## Electrical Steels for High-functional Automotive Electrical Components Corresponding to Energy Saving\*



Masaki Kawano Senior Researcher, Electrical Steel Lab., Technical Res. Labs.



Toshiro Fujiyama Staff Manager, Electrical Steel Quality Cotrol Sec., Products Servise & Development Dept., Mizushima Works



Tatsuya Aoki Assistant, Material Engineering R&D Dept., DENSO Corp.

### Synopsis:

Electrical steels are applied to some kinds of functional automotive electrical components such as an electrical power steering and a fuel pump. Kawasaki Steel has developed a new electrical steel suitable for the newly developed alternator, which improves the efficiency and the output power. The developed material can attain superiority in both the magnetic properties, namely higher flux density and lower iron losses in a high-frequency range, and the workability for helical winding process. A grain oriented electrical steel with high flux density, suitable for the compactness of direct ignition cores, are also described.

### **1** Introduction

As a means of reducting  $CO_2$  emissions and improving fuel economy to both protect the environment and improve the comfort and decorativeness of automobiles, progress is being made in the high function design of various types of electrical components used in automobiles and the application of electrical components in part of actuator parts.

Spurred by the development and practical application of electric vehicles (EV) and hybrid electric vehicles (HEV), the 42-V system of recent automotive power supplies<sup>1)</sup> and proposals for an ISG (integral starter and generator) system, the development of new automotive electrical components has become active especially in Japan, North America and Europe. Because these automotive electrical components are mounted in a limited car space, they are developed always aiming at small size, light weight, high power output, high efficiency and low cost. Also, core materials for motors and actuators that constitute these automotive electrical components should be materially developed to meet these objectives.

This report describes the application of electrical

steels to automotive electrical components. As examples of electrical steels, a newly developed electrical steel suitable for high-efficiency alternators and an electrical steel for direct ignition are described.

### 2 Application of Electrical Steels to Automotive Electrical Components

In order to improve the comfort, power performance and fuel economy of automobiles, electrical steels as core materials and precision motor parts are used for these motors and actuators.

### 2.1 Application to Motors

There are from 20–60 small-size motors in automobiles that are used for various kinds of electrical components. **Figure 1** shows examples of electrical components in which motors are used. Cold-rolled steels represented by SPCC are mainly used as motor core materials, and motors are mostly DC motors with brush.<sup>2)</sup>

Figure 2 shows are relationship between core weight and Si content of steel for some motors used in the 2 000 cc class of automotive electrical components. The core weight and Si content were investigated by disassembling currently used electrical components. The Si

<sup>\*</sup> Originally published in *Kawasaki Steel Giho*, **34**(2002)2, 96–100



Fig. 1 Several kinds of motors applied to cars



Fig. 2 Relationship between the weight of a motor core and Si content of core materials in several automotive components

content was used as an index to determine whether core materials are electrical steels.

As shown in Fig. 2, whether a steel used in a motor core is an electrical steel or an ordinary steel has no relation to motor weight. SPCC class cold-rolled steels are used in power windows and wiper motors, and electrical steels containing not less than 1%Si are used in fuel pumps and motors for electrical power steering. **Photo 1** shows a power steering mechanism and rotor as examples of parts that contain electrical steels.

In power windows and wipers, which are not constantly used, inexpensive cold-rolled steels having are used as core materials in place of low-iron-loss electrical steels, in order to improve torque rather than motor efficiency. In contrast to this, low-iron-loss electrical steels are used in constantly operating fuel pumps to improve motor efficiency. In addition, electrical steels with reduced hysteresis loss are used in power steering systems to reduce torque loss during steering.<sup>3,4)</sup>

It is expected that with the development of EV and HEV and the 42 V design of automotive power supplies, electrical steels will increasingly be employed in motors and generators for ISGs, power air conditioners and powder steering systems<sup>5)</sup> that emphasize efficiency.

