Electromagnetic Properties of 0.18 mm Thin-gauge Grain-oriented Silicon Steel and Its Application in Transformer Cores

The electromagnetic properties of grain-oriented silicon steel significantly affect the service performance of transformer cores. The product (18PTD075) of 0.18 mm thin-gauge grain-oriented silicon steel shows a remarkable thickness uniformity and an excellent electromagnetic property. The iron loss ($P_{1.7/50}$) can be reduced to 0.73 W/kg, achieving a high grade. Thus, the low iron loss can improve the comprehensive performance and energy efficiency level of transformers, save energy, and reduce carbon emissions.

Key words:
Grain-oriented silicon steel; Thin-gauge; Transformer core; Iron loss.

by **Qingsong Zhang** R&D engineer
at Wuxi Putian Iron Core Co., Ltd.
PTTX

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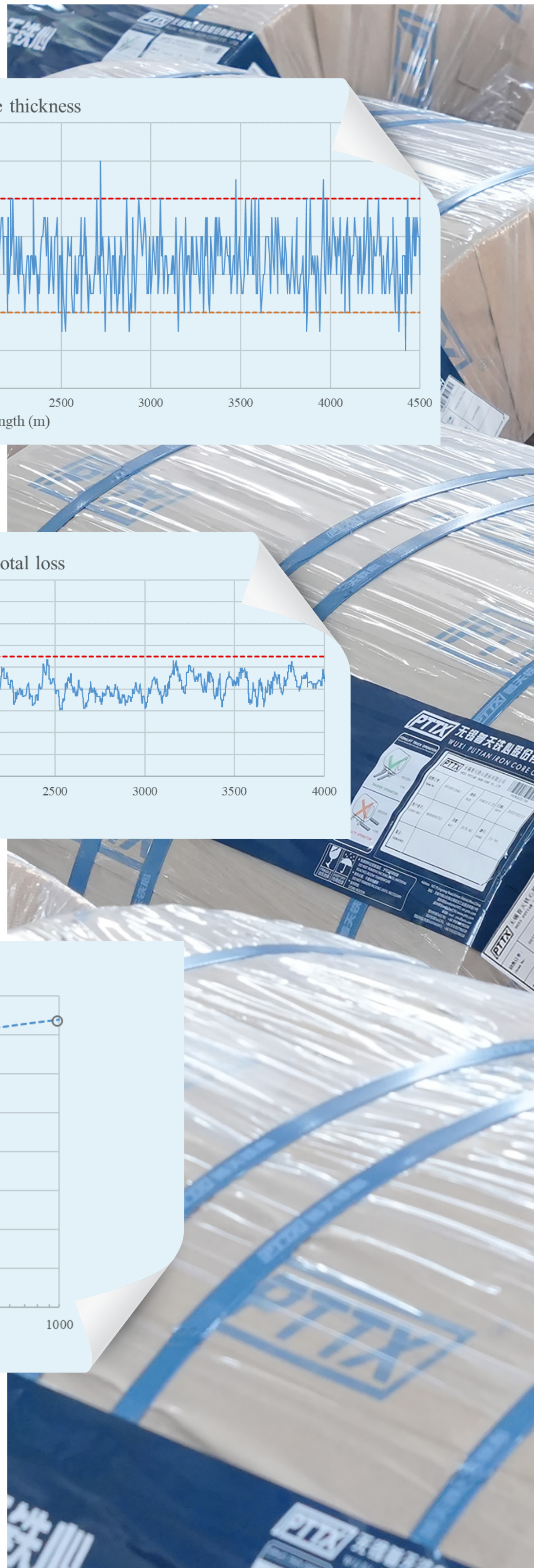
Grain-oriented silicon steel is a kind of functional soft magnetic material that is used as the raw material for transformer cores manufacturing. The service performance of transformer cores mainly depends on the electromagnetic properties of grain-oriented silicon steel. Therefore, it is crucial to improve the electromagnetic properties. Thinning the thickness can significantly reduce the iron loss [1]. Therefore, the research and development (R&D) of thin-gauge grain-oriented silicon steel is the trend of the industry [2]. At present, thin-gauge and ultra-thin-gauge product is mainly applied in the transformer under a medium or a high frequency. However, there is less research on the application of thin-gauge product in the large-power transformer under a low frequency. Therefore, this report focuses on demonstrating the electromagnetic properties of the 0.18 mm thin-gauge grain-oriented silicon steel (18PTD075, Figure 1) and its application in the large-power transformer core under a frequency of 50 Hz.

