Direct Drive Technology and Its Impact on Gearmotor Business

Masazumi Suzuki

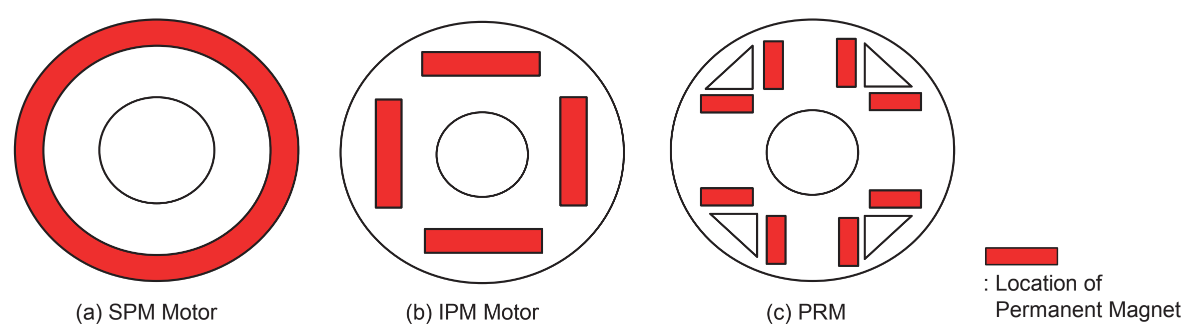

Figure 1—Rotor construction of permanent magnet motor.

Introduction

Sumitomo Drive Technologies manufactures PTC (power transmission and control)-related products such as gearmotors, gearboxes and inverters used in various industries. Paramax parallel and right-angle gearboxes are used in the steel industry, mining conveyors and material handling machinery, etc. Cyclo-concentric gearmotors and hyponic right-angle gearmotors are used in automotive conveyors, food machinery and other applications. Although the gearmotors have been used primarily in industrial manufacturing processes, they are now being used in consumer products such as residential elevators and wheelchairs.

At the same time, environmental concerns and attention to energy saving are growing. Global warming impacted by large consumption of energy is one of the biggest environmental concerns worldwide. Therefore, energy saving, high efficiency and recycling are becoming very important, as well as low noise and vibration. As a result, direct drive (sometimes called DD) motor systems become attractive for home electric appliances and other uses. DD motors do not require gears, theoretically increasing efficiency, reliability, maintainability and responsiveness. This paper discusses direct drive technology trends and investigates their potential impact on gearmotor business based on application examples using DD motors.

DD Motor Technology Trends

Induction motors are commonly used in applications ranging from home electric appliances to industrial process equipment, providing advantages such as simple construction, durability, reasonable cost and ease of control. But, increasing the efficiency of induction motors is a big obstacle due to the large copper loss. As previously mentioned, environmental and energy concerns are driving development of higher efficiency in motors—e.g., upwards of 70% of energy consumption in industry is by motors. So for example, highly efficient, brushless DC motors are beginning to be used in place of induction motors for home electric appliances and other applications. Brushless DC motors use permanent magnets in their rotors. This eliminates copper losses in rotors and results in higher efficiency.

DD motors are, by definition, motors that transmit power to the application directly without the use of mechanical reduction elements like gears, pulleys, chains or belts. DD motors within this broad definition are used in a wide range of applications and come in different forms. But for this presentation, we are interested in applications that until recent history had normally used gearmotors. By replacing a gearmotor with only a motor, a DD motor must typically be able to provide high torque at low speeds—not a strong feature of induction motors. Thus, commonly, most DD motors are some type of permanent magnet (PM) motors operated by an electronic controller.

Types of Permanent Magnet Motors and Rotor Construction

Permanent magnet motors are roughly classified into two types—SPM (Surface Permanent Magnet) motor and IPM (Interior Permanent Magnet) motor (Fig.1). An SPM motor requires a holding tube that secures permanent magnets to prevent them from flying apart due to centrifugal forces at high speeds. The increase in iron loss from this holding tube degrades the efficiency. To decrease the iron content and improve the efficiency, the IPM motor has permanent magnets located in the rotor. This construction prevents the centrifugal forces from damaging the permanent magnet. This is one of the main reasons the IPM motor is used.

