BAOSTEEL 宝钢股份

BeCOREs 宝钢硅钢

无取向硅钢 EVI

Non-oriented Electrical Steel

1 宝钢应用技术理念 | EVI (Eearly Vendor Involvement) Philosophy in Baosteel

成为用户真诚可靠的材料供应商及其解决方案的合作者，实现可持续、共赢发展。

To be a sincere and reliable partner for our customers in providing electrical steels and solutions to achieve win-win collaboration for sustainable development.

2 宝钢应用技术文化 | EVI Culture in Baosteel

用户思维——源于用户、服务用户、成就用户

协同思维——同一目标、网式工作、众口同声

进取思维——精于专业、诚于奉献、超越期待

Customer Thinking——From customer, Serve customer, Achieve customer

Synergy Thinking——Same target, Net-working, One voice

Enterprising Thinking——Professional, Sincere dedication, Exceed expectation

3 宝钢无取向硅钢应用技术 | Non-oriented Electrical Steel's EVI in Baosteel

宝钢为用户提供从设计选材到产品量产的技术支持

- 电机设计选材支持，实现卓越的性能和成本控制；
- 铁芯用材和结构优化，实现性能提升或技术降本；
- 铁芯加工制造支持，实现材料与装备最佳匹配；
- 新产品、新技术的推荐应用，提升竞争力。

Baosteel could offer a variety of specialized services and technical support from material selection in design stage to traction motor iron core manufacturing, including:

- To support customers in electrical steel grade selection for motor design, in order to achieve excellent performance and cost control.
- To support customers in optimization of material and structure of motor core to achieve performance improvement or cost reduction.
- To support customers in iron core manufacturing to achieve a good match between material and working facilities.
- To recommend customers with new products and new technology to improve the competency of their new products.

4 无取向电工钢产品体系 | Non-oriented Electrical Steel Product System

宝钢产品具有低铁损、高磁感和高强度的特点，满足各类电机设计和制造需求。

- 普通型：具有低铁损特点；
- 高效型：具有高磁感特点；
- 高效高强度型：磁感、铁损、强度三者综合性能优异；
- 高磁感型：更高的磁感，满足高转矩、电机小型化的需求；
- 高强度型：高强度，应用于高转速或超高转速转子；
- 消除应力退火型：经消除退火后，产品具有低铁损、高磁感特点。

Non-oriented electrical steel series in Baosteel could meet the requirements from all kinds of high performance motors with features of low iron loss at mid and high frequency, high induction density and high strength.

- Low loss series: low iron loss, high strength;
- High efficiency series: low iron loss, high induction;
- High efficiency-Higher strength series: excellent overall performance in loss, induction, and strength;
- Super induction series: high induction density to satisfy the needs for high torque and compact design of motors;
- High strength series: high strength for high speed rotor of high speed motors;
- Stress relief annealing series: low iron loss and high induction after stress relief annealing.

4.1 宝钢硅钢产品树——以新能源牌号为例无取向电工钢产品树

Product Tree of Non-oriented Electrical Steels for Traction Motors of NEV

4.2 宝钢无取向硅钢应用技术解决方案

Application Solutions of Non-oriented Electrical Steel

A

涵盖宝钢所有牌号产品的电磁、力学、涂层性能。

Covering all Baosteel grades, including the magnetic, mechanical and coating properties of the products.

B

利用电磁仿真软件有效分析各牌号应用的电机特性（效率、力矩）

Analysis of motor performance (i.g., efficiency, torque) with simulation software

C

铁芯片激光切割设备
铁芯片线切割设备
铁芯损耗测试仪
电机性能测试平台

Laser cutting machine, and wire-electrode cutting machine for prototype core making; Iron loss tester, motor testing platform

D

总结整理冲片、叠片、焊接、装配等一般性规律，为快速处理类似问题提供指导。

Manufacturing problem solving solutions accumulated for reference guidance to quick trouble shooting in punching, laminating, welding, assembling process

完善的材料数据库支持 Complete Material Database Support

电磁仿真设计

- 各种交直流磁化曲线数据
- 特殊波形下交流磁性

Magnetic simulation for motor design

- DC &AC magnetization curves
- AC magnetization curves under special waveforms

安全性设计

- 高低温下力学性能变化
- 高低温下磁性变化

Safety design

- Changes in mechanical property with temperature
- Changes in magnetic performance with temperature

转子应力分析

屈服强度、抗拉强度
疲劳强度、弹性模量

Stress analysis in rotor

Yield strength, tensile strength,
fatigue strength, elastic modulus

冷却系统设计

导热系数、热膨胀系数

Cooling system design

Heat coefficient, expansion coefficient

持续更新和完善的电机用无取向电工钢性能数据库，为用户提供从机械性能、基础电磁性能及特殊工况性能等一系列全套的数据支持。根据用户的多样化需求，可提供性能指标与原始曲线数据等各种形式数据。

An updating and complete database of non-oriented electrical steel provides our customers a strong support with data of mechanical properties, magnetic properties under normal and special working conditions. Data could be in format of performance index or original test curves points according to customers' requirement.

无取向电工钢性能数据库 Non-oriented Electrical Steel Database for NEV		
典型电磁性能 Typical magnetic properties	高低温机械性能 (-40°C~250°C) Mechanical properties at various temperatures (-40°C~250°C)	其他物理性能 Other physical properties
20Hz~10kHz交流磁化曲线 20Hz~10kHz AC Core loss Curves	屈服强度 Yield strength	导热系数 Heat coefficient
直流磁化曲线 D.C. Magnetization Curves	抗拉强度 Tensile strength	膨胀系数 Expansion coefficient
20Hz~10kHz高低温磁化曲线 (-40°C~150°C) 20~10kHz Magnetization Curves at various temperatures (-40°C~150°C)	延伸率 Elongation	弹性模量 Elastic modulus
特殊波形磁化曲线 AC iron loss curves under special waveform	疲劳强度(室温) Fatigue strength(ambient temperature)	弯曲次数 Number of bends

磁性测试平台 Magnetic Properties Test Platform

完备的材料性能测试平台，可为用户提供各种尺寸的材料在很宽频率范围（20Hz~10kHz）、较宽场强范围下（~100kA/m）的磁性数据，以及J-P、J-H、H-v等各种电磁性能曲线的测量，最大程度地挖掘材料特性。

With complete material properties test platform, Baosteel could provide customers with magnetic properties data at any frequency between 20Hz and 10kHz and magnetic flux density up to 100kA/m, the measurement of B-P, B-H and B-μ and other forms of magnetic properties curves, to fully make use of the material properties to the greatest extent.

4.3 无取向电工钢性能

Properties of Non-oriented Electrical Steel

4.3.1 磁性及机械性能 Magnetic and Mechanical Properties

类型 Type	牌号 Grade	密度 Density (g/cm^3)	铁损 $P_{1.0/400}$ Core loss(W/kg)		铁损 $P_{1.0/800}$ Core loss(W/kg)	磁极化强度 J_{5000} Magnetic polarization(T)		屈服强度 Yield strength(MPa)
			保证值 Guarantee value	典型值 Typical value	典型值 Typical value	保证值 Guarantee value	典型值 Typical value	典型值 Typical value
普通AV系列 Low loss AV series	B20AV1200	7.60	≤12.0	10.6	28.7	≥1.61	1.63	425
	B20AV1300	7.65	≤13.0	12.0	31.5	≥1.63	1.64	395
	B25AV1300	7.60	≤13.0	12.0	33.2	≥1.62	1.63	430
	B27AV1400	7.60	≤14.0	13.2	37.5	≥1.62	1.64	429
	B30AV1500	7.60	≤15.0	14.2	41.0	≥1.63	1.64	435
	B35AV1700	7.60	≤17.0	16.2	47.5	≥1.64	1.66	438
	B35AV1800	7.60	≤18.0	17.2	50.5	≥1.64	1.66	413
	B35AV1900	7.65	≤19.0	17.5	52.5	≥1.65	1.67	400
	B35AV2000	7.65	≤20.0	18.5	54.8	≥1.65	1.68	380
	B35AV2100	7.65	≤21.0	19.5	57.1	≥1.66	1.68	355
高效AHV系列 High efficiency AHV series	B20AHV1200	7.65	≤12.0	10.8	29.4	≥1.64	1.65	395
	B20AHV1300	7.65	≤13.0	12.2	32.5	≥1.65	1.67	360
	B27AHV1400	7.65	≤14.0	13.3	38.4	≥1.65	1.66	390
	B30AHV1500	7.65	≤15.0	14.2	40.8	≥1.66	1.67	395
	B35AHV1700	7.65	≤17.0	16.0	47.0	≥1.66	1.68	397
高磁感APV系列 High induction APV series	B20APV1200	7.65	≤12.0	10.6	28.9	≥1.68	1.69	395
	B25APV1300	7.65	≤13.0	12.2	33.8	≥1.68	1.69	383
	B27APV1400	7.65	≤14.0	13.1	37.0	≥1.68	1.69	385
	B30APV1500	7.65	≤15.0	13.8	40.8	≥1.68	1.69	390
	B35APV1700	7.65	≤17.0	15.8	45.9	≥1.68	1.69	395

类型 Type	牌号 Grade	密度 Density (g/cm^3)	铁损 $P_{1.0/400}$ Core loss(W/kg)		磁极化强度 J_{5000} Magnetic polarization(T)		屈服强度 Yield strength(MPa)	
			保证值 Guarantee value	典型值 Typical value	保证值 Guarantee value	典型值 Typical value	保证值 Guarantee value	典型值 Typical value
高效高强度AHV-M系列 High efficiency-Higher strength AHV-M series	B25AHV1300M	7.60	≤13.0	12.0	≥1.65	1.66	≥420	442
	B27AHV1400M	7.60	≤14.0	13.1	≥1.65	1.66	≥420	441
	B30AHV1400M	7.60	≤14.0	13.7	≥1.65	1.67	≥420	440
	B30AHV1500M	7.60	≤15.0	13.7	≥1.65	1.67	≥420	440
高强度AHS系列 High strength AHS series	B35AHS500	7.60	≤25.0	23.0	≥1.64	1.66	≥500	532
	B35AHS550	7.60	≤32.0	30.0	≥1.63	1.66	≥550	575
	B35AHS600	7.60	≤35.0	33.0	≥1.60	1.65	≥600	636
消除应力退火型 Stress relief annealing AHVR series	B25AHVR1150*	7.60	≤11.5	11.2	≥1.62	1.64	≥470	485

注：磁性能数据是指试样在800°C，经2小时退火后的测量值。

* Magnetic properties are measured after annealing at 800°C, 2h.

类型 Type	牌号 Grade	密度 Density (g/cm³)	铁损 $P_{1.5/50}$ Core loss(W/kg)		磁极化强度 J_{5000} Magnetic polarization(T)		屈服强度 Yield strength(MPa)
			保证值 Guarantee value	典型值 Typical value	保证值 Guarantee value	典型值 Typical value	典型值 Typical value
普通A/WW系列 Low loss A/WW series	B35A230	7.60	≤2.28	2.10	≥1.64	1.66	405
	B35A250	7.60	≤2.45	2.25	≥1.64	1.66	409
	B35A270	7.65	≤2.65	2.40	≥1.64	1.67	395
	B35A300	7.65	≤2.90	2.55	≥1.64	1.68	385
	B50A250	7.60	≤2.48	2.37	≥1.64	1.66	428
	B50A270	7.60	≤2.65	2.50	≥1.64	1.67	411
	B50A290	7.60	≤2.85	2.60	≥1.64	1.67	400
	B50A310	7.65	≤3.00	2.70	≥1.65	1.68	395
	B50A350	7.65	≤3.20	2.85	≥1.65	1.68	385
	B50A400	7.70	≤3.30	3.00	≥1.66	1.69	333
	35WW250	7.60	≤2.28	2.20	≥1.64	1.67	415
	35WW270	7.60	≤2.45	2.33	≥1.64	1.67	415
	35WW300	7.65	≤2.65	2.45	≥1.64	1.68	395
	35WW360	7.65	≤3.20	2.69	≥1.65	1.69	380
	50WW270	7.60	≤2.48	2.45	≥1.64	1.67	420
	50WW290	7.60	≤2.65	2.49	≥1.64	1.67	420
	50WW310	7.60	≤2.85	2.68	≥1.64	1.69	390
	50WW350	7.65	≤3.00	2.70	≥1.65	1.69	390
	50WW400	7.65	≤3.20	2.83	≥1.65	1.69	380
	50WW470	7.70	≤3.30	3.15	≥1.70	1.72	265
高效AH/WH系列 High efficiency AH/WH series	B50AH350	7.70	≤3.00	2.85	≥1.71	1.73	302
	B50AH470	7.75	≤3.50	3.20	≥1.72	1.74	244
	50WH470	7.70	≤3.00	2.86	≥1.71	1.73	300
	50WH600	7.75	≤3.50	3.21	≥1.72	1.73	265

