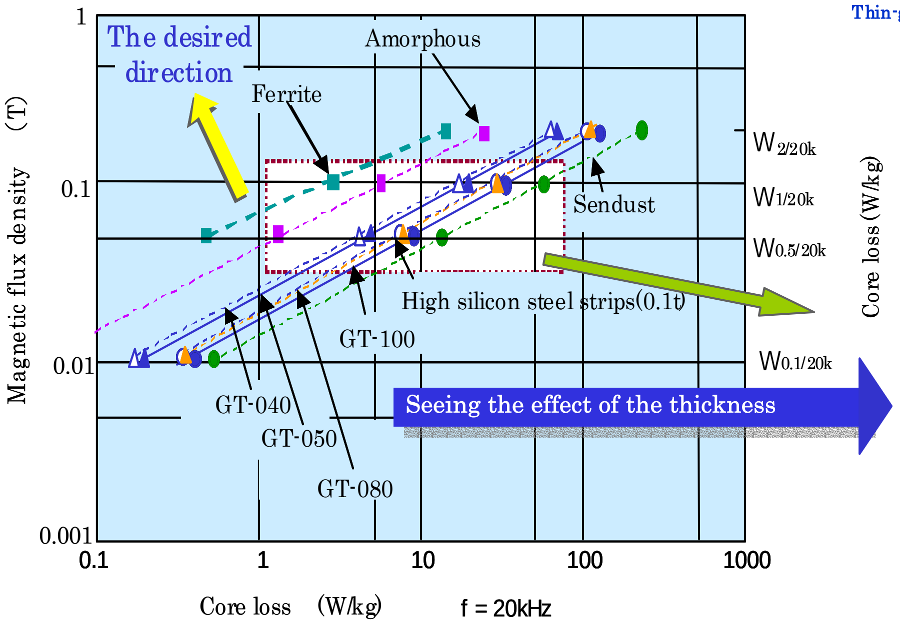
Core loss
- Hysteresis loss
- Eddy current loss



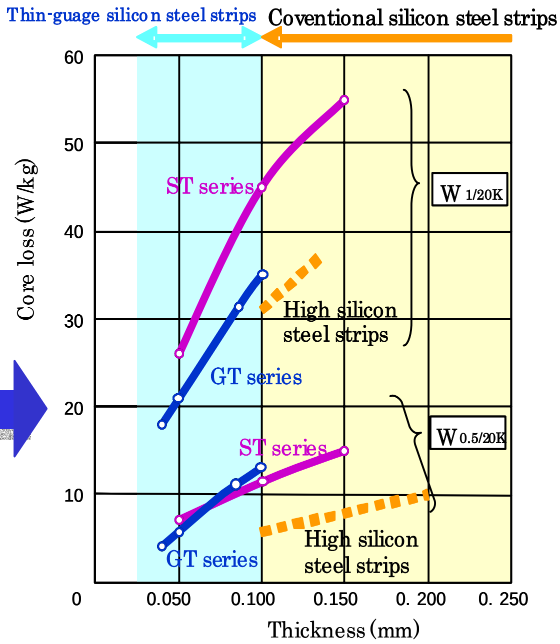


The joule heat caused by eddy currents increases the energy loss.

Core loss of thin gauge silicon steel strips at high frequencies



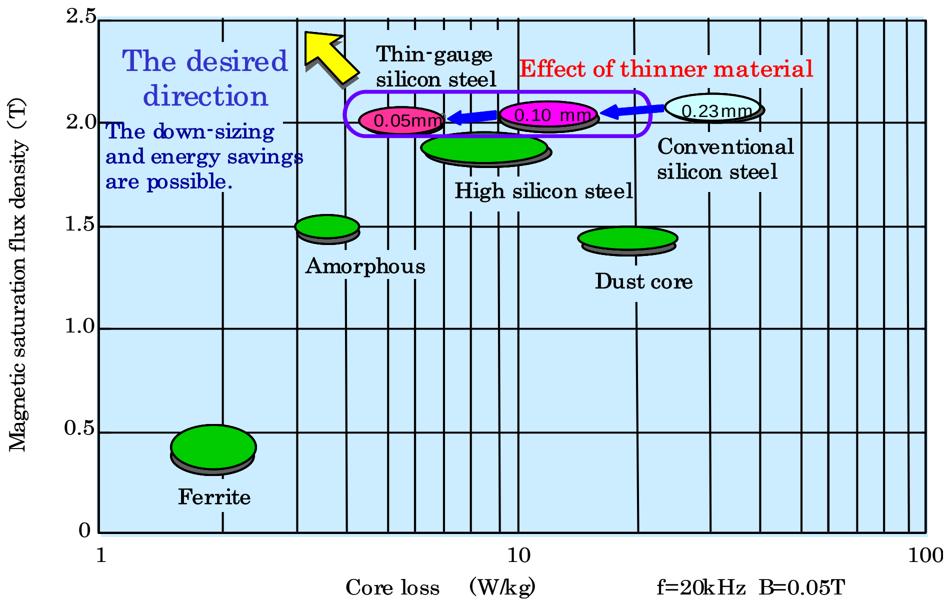
Comparison of core loss of oriented thin-guage silicon steel strips and other Magnetic materials



Relation between core loss and thickness in high-frequency ranges

The thickness significantly effects core loss, therefore, allowing thin with very low core loss at high frequencies to contribute to higher efficiency and saving energy.

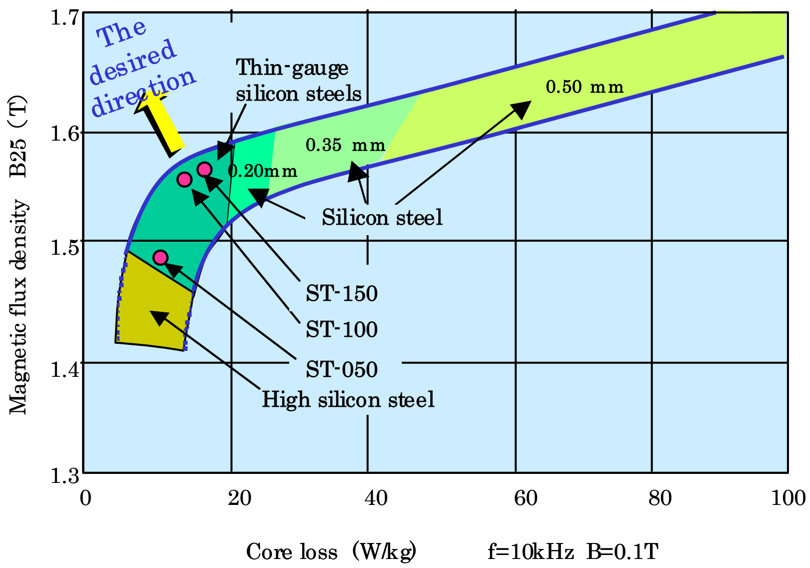
Magnetic saturation flux density of oriented thin gauge silicon steel strips



Comparison of magnetic properties of oriented thin-guage silicon steel strips and other magnetic materials

Thin-gauge silicon steel strips have high saturation flux density which contributes to the downsizing.

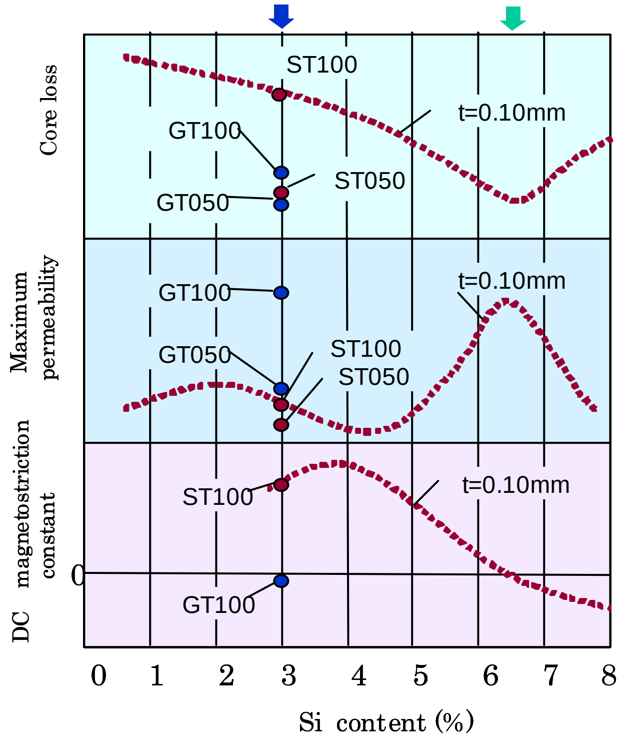
Magnetic flux density of non-oriened thin-guage silicon steel strips



Comparison of core loss of non-oriented thin-gauge silicon steel strips with other non-oriented silicon steel strips

Non-oriented thin-gauge silicon steel strips is the ideal material due to its low core loss and high saturation flux density.