The inductance of an IPM motor, as viewed from its stator core, changes in relation to the location of the permanent magnets in the rotor. In addition to the magnetic torque generated, the IPM motor also generates reluctance torque from inductance differences at different rotor angles generated by the intervening magnetic steel of the rotor. The IPM motor makes effective use of the reluctance torque to improve efficiency when compared to an SPM motor. A PRM (Permanent Magnet Reluctance Motor) is a kind of IPM motor. It is designed to enlarge the reluctance torque by optimally locating permanent magnets and cavities.

The output torque characteristics of PM motors are affected by magnet saturation in their cores, which depend on the size of magnets and their location. Therefore, PM motor design is optimized according to the analysis of the magnetic flux density distribution by using FEM (Fig.2).

Construction of the Stator Core of a Permanent Magnet Motor

A distributed winding system has been adopted for stators in the past. In this system, windings are wound in advance and then inserted into stator slots. The disadvantage of the distributed winding system is that the overall lengths of the windings become excessive. The effective winding length is the winding length in the slots. The windings at the ends serve no purpose other than for electrical connection, and they increase winding length by about 1/4 of the stator circumfer-

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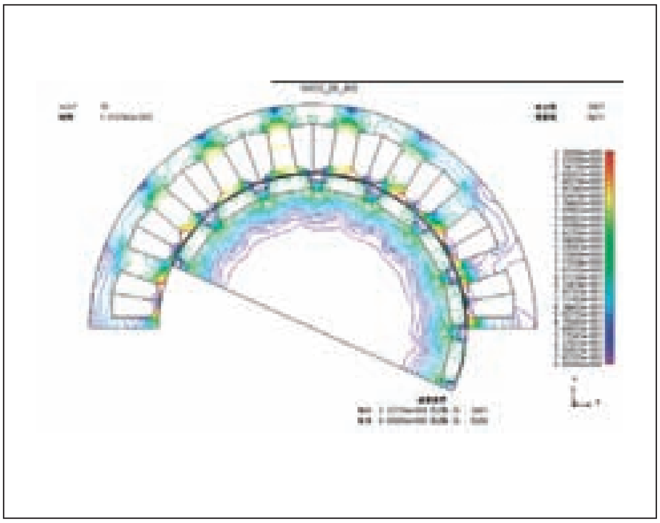


Figure 2—Static magnetic field analysis of a Sumitomo DD motor (3.3kW, 500r/min).

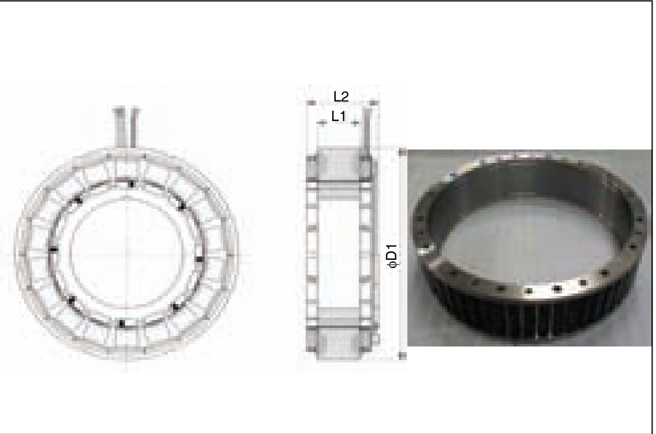


Figure 3—Sumitomo built-in type DD motor.

ence (Fig.4). The alternative to distributed windings is concentrated windings, sometimes called one-slot winding. This system uses windings wound directly on a single stator tooth. The benefit is that the overall length is shortened drastically. This system, used with thick wire and dense winding, achieves a drastic reduction of the winding resistance and results in higher efficiency. Compared to a traditional motor, this system can drastically reduce the amount of copper windings and helps to save natural resources, lower cost and reduce weight and size.

