

Electrical Steel, Properties, Types, Applications, and Advantages

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Electrical Steel: Properties, Types, Applications, and Advantages



Electrical steel is a specialty steel tailored to exhibit specific magnetic properties, making it essential in modern electrical systems. From transformers and electric motors to generators and inductors, electrical steel ensures efficient energy conversion, minimized energy losses, and reliable performance. Its growing relevance in renewable energy and electric vehicle industries underscores its vital role in the shift toward sustainable technologies.

What is Electrical Steel?

Electrical steel, also known as silicon steel or lamination steel, is a type of soft magnetic material used in the cores of electrical machines. Its primary function is to enhance magnetic properties such as permeability and minimize energy losses due to hysteresis and eddy currents.

This steel is engineered to have a high electrical resistivity and low core losses, which makes it suitable for use in alternating current (AC) magnetic circuits. It is often alloyed with silicon (Si), typically ranging from 1% to 6.5%, depending on the intended application.

Composition of Electrical Steel

- Iron (Fe) – The base metal.
- Silicon (Si) – Enhances resistivity, reduces core loss.
- Carbon (C) – Controlled to extremely low levels to prevent magnetic aging.
- Manganese (Mn), Aluminum (Al), Phosphorus (P) – Added in small quantities for grain growth and processing improvements.

Types of Electrical Steel

- Grain-Oriented Electrical Steel (GOES)
- Non-Grain-Oriented Electrical Steel (NGOES)

Manufacturing Process

1. Hot Rolling
2. Pickling
3. Cold Rolling
4. Annealing
5. Decarburization
6. Coating

1. Introduction

Electrical steel is a specialty steel tailored to exhibit specific magnetic properties, making it essential in modern electrical systems. From transformers and electric motors to generators and inductors, electrical steel ensures efficient energy conversion, minimized energy losses, and reliable performance. Its growing relevance in renewable energy and electric vehicle industries underscores its vital role in the shift toward sustainable technologies.

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3. Composition of Electrical Steel

The primary composition of electrical steel includes:

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- **Silicon (Si)** – Enhances resistivity, reduces core loss.
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- **Manganese (Mn), Aluminum (Al), Phosphorus (P)** – Added in small quantities for grain growth and processing improvements.

Element	Typical Content (% by weight)
Iron (Fe)	Balance
Silicon (Si)	1.0 – 6.5
Carbon (C)	< 0.005
Others	< 1.0 (Mn, Al, P, etc.)

4. Working Principle

Electrical steel functions by allowing magnetic flux to pass through it with minimal resistance and energy loss. In AC applications, the magnetic field changes direction periodically, causing **hysteresis losses** and **eddy current losses**. Electrical steel addresses both:

- **Silicon** increases **resistivity**, reducing eddy currents.
 - **Grain orientation** aligns the crystal structure to support magnetic flux in one direction (for GOES), minimizing hysteresis loss.
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5. Key Properties

Property	Description
High Permeability	Allows easy magnetization and demagnetization.
Low Hysteresis Loss	Enhances energy efficiency in AC applications.
High Electrical Resistivity	Reduces eddy current loss.
Low Core Loss	Critical for minimizing energy consumption.
Magnetostriction Control	Reduces noise and vibration in transformers.
Mechanical Workability	Can be cold-rolled or laminated for processing.

6. Types of Electrical Steel

6.1 Grain-Oriented Electrical Steel (GOES)

GOES has crystals aligned in the **rolling direction**, optimizing magnetic performance along one axis.

Characteristics:

- Used in **power transformers**
- Typically contains ~3% silicon
- Extremely low core loss
- High permeability in one direction

Applications:

- Distribution transformers
- Power transformers
- Instrument transformers

6.2 Non-Grain-Oriented Electrical Steel (NGOES)

NGOES has **randomly oriented grains**, making it suitable for rotating machinery.