Comparison of magnetic properties of silicon steel



Magnetic properties of silicon steels

The most suitable thin-gauge silicon steel strips can be selected according to the required magnetic properties.

The design of applied products

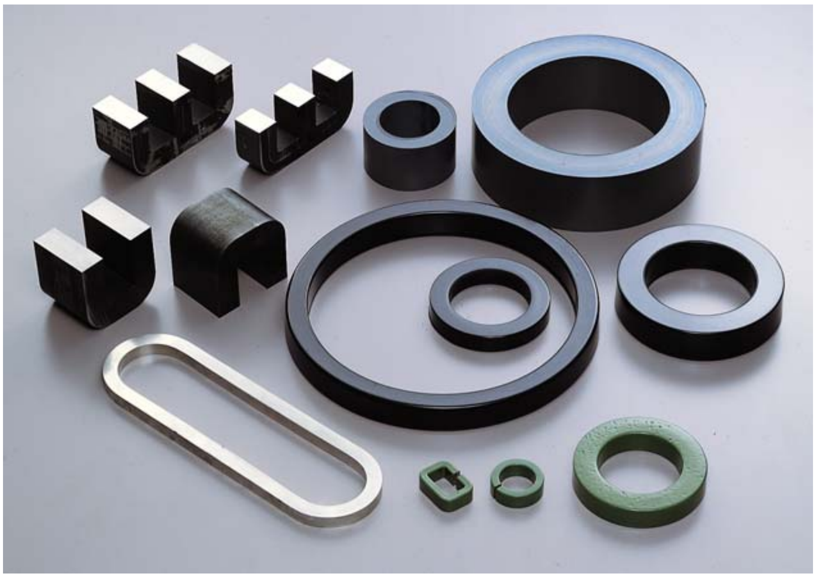
We sell thin-gauge silicon steel strips as well as designing, manufacturing, and sales of wound cores and applied products in which thin-gauge silicon steel strips are used.

Based on our wealth of technical experience, we can design and manufacture the products to meet your demands. We offer wound cores in small lots which exhibit excellent cost performances. Using our wound cores is less costly than stamped cores since die assembly is unnecessary.

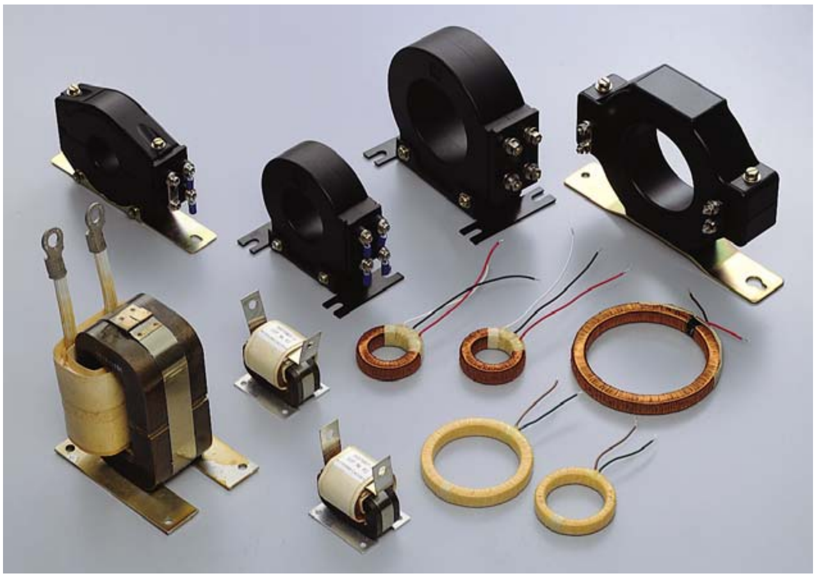
We assist customers in selecting suitable cores by using our wealth of technical experience.

Examples of application

We manufacture various wound cores and reactors.



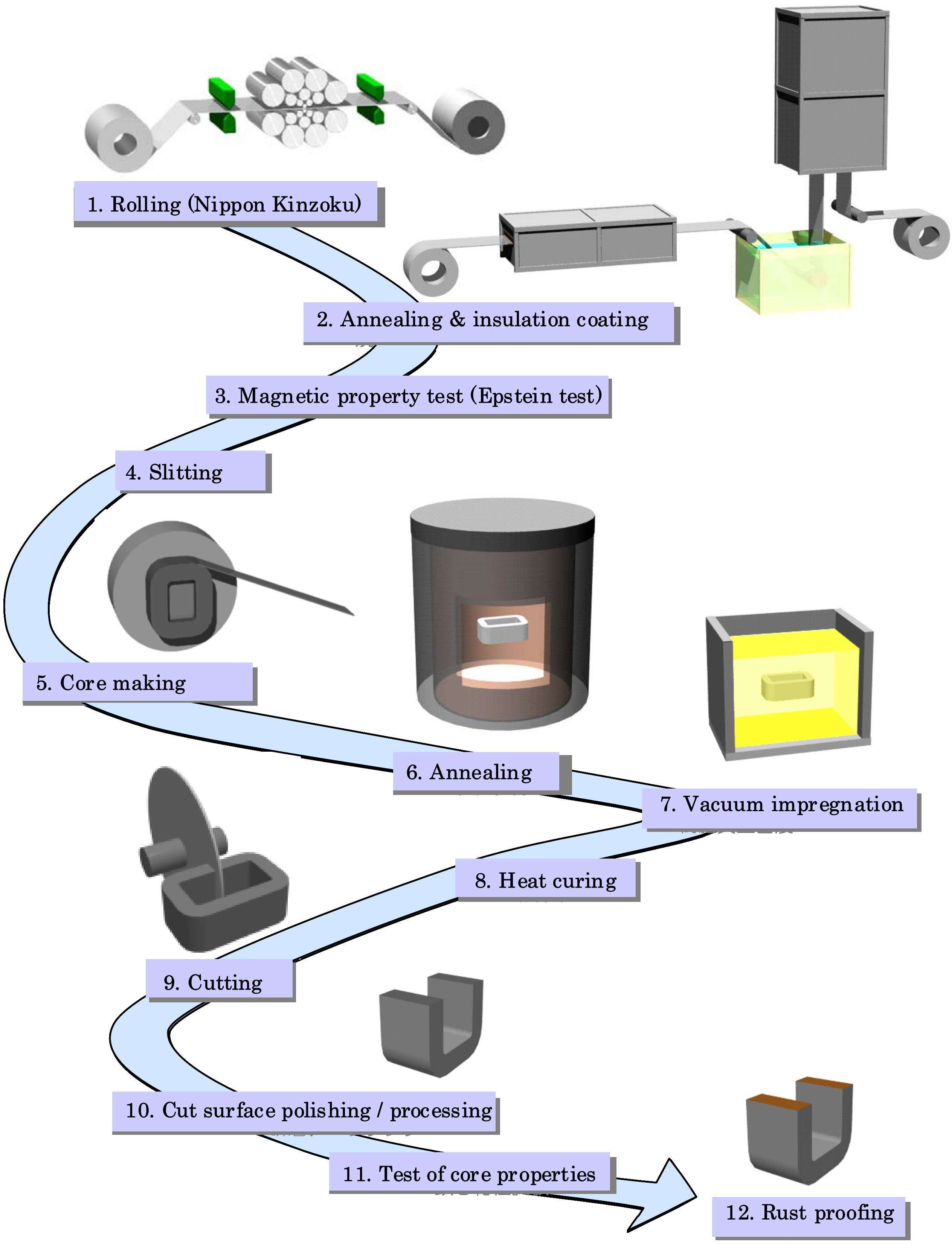
Wound cores



Applied products
(Electronic parts)

Manufacturing process of applied products

From rolling to assembly, we manufacture thin-gauge silicon steel strips and applied products under strict quality control.

