# Direct Drive Technology Trends
# And Its Impact on Gearmotor Business

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## 1. 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 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 our gearmotors are used in industrial manufacturing processes—with recent trends, it is now being used in consumer products such as residential elevators and wheelchairs.

Meanwhile, environmental concerns and attention to energy saving are growing. Global warming caused by large consumption of energy is one of the biggest environmental concerns on a global basis. Therefore, energy saving, high efficiency and recycling are becoming very important as well as low noise and vibration under these environmental concerns, and 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.

## 2. DD Motor Technology Trends

Induction motors are commonly used in applications ranging from home electric appliances to industrial process equipments providing advantages such as simple construction, durability, reasonable cost and ease of control. But, increasing the efficiency of induction motors is big obstacle, because of the large copper-loss. As previously mentioned, environmental and energy concerns are driving development of higher efficiency in motors, because 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 uses. 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 by this broad definition are used in a wide range of application and come in different forms, but in our discussion, we are interested in applications that until recent history had normally used gearmotors. By replacing 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.

### 2.1 Types of Permanent Magnet Motors and Rotor Construction

Permanent magnet motors are roughly classified into 2 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 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 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 compare to an SPM motor. A PRM (Permanent magnet Reluctance Motor) is a kind of IPM motor. They are designed to enlarge the reluctance torque by optimally locating permanent magnets and cavities.

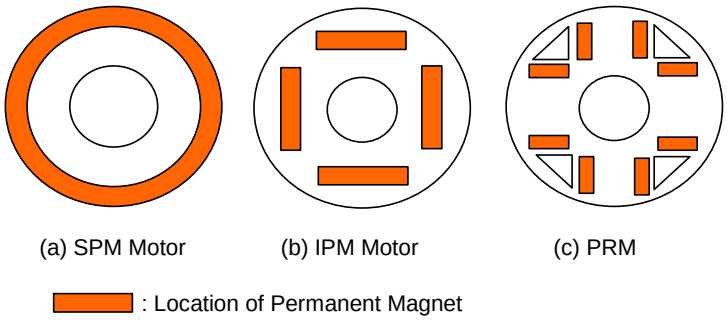



***Fig.1 Rotor Construction of Permanent Magnet Motor***

The output torque characteristics of PM motors are affected by magnet saturation in their cores, which depends 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).

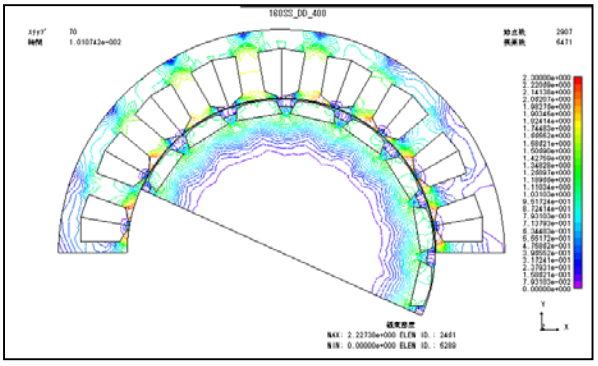


***Fig.2 Static Magnetic Field Analysis of a Sumitomo DD Motor (3.3kW, 500r/min.)***

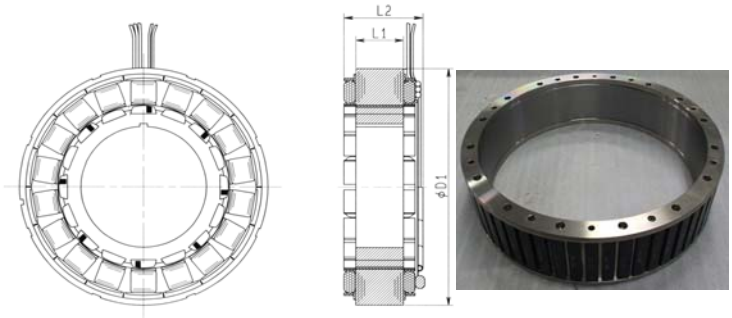



***Fig.3 Sumitomo Built-in type DD Motor***

## 2.2 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 long. The effective winding length is the winding length in the slots. The windings at the ends serve no purpose other than electrical connection and increase winding length by about 1/4 of the stator circumference (Fig.4). The alternative to distributed windings is concentrated windings or 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 this results in higher efficiency.

