Recent Servomotor Technology

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1. Introduction

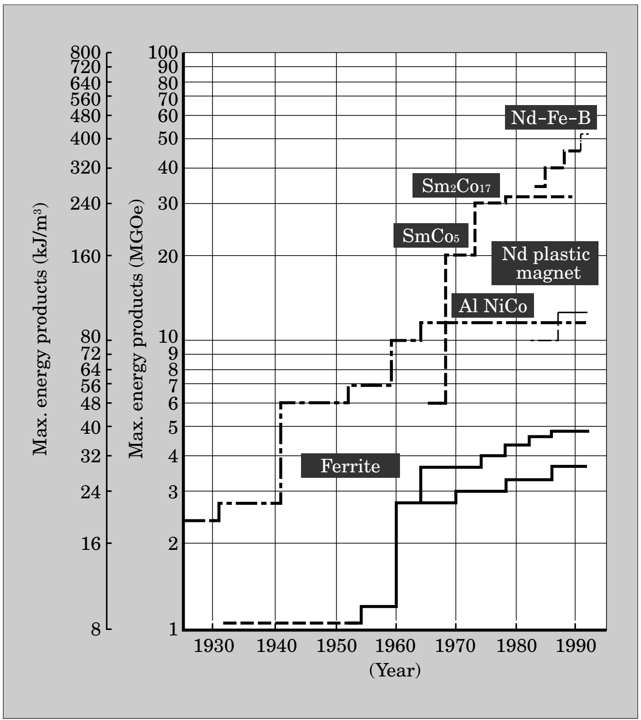
The trends toward compact-size and high-speed response of semiconductor manufacturing equipment and electronic parts machining equipment have increased in recent years. For this reason, the demand for compactness to save space and for low inertia to achieve high-speed response is increasing for the servomotors that drive these types of equipment.

Fuji Electric has been working on the development of an element technique for several years to achieve compact servomotors, and has successfully realized such a servomotor which is ranked as the top level compact unit in the business world. An overview of this achievement is described below.

2. Application of Rare Earth Magnet

A rare earth magnet is formed by sintering several minute powdered metals that contain rare earth elements such as Nd (Neodium) and Sm (Samarium). As shown in Fig. 1, the magnetic characteristics of rare earth magnets have improved remarkably in recent years, thus enabling the generation of a strong magnetic field comparable to that of an electromagnet.

Fig.1 Improvement of magnet characteristics



From early on, Fuji Electric challenged itself with the permanent magnet rotating machine, known for its difficulty, and since then has manufactured and delivered devices that utilize rare earth magnets such as the world's fastest gas turbine driving generator and the world's largest capacity torque machine for driving a coal mine conveyer.

Rare earth magnets include the Nd type, Sm type and Pr (Prasceodium) type, and each type has certain advantages and disadvantages. For this servomotor, an Nd type magnet was utilized because of its abundance as a natural resource, progress in mass production, and significantly improved characteristics.

The stability of magnetic force of an Nd type magnet was confirmed by placing the magnet by itself in air, which is magnetically the most severe condition, and then by leaving it in a 100°C environment for 1,000 hours. Even after these tests, no deterioration was observed as shown in Fig. 2.

Reliability of the magnet was secured by improving the magnet's rather inadequate mechanical strength with modifications to the support mechanism and by making it less susceptible to rust with the application