Examples of Applications where DD Motors are Used

Home electric appliances. The load characteristics of a washing machine are washing—which needs large torque at low speed; and spinning—which needs high speed but low torque. Laundry is agitated by the agitating blade during the wash cycle and spin-dried by rotating the load bin during the spin cycle. The drive mechanism of a washing machine is classified as a belt drive, gear drive or direct-drive system, as shown in Table 1. The belt drive system has been the most common mechanism used. Motor output torque is transmitted by a belt drive and a gear. Also, a reduction ratio changer is built into this mechanism. This mechanism can keep the motor load almost constant during spinning and reduce the required motor output torque during washing. However, the disadvantage is the noise and vibration generated by the belt and the gear.

Conversely, a direct drive system has the advantage of low noise and vibration because the motor directly drives the agitating blade and the spinning bin. It does not need a gear and belt, which generate noise and vibration. However, the direct drive system's motor load during washing is very large compared to that of the belt drive system's because there is

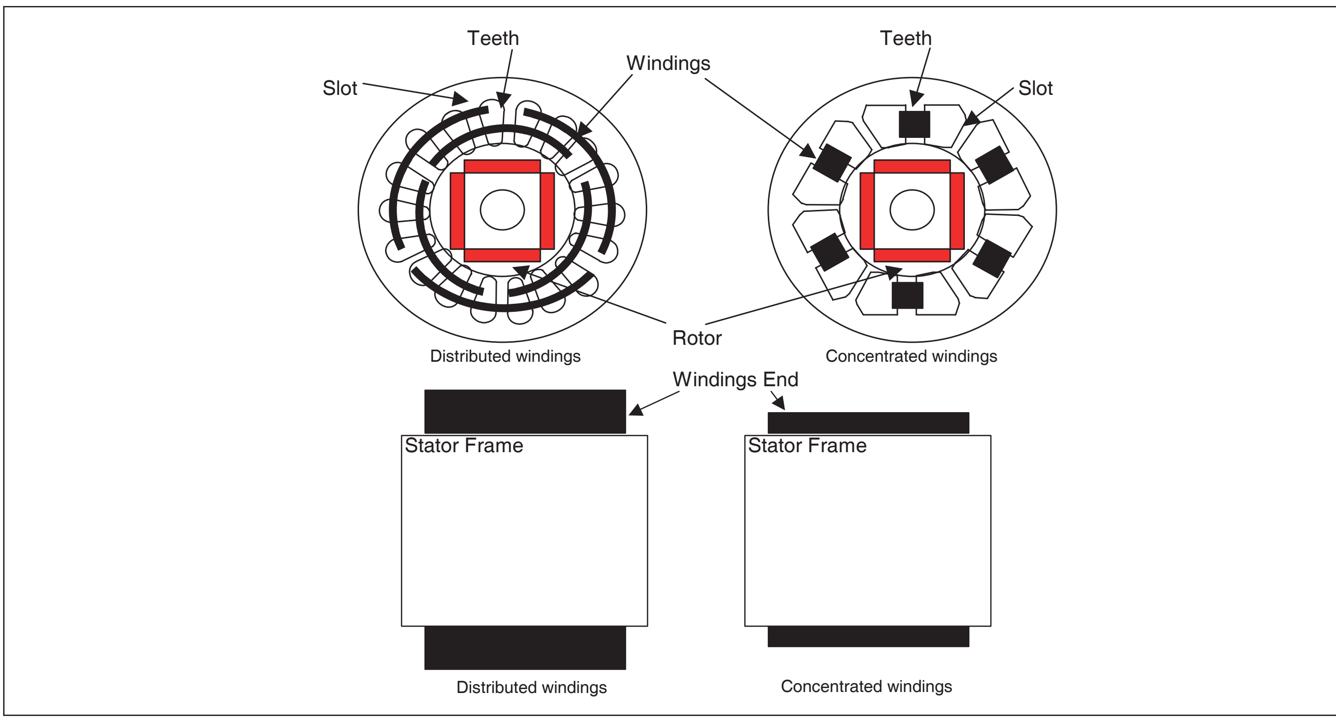
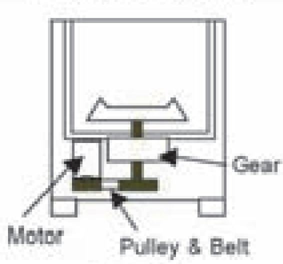
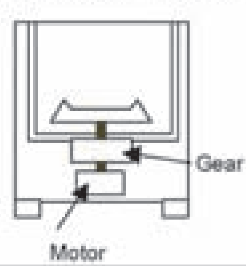
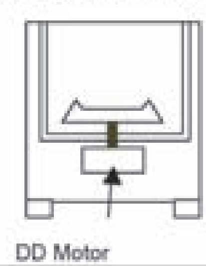