4.3.2 涂层性能 Coating Properties

涂层代码 Coating code		A/T4	H/T4H	K	M	J/C5	Z/C3
		常规(含铬) Normal (Cr containing)		环保(无铬) Environmental friendly (Cr free)			
ASTM属性 ASTM Class		C-5	C-5	C-5	C-5	C-5	C-3
涂层种类 Coating type		半有机涂层 Semi-organic	半有机涂层 Semi-organic	半有机涂层 Semi-organic	半有机涂层 Semi-organic	半有机涂层 Semi-organic	有机涂层 Organic
干膜厚度(μm／面) Coating thickness (um/surface)		0.2-0.5μm	0.6-1.0μm	0.3-0.7μm	0.7-1.2μm	2-4μm	3-7μm
涂层绝缘电阻① (Ωcm^2／片) Insolation resistance (Ωcm^2/piece)		≥1	≥3	≥1	≥3	≥20	≥25
附着性 Adhesiveness		1	3	1	3	1	1
冲片性②(X1000) 毛刺达到50μm的冲片次数 Punching ability (x1000) puching times until 50um burr		1000	1500	1000			
耐湿热性③ Humidity proof ability	表观变化 Appearance	未变化 No change	未变化 No change	未变化 No change	未变化 No change	未变化 No change	未变化 No change
耐油性④ Oil-proof ability		通过 Pass	通过 Pass	通过 Pass	通过 Pass	通过 Pass	通过 Pass
焊接性⑤(cm/min);焊道气泡<7个的最大焊接速度 Weld ability(cm/min); maximum weld speed bubble<7		80～100	20～60	80～100	20～60	10～60	不适用 Not suitable
耐热性⑥ Heat proof ability	长期／空气 long time/air	180°C	180°C	180°C	180°C	270°C	150°C
	短期／空气 Short time/air	210°CX2500hr/ 600°CX30min	210°CX2500hr/ 600°CX30min	210°CX2500hr/ 600°CX30min	210°CX2500hr/ 600°CX30min	300°CX2500hr/ 600°CX30min	不适用 Not suitable

以上数据均为一定条件下的实验室测量数据，反映了涂层产品的相关典型性能，但不应视为保证值。

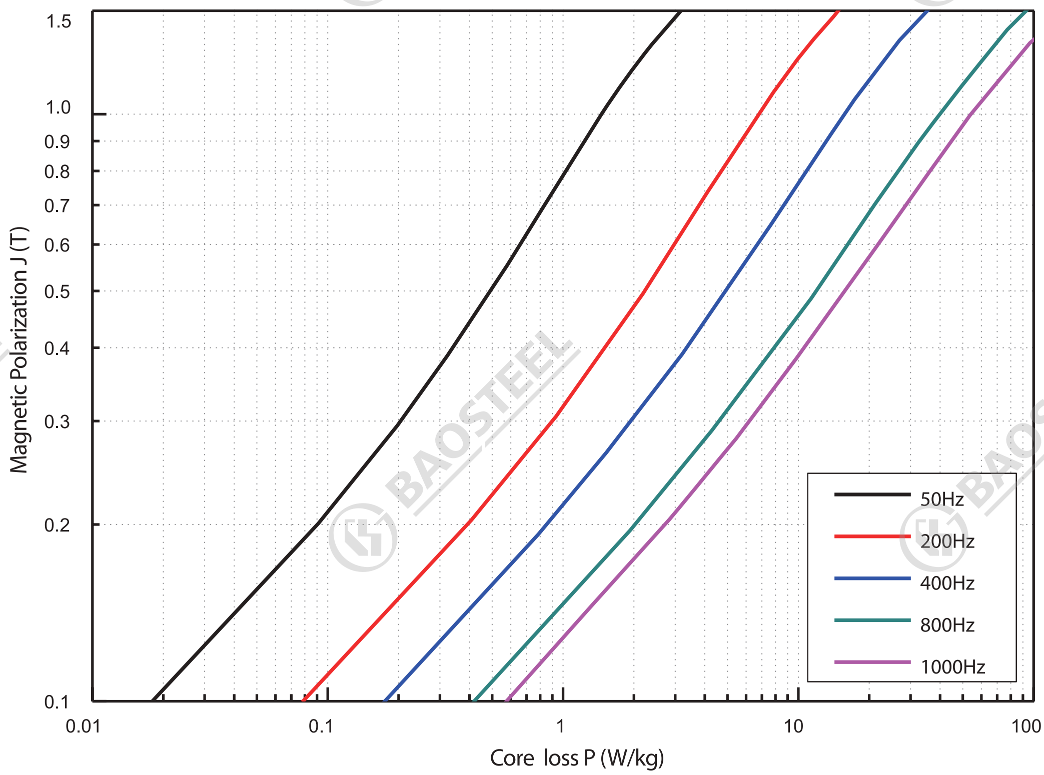
备注：① 表中数值为层间电阻(10个触头，总面积为6.45cm^2)
② 模具钢材质，冲制ø15mm圆片，间隙为板厚的5%，使用冲压油
③ 50°C，95%相对湿度，14天
④ 在180°C的 (99.5wt%的德士龙6号ATF油+0.5wt%水)的混合液体中浸泡504hr：表观无任何气泡、起皱及脱落现象，且质量差异＜5%
⑤ 氩气保护焊；焊接电流120A；电极Th-W 2.4mmø：焊枪间隔1.5mm；加压100kg/cm^2
⑥ DIN IEC 60404-12

Above are test data under certain condition in laboratory representing typical properties of coating but not guarantee values

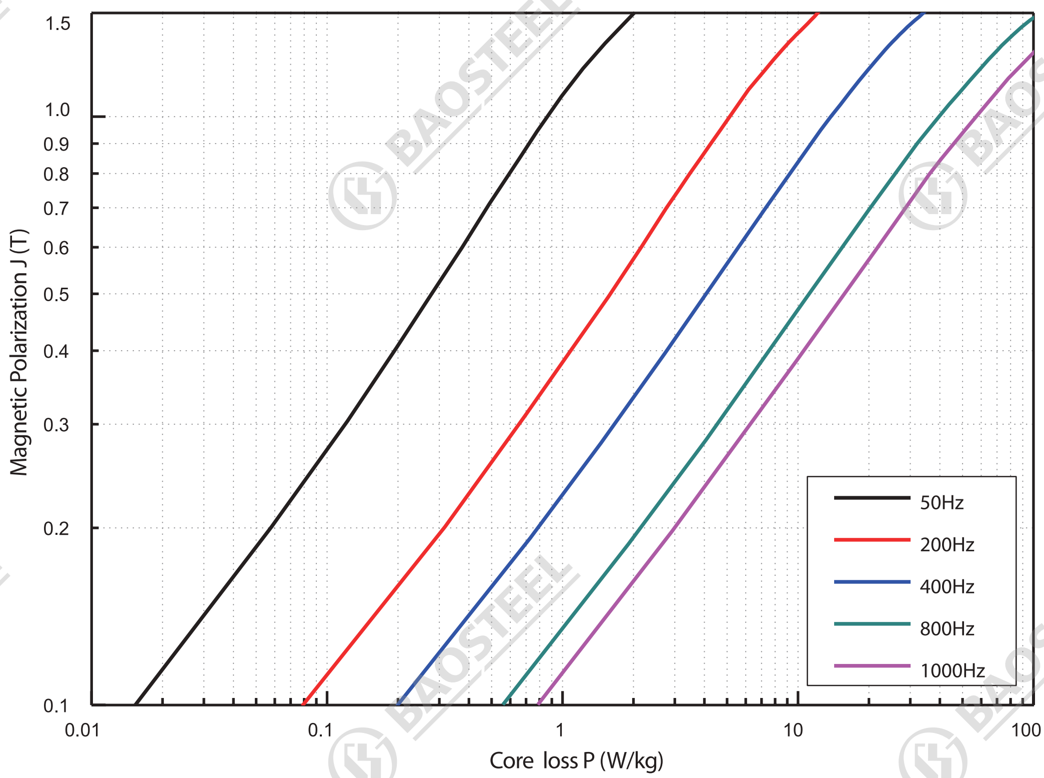
Note: ① inter-lamination resistance (10 head, toal area 6.45cm^2)
② STD11, F15mm round sample, clearance 5% of thickness, with stamping oil
③ 50°C, 95% humidity,14 days
④ In mixed liquid (99.5wt% METALUB ATF DEXRON (VI)+0.5Wt% water) at 180°C for 504hr: no bubble, nowinkle, nopeeling off, and quality difference<5%
⑤ Protective Ar gas; welding current 120A; F 2.4mm Th-W electrode; welding torch interval 1.5mm; pressure 100kg/cm^2
⑥ DIN IEC 60404-12

4.3.3 典型产品电磁性能曲线 Magnetic Property Curves of Typical Grades

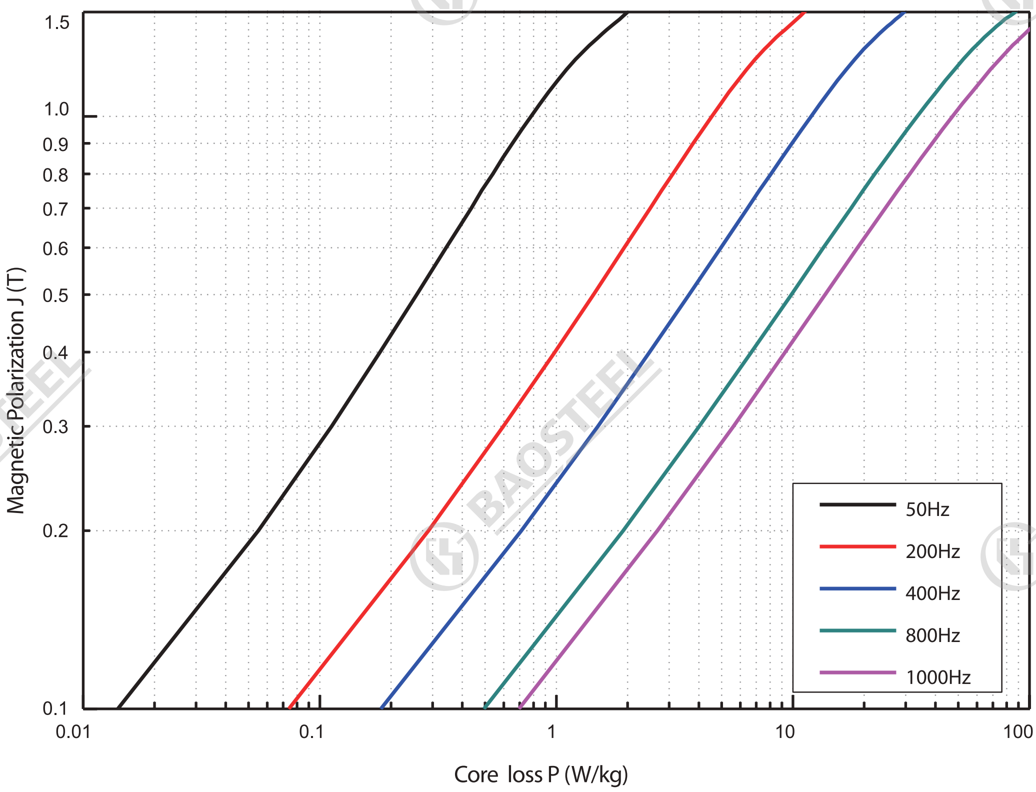
B25AHVR1150铁损曲线 B25AHVR1150 iron loss curves



