〈**Electrical Appliances**〉

The 4th Generation AC Controller

Forklift truck, Exhaust-gas restriction regulations, PM motor, Dustproof & waterproof, Environmental applications

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Abstract

The forklift truck is a major product in industrial machinery. In the sales in Japan, battery-operated forklift trucks increased its market share due to the needs for fuel cost reduction and lowering carbon footprint.

Over the years, we have been developing and manufacturing various kinds of motor controllers for battery-operated forklift trucks. Recently we newly developed a high efficiency controller that uses a low-loss Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET). The new product is applicable not only to the Induction Motor (IM), but also to the Permanent Magnet synchronous motor (PM motor) as an option. Compared with conventional products, the new product can offer higher IP54 level dustproof and waterproof characteristics. In addition, the use of materials that pose an environmental risk has been reduced in the product. The products comply with the EU's Restriction of Hazardous Substances (RoHS) Directives and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) Regulations. This product is also applicable to other types of motor-operated vehicles such as local yard carriages and parade floats.

1. Preface

Reflecting on the increased emission regulations for general automobiles, they were moved to strengthen the emission regulations in a phased manner on special cars and vehicles like industrial machines classified by the rated outputs according to Japanese laws since 2011. The battery-operated forklift truck, a typical industrial machine, increased market shares in Japan due to its attractive features such as no emission of exhaust gases and low noise level. Fig. 1 shows changes in sales turnover for forklift trucks in Japan. We project that battery type forklift trucks will increase its market share in the future. We have developed and manufactured electrical appliances for industrial vehicles for more than thirty years. Among the products that we offer, motors and controllers for battery type forklift trucks are our leading products. We developed our 4th generation AC controllers (AC400 Series hereafter) featuring improved higher efficiencies with a compact design and ingress protection level higher than our conventional models. This paper introduces the specifications and features below.

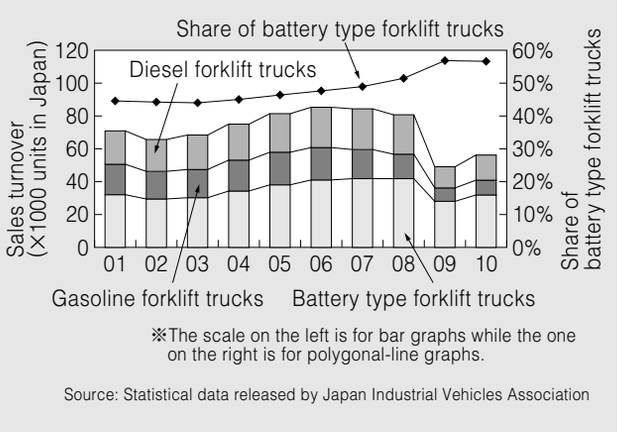

Fig. 1 Changes in Sales Turnover for Forklift Trucks in Japan

The scale on the left is for bar graphs while the one on the right is for polygonal-line graphs. In 2008, the market share of battery-operated vehicles exceeded 50%. This increase is an on-going trend.

2. Product Specifications

For model configuration, there are two types: Type S for small capacities (AC400S) and Type L for large capacities (AC400L), each working at a battery voltage of 48V or 72V. The product lineups come in 4 types which are applicable widely from small to large vehicles. Table 1 shows the product specifications for AC400 Series and Table 2 shows the control specifications. Figs. 2 and 3 show the external appearances of AC400S and AS400L, respectively. Figs. 4 and 5 show the major dimensions of each model.

3. Features

3.1 Metal-Based Main-Circuit Module

A newly developed main-circuit module has been adopted. It is a low-loss Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) mounted on a Metal Core Printed Circuit Board (MCPCB). The metal core consists of aluminum alloy. By simplifying vehicle cooling construction through the improved inverter efficiencies

Table 1 Product Specifications for AC400 Series

Features of the product specifications are that substances of environmental loads are reduced and the product conforms to the requirements of the Restriction of Hazardous Substances (RoHS) Directives and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) Regulations.

Type	AC400S		AC400L	
Nominal battery voltage (V)	48 (36)	72/80	48 (36)	72/80
Max. current (Arms) [3-minute rating, base temperature 80℃ Max.]	330	250	500	370
Dimensions/mass (terminal bolts excluded)	W132.0×H80.3×D250.0mm/2.4kg		W292.0×H80.3×D228.5mm/3.8kg	
Applicable motor/motor frequency	IM, PM/0～250Hz			
Control mode	Speed, torque control			
Working environmental temperature/ storage temperature	−20～+40℃ (starting possible at −40℃)/−40～+85℃			
Protective construction	IP54			
Cooling system	Heat dissipation to vehicle counterweight/Forced-air-cooled (Optional: heat sink, fan)			
Installation place	Inside the vehicle cabin (There should not be any uneven surface in the installation place. Apply heat-radiant grease.)			
Communication	CAN-BUS, RS-232-C			
Applicable standards	UL583 (Not a controller unit only, but a vehicle equipped with a controller conforming to the Standard), EN1175-1			

Table 2 Control Specifications for AC400 Series

Features of the control specifications are that the product is also applicable to PM motors. System efficiencies can be raised.

