Development of New Motor and Controller Models for Battery Forklift Trucks

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Abstract

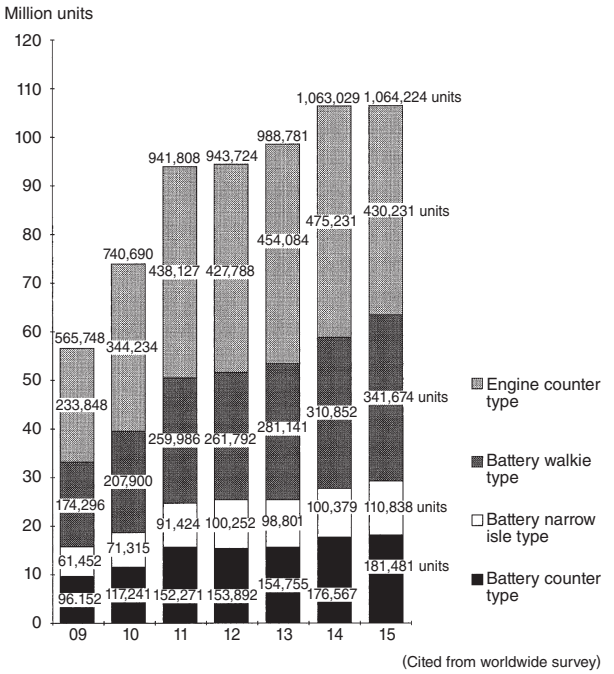
For more than half a century, we have supplied motors and controllers that are the motor drive units for battery forklift trucks. These machines are key devices for the forklift trucks industry.

Until now, most of the world forklift truck market consisted of Japan, North America, and European countries. Asian markets in China and other Asian countries are rapidly growing. In order to supply high-performance and inexpensive motor drive products to these new markets and establish a solid market position there, we are promoting the development of motors and controllers.

1 Preface

After the worldwide recession caused by the global financial crisis in 2008, the market sales of forklift trucks drastically declined. Afterward, there was a sharp market recovery mainly driven by markets in China and other newly developing countries. According to a record of worldwide unit sales achievements in 2015, the number of forklift truck sales reached 1,064,000 units; this is the highest achievement since the start of worldwide statistics. Fig. 1 shows the worldwide transition of sales in the forklift trucks sector. In 2015, there was recession of business transactions in China and also shrinkage of market in newly developing countries. Despite this, the requirements of mechanization in logistic systems are anticipated to expand in developing countries due to possible rises of labor costs in China. Steady growth of markets is expected in rising nations.

Regarding worldwide vehicle model sales from 2011 to 2015, business in total sales volume of engine type forklift trucks. It became evident that battery type forklift trucks became an overall market driver. The reasons for such business trends were that there was a rise in environmental consciousness and that the reduction of lifecycle cost is sought after through market penetration of motorized forklift trucks. Generally speaking, the initial cost is high for a battery forklift truck, but running cost is low. Overall lifecycle cost can consequently be low.



(Cited from worldwide survey)

Source: "Industrial Vehicles" (March 2016) [Japan Industrial Vehicles Association]

Fig. 1 Worldwide Transition of Sales in the Forklift Trucks Sector

Worldwide transition of sales in the forklift trucks sector is shown, with graphs classified for each model.

For classification by world region, the rate of electric forklift in leading countries is already exceeding 50%: 55% in Japan, 64% in North America, and 82% in EU countries. On the one hand, the rate of electric forklift is 30% in China, which is a comparatively low figure. In the past five years, however, the rate rose from 20% to 30%. In

the future, even in developing countries including China, the rate of electric forklift is estimated to rise rapidly.

We are developing a motor drive unit applicable to battery forklift trucks because the market for these machines is expected to expand substantially. The new models are developed to assure high quality and satisfactory functions that can be accepted in leading countries and be inexpensively priced in developing countries. This paper introduces the recently released frameless motors and the AC450 Series that is under development.