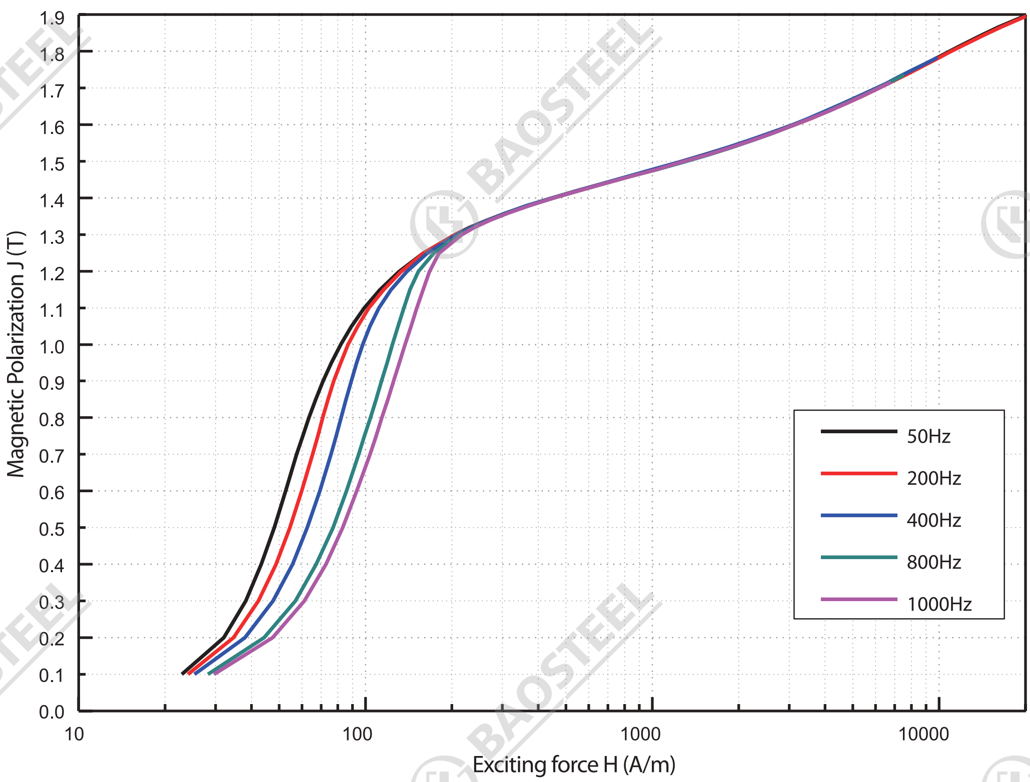
B30AHV1400M铁损曲线 B30AHV1400M iron loss curves



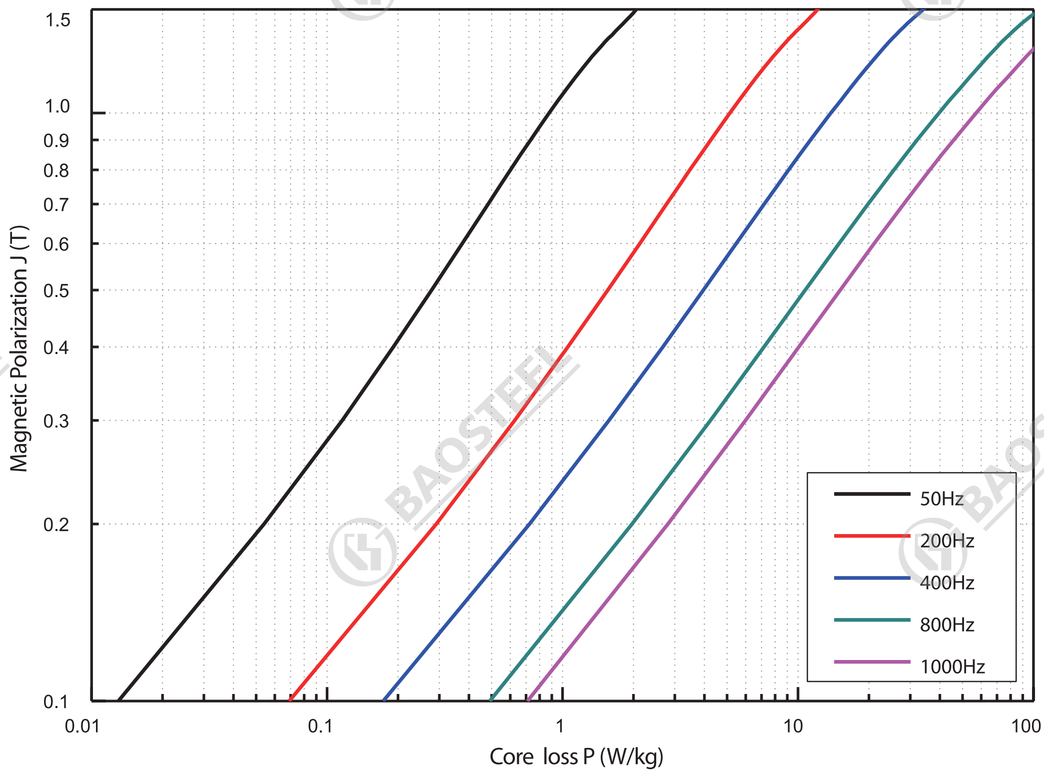
B25AHV1300M铁损曲线 B25AHV1300M iron loss curves



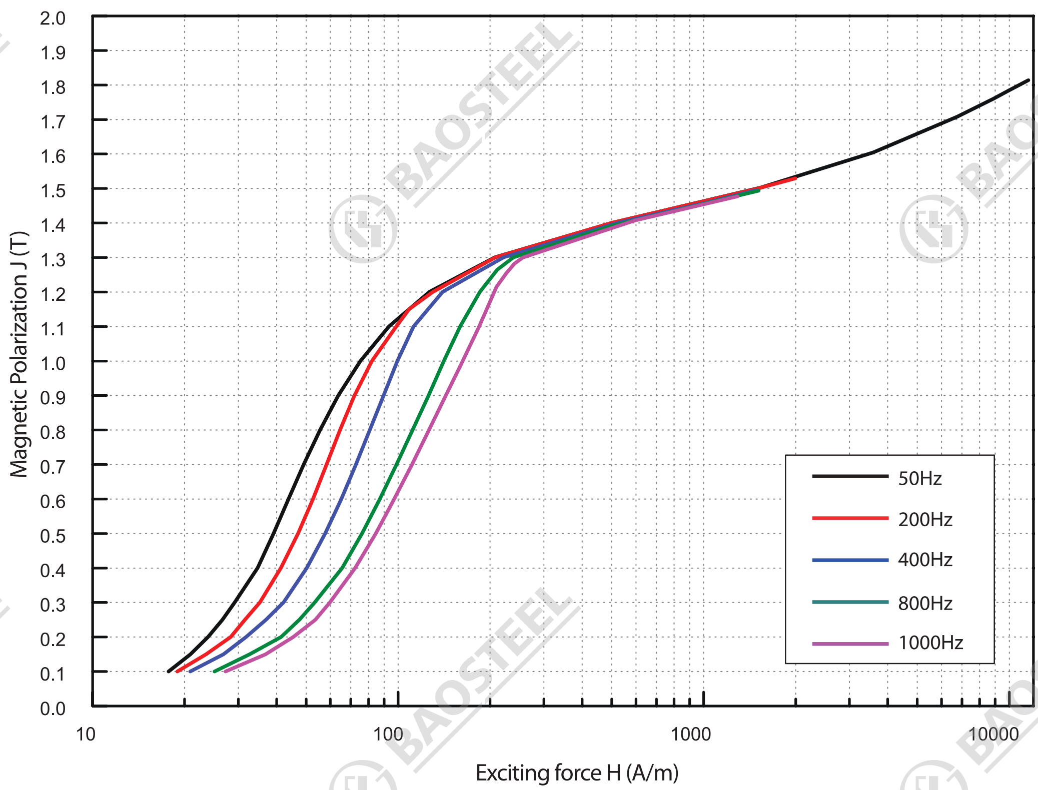
B25AHV1300M交流磁化曲线 B25AHV1300M AC magnetization curves



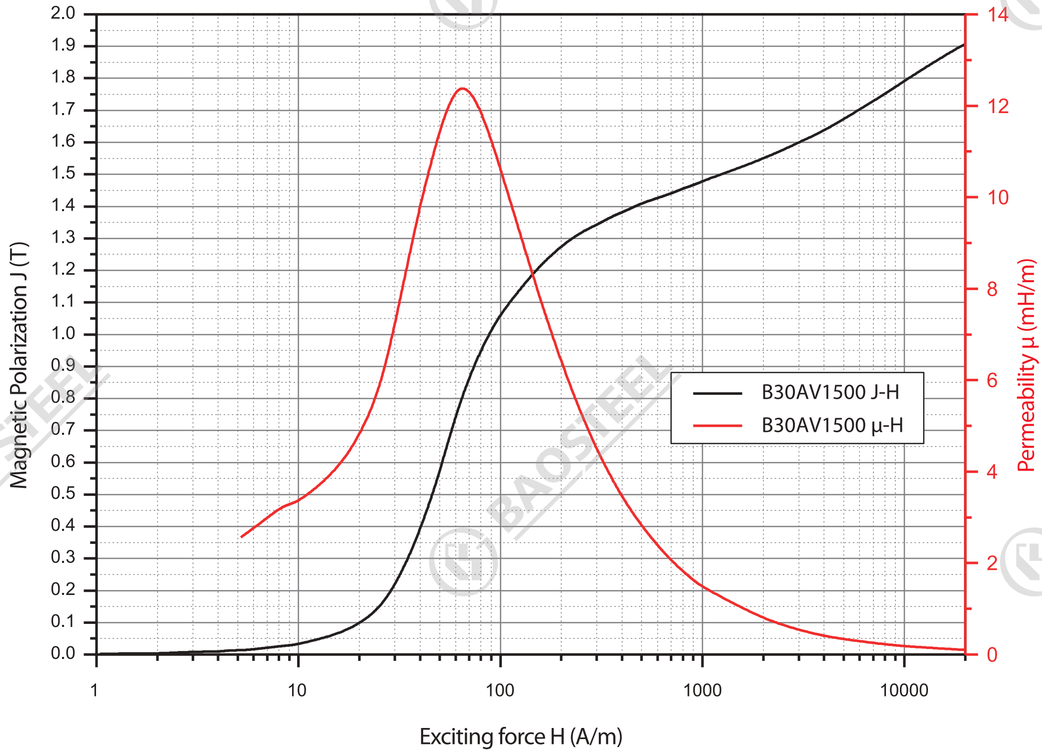
■ **B30AV1500铁损曲线** B30AV1500 iron loss curves