Fig.2 Deterioration of magnet characteristics

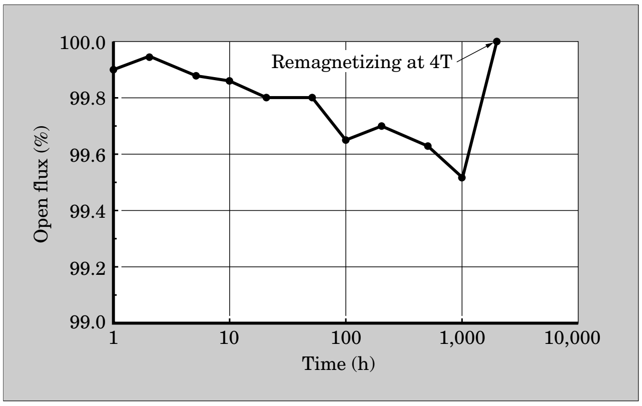
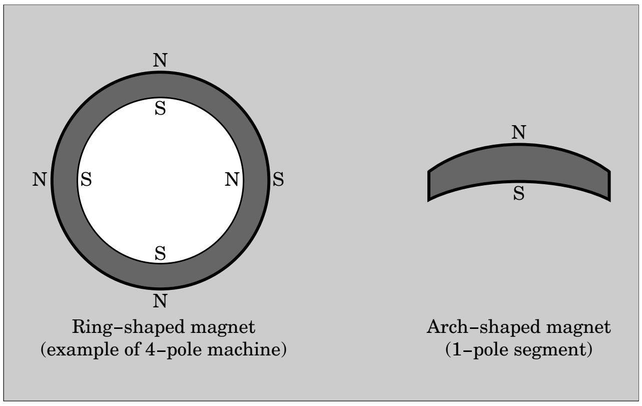


Fig.3 Ring-shaped magnet and arch-shaped magnet



of a resin coating.

The permanent magnet is shaped as a small simple ring or arch, as shown in Fig. 3, and is adhered and fixed to the surface of a solid rotor core that has been cut out together with the shaft. This simple construction has the advantage of being able to become magnetized after the magnet is fixed in place, aiming to improve the mass-productivity.

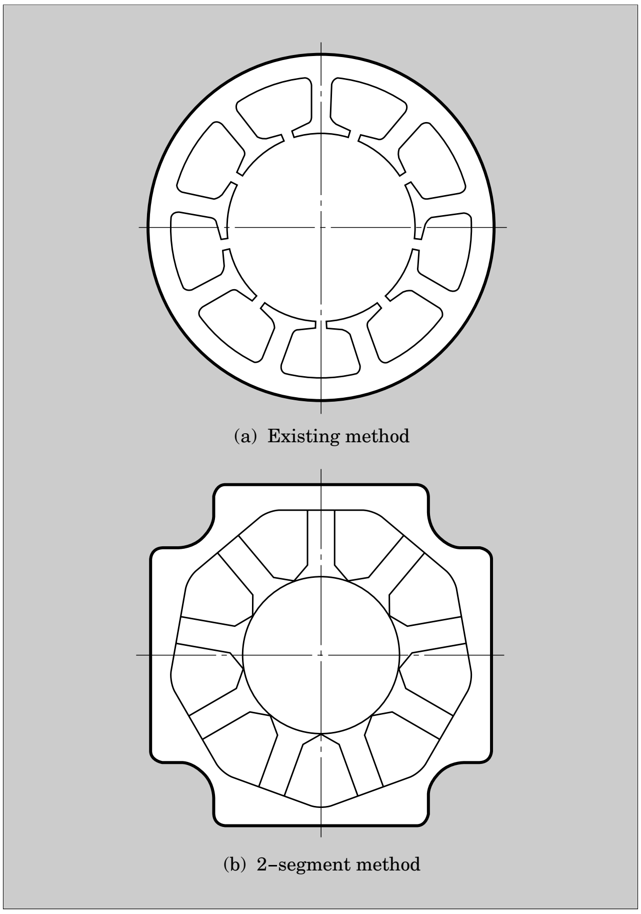
This method, using a small arch-shaped magnet, has been applied to large diameter units whose size exceeds the manufacturing limit of ring-shaped magnets. Based on application of magnetic field analysis that accounted for the advantageous ability to freely modify its sectional configuration, a configuration with minimum cogging torque was selected. As a result, the cogging torque could be reduced to 1/3 that of existing magnets.

3. Improvement of Coil Filling Ratio

In existing electric motors, as shown in Fig. 4 (a), the coil must be automatically inserted from an inconvenient angle and position into a slot located on the inner diameter side of the armature, resulting in only about a 50% filling ratio. Consequently, the current feeding per unit peripheral length was inadequate, leading to low torque density. In addition, there were a number of gaps in the slot which interfered with the discharge of coil heat through the core and further restricted the current feeding. Therefore, a method was utilized in which the core is segmented and after tightly winding the coil while keeping the slot portion wide open, the core is assembled into a solid construction. However, because the core is an important part that transmits magnetic flux and supports the construction, segmentation of the core must be prepared carefully, otherwise severe problems with characteristics and strength will result.