### 2.2 Application to Various Types of Actuators

Grain oriented electrical steels are used in the direct ignition cores of engine parts,<sup>6)</sup> as will be explained in detail later. Actuators, such as solenoid valves and sole-



Photo 1 Appearance of an electrical power steering part and the motor core shape

noid brake systems, have been proposed<sup>7)</sup> in order to improve the power performance, controllability and fuel economy of automobiles. It appears that electrical steels will be used in these new parts.<sup>8,9)</sup>

### **3** Electrical Steels Suitable for New-Type High-Efficiency Alternators

Since an automotive generator (alternator) which supplies power to a vehicle (**Fig. 3**) uses torque obtained from the engine as the drive source in power generation, an improvement in power generation efficiency directly helps to improve fuel economy and reduce  $CO_2$ . With the development of a new high-efficiency alternator by an electrical component maker, Kawasaki Steel developed an electrical steel suitable for the stator core of an alternator.<sup>10</sup>

### 3.1 New-Type High-Efficiency Alternators and Target Material Properties

In order to improve the efficiency of an alternator, it is effective to increase power output by the multi-polarization of a rotor which drives at high-frequency.<sup>11)</sup> The steel for the stator should be a high-frequency, low-ironloss material to suppress losses during high-frequency drive, and a high-flux density is required to ensure



Fig. 3 Appearance and structure of an alternator

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Fig. 4 Production method of stator core (helical winding method)



Fig. 5 Target of the magnetic and mechanical properties of the material for the development of high efficiency alternator

higher output current values. On the other hand, a stator core for alternators made of SPCC, a conventional material, is manufactured by a high-productivity helical winding process as shown in **Fig. 4**. The dimensional accuracy of products during this procedure is ensured by controlling the mechanical properties, particularly the yield point (Yp) of the materials.

To ensure the compatibility of improved efficiency with high productivity of the new alternator, a new steel (shown in **Fig. 5**) was developed which has  $W_{10/400}$  of not more than 70 W/kg and  $B_{50}$  of not less than 1.70 T as magnetic properties while maintaining workability of helical winding with Yp kept at conventional levels (180 to 245 MPa).

### 3.2 Essential Points of Material Developed

In general, the addition of Si to increase electric resistance is effective in lowering iron losses at high frequencies. Conversely, however, the addition of Si also reduces magnetic flux density and raises Yp, which decreases the workability of helical winding. Furthermore, Yp tends to vary due to age hardening caused by solute C, N. Therefore, in order to maintain the workability of helical winding, it is necessary to use the skinpass rolling process (SK) to suppress aging. For the development, Yp must remain in the target range even after skinpass rolling for stabilization while at the same time, high-frequency magnetic properties not provided by conventional steels must be ensured. For the newlydeveloped steel, the following technique, which ensures compatibility between high-frequency magnetic properties and workability, was adopted for a low-Si steel (Si 0.1%) with a Yp level equivalent to a conventional one.



Fig. 6 Influence of SK rolling reduction on Yp and iron loss

### 3.2.1 High-frequency low iron loss in which SK-induced strain is considered

Figure 6 shows the results of an iron loss evaluation with SK-induced strains of up to several percent in which Yp control is considered. Yp changes substantially in proportion to the SK rolling reduction. On the other hand, although iron loss increases remarkably at an SK rolling reduction of 0.8%, iron loss deterioration is moderate at SK rolling reductions exceeding 0.8% and low in the high-frequency range of 400 Hz to 1 kHz, which provides the drive frequencies of the alternator, in comparison with the power frequency of 50 Hz. Therefore, it was thought that if the iron loss  $W_{10/400}$  before skinpass rolling could be improved by about 30% over a target, it would be possible to obtain target magnetic properties even after an iron loss deterioration while simultaneously providing the mechanical property Yp by controlling the skinpass rolling reductions from 0.8 to 5.0%.