■ **B30AV1500交流磁化曲线** B30AV1500 AC magnetization curves

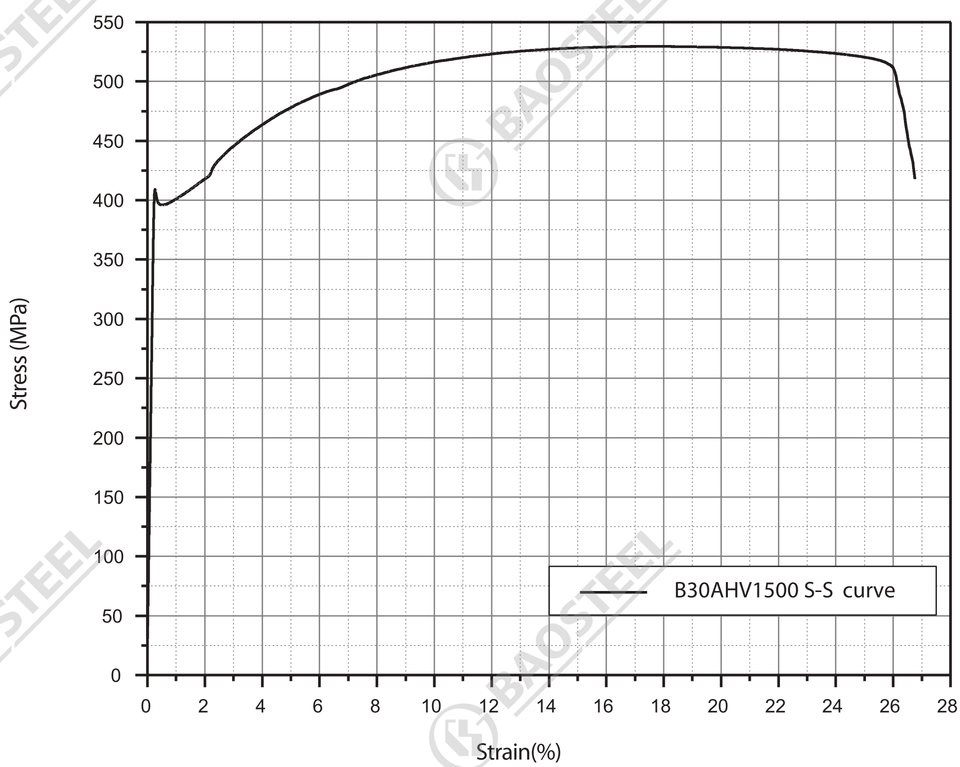


■ **B30AV1500直流磁化及磁导率曲线** B30AV1500 DC magnetization curves

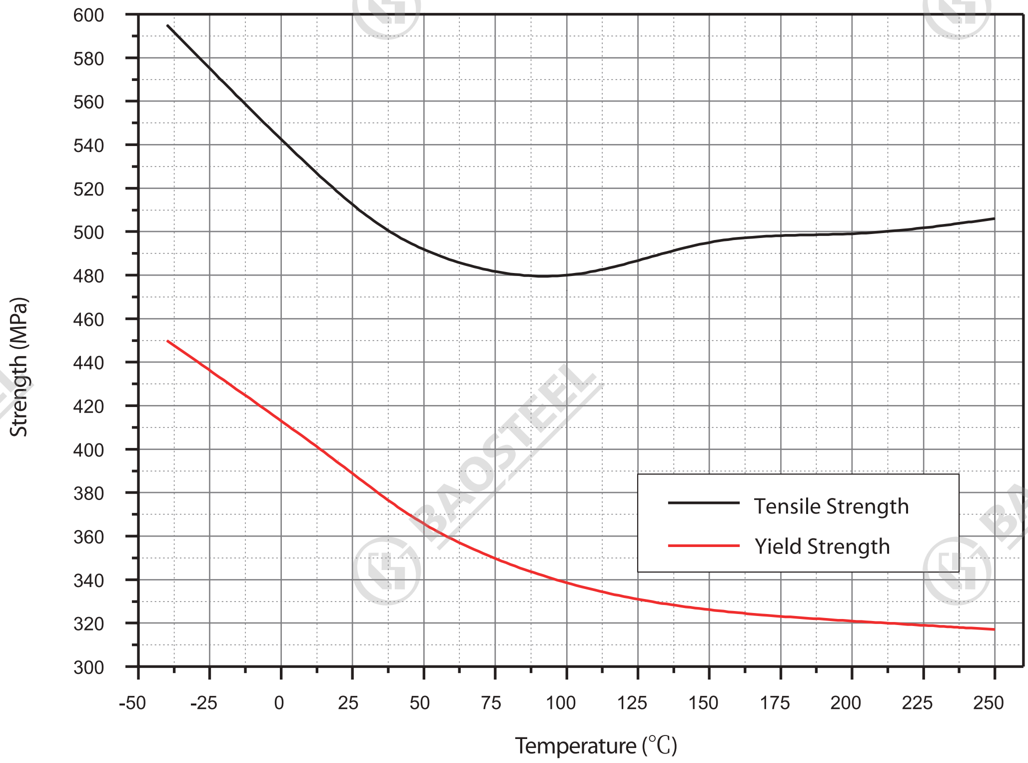


4.3.4 典型产品机械性能曲线 Mechanical Property Curves of Typical Product

■ **B30AHV1500常温应力应变曲线** B30AHV1500 strain-stress curve at ambient temperature

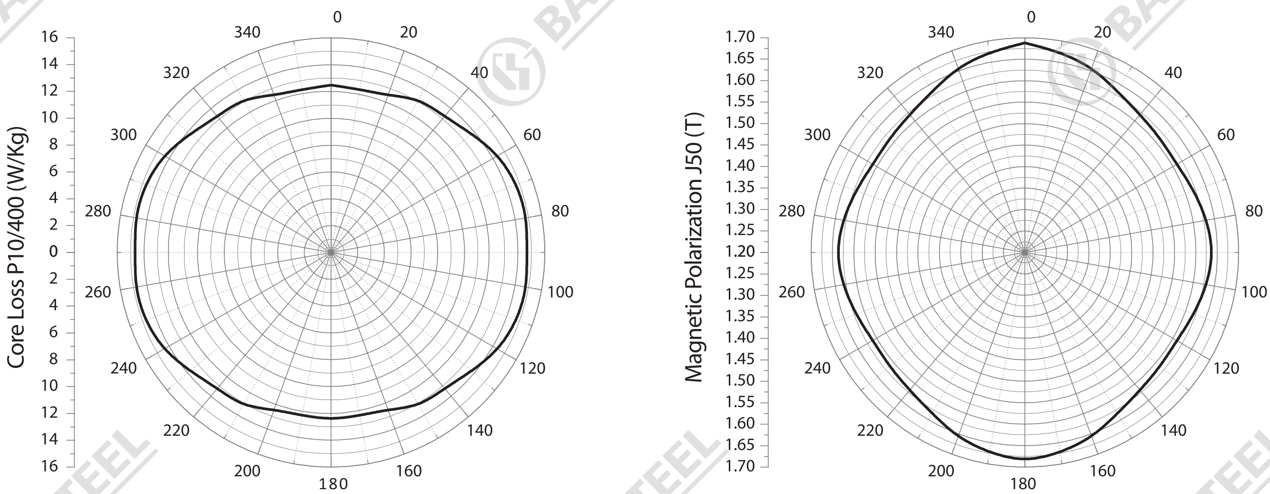


■ **B30AHV1500在不同温度下的屈服和抗拉强度** B30AHV1500 yield strengths and tensile strengths at various temperatures

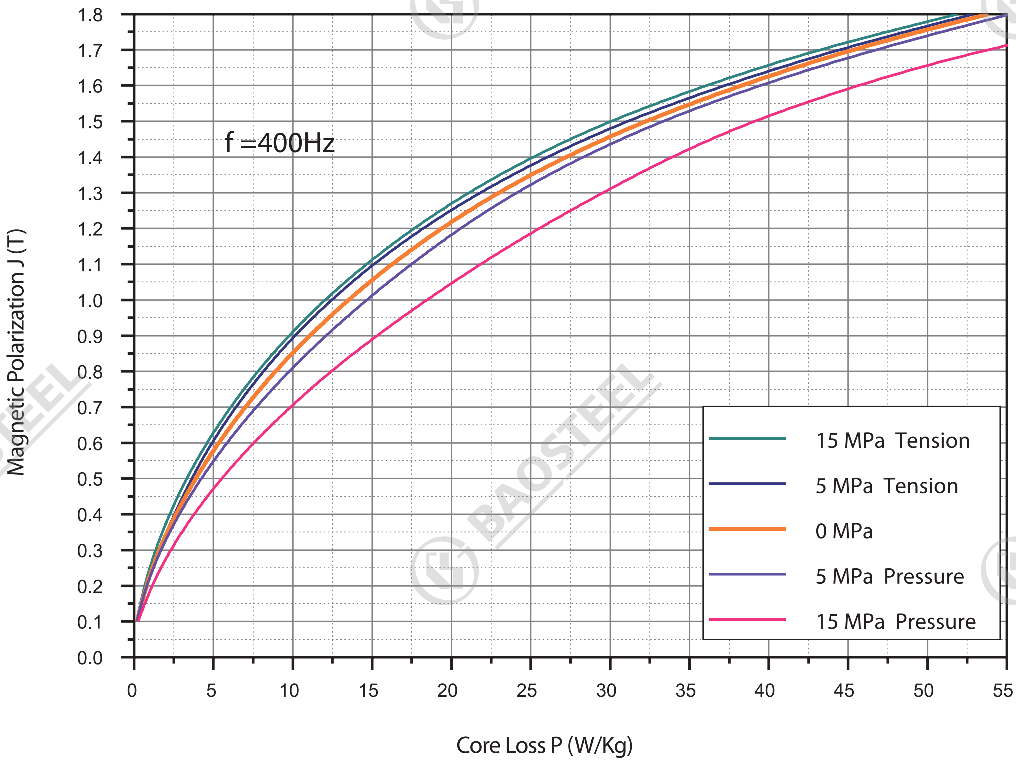


4.3.5特殊条件下的磁性曲线 Magnetic Property Curves Under Special Condition

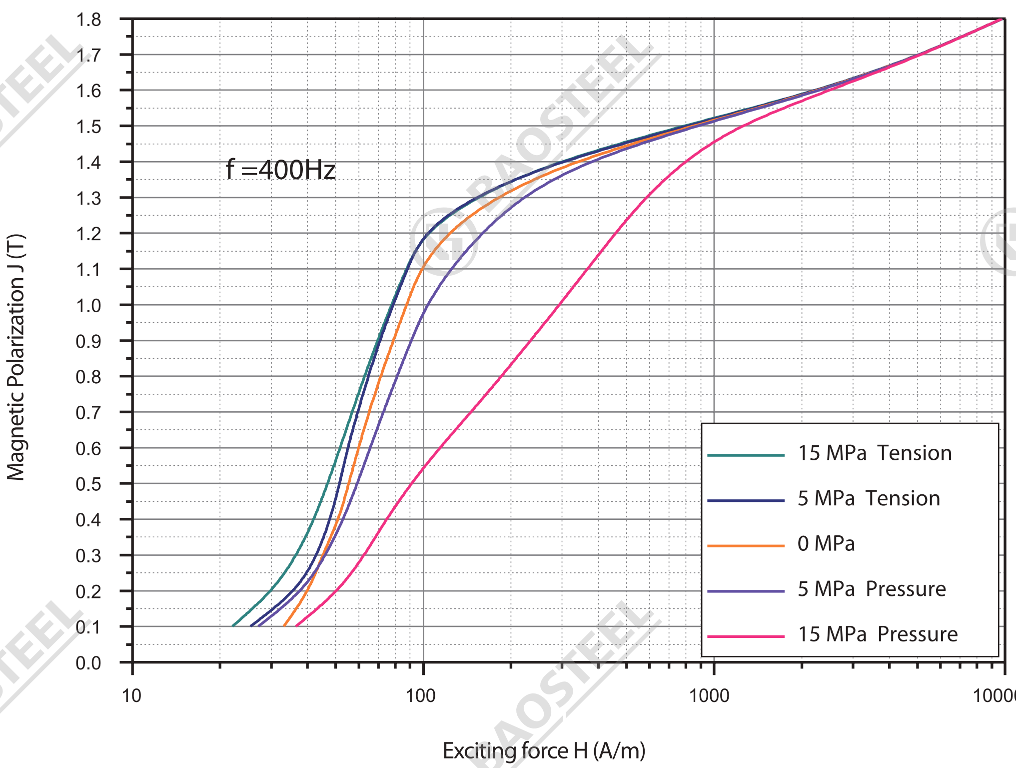
■ **B30AHV1500在不同方向下的磁性** B30AHV1500 magnetic properties along various directions



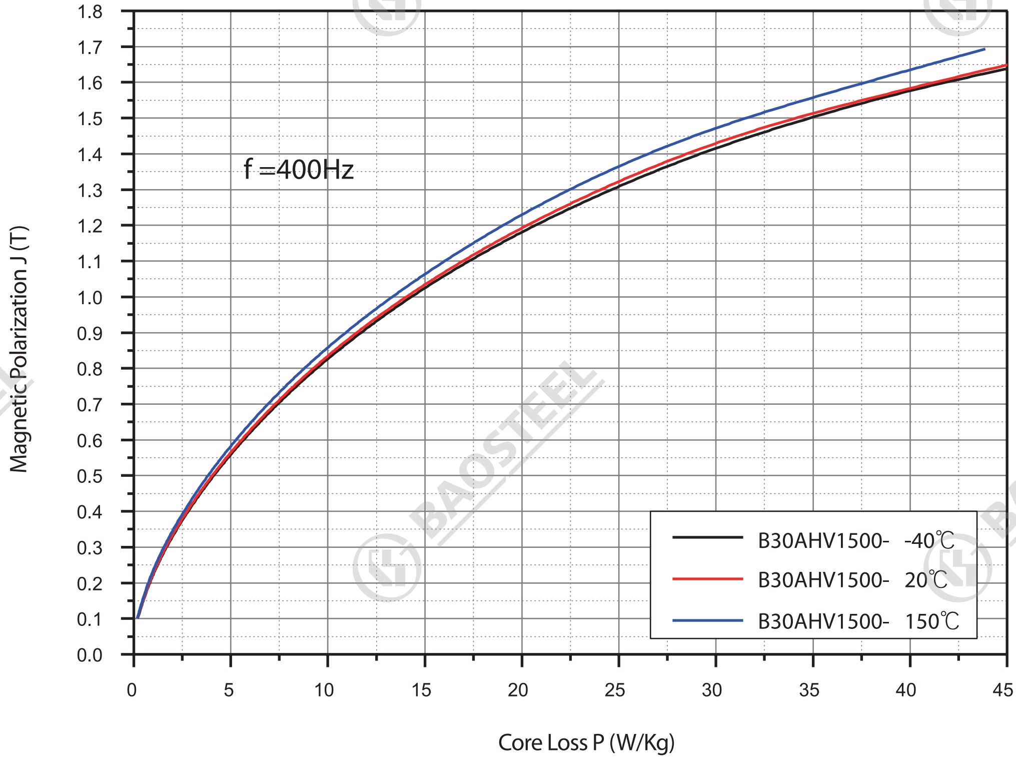
■ **B30AHV1500在轧向不同应力下的铁损曲线** B30AHV1500 iron loss under various stress along rolling direction