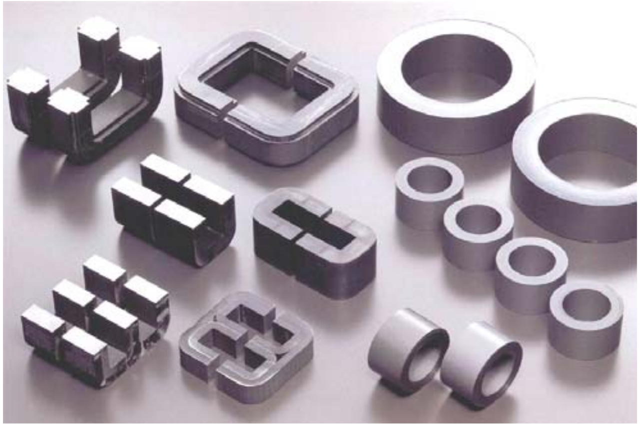


Standard cores：CS series, SC series, EC series

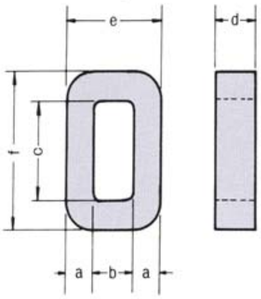
Wound cores are available to meet customers requirements.
Please specify the following.

Table 2 Dimensional notations

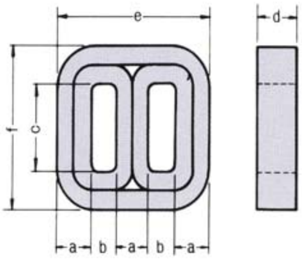
Shape	Notations
SN	SN a×b×c×d (×e×f−R)
EN	EN a×b×c×d (×e×f−R)
TN	TN a×d×Di (×Do)
SC	SC a×b×c×d (×e×f−R)
EC	EC a×b×c×d (×e×f−R)
TC	TC a×d×Di (×Do)
ECP	a1 d1 ECP a2×b×c×d2(×e×f−R) a3 d3
SCP	SCP a1×b×c×d1(×e×f−R) a2 d2



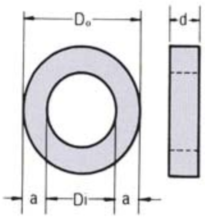
SN shape



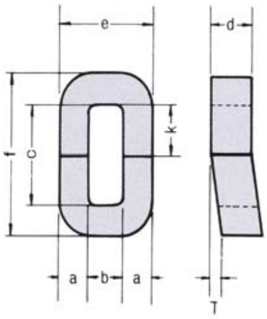
EN shape



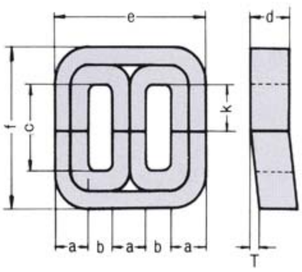
TN shape



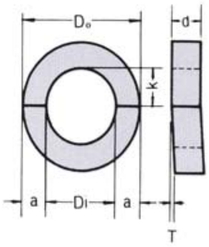
SC shape



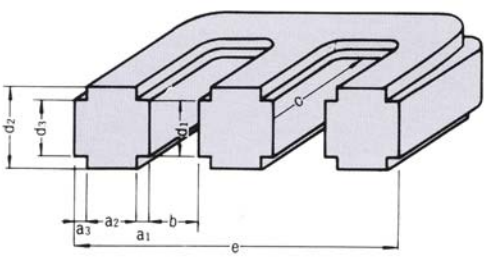
EC shape



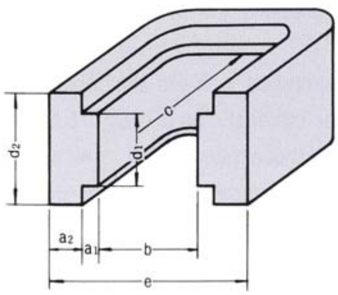
TC shape



ECP shape

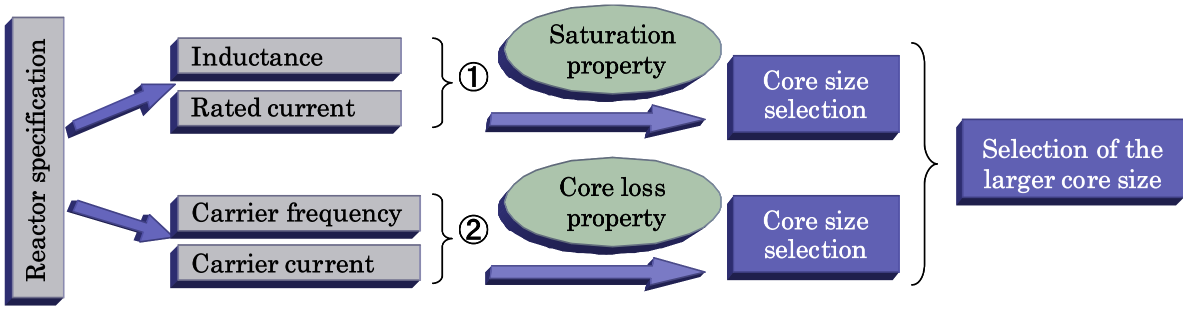


SCP shape



Design examples

The following is the example of a reactor for 4kVA photovoltaics generation.
We can design the optimal reactor, by the specifications of inductance, rated current, carrier frequency, carrier current, etc.



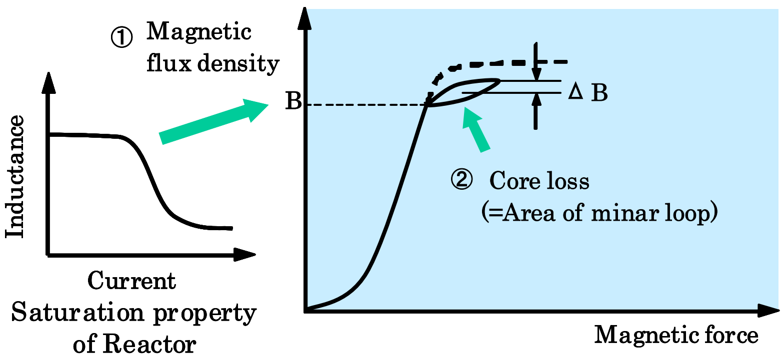


Table 3　Comparison of designs of reactors between various magnetic materials

	Parameters \ Materials	GT-100	GT-080	GT-050	GT-040	High silicon steel 0.1t	Amor-phous	Sendust	Ferrite Mn-Zn
Electrical specification	Inductance(μH)	1000	←	←	←	←	←	←	←
	Rated current (A)	25	←	←	←	←	←	←	←
	Frequency(kHz)	20	←	←	←	←	←	←	←
	Carrier current(Ap-p)	5	←	←	←	←	←	←	←
	Inductance(μH)at50A	≧600	←	←	←	←	←	←	←
	Temperature rise(K)	≦70	←	←	←	←	←	←	←
Core	B(T)	0.90	1.03	1.06	1.06	0.87	0.91	0.39	0.46
	Core loss(W)	19.1	14.4	11.5	9.2	14.8	3.2	5.7	1.1
	Mass(kg)	1.27	1.11	0.96	0.92	1.23	1.27	2.27	1.10
	Ratio of cost *1	1.00	0.92	0.97	0.97	1.03	1.16	1.19	1.20
Coil	DC resistance(mΩ)	20.1	18.9	20.3	20.7	20.1	19.4	31.5	38.4
	Copper loss(W)	12.6	11.8	12.7	13.0	12.6	12.2	19.7	24.2
	Mass(kg)	0.60	0.57	0.61	0.62	0.60	0.58	1.13	1.63
	Ratio of cost *1	1.00	0.95	1.02	1.03	1.00	0.97	1.88	2.72
Reactor	Total mass(kg)	1.87	1.68	1.57	1.54	1.83	1.85	3.40	2.73
	Ratio of Loss(%) *2	0.79	0.66	0.61	0.56	0.69	0.39	0.64	0.63
	①Ratio of volume *1	1.00	0.92	0.87	0.83	1.00	1.09	2.00	1.99
	②Ratio of loss *1	1.00	0.83	0.77	0.70	0.86	0.49	0.80	0.80
	③Ratio of cost *1	1.00	0.93	0.98	0.98	1.02	1.11	1.36	1.57
	④Index of cost performance *3	1.00	0.71	0.65	0.57	0.88	0.59	2.18	2.49