Compared to a traditional motor, this system can drastically reduce the amount of copper windings and helps to save our natural resources, to lower cost, and to reduce weight and size.

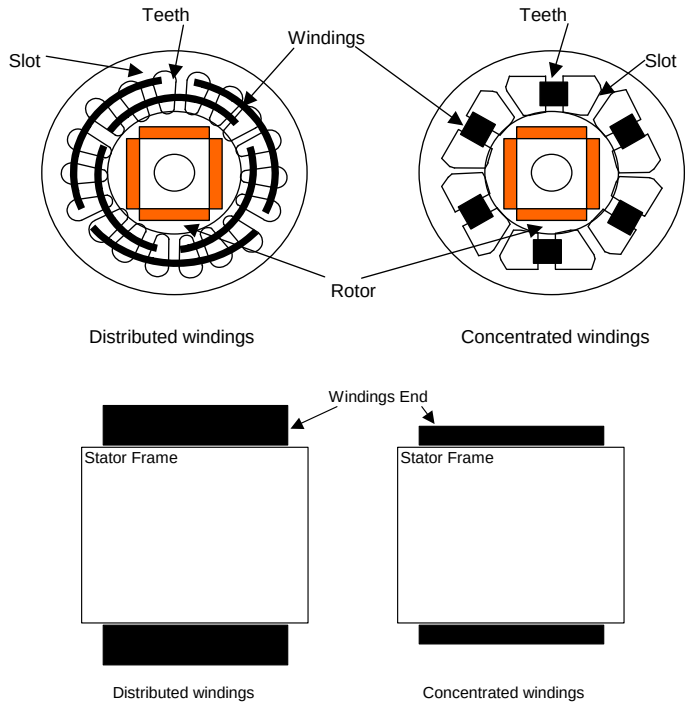



Fig.4 Stator Core Construction

## 3. Examples of Applications where DD Motors Are Used

### 3.1 Home Electric Appliances

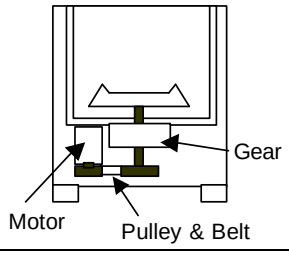
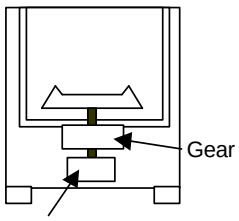
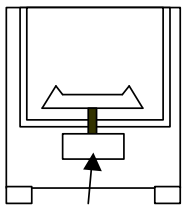
The load characteristics of a washing machine are "*washing* " which needs large torque at low speed and "*spinning*" which needs high speed but low torque. Laundry is agitated by the agitating blade during "*washing*" and spin-dried by rotating the bin during "*spinning*". The drive mechanism of a washing machine is classified as a belt drive, gear drive or direct drive system as shown in Table 1. The belt drive system is the most common mechanism that has been used in the past. 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 large noise and vibration that are generated by the belt and the gear.

On the other hand, 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 belt drive system's motor load because there is 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 with other improvements are used to reduce torque fluctuation.

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 |

### 3.2 Machining centers

In this industry, demand for 5-axis machining centers and multi-axis machining centers are rapidly increasing. Benefits of 5-axis machining centers are “process integration” and “high precision” which are achieved by simultaneous 5-axis control.

Generally, a 5-axis machining center includes 3 axes of the linear motion and 2 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 makes the speed of a 5-axis machining center slow. To avoid a speed unbalance between the linear and rotational axis, DD motors are beginning to be used (Fig.5 and Fig.6).