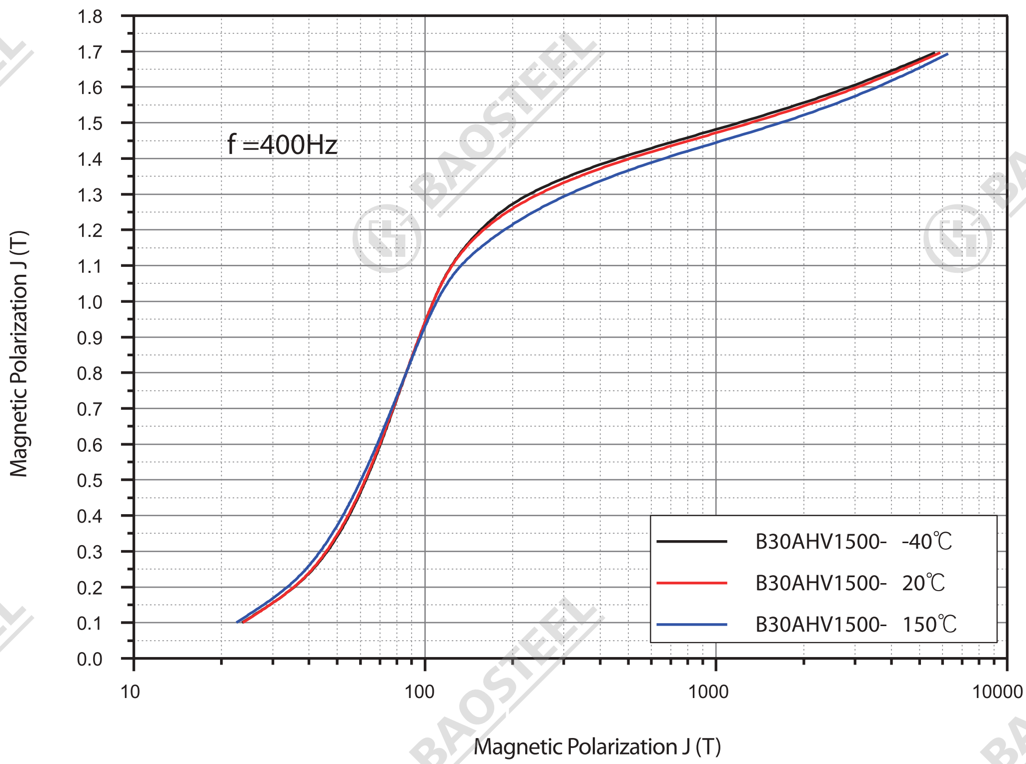
■ **B30AHV1500在轧向不同应力下的交流磁化曲线** B30AHV1500 AC magnetization curves under various stress along rolling direction



■ **B30AHV1500在不同温度条件下的铁损曲线** B30AHV1500 iron loss curves under various temperatures



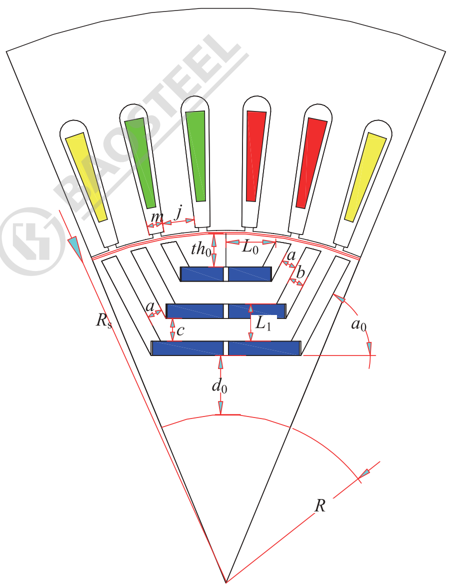
■ **B30AHV1500在不同温度条件下的交流磁极化曲线** B30AHV1500 AC magnetization curves under various temperatures

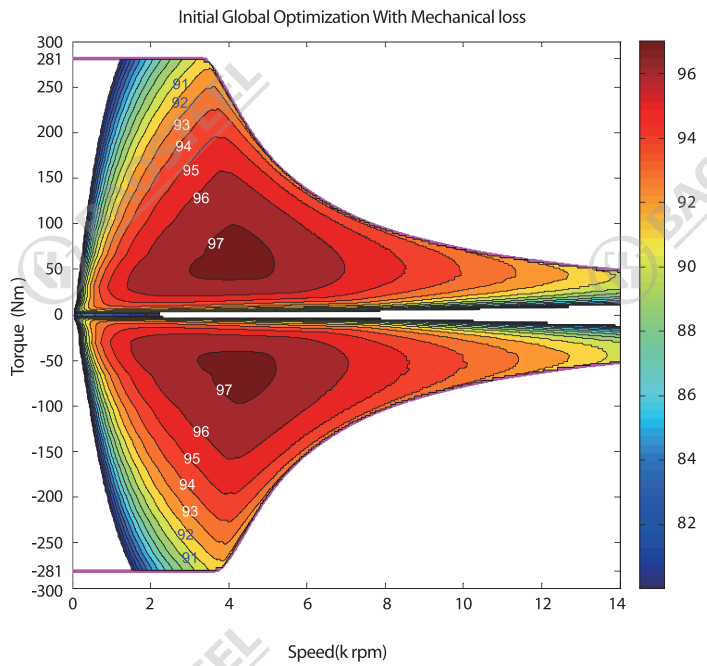


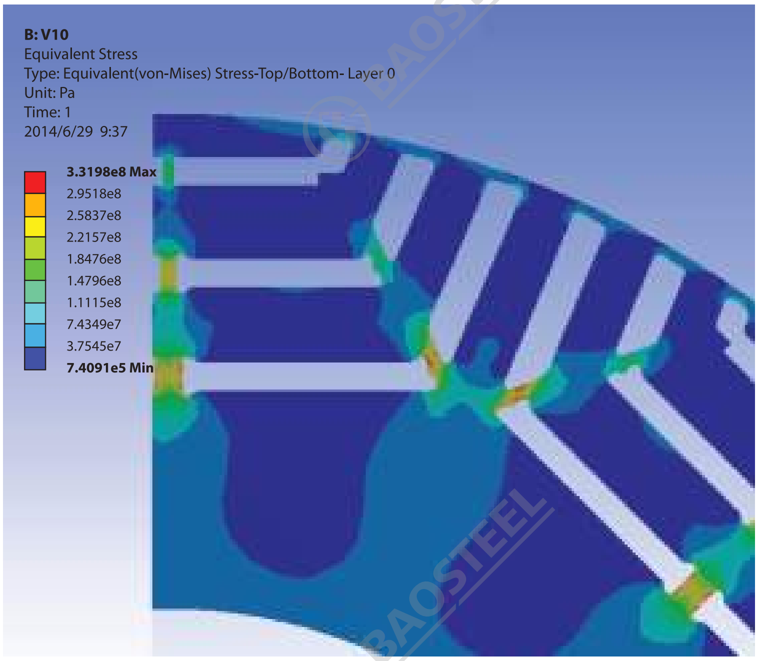
4.4 仿真能力 Simulation Analysis Capability

- 分析铁芯磁路，选取更优磁感材料
- 分析电机效率云图，选择更优铁损材料
- 分析转子铁芯应力分布，选择更安全的材料

- Magnetic path analysis for material selection
- Motor efficiency cloud map analysis for material selection;
- Stress distribution analysis for safety







4.5 材料冲压加工技术支持 Punching And Lamination Process Support

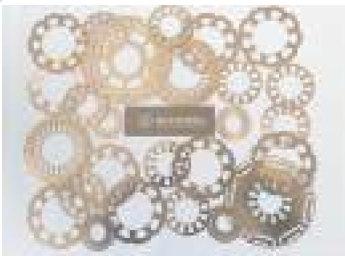
4.6 样机铁心制作及测试平台 Prototype Iron Core Build & Test Platform

■ 电工钢使用技术服务平台：铁心样机切割与检测

Technical service platform for electrical steel application technology: prototype iron core cutting and testing.

激光切割 Laser cutting

线切割 Wire-electrode cutting



电机铁芯 Motor core

铁芯测试 Core testing

整机测试 Motor testing

- 样机铁芯切割服务：在新品开发早期为用户提供样机材料、铁芯加工一揽子服务，减少样机冲片模具制作投资、缩短开发周期。
- 性能测试：铁芯损耗测试，电机效率测试。

- Prototype iron core cutting service: To provide our customer with electrical steel material, iron core cutting service to avoid prototype punching die building investment in early stage of new product development to shorten the R & D cycle.
- Properties testing: Iron core testing, motor testing.

5 应用案例 | Application Cases

综合考量材料性能、价格等因素，为电机铁芯设计进行选材支持。根据铁芯设计、加工以及性能检测，对比不同材料的使用效果，以实现性价比最优。

To support customers for electrical steel selection for design of traction motor of clean-energy vehicle considering cost and performance, comparison would be done according to core design, manufacturing process design by simulation and experiments to realize an optimized performance price ratio.

案例一：电工钢材料厚度选择

Case 1: Thickness selection of electrical steel

(1)、新能源汽车电机转速和频率 Motor Speed And Frequency

要提高功率密度，需要进一步提升电机的转速，其相关参数可见下表：

It needs to increase motor speed in order to increase motor's power density, the relevant parameters are listed in the following table

电机转速（rpm-4p） Motor speed (rpm-4p)	电频率（Hz） Working frequency(Hz)
9000	600
10500	700
12000	800
15000 转速提升至18000/21000	1000

(2)、电工钢材料的频率-损耗特性 Frequency-loss Relationship of Electrical Steel Material

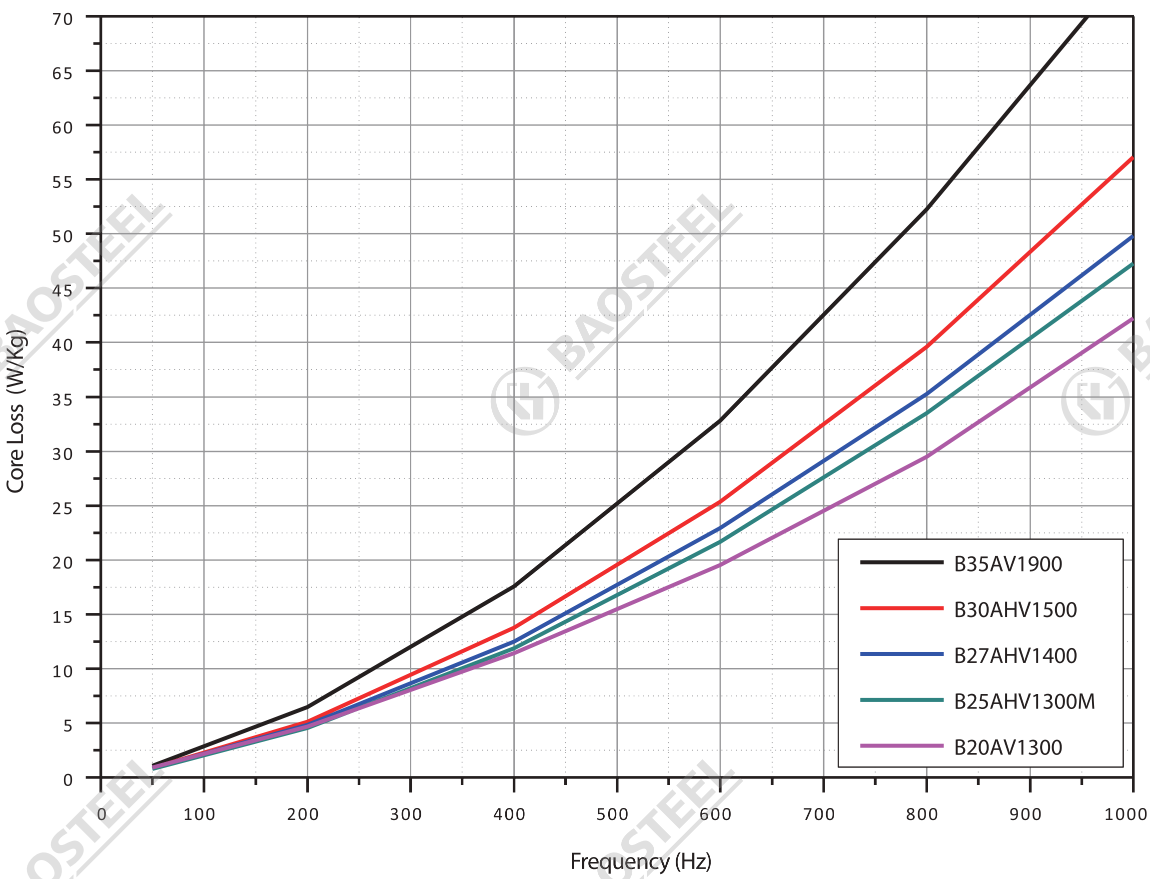
电工钢材料的损耗（Ph、Pe）同频率(f)密切相关，其中磁滞损耗（Ph）与频率（f）成正比，而涡流损耗(Pe)与频率(f)的平方成正比(如下式所示)：