*1 Values are calculated on the condition that values of GT-100.are set at 1.00.
*2 Ratio of loss is the ratio of total loss (core loss plus copper loss) to capacity (4kVA).
*3 Index of cost performance is calculated as ①×②×③.(The smaller number, better cost performance)

Dimension of thin-guage silicon steel strips

Table 4　Dimension

Grade	Thickness		Cross-directional thickness deviation (mm)	Width		Coil inner diameter (mm)
	Dimension (mm)	Tolerance (mm)		Dimension (mm)	Tolerance (mm)	
GT-100	0.10	+0.010 −0.015	0.010	MAX 300	±0.4	250
GT-050	0.05	+0.008 −0.010	0.010	MAX 300	±0.4	250
ST-150	0.15	±0.020	0.020	MAX 300	±0.4	250
ST-100	0.10	+0.010 −0.015	0.010	MAX 300	±0.4	250
ST-050	0.05	+0.008 −0.010	0.010	MAX 300	±0.4	250

Standard values of thin-guage silicon steel strips

Table 5　Standard values of thin-guage silicon steel strips

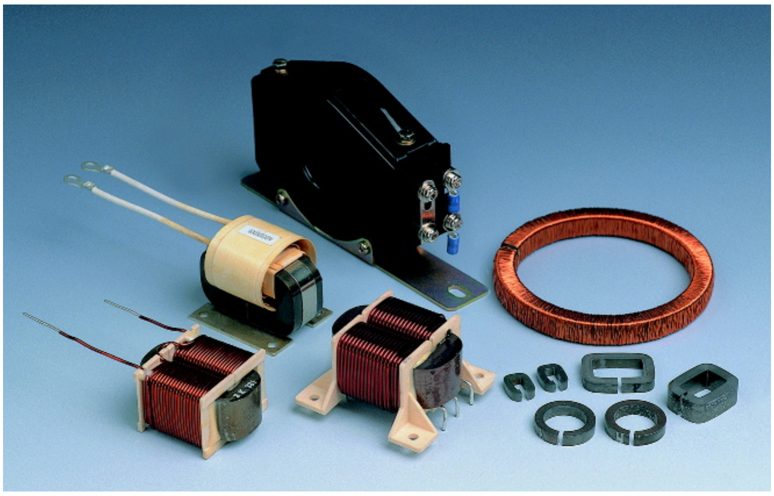
Grade	Core loss(W/kg)			Magnetic flux density(T)	
	$W_{10/400}$	$W_{15/400}$	$W_{10/1000}$	B_8	B_{50}
GT-100	—	≦15	—	≧1.7	—
GT-050	—	—	≦24	≧1.6	—
ST-150	≦14	—	—	—	≧1.6
ST-100	≦13	—	—	—	≧1.6
ST-050	—	—	—	—	≧1.5

Notes) 1. For GT series, the specimens are taken from the strips parallel to the rolling direction. The measurements are in accordance with JIS C 2550 after stress relief annealing.

2. For ST series, the specimens are taken from the strips in both directions of parallel and transverse to the rolling direction. The measurements are in accordance with JIS C 2550.

3. $W_{10/400}$,$W_{15/400}$ and $W_{10/1000}$ show core losses at magnetic flux densities 1.0T(10kG),1.5T(15kG) and 1.0T(10kG), and frequencies 400Hz, 400Hz and 1000Hz, respectively.

4. B_8 and B_{50} show magnetic flux densities at magnetic force 800A/m and 5000A/m.



Magnetic properties of thin-guage silicon steel strips

Table 6 Core loss properties

Grade	Core loss (W/kg)							
	$W_{15/50}$	$W_{15/100}$	$W_{10/400}$	$W_{10/1000}$	$W_{5/2000}$	$W_{2/5000}$	$W_{1/10000}$	$W_{0.5/20000}$
GT-100	1.2	3.0	6.1	21.3	18.0	15.2	10.4	13.0
GT-050	1.7	5.0	7.3	17.0	13.0	10.2	7.1	5.3
ST-150	2.3	—	11.6	39.4	30.0	21.5	17.2	14.2
ST-100	2.7	—	11.0	34.1	25.3	17.0	12.9	10.2
ST-050	6.1	—	25.4	65.8	40.8	21.4	11.6	6.7

Table 7 Permeability and magnetic flux density properties

Grade	Alternating permeability $\times 10^{-3}$(H/m)					Magnetic flux density(T)		
	$\mu_{10/400}$	$\mu_{10/1000}$	$\mu_{5/2000}$	$\mu_{1/10000}$	$\mu_{0.5/20000}$	B_8	B_{25}	B_{50}
GT-100	20.4	16.2	9.6	2.8	1.2	1.82	—	—
GT-050	16.6	16.0	9.9	2.7	1.5	1.75	—	—
ST-150	9.61	8.17	5.57	1.70	1.15	—	1.56	1.66
ST-100	8.54	7.87	5.81	2.00	1.39	—	1.55	1.65
ST-050	3.13	3.11	2.65	1.00	0.93	—	1.47	1.58

Notes) 1. For GT series, the specimens are taken from the strips parallel to the rolling direction. The measurements are in accordance with JIS C 2550 after stress relief annealing.
2. For ST series, the specimens are taken from the strips in both directions of parallel and transverse to the rolling direction. The measurements are in accordance with JIS C 2550.

Table 8 Mechanical and electric properties

Grade	Density (g/cm^3)	Space factor (%)	Tensile strength (N/mm^2)	Elongation (%)	Hardness (Hv)	Specific resistance ($\mu\Omega$cm)
GT-100	7.65	93	420	9	202 *2	48
GT-050	7.65	90	387	11	179 *3	48
ST-150	7.65	94	496	15	205 *1	52
ST-100	7.65	93	476	13	198 *2	52
ST-050	7.65	90	487	12	182 *3	52

Notes) 1.Tensile strength and elongation are measured parallel to the rolling direction.
2. Hardness are measured by *1: H; 0.5kg, *2: H; 0.3kg, *3: H; 0.1kg.

Table 9 Comparison of properties between various magnetic materials

Material	Magnetic flux density B_8(T)	DC max relative permeability μm	Core loss $W_{1/20000}$ (W/kg)	Specific resistance (μΩm)
GT-100	1.82	24,000	35	0.48
GT-080 ※	1.80	20,000	31	0.48
GT-050	1.75	14,000	21	0.48
GT-040 ※	1.70	10,000	18	0.48
ST-150	1.44	10,000	55	0.52
ST-100	1.42	7,000	44	0.52
ST-050	1.26	2,500	26	0.52
High silicon steel(0.1t)	1.29	23,000	31	0.82
Amorphous	1.56	300,000	6	1.30
Nanocrystalline soft magnetic alloys	1.23	70,000	4	0.01
Dust core(Sendust)	0.65	150	62	>10000
Ferrite (Mn-Zn)	0.45	3,500	3	>100000

Notes) Grade(※) shows newly developed products.