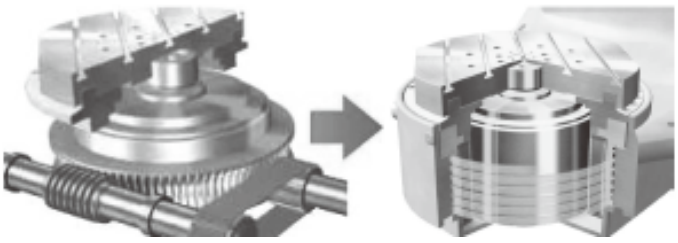


***Fig.5 Worm Gear System and Direct Drive System***

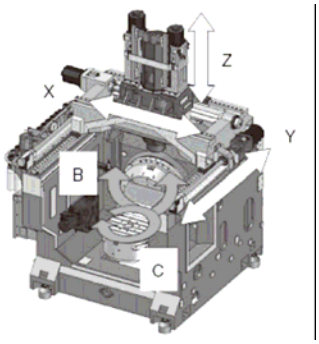



***Fig.6 Five-Axis Machining Center***

### 3.3 Extruders

Energy saving is addressed in the extruder industry as well as other industries due to recent environmental concerns. The drive mechanism has been constructed of motors, pulleys, belts and gearboxes in the past (Fig.7). However, the drive mechanism using gearboxes is gradually being replaced with the direct drive system using DD motors connected directly to the screws (Fig.8). This construction not only improves energy efficiency but 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 flexibility of layout of extruders for multilayer blown film process. This achieves increasing workability of an operator because large space is available. Some extruder manufacturers report that the power consumption is reduced by 15-20% by means of using DD motors.

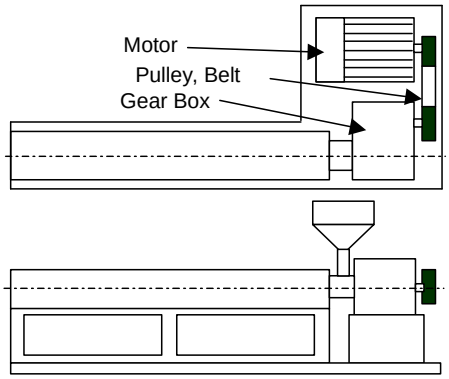



*Fig.7 Belt and Gearbox System*

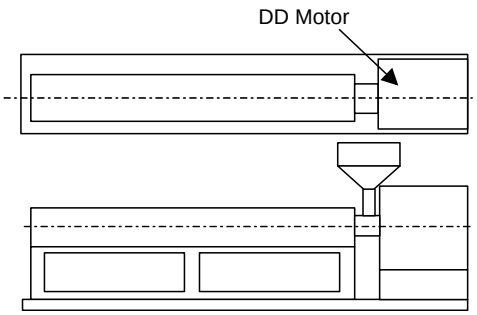



*Fig.8 Direct Drive System*

### 3.4 Injection Machines

Belt drive systems also have been used in injection machines in the past. However, noise from the belt drive mechanism, belt wear and maintainability are problems. To avoid such problems, 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.