Loss of electrical steel is closely related to frequency(f), where hysteresis loss Ph is proportional to frequency f, while eddy current loss Pe is proportional to frequency f square (shown as following equation):

$$P_h = k\ Vol\ f\ (B_{max})^n\ [W] \qquad P_e = \frac{Vol\,\pi^2 f^2 t^2 (B_{max})^2}{6\rho}\ [W]$$

为了提高电机效率，需要大幅度降低电工钢材料本身的损耗特性，其中最直接的方法就是减薄。不同厚度电工钢材料在不同频率下处于磁感应强度1.0T时的损耗变化如下图：

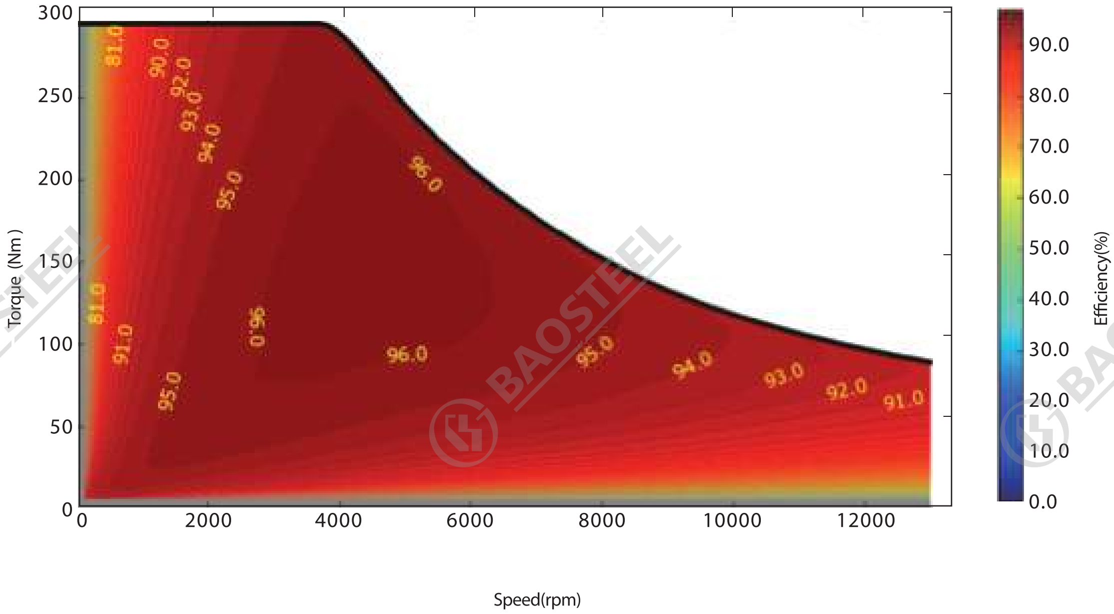
In order to increase motor efficiency, it's necessary to decrease iron loss of electrical steel greatly. The effective way is to reduce the thickness of electrical steel sheet. The iron losses of various thicknesses at magnetic induction density 1.0T under various frequencies are shown in following figure:



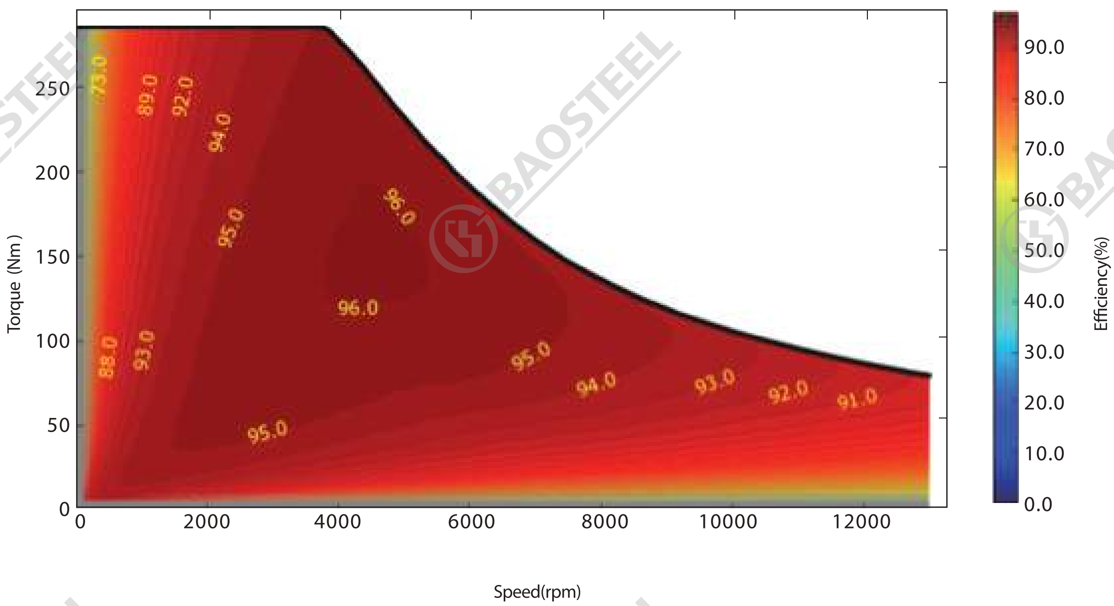
(3)、不同厚度材料的效率云图的变化 Changes of Efficiency Map with Various Thickness of Electrical Steels

宝钢选择了若干个牌号电工钢进行仿真计算，得到效率图，0.25mm材料高效区明显大于0.35mm材料。

Simulation has been done with various thickness grades, the efficiency maps indicated that high efficiency area of 0.25mm material is much better than 0.35mm material's.



0.25mm material



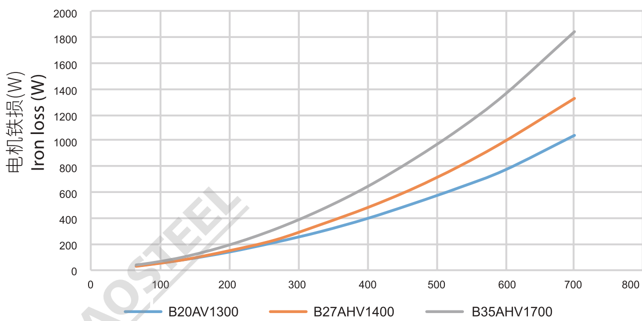
0.35mm material

(4)、不同频率下的效率仿真和实测 Motor Efficiency Simulation and Testing Under Various Frequencies Electrical Steels

为实际验证不同厚度材料对效率的影响，利用另外一个设计方案，分别进行了仿真和实测。铁耗的计算值如图所示：

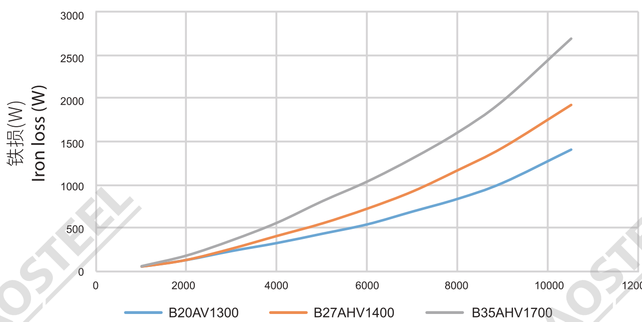
In order to verify the effect of thickness of electrical steel, a design model has been used to do simulation analysis and experimental testing. Iron loss calculation results are shown in following figures.

空载铁损仿真对比曲线
No load iron loss simulation result



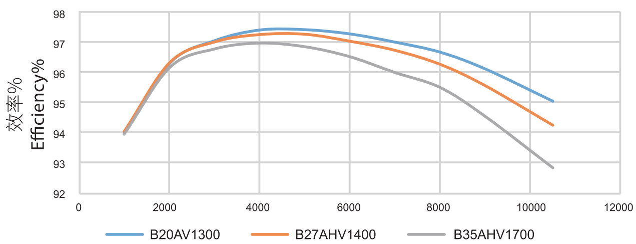
频率Hz
Frequency Hz

负载铁损仿真对比曲线
Load iron loss simulation result



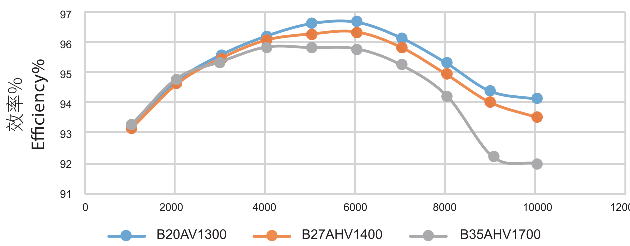
转速RPM
Speed RPM

额定工况仿真效率对比
Efficiency comparision under rated condition by simulation



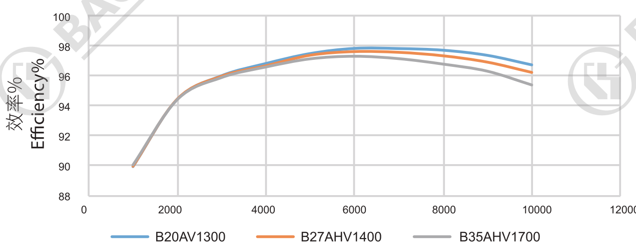
电机转速RPM
Motor speed RPM

额定工况实测效率对比
Efficiency comparision under rated condition by motor test



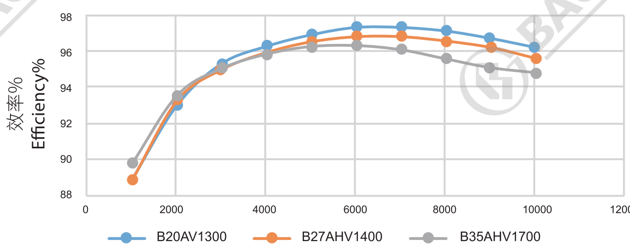
电机转速RPM
Motor speed RPM

峰值工况仿真效率对比
Efficiency simulation results under peak condition



电机转速RPM
Motor speed RPM

峰值工况实测效率对比
Efficiency comparision under peak condition by motor test



电机转速RPM
Motor speed RPM

(5)、结论 Conclusions

采用薄规格无取向硅钢材料，有助于降低高速区负载损耗，提升电机效率。根据电机的最高转速（频率）、额定转速（频率）、高效区间等性能因素以及成本来选择电工钢的厚度和牌号。

The thickness and grade of electrical steel should be determined by maximum speed (frequency), rated speed(frequency), high efficiency region, and other factor regarding motor performance and cost. Thin gauge non-oriented electrical steels are good in reducing load loss in high speed region therefore improving motor efficiency.

案例二：新能源汽车硅钢材料强度选择
Case 2: Selection of strength of electrical steel

(1)、电工钢材料的强度　Strength of Electrical Steel

随着电机功率密度的提高，其频率和转速都呈增长的趋势。磁桥是整个电机（转子）受力最为集中的区域，是整台电机结构上的薄弱点。因此电工钢材料的强度选择是十分重要的。

With increasing motor power density, the working frequency and motor speed are increasing. High strength is needed for electrical steel at the magnetic bridge area of rotor because the stress concentration in this area makes it the weakest point of motor in structure.

(2)、转子磁桥应力分析　Stress Analysis in Magnetic Bridge Area of Rotor

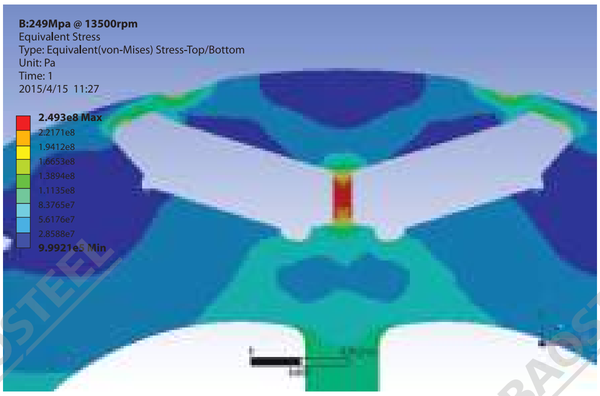
对电机转子应力分析，基本数据如下表：（电工钢材料屈服强度按403MPa计）
Basic data for stress analysis in rotor is shown in the following table: (yield strength of electrical steel is taken as 403MPa)

电机设计 Motor design			等效应力(MPa) Equivalent stress	安全系数 Safety coefficient
Tmax(Nm)	隔磁桥 Magnetic bridge	宽度 Width(mm)		
250.9	一处 One place	1.87	249	1.62

其中系数1.62是包括了各种不确定因素在内的安全系数，不确定因数包括但不仅限于：磁桥实际尺寸变化、材料强度的波动、温度的影响、加工应力、超速、装配公差、单边磁拉力等。

Safety coefficient 1.62 is the safety factor considering all uncertain factors, which includes but not be limited to: actual size change of magnetic bridge, variation of material strength, effect of temperature, manufacture resulted stress, speed excess, assembly tolerance, one side magnetic pulling force, etc.