2 Motor for a Forklift Truck

For electric vehicles, PM motors are generally used for its compact design, light weight, and high efficiency. Even for the same application to vehicles, induction motors tend to be adopted for forklift trucks because of the low price. This is because there is a large difference in characteristics between two types of vehicles. Since the forklift truck is equipped with a counterweight for the purpose of the prevention of falling down during cargo handling of heavy articles, the light weight of the driving motor is not significantly noticed. In addition, unlike the case of motors for electric vehicles, restrictions for the motor mounting space are not very rigorous. As such, requests for compact design are rare. Even a motor in a sufficiently large size can be adopted and performance of high efficiency can be attained even by an induction motor.

For comparison of motors for forklift trucks with those for electric vehicles, there is a great difference in specifications of the protection construction. Compared with electric vehicles, battery voltage is low for forklift trucks. Accordingly, it is constructed to prevent contact with the live part. It is, therefore, unnecessary to establish a completely waterproof structure. An enclosure structure called the “open type” is generally adopted. The enclosure may not have an opening greater than 12 mm in diameter.

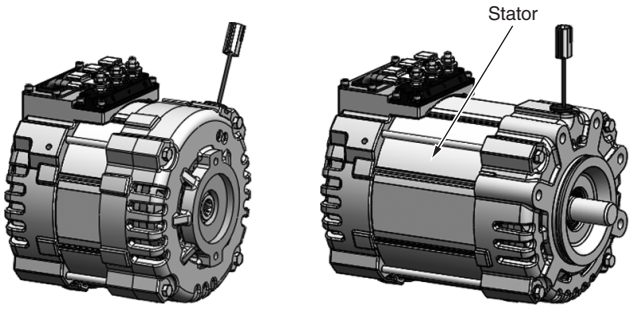
2.1 Frameless Motor

The “open type” motor to be applied to a forklift truck is designed so that the stator coils are chilled by direct wind through vanes on both sides of the rotor. Due to the structure, it is unnecessary to dispel motor heat generation through the motor frame. To achieve further cost competitiveness with forklift truck motors, we adopted a frameless structure and promoted an optimal design according to the application.

2.2 Optimal Design Specialized for Application to Forklift Trucks

The forklift truck is equipped with two types of motors, one for traveling and the other for cargo handling. There are also two types of vehicles, counter type and reach type. The performance required for the motor is respectively different among the traveling, cargo handling, counter type, and reach types. Drawing on our track records and experiences for more than 50 years, we designed the most suitable motors applicable to forklift trucks of traveling, cargo handling, counter, and reach types. We supply such vehicles ranging from 1t to 3t classes. Fig. 2 shows the minimum and maximum models of our frameless motors. We realized the use of common parts by changing the stator length to realize a wide range of characteristics and unified the stator diameter.

The most important factor needed in designing the motors for forklift trucks is to secure a wide range of operations from low to high motor speed and light to heavy cargo handling, and assure a high efficiency in a regular operational range where the forklift truck is operated most frequently. Such a motor design approach results in the reduction of vehicle battery consumption and the extension of per-charge traveling distance (traveling distance possible by one-time charging). For a frameless induction motor where construction is simple, and the number of parts is small, the rate of stator cost occupying the overall motor cost is extremely high.



(a) Minimum model (b) Maximum model

Fig. 2 **Minimum and Maximum Models of Frameless Motors**

Minimum and maximum models of frameless motors are shown.
Applicable models: 1t class counter/reach type, 2t class counter/reach type, 3t class counter/reach type
Application: Traveling and cargo handling

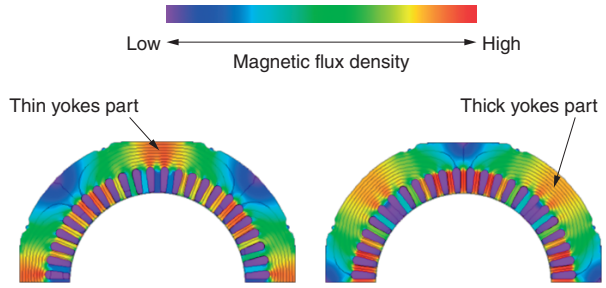


Fig. 3 Result of Stator Magnetic Flux Density Distribution Analysis

Compared with a part of the stator where yokes are thick, the magnetic flux density is high in the part where yokes are thin. We determined the most optimal thickness without causing magnetic saturation.