Motor control	Applicable to IM/PM motors (vector control) Regenerative braking (acceleration-OFF regeneration, brake-pedal regeneration, directional regeneration) Inching control (reduction of torque by simultaneous operation of accelerator and brake) Ascending and descending restrictive control Operation possible with oil-hydraulic power-steering signal inputs for oil-hydraulic motor control (pulse, analog)
Control functions	System-building is possible without using the master controller (vehicle integrated controller). (Acceleration signals and others are directly acceptable and operation is possible.) We could offer battery drain measuring function (BDI control) (with track records) Magnetic brake coil driving output
Safety protection functions	Independent operation possible in the case of CAN line error (only in case it is deemed safe) Operation for temperature sensing and protection (reduced output) (motor, controller main circuit) Operation for output reduction in the case of battery voltage is lowered. Protective pitching control in the case of a sudden change in operation as a result of a broken motor rpm sensor (vehicle vibration restrictive control during running) Various self-diagnostic protective operation and error message data communication (CAN communication)
Communi-cation functions	Adjustment of parameters (relating to vehicle operating comfort) possible with the use of CAN line Internal program rewriting possible with the use of CAN line

Fig. 2 AC400S

An external appearance of Type S for a small current capacity is shown. The overall body is covered with a resin casing that greatly improves dustproof and waterproof performance.

Fig. 3 AC400L

An external appearance of Type L for a large current capacity is shown. The overall body is covered with a resin casing that greatly improves dustproof and waterproof performance.

and the adoption of thin shape MCPCB, we succeeded in 86% reduction of controller size compared with conventional versions. This compactness contributes to space saving in installation.

3.2 Applicable Motors

Responding to the recent trends of going AC, it has been over ten years since we designed AC controllers for forklifts to work with Permanent Magnet synchronous motors (PM motors) on top of Induction Motors (IMs) application. PM motors offer higher efficiencies than IMs. It is consistent with recent trends such as an increase of battery-operated vehicles and the requirement of higher output. The PM motor drive

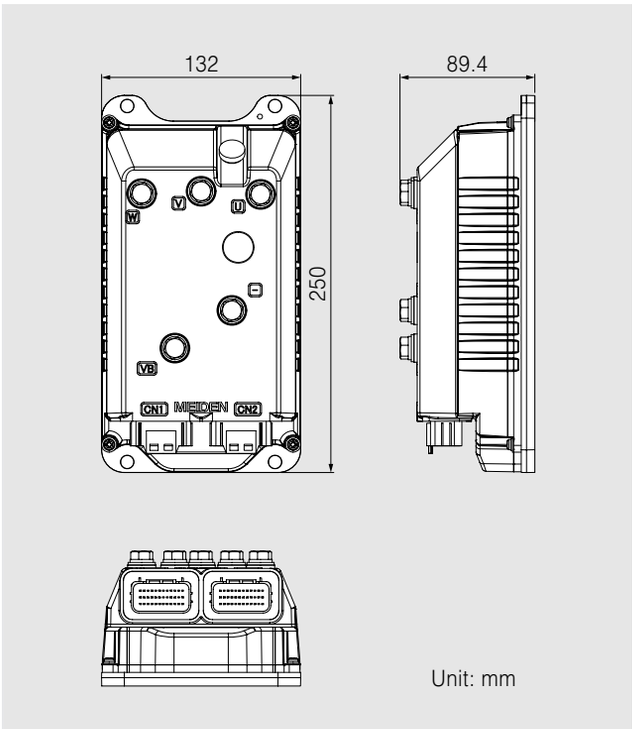

Fig. 4 Major Dimensions of AC400S

Major dimensions of Type S for a small current capacity are shown. Compared with conventional products, both volume and mass have been reduced to 86%, substantially emphasizing compactness and lightweight.