One of the methods applied to this electric motor is called the 2-segment method, shown in Fig. 4 (b). In other words, the inner core is shaped like a gear composed of teeth and bridges that connect the teeth, and a bobbin, made of resin on which the coil has been

Fig.4 Shape of armature core



wound, is attached to each tooth. This assembly is fitted into a ring yoke, forming the completed armature core. The fitting clearance at each tooth between outer and inner cores must be maintained as even as possible to obtain better characteristics.

The bridge is a vital part for the nonstructural support of the inner core, and is also effective in regulating the ripple torque that results from interference between the magnetic flux and teeth. However, excessively increasing its thickness in expectation of these effects will result in unnecessary bypass of the magnetic flux between poles, thus decreasing the usage percentage of the magnetic flux.

The optimum bridge configuration, which has a high magnetic saturation, was evaluated and determined using 2-dimensional static field FEM (Finite Element Method), instead of the conventional analysis method. Figure 5 shows an example of magnetic flux passing over the bridge. The method was not only useful in determining the optimum configuration but was also greatly effective in specifying the permissible manufacturing tolerances and the relation between core dispersion and cogging torque as shown in Fig. 6.

4. High Thermal Conductive Resin Mold

Because the thin bridge portion is not strong

Fig.5 Analysis of magnetic flux distribution

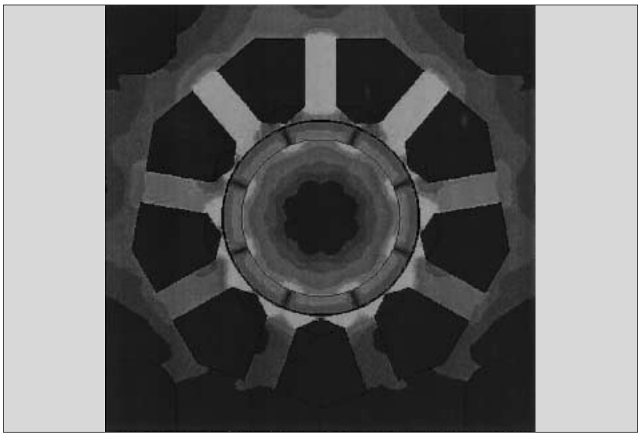
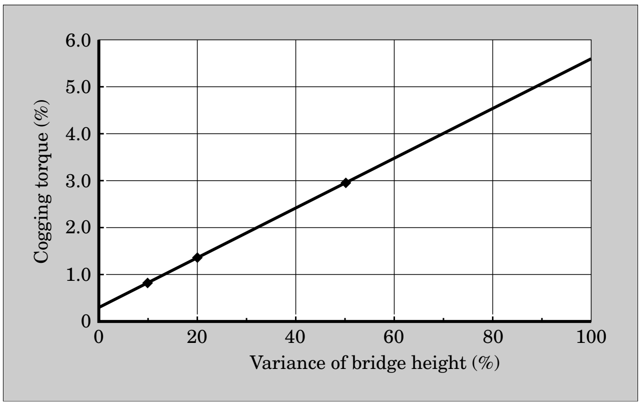


Fig.6 Core dispersion vs. cogging torque



enough by itself to support the core structure, the core, into which coils have been inserted, needs to be molded in resin to achieve stronger construction. To protect the coil and core in a severe environment, the molding resin must have high thermal conductivity in order to reduce anti-environmental characteristics and to lower the coil temperature. On the other hand, the molding resin needs to be highly fluid (low viscosity) to minimize damage to the coil during molding and to allow the resin to fill down into small areas of the coil.

In general, unsaturated polyester BMC (Bulk Molding Compound) is widely used as the molding resin for molded motors. However, further improvements have been made to oil resistance and thermal conductivity, and a new resin that allows low-pressure molding was developed and applied in order to satisfy the above requirements.