Characteristics:

- Isotropic magnetic properties

- Slightly higher losses than GOES
- Easier to manufacture and shape

Applications:

- Electric motors
 - Generators
 - Household appliances
 - Ballasts and inductors
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7. Manufacturing Process

The production of electrical steel involves several steps designed to control crystal structure and impurities:

Steps:

1. **Hot Rolling** – Reduces slab thickness.
2. **Pickling** – Removes oxide scales.
3. **Cold Rolling** – Achieves final thickness.
4. **Annealing** – Recrystallizes grains for GOES or maintains random orientation for NGOES.
5. **Decarburization** – Removes carbon to prevent magnetic aging.
6. **Coating** – Applies insulation coating to prevent eddy currents between laminations.

The control of **grain size, orientation, and impurities** during these steps is critical to achieving the desired magnetic properties.

8. Applications of Electrical Steel

Industry	Application
Power Generation	Transformer cores, stators
Automotive	EV motors, alternators
Appliances	Washing machines, compressors
Renewable Energy	Wind turbine generators, inverters
Electronics	Inductors, relays, ballasts

9. Advantages of Electrical Steel

- **Energy Efficiency:** Reduces power losses in electrical systems.
 - **Compact Design:** High magnetic permeability enables smaller component design.
 - **Durability:** Maintains properties over long periods with minimal degradation.
 - **Noise Reduction:** Low magnetostriction reduces operational humming.
 - **Cost-Effectiveness:** Lower operational costs due to efficiency gains.
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10. Comparison with Other Steels

Property	Electrical Steel	Mild Steel	Ferritic Stainless Steel
Magnetic Permeability	High	Medium	Low
Electrical Resistivity	High	Low	Medium
Core Loss	Low	High	Medium
Silicon Content	High	Low	Low
Application	Transformers, motors	Structures	Kitchenware

11. Challenges and Limitations

- **Brittleness:** High silicon content increases brittleness.
 - **Cost:** More expensive than plain carbon steel.
 - **Processing Difficulty:** Grain orientation control is complex and energy-intensive.
 - **Magnetic Aging:** Impurities like nitrogen or carbon can cause property deterioration over time.
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12. Environmental Considerations

Electrical steel supports **energy conservation**, contributing to:

- Lower electricity consumption

- Reduced CO₂ emissions
- Enhanced performance in renewable energy systems

Modern production methods also focus on **recyclability** and **cleaner processes**, aligning with sustainability goals.

13. Future Trends in Electrical Steel

- **High Silicon (>6.5%) Steel**: Offers near-zero core loss, though harder to process.
 - **Thin-Gauge NGOES**: Improves motor efficiency in EVs.
 - **Amorphous and Nanocrystalline Alloys**: Even lower core losses, emerging alternatives.
 - **AI-Optimized Design**: For core shapes and magnetic efficiency.
 - **Green Steel Production**: Focus on carbon-neutral manufacturing processes.
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14. FAQs

Q1: What is the difference between GOES and NGOES?

GOES has aligned grains and is used in transformers; NGOES has random grains and is used in rotating machines like motors.

Q2: Why is silicon added to electrical steel?

Silicon improves electrical resistivity and reduces core loss due to eddy currents.

Q3: Can electrical steel be recycled?

Yes, it is fully recyclable and can be reused in manufacturing with minimal performance degradation.

Q4: What is lamination in electrical steel?

Lamination is the process of layering thin sheets to reduce eddy currents and improve efficiency.

15. Conclusion

Electrical steel is a foundational material in modern electrical and electronic infrastructure. Its unique magnetic properties and energy efficiency make it indispensable in transformers, motors, generators, and other core applications. As industries move toward sustainability and electrification—especially in electric vehicles and renewable energy—electrical steel will continue to evolve to meet higher performance and efficiency standards.

From GOES in high-voltage transformers to NGOES in motors, electrical steel continues to drive innovation in power systems, helping achieve global energy goals.