Figure 1. Product of 0.18 mm thin-gauge grain-oriented silicon steel (18PTD075).

Thickness Uniformity

Precise full-process production control technology can ensure the thickness uniformity of the product of 0.18 mm thin-gauge grain-oriented silicon steel. The results of in-line thickness tests of the product are shown in Figure 2, with an average thickness of 0.175 ± 0.003 mm. The thickness fluctuations are small throughout the length, ensuring a superior surface quality of the product.



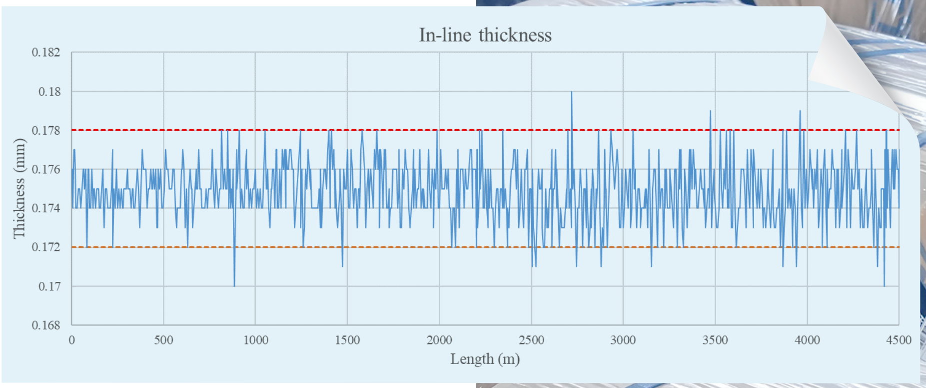


Figure 2. Results of in-line thickness tests.

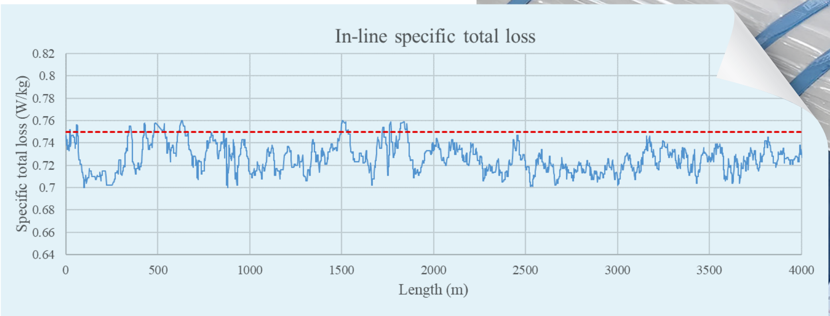


Figure 3. Results of in-line specific total loss tests.

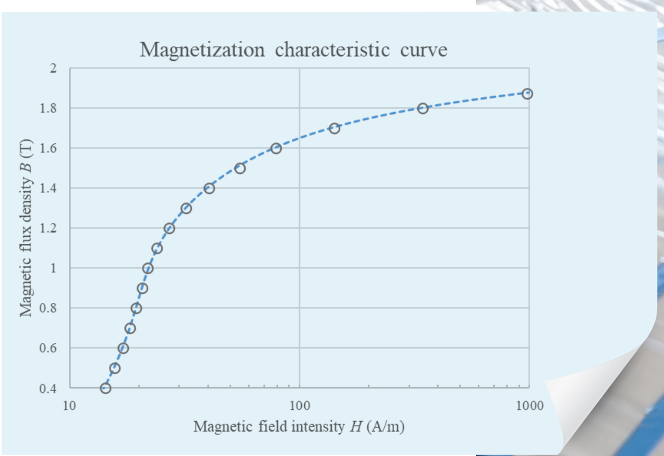
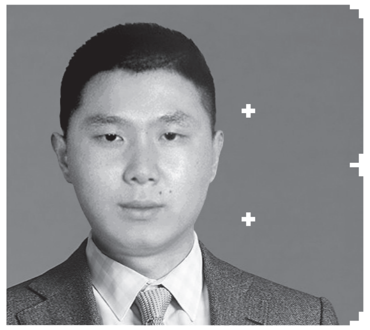


Figure 4. Magnetization characteristic curve of 0.18 mm thin-gauge grain-oriented silicon steel.