应力分布如图所示
Stress distribution is shown as following figures



(3)、转子的转速-应力特性 Stress Dependence of Speed in Rotor

转子受力主要由如下几部分组成：

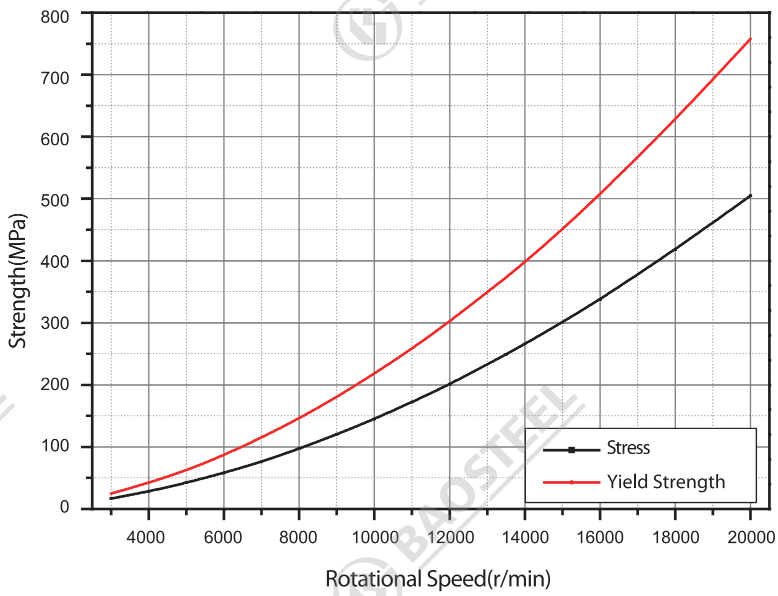
- 外圆（即由磁桥围成的部分）和磁钢的离心力，与转速成平方关系。
- 电机运行时的定转子之间的电磁力，然后传递到铁心并且主要由磁桥承担受力，在额定转速以上大体上同转速成反比关系。
- 由于磁场分布不均匀和装配间隙等因素产生的单边磁拉力，基本是固定值，与转速无关。

Stress in rotor mainly composes of following parts:

- Centrifugal force of outer circle (i.e., surrounding bridges) and steel magnet, being proportional to speed square.
- Magnetic force between rotor and stator when motor is running, passing on to iron core mainly at bridge, being roughly in inverse proportion to speed above rated speed range.
- One side pulling force due to uneven magnetic field, assembly gap, etc, being a fixed value basically and irrelevant to speed.

磁桥的应力是由上述三部分力共同组成。总体上同转速的关系介于正比和平方之间。此处暂按应力-转速成1.8次方估算。

Stress in magnetic bridge composes mainly of above three parts, being generally proportional to speed by power between1 to 2, where taking power 1.8.



(4)、转速提高的应对方案 Solution to Speed Rise

当电机转速在1.2万转以下时，当前普遍使用的材料（屈服强度400Mpa左右）可以放心使用。当电机转速达到1.5万转时，对电工钢屈服强度的要求会增加到450Mpa左右，需要采用更高强度转子专用材料。如果转速进一步提升，强度超出了现有电工钢的极限，则必须采取其他方面的措施。

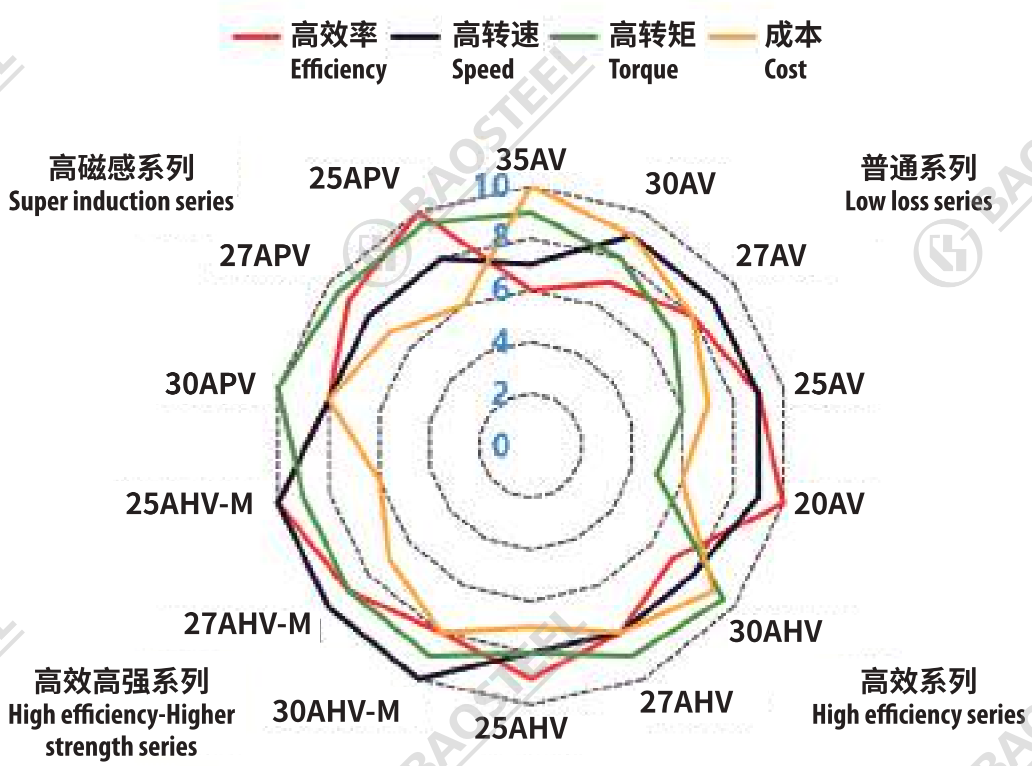
It can been seen that normal electrical steel grades (yield strength around 400MPa) could be used without any problem when motor speed is lower than 12krpm, but electrical steel with higher strength (yield strength above 450MPa) are necessary when motor speed reaches 15krpm.

Other measures should be taken if strength requirement exceeds the strength limit of electrical steel.

根据电机的转速（频率）来选择无取向电工钢材料，基于宝钢EVI工作，推荐产品如下：

Recommended electrical steel grades in Baosteel are listed in following table according to motor speeds based on our EVI research results

类别 Type	电机最高转速，rpm Max revolution , rpm	无取向电工钢产品推荐 Recommended electrical steel grades
乘用车 Passenger cars	≤10500	B30AV1500/B30AHV1500、B35AV1700、B35AV1800、B35AV1900
	12000	B27AV1400/B27AHV1400、B30AV1500/B30AHV1500
	13500	B25AHV1300M、B25AV1300、B27AHV1300M、B27AV1400/B27AHV1400
	15000	B20AV1200、B20AV1300、B25AHV1300M、B25AV1300、B27AHV1300M
	>15000	定子stator: B20AV1200/B20AHV1200、B20AV1300/B20AHV1300
		转子rotor: B35AHS500/B35ASH550/B35ASH600
商用车 Commercial cars	≤3000	B35AV1900、B35AV2000、B35AV2100
	4000	B35AV1800、B35AV1900、B35AV2000
	6000	B35AV1700/B35AHV1700、B35AV1800
	8000	B30AV1500/B30AHV1500、B35AV1700/B35AHV1700
	>9000	B27AV1400/B27AHV1400、B30AV1500/B30AHV1500



案例三：高牌号硅钢铁芯退火气氛性能影响与应用建议

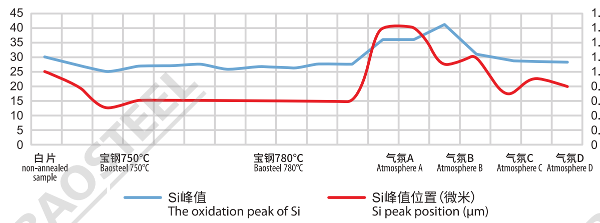
Case 3: The effect of annealing atmosphere on performance of high grade silicon steel core and application suggestions

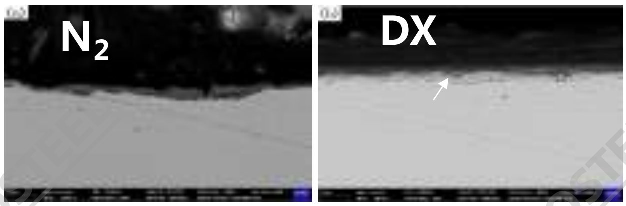
高牌号硅钢因其含硅量较高，同时钢厂制造过程中温度较高，使得其在制成铁芯后再进行退火时，铁芯的性能与铁芯退火工艺的气氛控制相关性较大。

Because of its high silicon content and high temperature in the manufacturing process of steel mill, the performance of the iron core is closely related to the atmosphere control of the annealing process.

Si氧化峰值及位置

The oxidation peak and location of Si



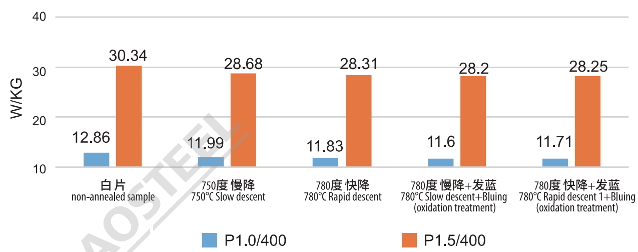


如图所示，N_2气氛下退火SiO_2深度较为理想，DX气氛A、B、C退火SiO_2深度1.6um，同为N_2的气氛D的SiO_2深度0.7μm，表明DX气氛A、B、C退火氧化膜厚，且氧化深度与其气氛的氧化性强弱一致。

As shown in the figure, the SiO_2 depth of annealing in N_2 atmosphere is relatively ideal, the SiO_2 depth of annealing in DX atmosphere A, B and C is 1.6μm, and the SiO_2 depth of annealing in D atmosphere is 0.7μm, which indicates the thickness of the oxide film annealed in DX atmosphere A, B and C, and the oxidation depth is consistent with the oxidation strength of the atmosphere.

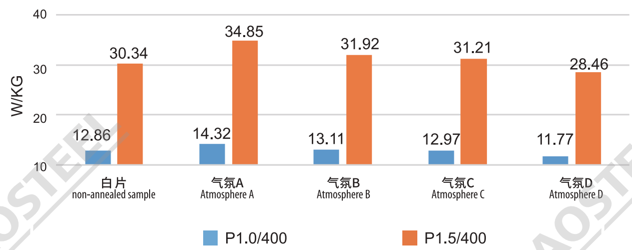
宝钢退火工艺400Hz铁损

Iron loss at 400Hz under Baosteel annealing process



试样不同气氛退火400Hz铁损

Iron loss at 400Hz of samples annealed in different atmospheres



针对高牌号材料制备的铁芯进行了不同气氛的退火后性能测试对比，试样在N_2气氛进行退火后的性能与工艺参数的变化规律一致，表现为白片（不退火）试样的铁损最高，随着温度的提升铁损下降，保温780°C的工艺下硅钢性能最优。DX气氛退火工艺研究表明铁芯退火后性能与温度及时间规律不一致，A/B/C气氛试样表现为退火后铁损较白片上升。

所以针对高硅高牌号硅钢进行铁芯退火建议为：

- 控制良好的退火气氛，避免形成内氧化层。
- 如用户退火炉设备变更气氛困难，则建议可根据实际使用情况采取电机铁心不退火等措施，即稳定了性能又节省了退火成本。

The properties of iron cores prepared from high grade materials were tested and compared in different atmospheres after annealing. The properties of samples annealed in N_2 atmosphere are consistent with the variation of process parameters. It shows that the iron loss of non-annealed sample is the highest, and the iron loss decreases with the increase of temperature. and the performance is the best when the temperature is kept at 780°C The results of DX atmosphere annealing process show that the performance of iron core after annealing is inconsistent with the rule of temperature and time, and The iron loss of A/B/C atmosphere samples after annealing is higher than that of the non-annealed sample.