*Fig.9 Injection Machine Sumitomo SE-DU Series*

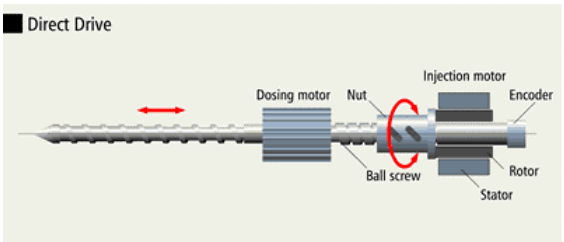



*Fig.10 Drive Mechanism of Injection Screw*

### 3.5 Residential Elevators

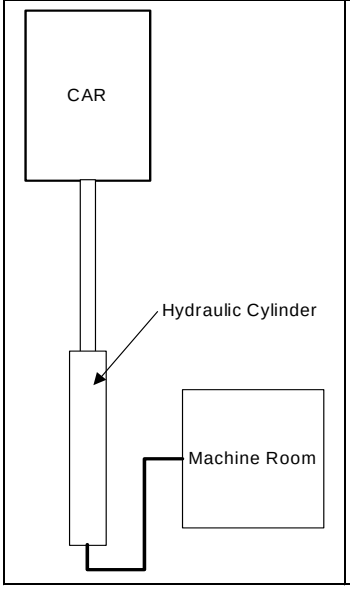
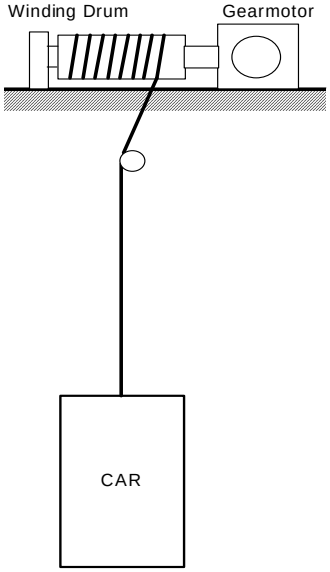
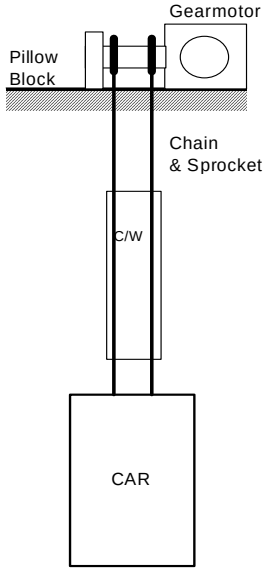
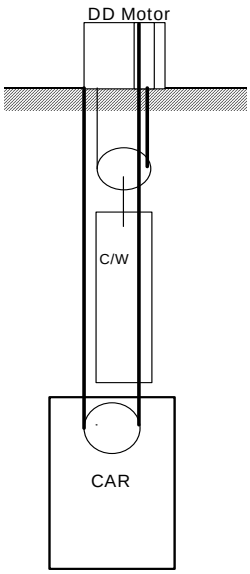
There are 4 kinds of lift mechanisms for residential elevators. They are ***hydraulic***, ***geared winding drum***, ***geared traction*** and ***direct drive systems***. The hydraulic system seems to be most popular in the market, but many manufacturers are using the geared winding drum system as well.

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

***Fig. 11 Hyponic Gearmotors***

The disadvantages of systems using gearmotors are that gearmotors still transmit gear noise even though the 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 application 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 recently to eliminate gear noise and achieve smooth ride. But, DD motors are still expensive for the general market at this point.

***Table 2 Lift Mechanisms of Residential Elevators***

| Hydraulic System | Geared Winding Drum System | Geared Traction System | Direct Drive System |
|---|---|---|---|
|  |  |  |  |

## 4. Potential Impact on Gearmotor Business

This paper discussed DD motor technology trends and some examples of applications. There are some important key points in these examples (Table 3). They are high efficiency, high precision, fast response, compactness, lightweight, low noise, low vibration, and increased maintainability. Based on these advantages, we would like to discuss the potential impact on gear business that DD motors provide as closing of this paper.

***Table 3. Summary of Values in the Applications***

| Applications | High Torque at Low Speed | High Efficiency | High Precision | Fast Response | Low Noise and Vibration | Maintainability | Compactness |
|---|---|---|---|---|---|---|---|
| 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 |

### 4.1 Technology Evolution and Customer Needs

Generally, the technology develops like the curve as shown in Fig.12. This figure is a time history of technology evolution. This curve is known as 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 exceed customer needs but it is close to the intersection of the S-curve with customer needs. On the other hand, it is thought that DD motors are in developing stage of the technology evolution.

This is explained by using the concept of product architecture. Fig.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 into well-defined/general needs and potential/custom needs. It is thought that gearmotors are located in the 1st and the 2nd quadrants. On the other hand, it is thought that DD motors are still 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 2nd quadrant in the future. But probably time will be required to modularize and to standardize because DD motor 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.