Figure 4—Stator core construction.

Table 1—Drive Mechanism of Washing Machine			
	Belt Drive System	Gear Drive System	Direct Drive System
Construction			
Ratio of Pulley	about 2:1	-	-
Ratio of Gear	about 7:1	about 7:1	-
Balance	Not Good	Good	Good
Low Noise	Not Good	Good	Very Good
Motor	Induction Motor/ Brushless DC Motor	Brushless DC Motor	Brushless DC Motor
Torque	Small	Medium	Large
Cost	Very Good	Good	Not Good

no gear reduction mechanism; this results in a larger motor torque requirement.

Therefore, IPM-type, brushless DC motors that provide both magnet torque and reluctance torque are used to achieve high torque capacity and high efficiency. Additionally, concentrated windings are adopted for reducing copper loss in the stator core and optimization of the permanent magnet shape, and other improvements are used to reduce torque fluctuation.

Machining centers. In this industry, demand for five-axis machining centers and multi-axis machining centers is rapidly increasing. Benefits of five-axis machining centers are process integration and high precision, which are achieved by simultaneous five-axis control.

Generally, a five-axis machining center includes three axes of the linear motion and two axes of rotational motion. The linear motion mechanism is highly developed to achieve high speed and high precision through the technology advancement of the servomotor and the feed screw. On the other hand, the drive system of the rotational motion still uses a worm gear reduction mechanism. The rotational speed is about several dozen rpm and positioning accuracy is limited due to the backlash generated by the worm gear. Therefore, the speed of machining a curved surface—which needs synchronization of the linear and rotational axis—is limited by the feed performance of the rotational axis, even though the feed performance of the linear axis is high. So, the worm gear rotational mechanism is the factor that slows the speed of a five-axis machining center. As a result, DD motors are beginning to be used (Figs. 5 and 6) to avoid a speed unbalance between the linear and rotational axis.

Extruders. As mentioned, energy saving is addressed in the extruder industry as well as other industries due to recent environmental concerns. In the past, the drive mechanism has been constructed of motors, pulleys, belts and gearboxes (Fig.7). However, the drive mechanism using gearboxes is gradually being replaced with the direct drive system using

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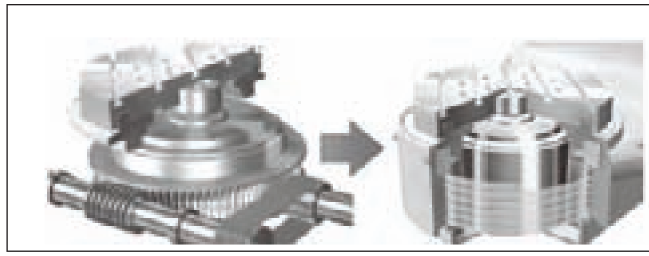


Figure 5—Worm gear system and direct drive system.