Qingsong Zhang obtained his Ph.D. degree in Materials Science and Engineering from China Southwest Jiaotong University in 2020. He visited the Spain National Centre for Metallurgical Research during 2019 as a joint training student. He previously worked at China Huazhong University of Science and Technology as a postdoctoral researcher, focusing on service performance and surface strengthening of metallic materials. Then, he joined Wuxi Putian Iron Core Co., Ltd. (PTTX) as a R&D engineer, working on thin-gauge and high-grade grain-oriented silicon steel. PTTX is a world-class power transformer core full process solution provider, with products including global high-end low-carbon electrical steel and materials, large ultra-high voltage electrical transmission and distribution equipment, and smart international logistics services.

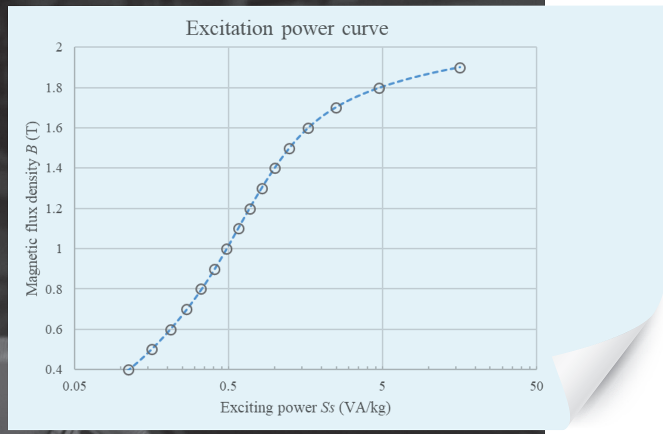


Figure 5. Excitation power curve of 0.18 mm thin-gauge grain-oriented silicon steel.

Figure 6. Magnetic domain morphology of 0.18 mm thin-gauge grain-oriented silicon steel.

The complex mechanism of core loss is related to the specific total loss, core structure, and manufacturing process.

Figure 7. Core loss tests of 50MVA type core at 50 Hz.

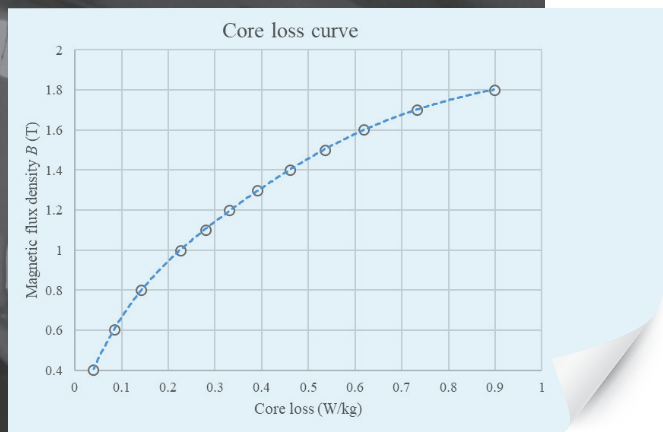
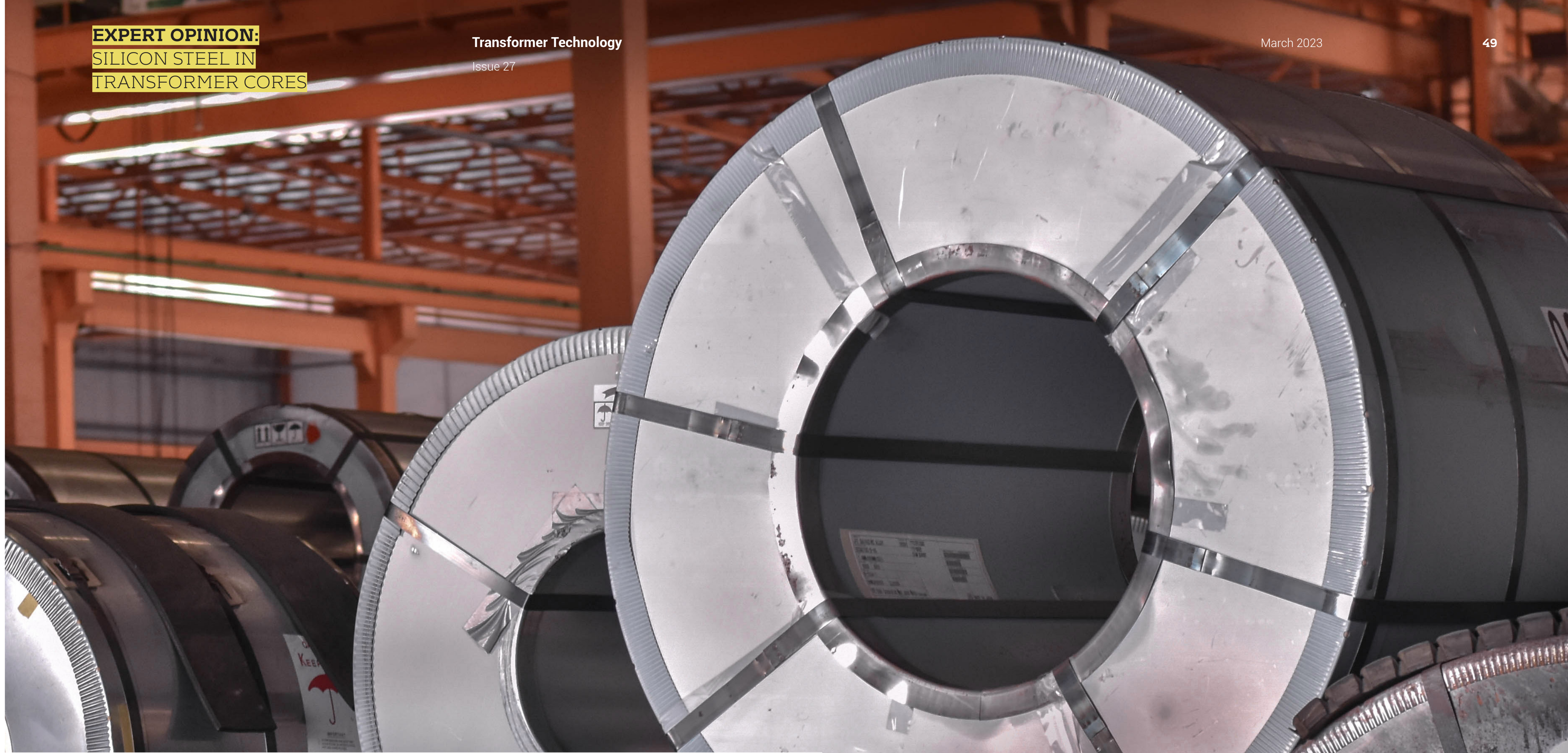