Although characteristics differ for improving thermal conductivity and resin flow by adding inorganic filler, a thermal conductivity higher than that of generally applied resin and a lower molding pressure were achieved by selecting a filler with optimum average particle diameter and optimum particle distribution.

As shown in Fig. 7, the water-soluble machining oil resistance, necessary when a motor is used for metal processing machines, is also better than that of

Fig.7 Machining oil resistance of mold plastic

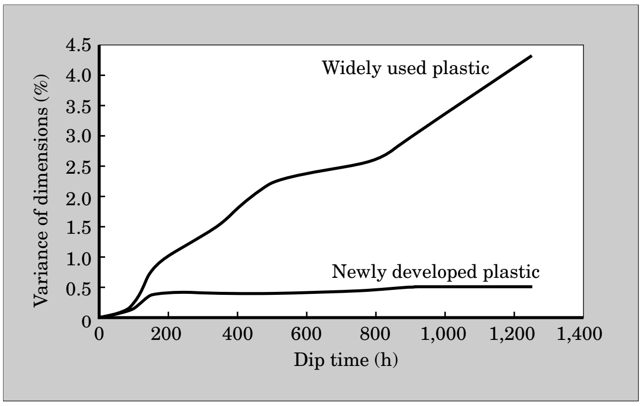
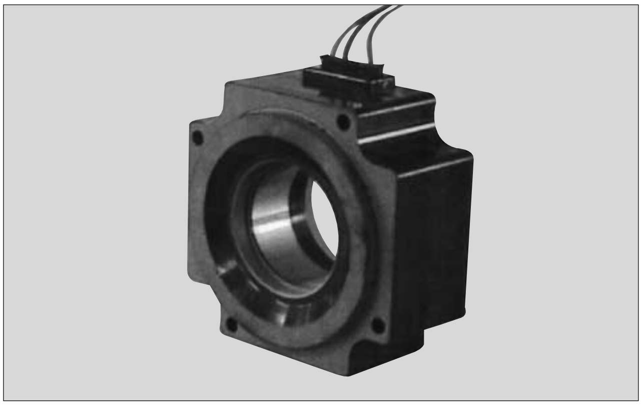


Fig.8 Molded core



general-use resin. No cracking was observed on the new resin, neither after a −20°C ↔ +130°C heat cycle test on a resin-molded 750W electric motor core, nor in the results of tests performed afterward. Therefore, it is safe to say that excellent non-cracking characteristics have been achieved compared to general application resin where cracks occur at less than 10 cycles.

An example of the model 2-segment core with coil inserted and molded in resin is shown in Fig. 8. Both cores are firmly coupled by filler resin, and both bobbin and coil are tightly stored in their slot, thus demonstrating the significant effect of the improved environmental characteristics and cooling function. In this example, the coil filling ratio has exceeded 80%, far surpassing the above goal.

5. Frameless Construction

For small power units that utilize a 2-segment core, a sturdy armature can be constructed with only a laminated core, and therefore further compactness can be realized by eliminating the aluminum or other type of frame. The external shape of the core, which is square and fixed in place at its 4 corners with run-through bolts, allows convenient handling and storing. Although the material of the laminated core itself is susceptible to corrosion, application of the previously mentioned resin mold to the rear of the core resulted in

Fig.9 Existing type (left) and newly developed type (right)