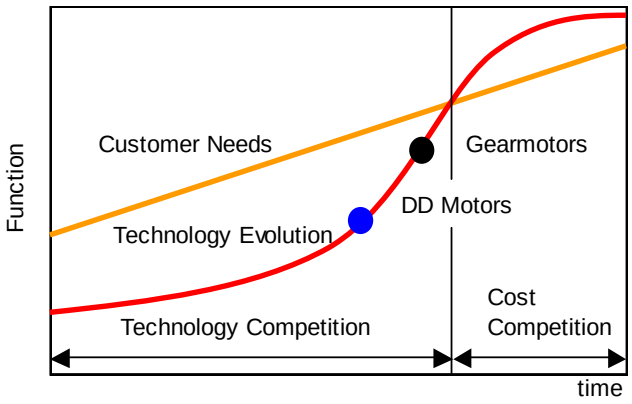



***Fig.12 S-curve of Technology and Customer Needs***

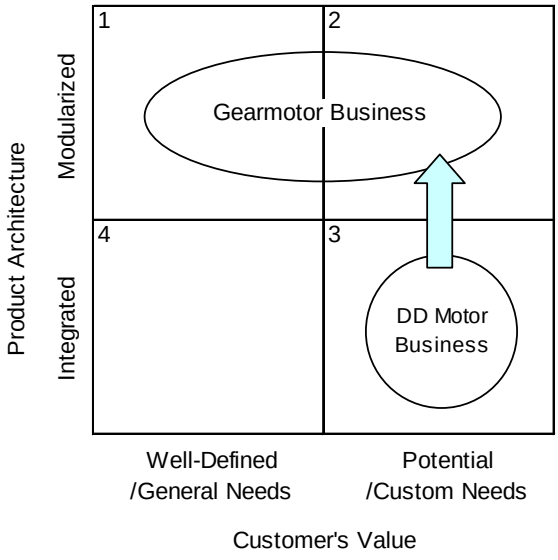



***Fig.13 Product Architecture Map***

### 4.2 Will Gearmotors Be Replaced with DD Motors?

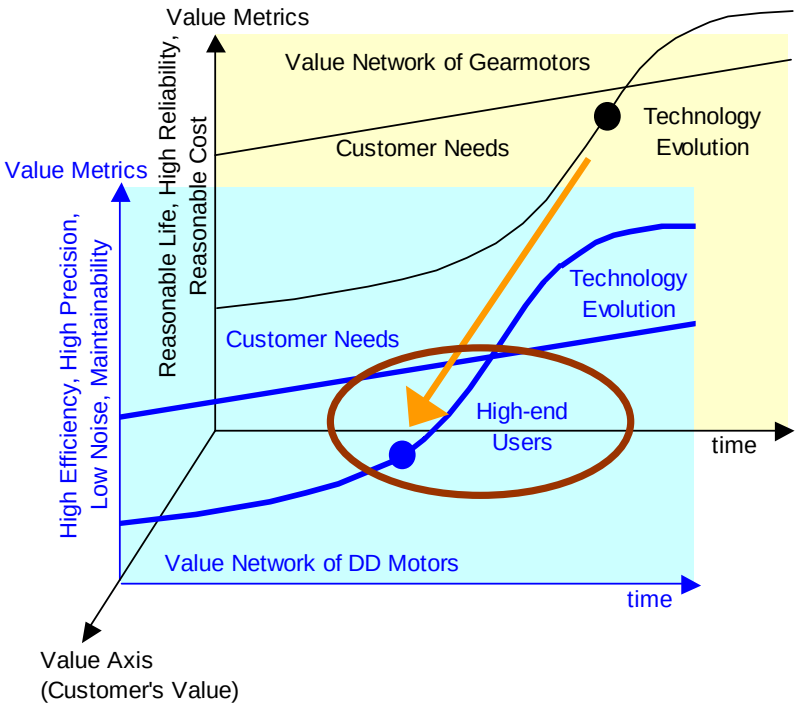
The examples that are discussed in this paper show that DD motors create new customer's values. The values are high efficiency, low noise, increased maintainability, etc. as previously mentioned. These create added values and DD motors can be used for specific applications even though they are expensive.

If the customer's value is mapped within the concept of "value network", Fig.14 results, which shows 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. You should think that different customer needs are dotted 3-dimensionally around the customer needs line. Likewise, the different variations of the products are distributed 3-dimensionally around the product technology evolution line. As time progresses the customer needs line and the product technology line can begin to encroach on each other or separate from each other. Currently the value metrics for the gearmotor network are reasonable life, high reliability and reasonable cost. On the other hand, value metrics of the DD motor network are high efficiency, high precision, low noise and maintainability.

As previously mentioned, the DD motor technology is still in a development stage of the 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 the size of the DD motor market is still small. The whole gearmotor market in the PTC industry incorporates wide range of applications some of which are well outside of the realm of the DD market. If we restrict the examination of the gearmotor market to ones involving speed control, ***gearmotors still provide advantages such as familiarity, reasonable life, high reliability and reasonable cost***. Gearmotors are still moving target and can still be fitted with PM motors to improve efficiency and new lubrication technologies are continuing to improve gearbox efficiencies.

DD motor applications that can accept tradeoff between high efficiency and high performance versus high cost and integrated packages are still few in numbers. However, new values such as energy savings, sustainability costs, improved performance, etc. due to growing of attention to 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.

***Fig.14 Metrics of value and the value network***



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