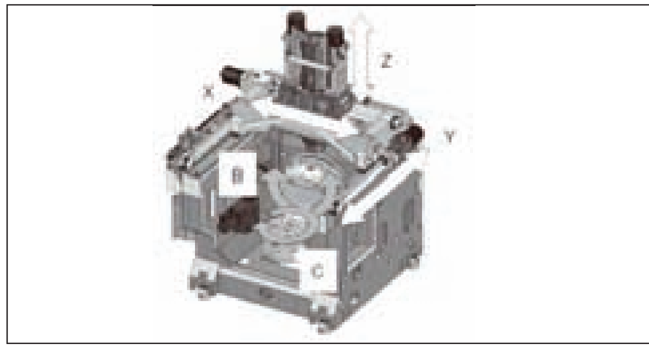


Figure 6—Five-axis machining center.

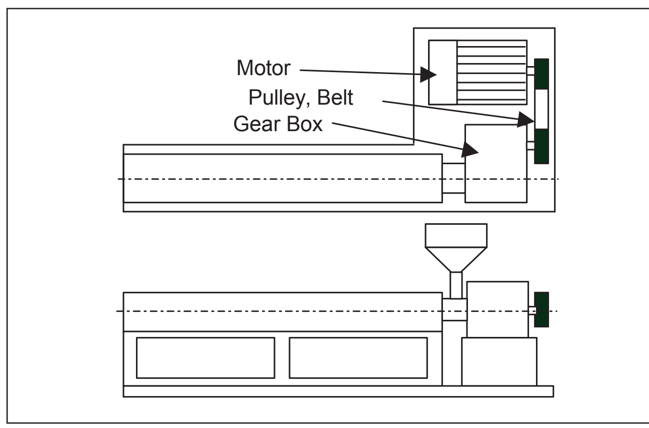
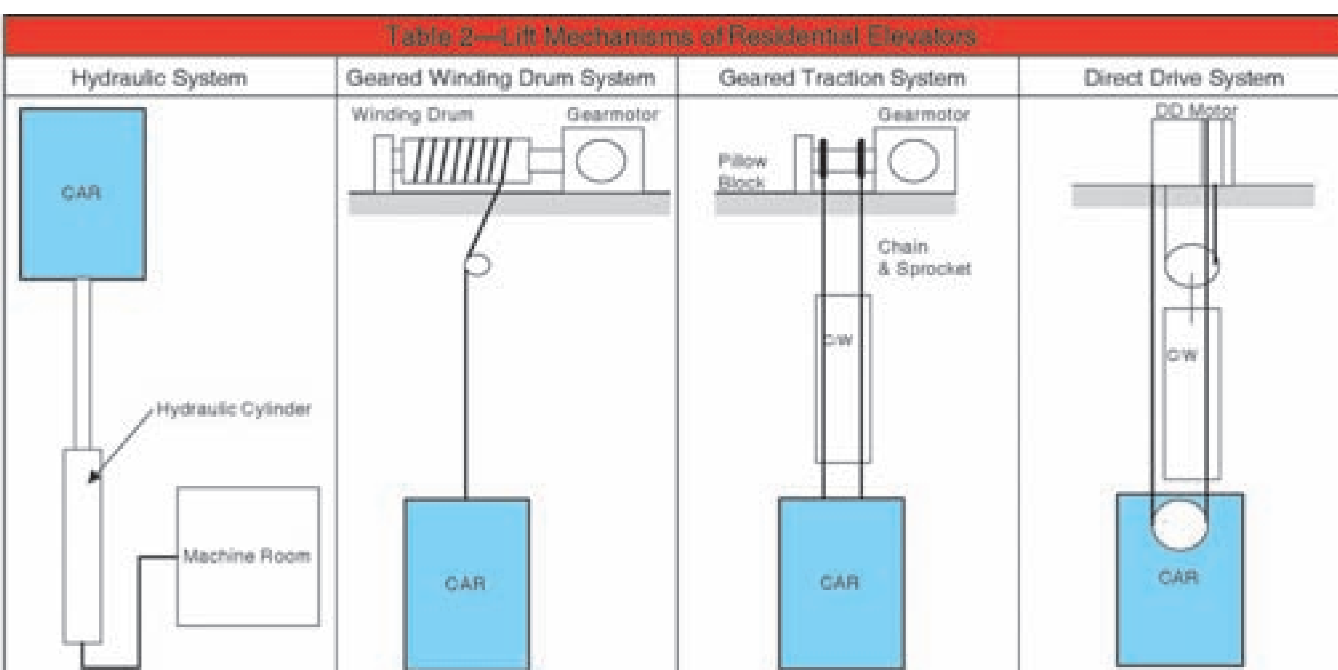


Figure 7—Belt and gearbox system.