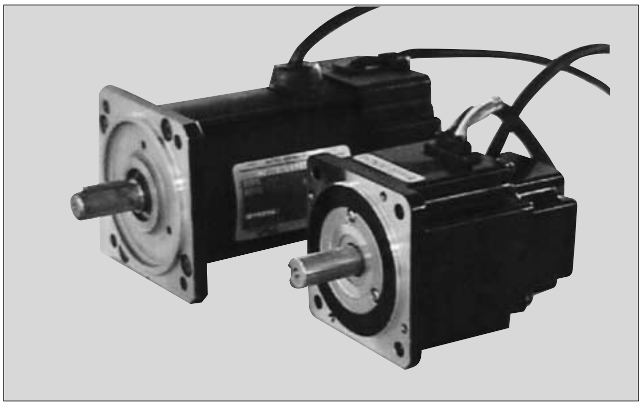


Fig.10 Waveform of cogging torque

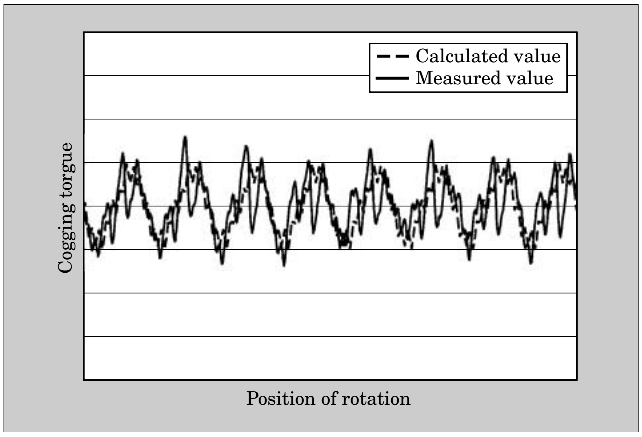
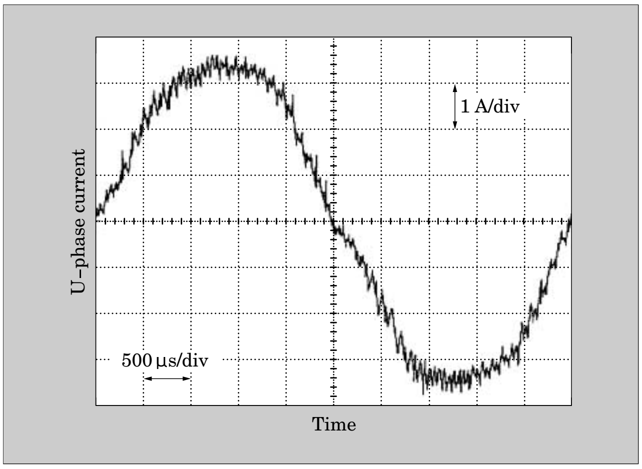


Fig.11 Waveform of current



an excellent surface coating with luster and anti-corrosion characteristics.

6. Cooling Technique

The improvement of magnetic density by using a rare earth magnet will lead to increased core loss, and the generation of a large current by a tightly wound coil will result in increased copper loss. On the other hand, an over-heated rare earth magnet may possibly cause de-magnetization, and enamel wire, molding resin and encoder at the shaft end have their own temperature limits expectively. Therefore, measures were carried out to achieve the operation of each part at an appropriate temperature by compensating the increase of loss density with a well-designed cooling mechanism.

For this reason, a thermal network was compiled which shows the heat source and heat transmission in details, and by assigning appropriate material values, analysis was performed for numerous cases. Heat flow was controlled by, among other things, providing a heat rejection mechanism between the servomotor and encoder. This is in contrast to the aforementioned high thermal conductivity resin, but achieves a construction where there is only natural heat discharge and no over-heating area at the specified loaded condition, regardless of the angle at which a servomotor is operated.

7. Model Unit and Measured Result

Figure 9 shows a model unit and an existing 400W unit, side by side. Considerable compactness was achieved to realize the top-level high power density servomotor in the business world.

The cogging torque wave while the terminal is opened is shown in Fig. 10 along with the predicted value of the design. There is a difference of amplitude. Nevertheless, similarity of the waveform is remarkably good, verifying the excellency of the analysis accuracy.

Figure 11 displays the current waveform during inverter driven operation. Although high harmonic current due to the 10kHz carrier is observed, the noise at 5,000r/min is 50 dB and the vibration is only 2µm even under such conditions. Therefore, significantly improved characteristics were achieved compared with the existing unit.

The temperatures of the coil, magnet and encoder during servo-amp driven operation are all within the permissible values even under the condition where harmonic current increases loss. Thus, it was verified that the thermal transmission mechanism with a combination of various materials functionates as expected.

8. Conclusion

The top-level compact servomotor was achieved with the support of radical new materials such as a rare earth magnet and high thermal-conductive resin, and with the use of a high level analysis method represented by the Finite Element Method. Applying the technologies cultivated during this development work, the authors intend to carry out further research and to continue to contribute novel servomotors to the market.