Oriented thin-guage silicon steel strips GT-100

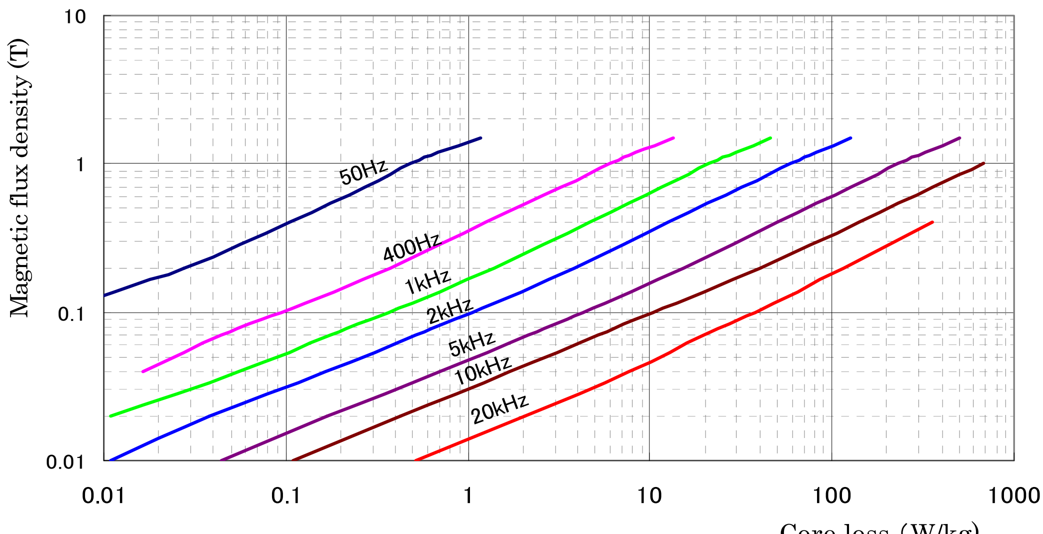


Fig.1A Core loss cuves of GT-100

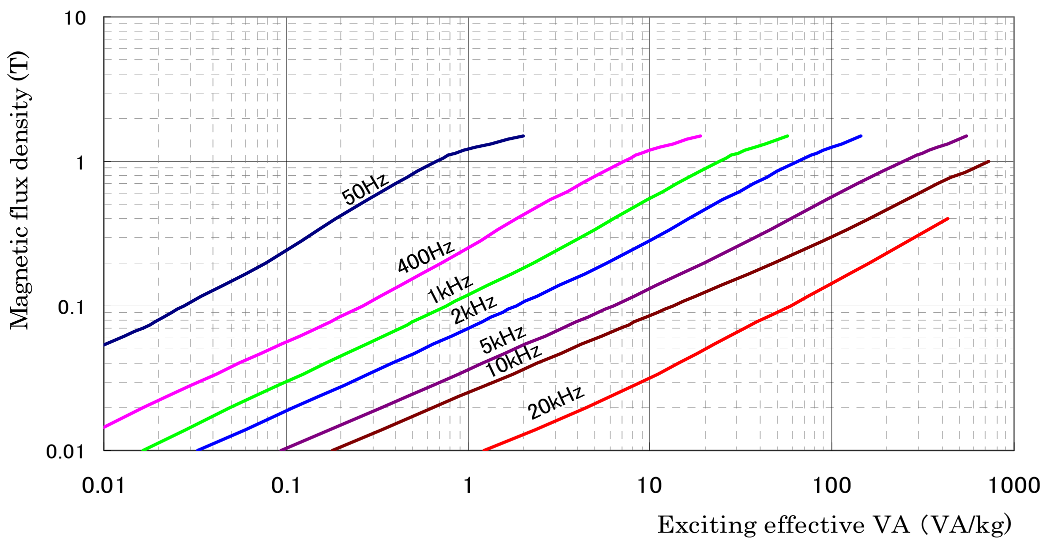


Fig.1B Exciting power curves of GT-100

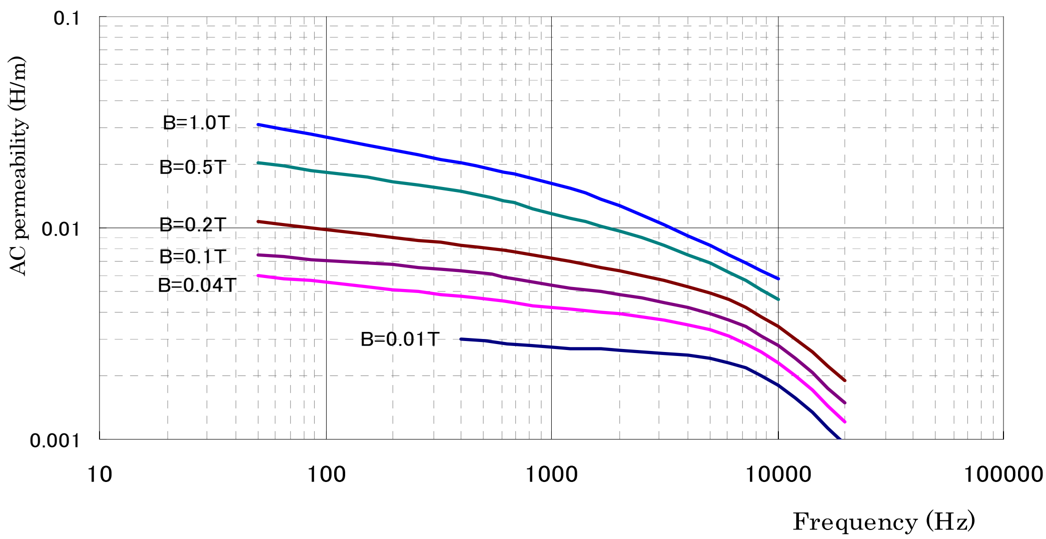


Fig.1C Frequency permeability characteristics curves of GT-100

Oriented thin-guage silicon steel strips GT-050

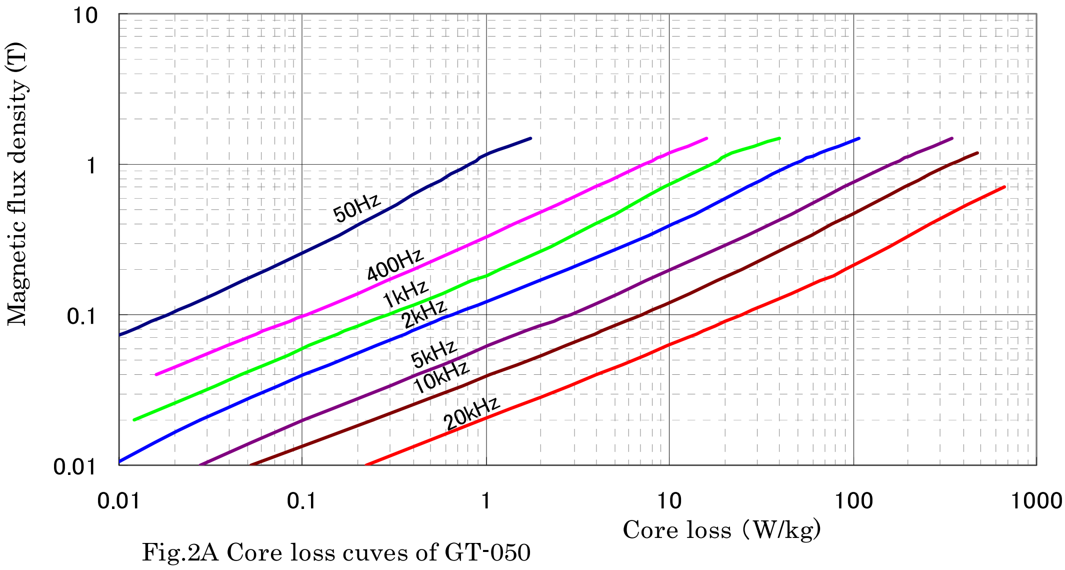


Fig.2A Core loss cuves of GT-050

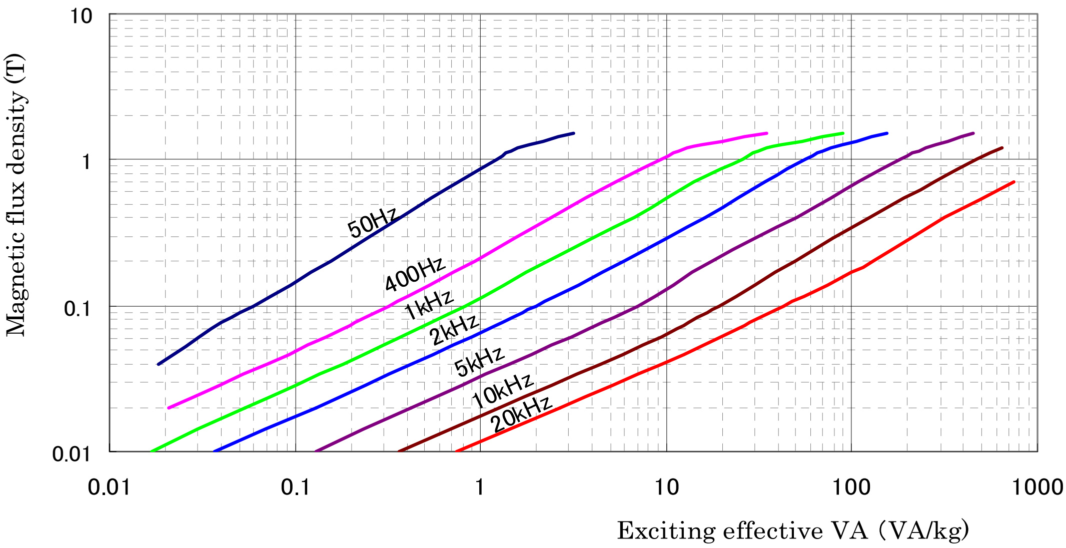


Fig.2B Exciting power curves of GT-050

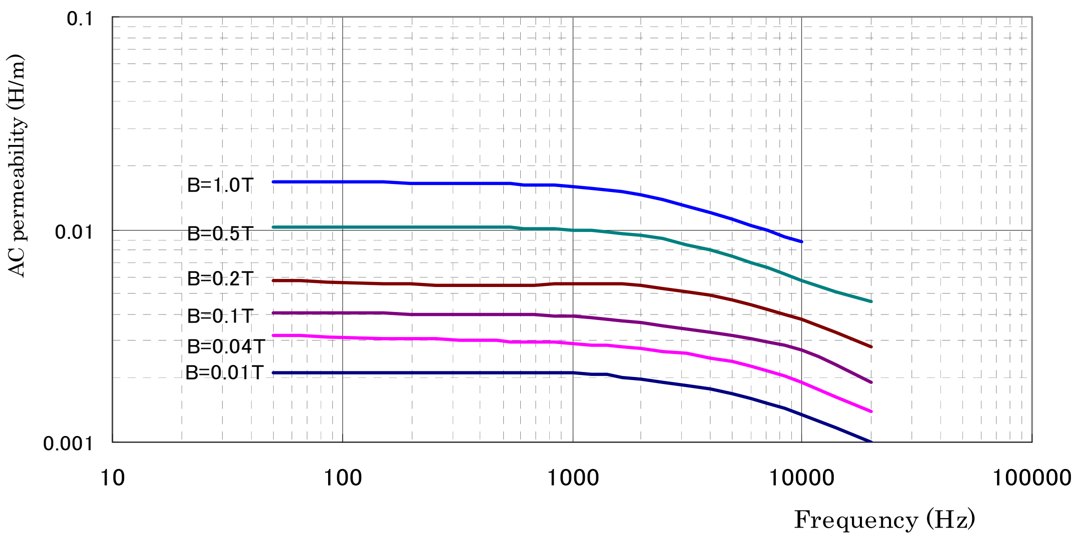


Fig.2C Frequency permeability characteristics curves of GT-050

Non-oriented thin-guage silicon steel strips ST-150

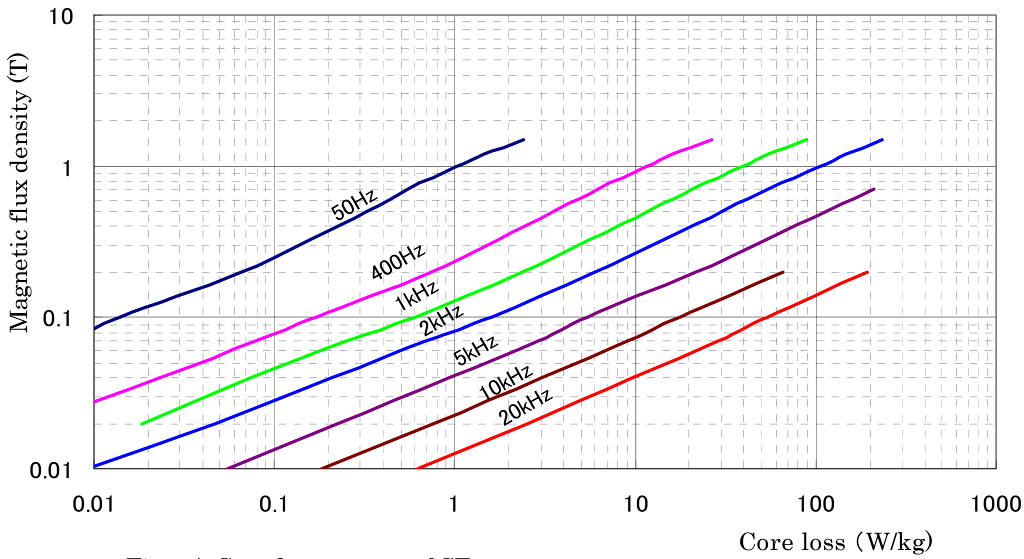


Fig. 3A Core loss curves of ST-150

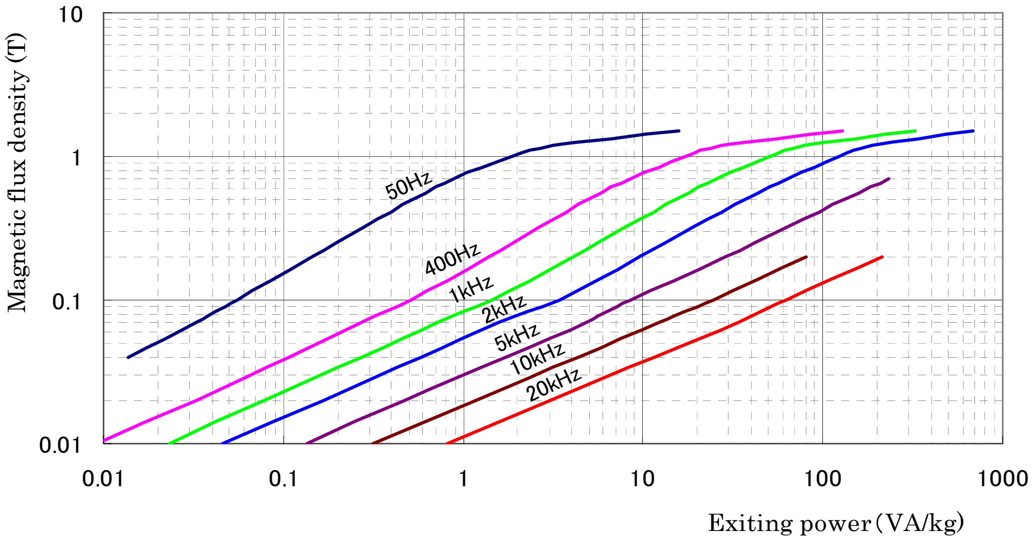


Fig.3B Exiting power curves of ST-150

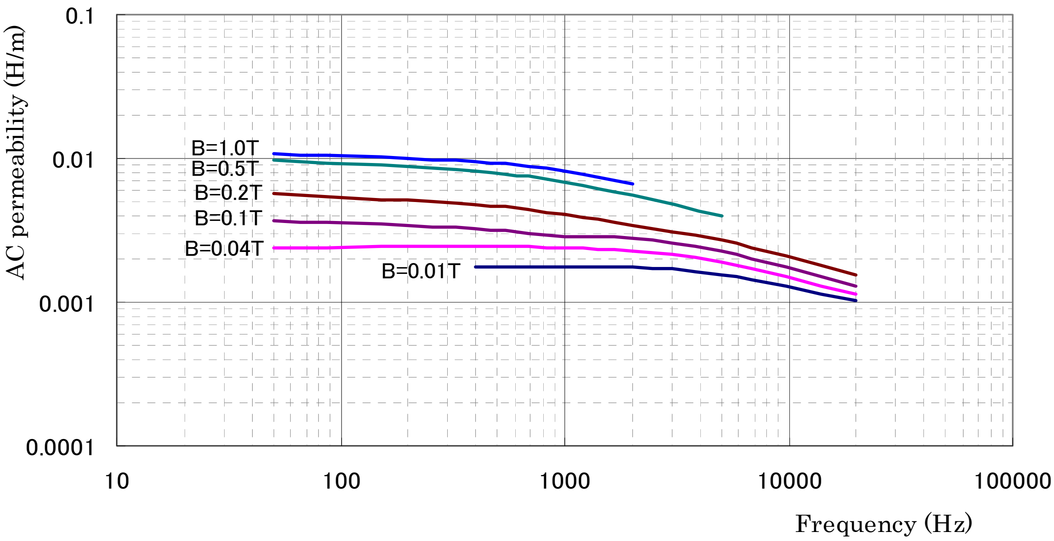


Fig.3C Frequency permeability characteristics curves of ST-150

Non-oriented thin-guage silicon steel strips ST-100