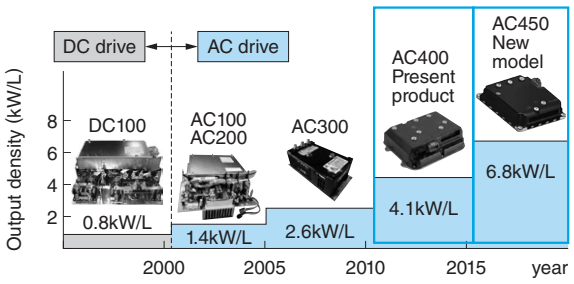


Fig. 4 Transition of Controller Output Density

Transition of improvement of output density is shown for controllers produced formerly.

Fig. 5 AC450S

An image of controller AC450S is shown.

Fig. 6 AC450L

An image of controller AC450L is shown.

For this reason, reduction of the required stator materials is the most important challenge for motor designing.

To find a suitable solution for the aforementioned, we researched the most optimal stator and rotor shapes making full use of electromagnetic field analysis. As a result, high-efficiency motors suitable for application to forklift trucks have been developed. Fig. 3 shows the result of stator magnetic flux density distribution analysis.

3 Controller for Forklift Trucks

Regarding the controller for battery type forklift trucks, high efficiencies and a high level of compact design are essential. Fig. 4 shows the transition of controller output density for the controller for battery type forklift trucks. The initial AC drive available around Y2000 offered an output density of 0.8kW/L. In the case of a recent AC450 machine, the density value has been raised to 6.8kW/L and efficiency has also been improved.

Regarding essential the model configuration of the AC450 Series that has been developed newly, there are two types like the present AC400 Series: Type S for a small capacity (“AC450S” hereafter) and Type L for a large capacity (“AC450L” hereafter). For the respective capacities, battery voltages of 48V system and 72V system are available. Fig. 5 shows an external appearance of the AC450S and Fig. 6 shows that of the AC450L.

3.1 High Efficiency

Since a new type of Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) is adopted, it is possible to reduce the ON-resistance of the power semiconductor. In addition, the switching system has been reviewed to reduce further switching losses. By taking such actions, inverter efficiencies have been improved, from a maximum of 96% for the AC400L to a maximum of 97.5% (calculated value) for the AC450L.

3.2 High Output Density

Due to the adoption of new large-capacity MOSFETs and reduction of losses by reviewing the switching system, we reduced the number of power

semiconductors used. In addition, we also reduced the number of control connectors used by optimizing the number of I/O points in digital I/O and analog input circuits. As a result, areas of the power and control circuit boards were greatly reduced for the AC450 Series, and the controller mounting space was decreased to about 70% compared with the previous model.

3.3 Protection Degree

The protection degree for the AC400 is Level IP54. In consideration of use under more rigorous conditions, however, the protection construction was reviewed. The resin cover and the connector housing are joined into an integral body to eliminate any joint parts. To prevent possible intrusion of water due to hydraulic pressure through a clearance between the resin cover and the base, formerly adopted use of gaskets was modified for hermetic sealing by using an adhesive agent. By taking the above measures, we realized the protection degree of IP65.

4 Postscript

By switching to electric forklift trucks, we expect a reduction of CO_2 emission. As a top supplier of motors and controllers of forklift trucks in Japan, we are promoting the development of products with improved performance characteristics for battery type forklift trucks based on more than half a century of our track record and experience.

Compared with our conventional products, the frameless motors developed for this time and the AC450 Series under development are our latest products that demonstrate a remarkable compact design and high efficiencies. We intend to contribute to the reduction of environmental impact through the supply of these products.