Figure 8. Iron loss curve of 0.18 mm thin-gauge grain-oriented silicon steel.



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Specific Total Loss

Specific total loss is one of the most important electromagnetic properties of grain-oriented silicon steel and a major indicator of product performance. The specific total loss can be significantly reduced by laser scribing tech-nology [3]. As shown in Figure 3, the specific total loss ($P_{1.7/50}$) of the 0.18 mm thin-gauge grain-oriented silicon steel after laser scribing is less than 0.75 W/kg under a magnetic flux density of 1.7 T and a frequency of 50 Hz. The value achieves a high grade. The low specific total loss means that the 0.18 mm thin-gauge product will have a large market potential and advantage.

Magnetization Characteristic Curve

The magnetization characteristic curve reflects the magnetic flux density (*B*) as a function of magnetic field intensity (*H*), which corresponds to the magnetizability of grain-oriented silicon steel. Figure 4 shows the magnetization characteristic curve of the 0.18 mm thin-gauge grain-oriented silicon steel under direct-current conditions. When the magnetic flux density is 1.7 T, the required magnetic field intensity is 139 A/m.

Excitation Power Curve

The excitation power (*Ss*) vs. the magnetic flux density (*B*) can reflect the magnetizing current of the transformer core under various excitation conditions. It is worth noting that the excitation power should be considered during transformer design. Figure 5 shows the excitation power curve of the 0.18 mm thin-gauge grain-oriented silicon steel under a frequency of 50 Hz. The required excitation power is 2.48 VA/kg under the magnetic flux density of 1.7 T.

Magnetic Domain Morphology

The magnetic domain morphology of grain-oriented silicon steel is closely related to the specific total loss and the magnetostriction [4]. A clear and regular domain was observed in the 0.18 mm thin-gauge grain-oriented silicon steel after laser scribing, as shown in Figure 6. Besides, the direction of the magnetic domain is almost parallel to the rolling direction and the spacing of the domains is also small. Therefore, there is good agreement between the regular magnetic domain morphology and the low specific total loss ($P_{1.7/50}$ <0.75 W/kg).