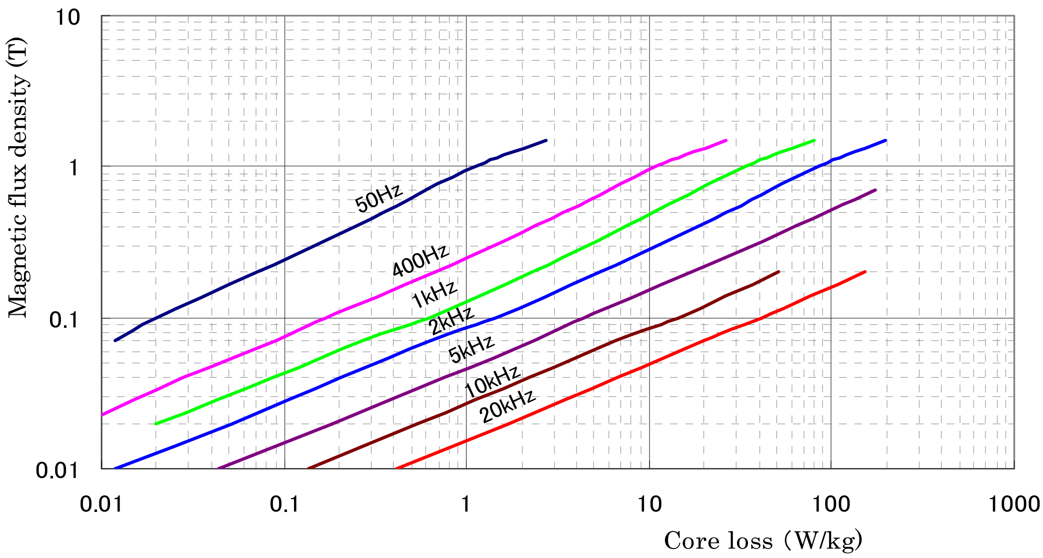


Fig. 4A Core loss curves of ST-100

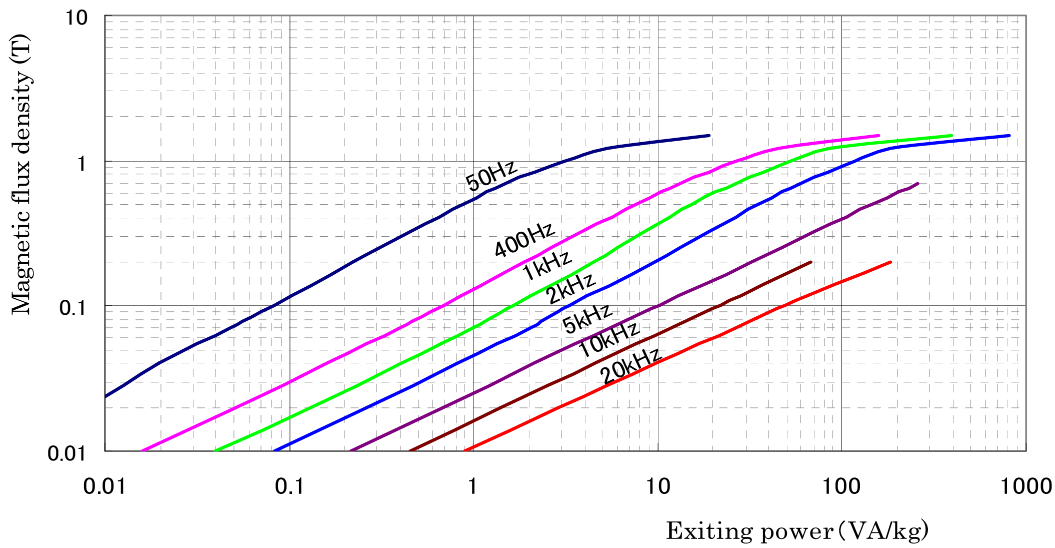


Fig.4B Exiting power curves of ST-100

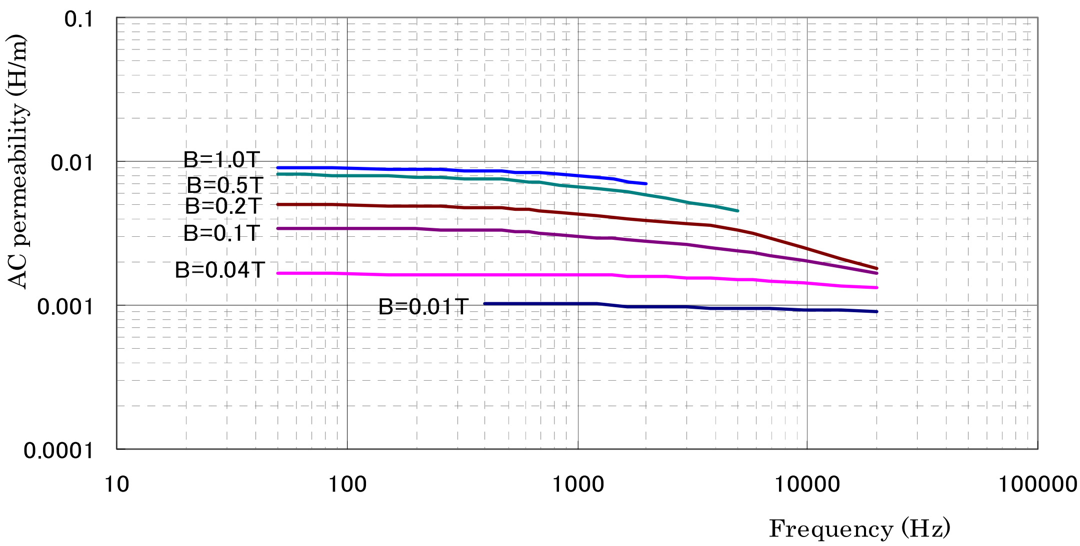


Fig.4C Frequency permeability characteristics curves of ST-100

Non-oriented thin-guage silicon steel strips ST-050

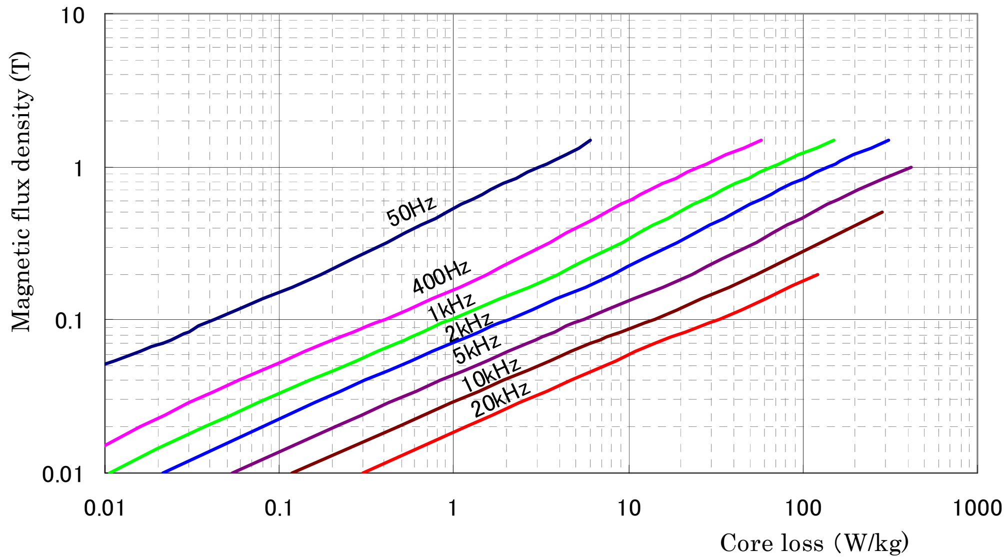


Fig. 5A Core loss curves of ST-050

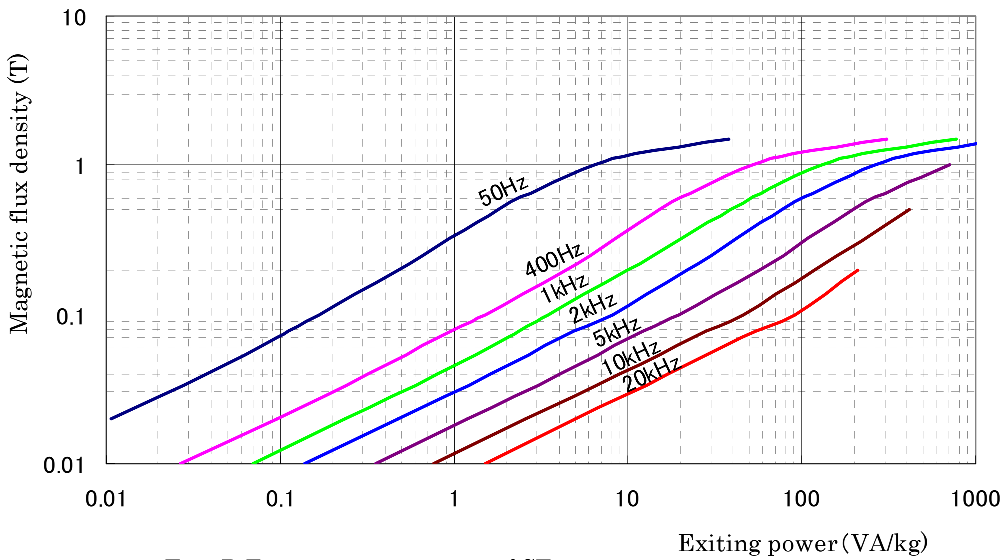


Fig.5B Exiting power curves of ST-050

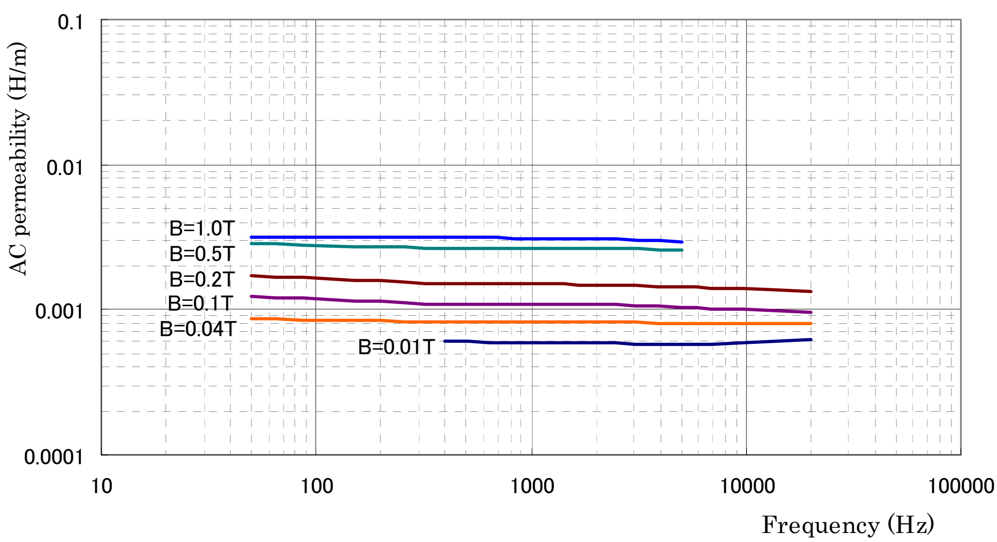


Fig.5C Frequency permeability characteristics curves of ST-050

The insulation coating

The insulation coating has the following characteristics.

1. The inorganic insulation coating is stable both thermally and chemically.
   Stress relief annealing is carried out in non oxidizing atmosphere at a temperature from 730 to 770℃, but the insulation coating has thermal resistance up to about 800℃.
   The coating is not damaged by transformer oil, and has high corrosion resistance.