The total iron loss of the material is divided into hysteresis loss and eddy current loss and formulated by the following equation:<sup>12)</sup>

> $W = W_{\rm h}$  (Hysteresis loss) +  $W_{\rm e}$  (Eddy current loss)  $\propto Af/D + BDt^2f^2/\rho$

(*A*, *B*: Parameter of structure factor)

(D: Grain side;  $\rho$ : Electric resistance; t: Sheet thickness; f: Frequency)

The reduction of eddy current loss by reducing sheet thickness is effective in improving iron loss in a high frequency range. In addition, coarsening the grain size and reducing the precipitates are effective in improving hysteresis loss.<sup>13)</sup> That is, the reason why the above deterioration in high-frequency iron loss by skinpass rolling was less than that in the power frequency of 50 Hz, was because the proportion of hysteresis loss to the total iron loss at high frequencies was low.

Therefore, in order to minimize the iron loss before



Fig. 7 Improvement of hysteresis loss and eddy current loss by the several methods

skinpass rolling, a reduction in sheet thickness (0.5 mm

0.35 mm) for eddy current loss and structure control for reducing hysteresis loss were examined. **Figure 7** shows the effect of reducing in sheet thickness and structure control on the improvement of iron loss. For structure control, the C content which induces precipitate in steel was minimized to ultralow C levels to reduce hysteresis loss, and the sheet thickness was also reduced. This enables iron loss to be reduced by about 50% compared to conventional materials even after skinpass rolling.

#### 3.2.2 High flux density design

It was ascertained that magnetic flux density decreased by about 0.02 T in terms of  $B_{50}$  due to strains by skinpass rolling, so it was necessary to increase magnetic flux density before skinpass rolling in order to achieve the target magnetic properties.

Therefore, texture control was performed in order to increase magnetic flux density. Effective control methods include the control of structure before cold rolling and rolling reduction control,<sup>14,15</sup> and optimization of chemical compositions.<sup>16</sup> Textures were improved by coarsening the structure before cold rolling as much as possible. This was done by utilizing the improvement in grain growth through the reduction of carbides, which was used as a means for reducing iron loss. As a result, it was possible to obtain a steel (**Fig. 8**) in which the {111} pole intensity unfavorable for magnetic properties was suppressed and the {100}, {110} pole intensities



Fig. 8 Improvement of  $B_{50}$  by texture control

 Table 1
 Magnetic and mechanical properties of the developed material

Material	Thickness (mm)	$W_{10/400}$ (W/kg)	В <sub>50</sub> (Т)	Yp (MPa)
Conventional	0.50	110	1.68	200-220
Newly developed	0.35	56	1.72	200-220

# Table 2Comparison of alternator efficiency<br/>between a conventional alternator and<br/>newly developed one

Type of alternator	Core material	Efficiency of alternator
Conventional	Conventional	(Standard)
New type	Newly developed	+10%

favorable for magnetic properties were increased, and  $B_{50}$  was improved greatly.

### 3.2.3 Stabilization of mechanical properties

When solute C and N are contained in steel, roomtemperature strain aging is suppressed by introducing mobile dislocations through skinpass rolling. However, when skinpass rolling is conducted with low rolling reductions or in some use environments, C and N are relocked on dislocations and Yp may sometimes increase abnormally. To prevent this phenomenon, change in Yp was suppressed as much as possible by minimizing the C content and by precipitating N as AlN through the addition of an appropriate amount of Al.

### 3.3 Properties of the Developed Material and Alternator

By applying the above development concepts and results, it was possible to develop a new core material for alternators in which high-frequency magnetic properties and workability of helical winding are combined without adding a large amount of Si.

The mechanical properties and magnetic properties of the developed steel are shown in **Table 1**.

**Table 2** shows a comparison of alternator efficiency between the developed steel and conventional steel. The use of the developed steel in the new alternator made it possible to suppress stator iron loss and improve efficiency by 10%. It is expected that the developed material will be used not only in alternators, but also in motors used in other fuel systems, cooling and air-conditioning systems, and new products such as starter generators for HEV.