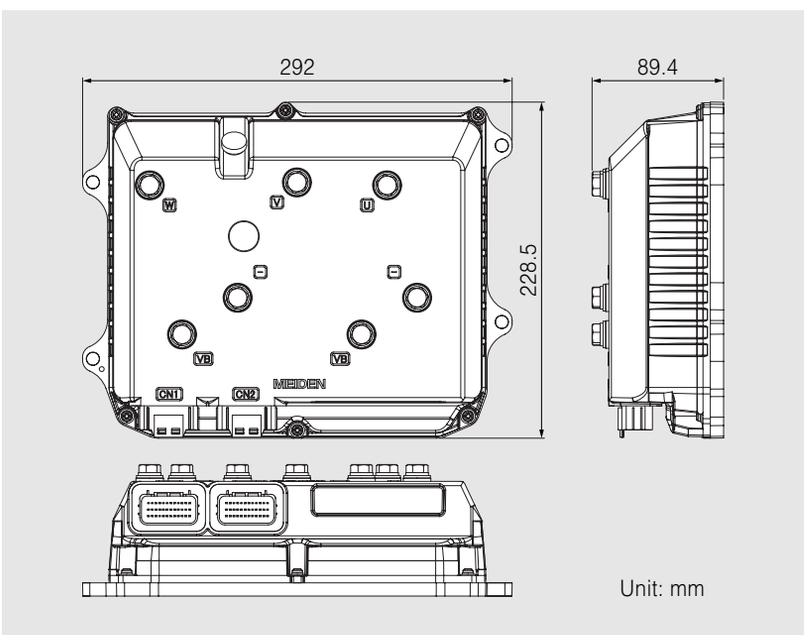

Fig. 5 Major Dimensions of AC400L

Major dimensions of Type L for a large current capacity are shown. Compared with conventional products, the volume has been reduced to 78%, while the mass has been reduced to 68%.

can improve system efficiencies.

3.3 Ingress Protection Construction

Our recently developed metal-based main-circuit modules have excellent heat transmission to the mounting plane and the heat dissipation around the module mounting surfaces is minimal. Since the temperature inside the controller does not rise, we adopted a hermetically sealed construction. To improve reliability, we adopted waterproof connectors and a hermetically sealed construction was adopted for the protective cover. As a result, both dustproof and waterproof characteristics were greatly improved and we could produce the IP54 level stipulated by the JIS C0920 Standard. Consequently, it is unnecessary to take any ingress protection against dust and water around the mounting spaces in the vehicle.

3.4 Material Use

(1) Compliance with the RoHS Directives

The AC400 Series does not contain any of the six specific hazardous substances such as lead, cadmium, mercury, hexavalent chromium, etc. The AC400 Series complies with the RoHS Directives of the EU environmental restrictions.

(2) Compliance with the REACH Regulations

We keep safety data after communicating with the suppliers on chemical substances contained in the product based on the Japan Automobile Manufacturers Association, Inc. (JAMA) safety data sheet. We built a system to provide the chemical substances data sheets in line with the EU's REACH Regulations.

3.5 Safety Standard

The AC400 Series Complies with the U.S. Standards UL583 and EN1175-1 on the safety of battery-powered industrial vehicles.

3.6 Control Performance

Compatible with digital inputs, analog inputs, and pulse inputs, this product can be applied to both driving and oil-hydraulic control application and smooth motor drive control is possible by the adoption of vector control. In addition, it can offer safe and comfortable operation by using useful functions such as inching control and backward movement restriction control on a road with a slope.

3.7 Communication Functions

Internal information of the individual controllers can be shared by Controller Area Network (CAN) communication. Therefore, a system in combination of multiple controllers can be easily set up. By using CAN communication, it is possible to rewrite the controller's internal programs from a personal computer; this improves maintainability.

3.8 Self-Diagnostic Functions

Self-diagnostic functions are available to detect any source voltage error, acceleration signal open/short conditions, overheating, main-circuit open/short conditions, and vehicle speed sensor disconnection, etc. The result of self-diagnosis can be displayed on on-board LEDs without using any specific diagnostic tools.

In addition, data transmission is possible by using the communication functions mentioned above.

3.9 Customization

By increasing the number of controllers with higher capacities, items of the AC400 Series may be adequately combined and the required contactors, fuses, and other components can be installed. They are then connected through copper bars to set up a controller assembly (ASSY); this controller ASSY is now available. In consideration of the installation space of a heat sink and a cooling fan, we can make a custom design. It is also possible to design a controller ASSY according to the customer's requirements such as vehicle operation comfort, operability, and control of auxiliary devices (turning signals, buzzer, etc.).

4. Postscript

Going forward, we will try to develop models with larger capacities so that we apply them to not only forklift trucks, but also a wide range of applications. We will make every effort to increase motor-powered vehicles so that we can further reduce CO_2 carbon footprint.