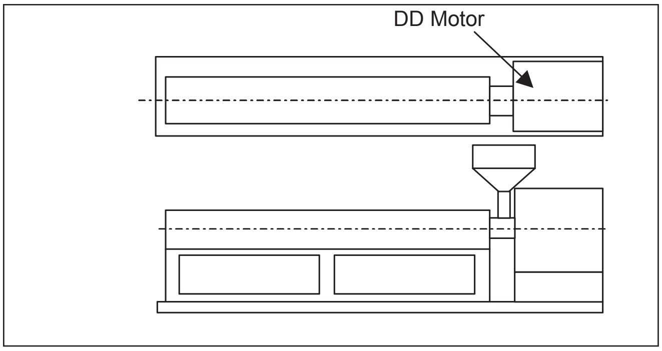


Figure 8—Direct drive system.

Figure 9—Injection machine Sumitomo SE-DU series.

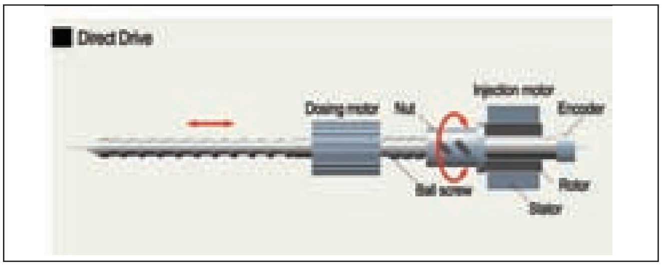


Figure 10—Drive mechanism of injection screw.

Figure 11—Hyponic gearmotors.

DD motors connected directly to the screws (Fig.8). This construction not only improves energy efficiency, it also improves maintainability by eliminating oil changes of the gearboxes and inspection of the pulley belt tension. The construction of the extruder using the DD motor is very simple and compact. This provides more floor space flexibility with extruders for multilayer, blown film processes, thus providing enhanced options for an operator because a larger space is available within to work. Also, some extruder manufacturers report that the power consumption is reduced by 15–20% by means of using DD motors.

Injection machines. Belt drive systems have also in the past been used in injection machines. However, noise from the belt drive mechanism, belt wear and maintainability, are problems. To avoid them, belt drive mechanisms are replaced with direct drive systems. The direct drive mechanism achieves fast response, high speed and energy saving, as well as low noise and increased maintainability.

Residential elevators. There are four kinds of lift mechanisms for residential elevators—hydraulic, geared winding drum, geared traction and direct drive systems. The hydraulic system seems to be most popular in the market, but many manufacturers are using the geared winding drum system as well.

The advantages of the hydraulic system are smooth ride and low noise, but, once installed, it requires a machine room and more aftermarket maintenance. But the geared winding drum system and the geared traction system require less aftermarket maintenance and are very reliable. This is why many manufacturers are now using these systems. For example, Sumitomo hyponic gearmotors are used in residential elevators (Fig.11). Typical specifications of gearmotors are right-angle type, low-noise gearing and braking and a square-shape motor shaft end to attach a hand wheel in emergencies. Low-noise gearing technology and other typical specifications for residential elevators are available in hyponic gearmotors.