2. The insulation coating is firmly adhered to the strip, so that it will not peel off during shearing and blanking.
3. The thin insulation coating allows high lamination factor.
4. The coating has high interlaminar resistance.

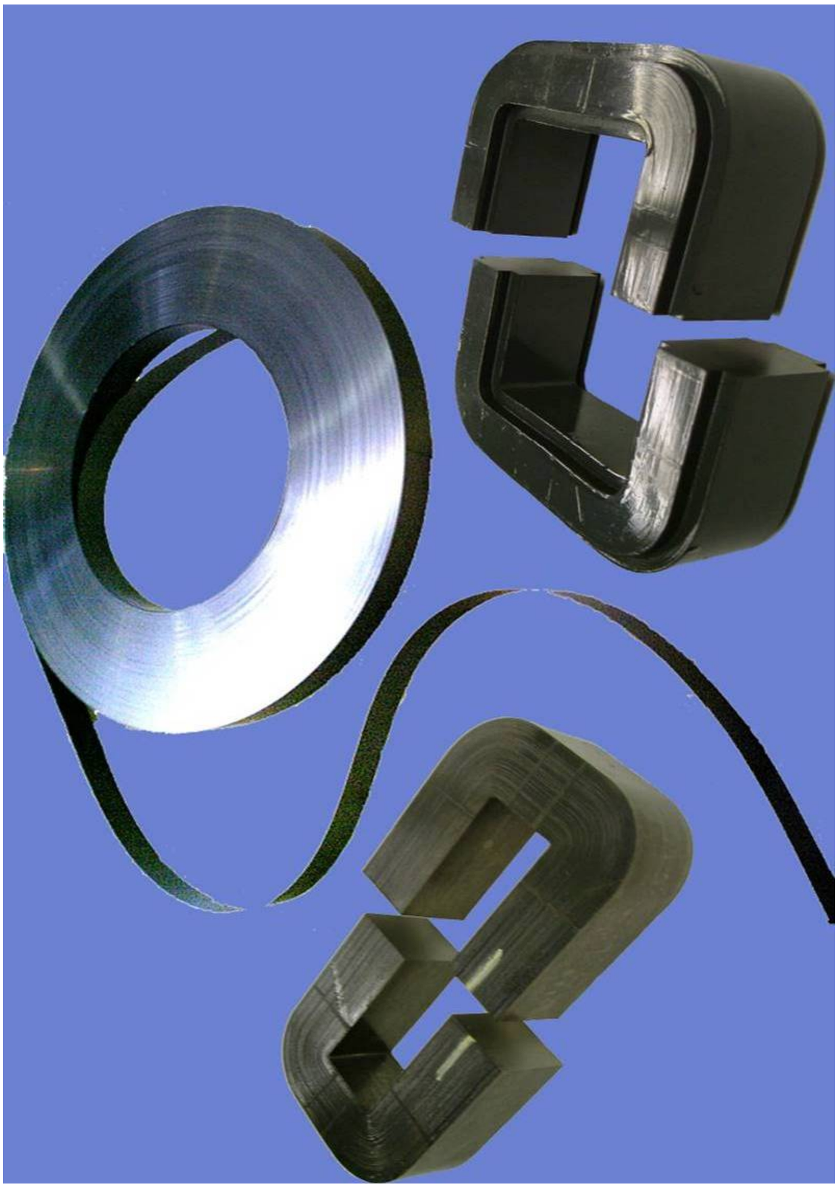
Stress relief annealing of wound cores

Stress from cutting, punching, bending have adverse effects on magnetic properties.
To relieve these stress, stress relief annealing should be performed if necessary.
The cautionary statements about stress relief annealing are as follows.

1. The atmosphere of stress relief annealing
   Compositions of atmosphere gas are needed to be highly pure Nitrogen or mixed gas of 5-10% Hydrogen and 90-95% Nitrogen with the dew point less than 0℃.
2. Avoiding Carbon contamination
   The thin-gauge silicon steel strips can be easily carburized by annealing, because they are low carbon steel. The spacer and the inner cover of batch-type furnace should be made from low carbon steel. Completely remove oil, paper and cloth.
3. Piling
   Stacked cores should be heated in the edge to edge direction for a more efficient heat transfer for uniform heating. The heat radiation and the heat transfer by convection of atmosphere should be considered. Unlevel surfaces of the bases reduce the performance of the cores because of the induced strains.
4. Annealing temperature and time
   Annealing temperature of 730～770℃, for 2～3 hours is recommended.
   Cooling at the rate of 50～100℃/hr, the temperature of the furnace below 350℃ when cores are removed will have the best results.

Substances of environmental concern

Our thin-guage silicon steel strips are compatible in the RoHS directive that the mercury and its compounds, the cadmium and its compounds, the lead and its compounds, hexavalent chromium compounds, PBB and PBDE are below the restricted value and do not intentionally add or use in the manufacturing process.



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