Transformer Core Loss

The transformer core acts as the application product of grain-oriented silicon steel, and its service performance can reflect the electromagnetic properties of grain-oriented silicon steel. The core loss is the ineffective electrical energy consumed by the core when it is magnetized under an alternating magnetic field of ≥50 Hz. The larger the core loss, the greater the electrical energy lost by the transformer. In addition, the energy efficiency level of the transformer is mainly determined by the core loss.

Figure 7 shows a 50MVA type core manufactured by the 0.18 mm thin-gauge grain-oriented silicon steel and its core loss was tested at a frequency of 50 Hz. Then, the iron loss was calculated by equation:

$$P_0 = \frac{P_T}{(k \cdot m)}$$

where P_0 is the iron loss with a unit of W/kg, P_T is the core loss with a unit of W, k is the technological coefficient of core, m is the core weight with a unit of kg. The relationship curve of the iron loss vs. the magnetic flux density was obtained, as shown in Figure 8. Specifically, when the magnetic flux density is 1.7 T, the iron loss is 0.73 W/kg, reaching a high grade.

Generally, the core loss (P_T) consists of hysteresis loss (P_h), eddy current loss (P_e), and anomalous loss (P_a) three parts. It is worth noting that the complex mechanism of core loss is related to the specific total loss, core structure, and manufacturing process [5]. Especially for the thin-gauge and high-grade grain-oriented silicon steel, the process of manufacture and the mechanism of core loss are more complex. Therefore, the electromagnetic properties of grain-oriented silicon steel should be further optimized to effectively reduce the core loss.

According to the above analysis, the iron loss ($P_{1.7/50}$) of the 0.18 mm thin-gauge grain-oriented silicon steel reaches a high-grade level with the value less than 0.75 W/kg. Therefore, the thickness thinning for the reduction of iron loss has a positive effect and an important significance.

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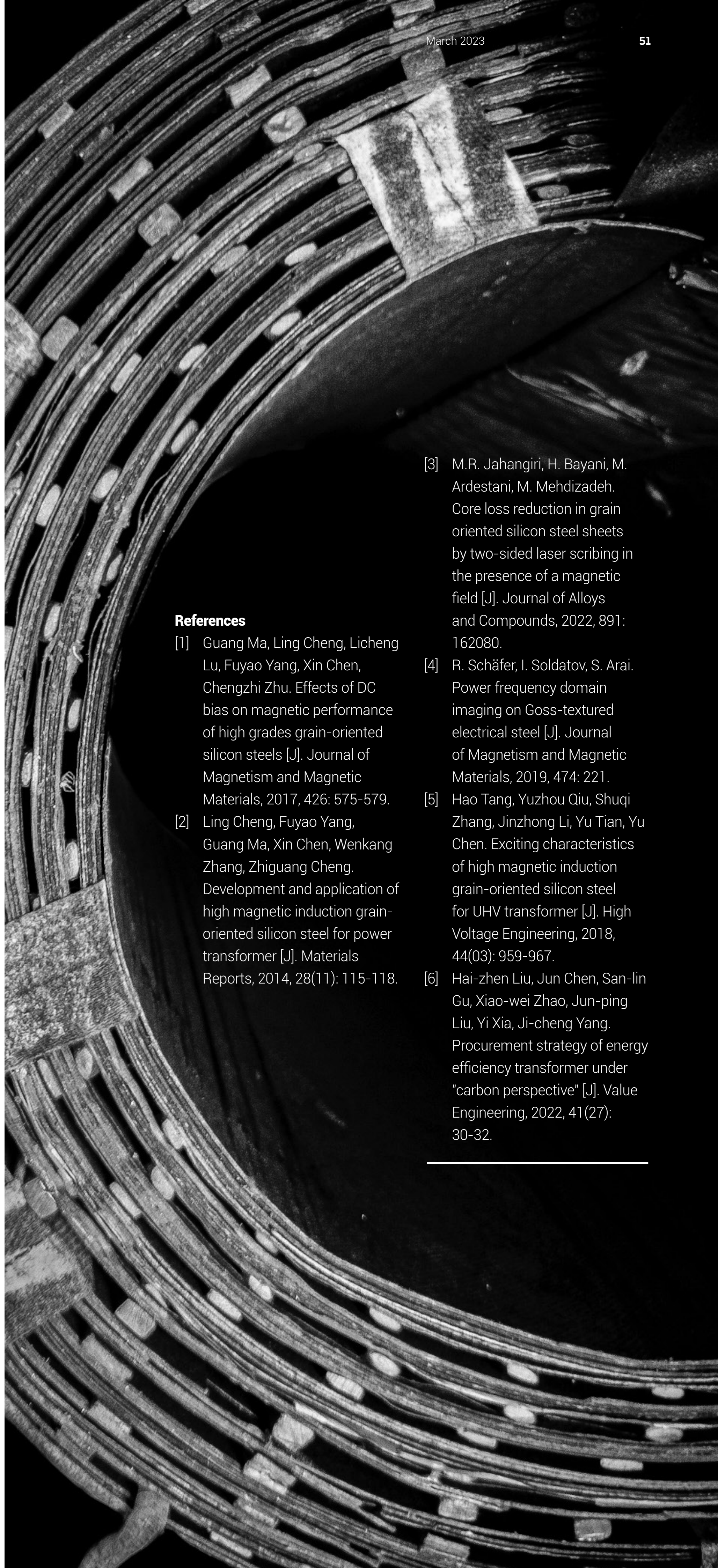
Prospect of Transformer Energy-saving