The disadvantages of systems using gearmotors are that gearmotors still transmit gear noise even though low-noise gearing is adopted. Also, the ride quality of a gearmotor system has no advantage over the hydraulic system because torque control is difficult at slow leveling speeds. High-end elevator applications in large buildings have used DD motors for decades to eliminate these types of issues. With the cost of DD motor systems coming down, some premium residential elevator markets are beginning to adopt DD motors to elimi-

Table 3—Summary of Values in the Applications

Applications	High Torque at Low Speed	High Efficiency	High Precision	Fast Response	Low Noise and Vibration	Maintain-ability	Compact-ness
Washing Machine	Yes	Yes			Yes		
Machining Centers		Yes	Yes	Yes		Yes	
Extruders	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Injection Machines	Yes	Yes	Yes	Yes	Yes	Yes	
Residential Elevators	Yes	Yes			Yes	Yes	Yes

nate gear noise and achieve smooth ride. But, DD motors are still expensive for the general market at this point.

Potential Impact on Gearmotor Business

This paper discussed DD motor technology trends and some examples of applications. There are some important points in these examples (Table 3). They are high efficiency, high precision, fast response, compactness, light weight, low noise, low vibration and increased maintainability. Based on these advantages, the potential impact on gear business that DD motors represent is presented in the conclusion of this paper.

Technology Evolution and Customer Needs

As a rule, technology develops like the curve as shown in Figure 12. This figure is a time history of technology evolution. The curve is known as the S-curve because of its shape. If the S-curve exceeds customer needs, commoditization results, followed by severe cost competition. It is thought that the S-curve of gearmotors does not yet exceed customer needs, but it is close. On the other hand, it is thought that DD motors are in a developing stage of the technology evolution.

This is explained by using the concept of product architecture. Figure 12 maps the customer value in the horizontal axis and the product architecture in the vertical axis. The integrated-type architecture needs a custom design and can be expensive. The customer value is roughly classified as well-defined/general needs and potential/custom needs. It is thought that gearmotors are located in the first and second quadrants. And yet, it is still thought that DD motors are custom and integrated architecture. Based on this product architecture, and with respect to the gearmotor market, the cost of DD motors is not yet competitive. However, with improved cost position, it is expected that the DD motors may move to the second quadrant in the future. But time will be required to modularize and to standardize DD motors because their design is still developing, and current options can be very flexible. There are various speed and torque characteristics and motor design architectures and motor control schemes available.

Will DD Motors Replace Gearmotors?

The examples that are discussed in this paper show that DD motors create new customer values. The values are high efficiency, low noise, increased maintainability, etc., as previously mentioned. These create added values, and DD motors can be used for specific applications even though they are expensive.

If the customer's value is mapped within the concept of a "value network," the metrics seen in Figure 14 result, which show time in the horizontal axis, the function (value metrics) in the vertical axis and the value network in the axis perpendicular to the page. The value networks of both products are shown in relation to each other, but on different "average" plains; different customer needs are dotted three-dimensionally around the customer needs line. Likewise, the different variations of the products are distributed three-dimensionally around the product technology evolution line. As time progresses, the customer needs line and the product technology line can begin to encroach on or separate from each other. Currently, the value metrics for the gearmotor network are reasonable life, high reliability and reasonable cost. The value

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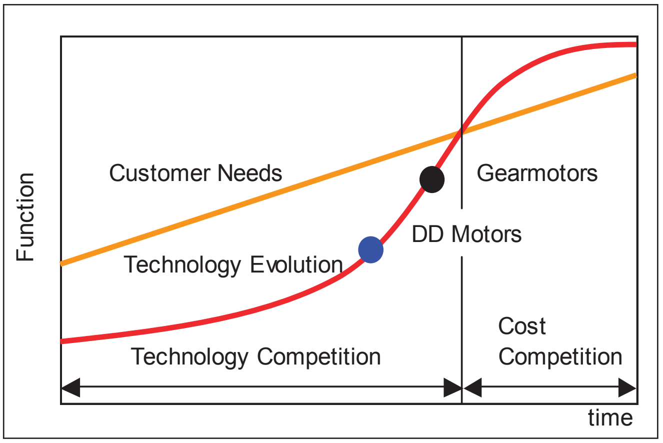

Figure 12—S-curve of technology and customer needs.