### 4 Electrical Steel Suitable for Direct Ignition Cores

Due to the adoption of electronic control, great progress has been made in engine ignition systems. The 1990s saw a shift away from the method of distributing power with a distributor to perform ignition toward a



Fig. 9 Cutaway drawing of stick type ignition coil<sup>17</sup>)

direct ignition system in which independent ignition in each engine cylinder is performed without a distributor.<sup>11)</sup> In recent years, a revolutionary stick-type direct ignition coil that can be mounted in a plug hole in the upper part of an engine was developed owing to further miniaturization.<sup>17)</sup> As shown in **Fig. 9**, the stick shape was obtained by charging the core material into the center of the ignition coil.

### 4.1 Magnetic Properties and Optimum Materials Necessary for Direct Ignition

An ignition coil is a kind of transformer which generates a high voltage necessary for ignition, and a secondary voltage necessary for the discharge of an ignition plug is generated during the cut-off of a current.<sup>18)</sup> In order to obtain this high voltage, the core magnetic energy generated by the primary current must be high and the response during the cut-off of the primary current must be excellent. This requires an orient electrical steel having high magnetic flux density and excellent magnetic permeability. In addition, because the increase in flux density permits the miniaturization of a core, it contributes directly to stick-type miniaturization.

Kawasaki Steel developed New RGH, an oriented electrical steel which has higher magnetic flux density than conventional oriented electrical steels. This new oriented electrical steel has earned a reputation as a high-quality material for transformer cores.<sup>19</sup> **Table 3** and **Fig. 10** show the magnetic properties and  $\mu$ -*H* and *B*-*H* properties, respectively, of New RGH of the 27P100 class (a representative example) in comparison with conventional RGH. New RGH provides magnetic flux density which is higher by 0.04 T in terms of  $B_8$  than RGH. New RGH also has excellent magnetic permeability in a low magnetic field. The application of New RGH to the core material of direct ignition should contribute substatially to the miniaturization of a stick-type direct ignition coil.

### **5** Conclusions

The use of electrical steels in various types of automotive electrical components and electrical steels suitable for high-functional electrical components has been Table 3Comparison of typical magnetic properties<br/>between 27RGH100N and 27RGH100

Material	Grade	Thickness Iron loss(W/kg) Flux density (T)				
		(mm)	$W_{15/50}$	$W_{17/50}$	$B_3$	$B_8$
New RGH	27RGH100N	0.27	0.71	0.97	1.90	1.93
RGH	27RGH100	0.27	0.71	0.98	1.81	1.89



Fig. 10 DC magnetization and permeability curves of 27RGH100-N and 27RGH100

described by referring to specific examples of application.

- (1) Small motors used in present automotive electrical components are mainly DC motors with brush. However, electrical steels with an Si content exceeding 1% are used in motors which require high-functionality and/or efficiency, such as in power steering and fuel pumps.
- (2) Kawasaki Steel developed a steel for the core of a new alternator which combines the workability of helical winding and magnetic properties with an Si content that is equivalent to that of cold-rolled steels (0.1%). This steel was used to create a high-efficiency alternator featuring a conventional helical winding process, which was put to practical use. It is expected that the application of this steel will be expanded to motors used in other fuel systems, cooling and airconditioning systems and new products such as starter generators for HEV.
- (3) A high-flux-density, oriented electrical steel suitable for the core of a stick-type small direct ignition coil was also described. The use of this oriented electrical steel of high *B* and high  $\mu$ , should contribute to the miniaturization of an ignition coil.

With the development of electric vehicles, hybrid electric vehicles and the 42 V system of automobile power supply, electrical steels will undoubtedly be used in a wider variety of parts. By developing electrical steels suited to uses of these diverse parts, Kawasaki Steel will contribute to the intelligent design of automobiles.

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