Therefore, the recommendation for core annealing of high grade silicon steel is as follows:

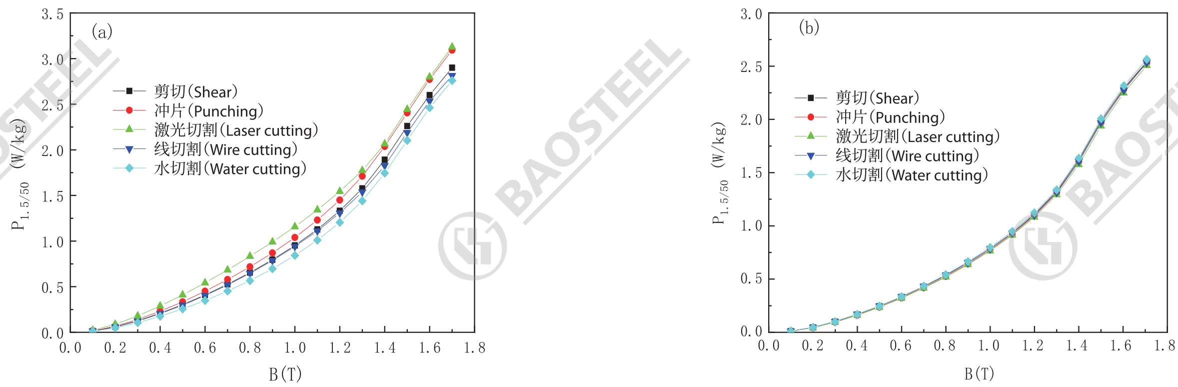
- Control annealing atmosphere to avoid forming inner oxide layer.
- If it is difficult for the user to change the atmosphere of the annealing, it is suggested that the motor core should not be annealed according to the actual use situation, which can stabilize the performance and save the annealing cost.

案例四：加工方式对高牌号硅钢性能的影响

Case 4: The effect of machining method on the properties of high grade silicon steel

宝钢高牌号无取向材料广泛用于工业电机客户制造高能效中小电机产品。但经过不同的加工工艺制成铁芯后，电机性能表现不一，为此针对连续冲片、激光切割、线切割、水刀切割对硅钢组织与性能的影响进行对比试验

Baosteel high grade non-oriented silicon steel is widely used to manufacture high energy efficiency small and medium motor products. However, after the iron core is made by different processing technology, the performance of the motor is different. Therefore, the effects of continuous punching, laser cutting, wire cutting and water knife cutting on the microstructure and properties of silicon steel are compared.

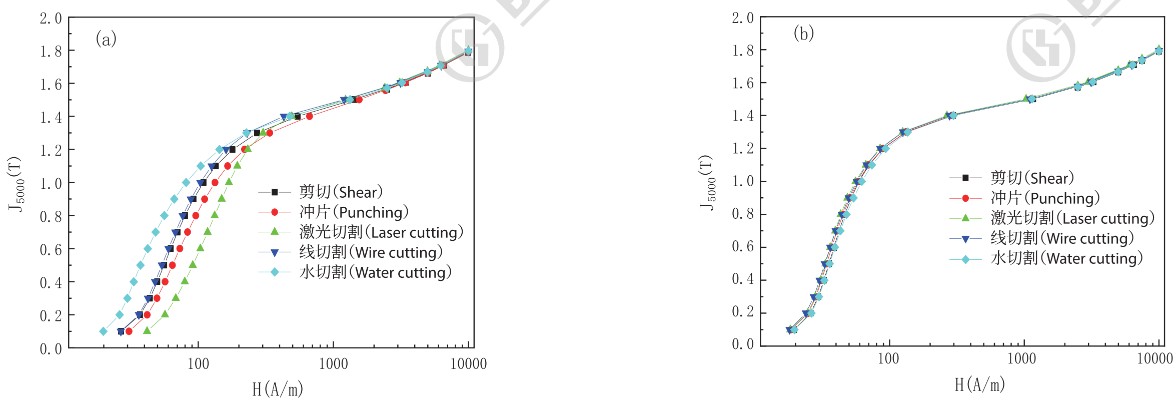


加工方式对试样铁损曲线的影响（a.退火前，b.退火后）

Effect of machining method on iron loss curve (a. Before annealing, b. After annealing)

激光切割后的试样铁损最高。冲片后的试样铁损稍低，磁感低于1.2T时，剪切后的试样和线切割后的试样铁损相当，但磁感高于1.2T时，剪切后的试样铁损稍大于线切割后的试样。水切割后试样的铁损最低。

The laser cut sample has the highest iron loss. The iron loss of the punching sample is slightly lower. When the magnetic polarization is lower than 1.2T, the iron loss of the sample after shear is similar to that of the sample after wire cutting, but when the magnetic polarization is higher than 1.2T, the iron loss of the sample after shear is slightly greater than that of the samples after wire cutting. The iron loss of sample after water cutting is the lowest.

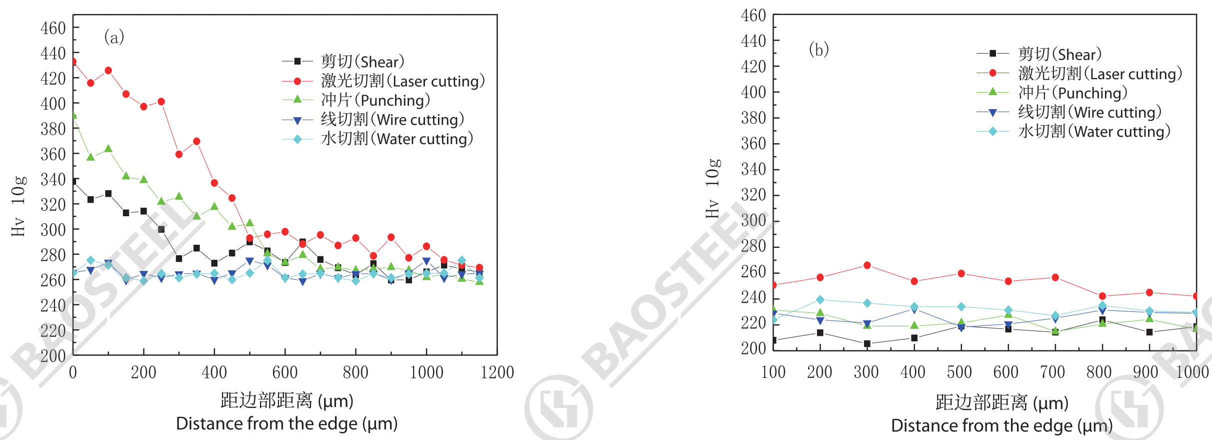


加工方式对试样磁化曲线的影响（a.退火前，b.退火后）

Effect of machining method on magnetization curve (a. Before annealing, b. After annealing)

消除应力退火前，当外加磁场小于200A/m时，激光切割后的试样磁感最差，冲片后的试样稍高，线切割和剪切后的试样磁感相当，比冲片后的试样要高，水刀切割后的试样磁感最高。

Before stress relief annealing, when the external magnetic field is less than 200A/m, the magnetic polarization of the sample after laser cutting is the worst, the punched sample is slightly higher, the magnetic polarization of the sample after wire cutting and shear is comparable, higher than the punched sample, and the magnetic polarization of the sample after water knife cutting is the highest.



不同加工方式加工后试样的硬度分布（a.退火前，b.退火后）

Hardness distribution of samples with different machining method (a. Before annealing, b. After annealing)

激光切割后的试样铁损最高，这是因为在激光切割过程中产生的快速加热和冷却会产生热应力，从硬度分布结果来看对应其边部的残余应力最大，这种残余应力对试样的磁性能极为不利。从实验结果来看，由于其边部残余应力最大，激光切割对试样铁损的恶化作用最为明显。水切割后试样的铁损最低，因为水切割属于冷变形，既不会产生热应力，也不会导致边部塑性变形。消除应力退火后各试样铁损趋于一致，因为退火后边部应力得到释放，异常损耗降低。

The iron loss of the sample after laser cutting is the highest, because the rapid heating and cooling generated in the laser cutting process will produce thermal stress. According to the results of hardness distribution, the residual stress at the edge is the largest, which is very unfavorable to the magnetic properties of the sample. It can be seen from the experimental results that laser cutting has the most obvious effect on the deterioration of iron damage due to the maximum residual stress at the edge. The iron loss of the sample after water cutting is the lowest, because water cutting belongs to cold deformation, neither thermal stress nor plastic deformation of the edge will be generated. After stress relief annealing, the iron loss of each sample tends to be the same, because after annealing, the edge stress is released and the abnormal loss is reduced.

解决方案推荐

- 选择合适的下料方式进行铁芯加工，以便达到预期目标；
- 在电机能效设计时，不仅需要考虑选材时的性能，还需要在铁芯加工方式上采用合理的装备系数，以最快的接近设计目标，发挥材料的性能。

Solution recommendation

- Select the appropriate way to process the core in order to achieve the desired goal.
- In the design of motor energy efficiency, it is not only necessary to consider the performance of material, but also to adopt reasonable equipment coefficient in the processing mode of iron core, so as to approach the design goal as quickly as possible and give a full play to the performance of material.

案例五：IE4电机选材对效率提升影响

Case 5: The effect of material selection on efficiency improvement of IE4 motor

宝钢高牌号无取向材料广泛用于工业电机客户制造高能效工业电机产品，但硅钢随着牌号的提升，铁损呈下降分布，同时磁感也呈现一定的下降趋势，因此铁芯材料牌号的提升与铁损损耗的降低幅度并不一致。

Baosteel's high grade non-oriented silicon steel is widely used to manufacture high energy efficiency industrial motor products. However, with the improvement of the grade of silicon steel, the iron loss distribution shows a decreasing trend, and the magnetic induction also shows a certain decreasing trend. Therefore, the improvement of iron core material is not consistent with the reduction in iron loss.

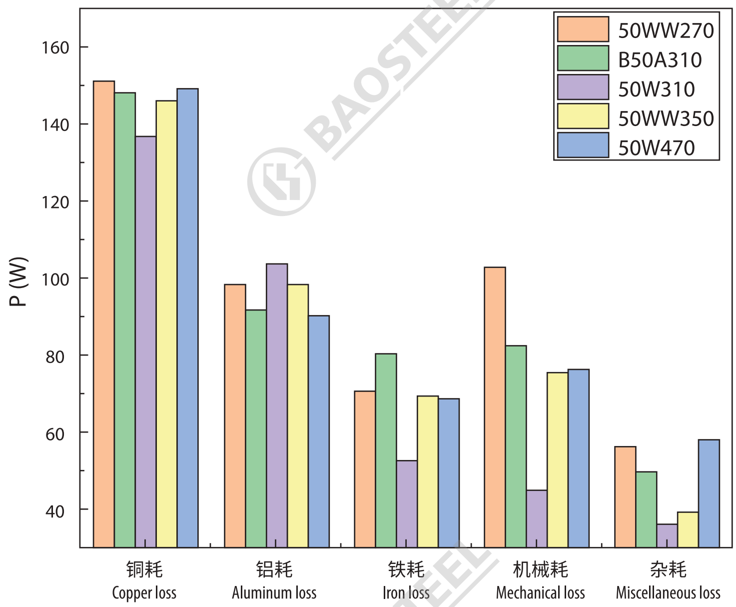
各牌号典型性能

Typical properties of each grade

序号	牌号	$P_{1.5/50}$ (W/kg)	J_{5000} (T)
1	50WW470	3.15	1.72
2	50WH470	2.86	1.73
3	50WW350	2.70	1.69
4	B50AH300	2.70	1.70
5	B50A250	2.37	1.66

可见，硅钢产品跨度较大，性能差异较大。

It can be seen that the span of silicon steel products is large, and the performance difference is large.



不同牌号同一机型损耗分析

Loss analysis of the same model with different grades

由上图可见，同一机型各类损耗值在牌号不同时也表现出不同的情况，铜损较高的占比掩盖了硅钢牌号升级带来的铁芯损耗降低，从而使得整体效率提升与单一的硅钢原料性能提升不匹配，达不到预期。

解决方案推荐

- 电机效率的提升不能简单的套用原有设计，如仅提高硅钢原料牌号，降低铁芯损耗，还应在槽型设计、绕组设计上有变化，以发挥硅钢高牌号的作用。
- 高牌号硅钢原料的选用中，在关注铁损的同时，也应关注磁感的变化，关注电机各类型损耗占总损耗的比重，从而针对性的选用或改进以降低主要损耗。

As can be seen from the figure above, the loss of the same model in different grade also show different situations. The high proportion of copper loss covers the reduction of core loss caused by the upgrade of silicon steel grade, so that the overall efficiency improvement does not match the performance improvement of silicon steel raw material, and cannot reach expectations.

Solution recommendation

- The improvement of motor efficiency cannot simply apply the original design. If only the grade of silicon steel raw material is improved and the loss of iron core is reduced, there should also be changes in groove design and winding design, so as to make full use of the high grade silicon steel.
- In the selection of high grade silicon steel raw materials, while paying attention to iron loss, we should also pay attention to the change of magnetic induction, and the proportion of each type of motor loss, so as to select or improve raw material to reduce the main loss.

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