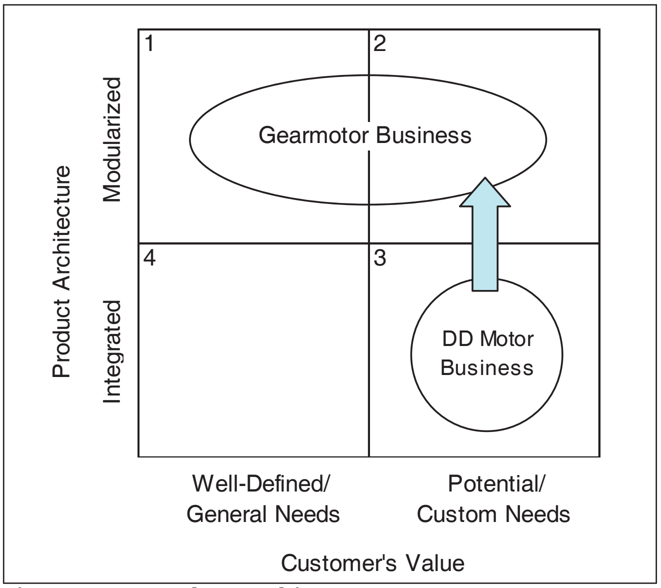

Figure 13—Product architecture map.

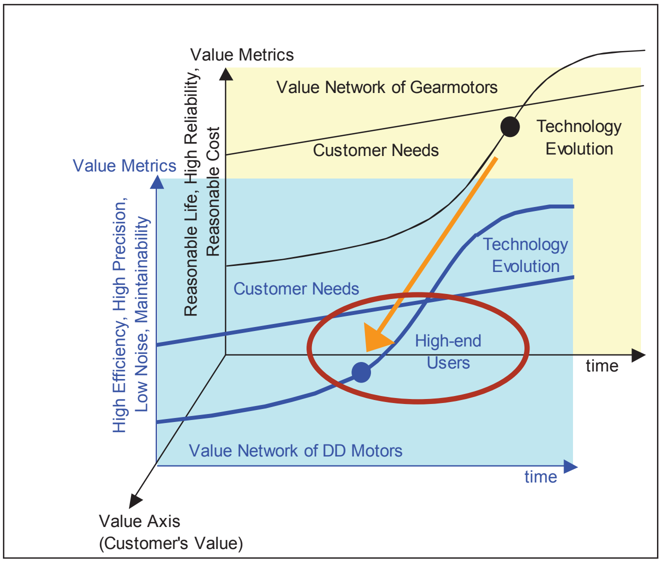

Figure 14—Metrics of value and the value network.

metrics of the DD motor network are high efficiency, high precision, low noise and maintainability.

As mentioned, DD motor technology is still in a development stage of technology evolution, and yet to be modularized. Therefore, it is thought that DD motors are used only for specialized applications for high-end users and that the size of the DD motor market remains small. The entire gearmotor market in the PTC industry incorporates a wide range of applications—some of which are well outside the realm of the DD market. If we restrict the examination of the gearmotor market to ones involving speed control, gearmotors continue to provide advantages such as familiarity, reasonable life, high reliability and reasonable cost. Gearmotors are still a moving target and can be fitted with PM motors to improve efficiency, and new lubrication technologies are continuing to improve gearbox efficiencies.

DD motor applications that can accept tradeoffs between high efficiency and high performance versus high cost and integrated packages are still few in number. However, new values such as energy savings, sustainability costs, improved performance, etc.—due to growing environmental concerns such as increasing CO_2—could nudge macroeconomic factors to replace more gearmotors with DD motors. Other factors that will impact the market toward DD motors could include new technologies involving design and manufacturing techniques yet to be discovered. Further, governmental regulations and development of industry standards that may tip the momentum toward more DD motor applications may be around the corner. Consequently, we should continue to watch macro trends in the future.

Masazumi "Mack" Suzuki *is an application engineer for Sumitomo Heavy Industries, Ltd. Mack graduated with a master's degree in mechanical engineering from Nagoya Institute of Technology in Japan. He has over 13 years of mechanical engineering experience and is currently an expatriate engineer for Sumitomo Machinery Corporation of America, since 2005.*

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