With the rapid development of global technology, low carbon environmental protection and sustainable development have become the social focus. Therefore, it is crucial to save energy and reduce emission. The development of thin-gauge and high-grade grain-oriented silicon steel products through thickness thinning can reduce the iron loss and improve the energy efficiency level of transformer, thus saving energy [2]. It has been proved that the high-efficient transformer made of high-grade grain-oriented silicon steel can reduce the carbon emissions by 13~18% under 50% load [6]. The product of 0.18 mm thin-gauge grain-oriented silicon steel shows a remarkable thickness uniformity, ensuring the safety of the core laminations. The low iron loss decreases the temperature rise of the transformer during service, thus significantly improving the operation stability. In addition, the thin-gauge product also reduces magnetostriction and transformer noise. Therefore, the application of 0.18 mm thin-gauge product in cores can improve the comprehensive performance and energy efficiency level of transformers, thus achieving energy saving and emission reduction.

Conclusion

The mentioned 0.18 mm thin-gauge grain-oriented silicon steel shows a remarkable thickness uniformity, ensuring the surface quality of the product. After laser scribing, the product shows a homogeneous magnetic domain morphology, inducing an excellent electromagnetic property. Such excellent properties can promote the structural optimization of transformer cores, thus reducing core loss. In addition, the iron loss (P1.7/50) of the 0.18 mm thin-gauge grain-oriented silicon steel applied to a large-power transformer core is 0.73 W/kg, reaching a high grade. The application of this product in cores can effectively improve the comprehensive performance and energy efficiency level of transformers, thus saving energy and reducing carbon emissions.



References

[1] Guang Ma, Ling Cheng, Licheng Lu, Fuyao Yang, Xin Chen, Chengzhi Zhu. Effects of DC bias on magnetic performance of high grades grain-oriented silicon steels [J]. Journal of Magnetism and Magnetic Materials, 2017, 426: 575-579.
[2] Ling Cheng, Fuyao Yang, Guang Ma, Xin Chen, Wenkang Zhang, Zhiguang Cheng. Development and application of high magnetic induction grain-oriented silicon steel for power transformer [J]. Materials Reports, 2014, 28(11): 115-118.
[3] M.R. Jahangiri, H. Bayani, M. Ardestani, M. Mehdizadeh. Core loss reduction in grain oriented silicon steel sheets by two-sided laser scribing in the presence of a magnetic field [J]. Journal of Alloys and Compounds, 2022, 891: 162080.
[4] R. Schäfer, I. Soldatov, S. Arai. Power frequency domain imaging on Goss-textured electrical steel [J]. Journal of Magnetism and Magnetic Materials, 2019, 474: 221.
[5] Hao Tang, Yuzhou Qiu, Shuqi Zhang, Jinzhong Li, Yu Tian, Yu Chen. Exciting characteristics of high magnetic induction grain-oriented silicon steel for UHV transformer [J]. High Voltage Engineering, 2018, 44(03): 959-967.
[6] Hai-zhen Liu, Jun Chen, San-lin Gu, Xiao-wei Zhao, Jun-ping Liu, Yi Xia, Ji-cheng Yang. Procurement strategy of energy efficiency transformer under "carbon perspective" [J]. Value Engineering, 2022, 41(27): 30-32.