General-Purpose Inverter FRENIC5000G9S/P9S

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1. Introduction

General-purpose inverters have expanded their application in the variable speed control field beginning with use for fans, pumps, etc. in order to save energy. In 1990 Fuji Electric began marketing general-purpose inverters, the FVR-G7S using 32-bit DSP (Digital Signal Processor) and the FRENIC5000G7, which uses a torque calculation function. For the last several years, the trend in general-purpose inverter application has been toward higher starting torque, lower rotation ripple, lower noise and facilitated operation. This paper outlines Fuji Electric's newly developed and marketed general-purpose inverter FRENIC5000G9S/P9S, utilizing state-of-the-art technology including torque vector control and automatic tuning, to meet market trends.

2. Main Features and Specifications

To satisfy various market requirements, the new general-purpose inverter FRENIC5000G9S/P9S has been developed as "friendly, smart and powerful," integrating the former FVR-G7S and FRENIC5000G7. Figure 1 shows the product series, and Table 1 shows the specifications. Its main features are described below.

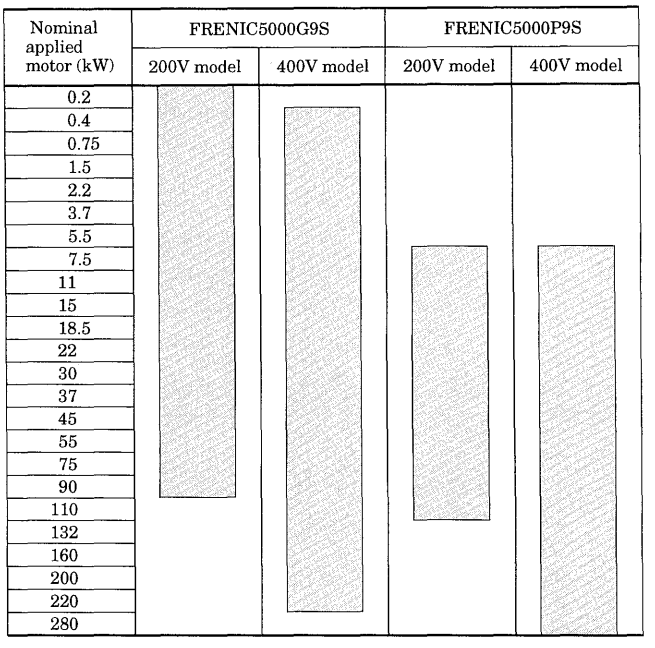
(1) Wide product range

As shown in Fig. 1, there is a broad range of products. For the FRENIC5000G9S, 200V models are available from 0.2 to 90kW; for the 400V series, 0.4 to 220kW. For the FRENIC5000P9S, 200V models are available from 7.5 to 110kW; and for the 400V series, 0.4 to 220kW. Selection of an inverter for a specific use is now possible.

(2) Powerful features

To meet the demand for higher starting torque at low speeds, Fuji Electric has achieved more than 150% of rated torque at low speeds through the newly developed torque vector control. The FRENIC5000G9S/P9S can suitably control its output voltage depending on load, allowing for high torque output without overexcitation at light loads. Overload capacity of the FRENIC5000G9S is 200%–0.5s (below 22kW) and 180%–0.5s (above 30kW), in addition to the 150%–1min overall specification.

Fig.1 FRENIC5000G9S/P9S product series



(3) Facilitated operation

Without having to use a manual, operation is facilitated by an ineteractive keypad panel with a large LCD screen, light keypads, and various useful functions. Either Japanese or English can be used on the keypad panel, thus taking the international market into consideration.

(4) Ultra-low noise

Ultra-low noise has been realized by applying the higher carrier frequency PWM system to the entire line of IGBT products. In addition, the adoption of Fuji Electric's own current waveform improvement method has substantially reduced rotation ripple with higher carrier frequency PWM.

3. Circuit Configuration and Structure

Figure 2 shows the circuit configuration of the 30kW FRENIC5000G9S. The main features are described below, although there are some differences in

configuration depending on inverter capacity.

3.1 Control circuit

(1) The CPU has a function suitable for inverter control, and a built-in DSP function. Its functions and performance have been greatly improved by the adoption of an optimally-designed ASIC for inverters.

(2) Reduction of torque ripple at low speeds has been realized by digitizing the former sinusoidal PWM with flux control for models of more than 30kW, and adopting a current waveform improvement method for ones less than 22kW.

(3) Models of more than 30kW are provided with the following to meet application requirements inherent in large-capacity machines: an auxiliary control circuit power source terminal, a frequency setting input terminal (optional for those less than 22kW), and a power source contactor opening command output terminal.

3.2 Main circuit

To realize ultra low noise, the third generation IGBT has been adopted as the main circuit device because of its high-speed switching capability and reduced loss as compared with the previous generation. Its technical features are described below.

(1) In models handling less than 22kW, a remarkable size reduction (60% maximum) has been achieved by the reduction of dissipated power and an improvement in cooling efficiency.

(2) In models handling from 0.2kW to 0.75kW, an exclusive main circuit module that incorporates a converter, inverter, DB (dynamic brake) transistor, etc. has been developed to reduce size.

(3) The input power factor has been greatly improved by inserting a DC reactor in the DC intermediate circuit. All models have the terminals for the DC reactor connection, and models of more than 75kW are normally provided with DC reactors.

(4) The IGBT enables high-speed switching but raises the problem of a higher initial reverse voltage ($\Delta V = L\, di/dt$). To suppress an initial reverse voltage in large-capacity machines, an exclusive small-sized snubber module with a short wiring length was developed, because the inductance of snubber circuit wiring could not be neglected. In addition, an attached di/dt limiting circuit moderates the influence of the difference in switching speed upon an initial reverse voltage.

Table 1 Specifications of FRENIC5000G9S/P9S

Item \ Classification			FRENIC5000G9S		FRENIC5000P9S	
Output	Capacity	200V series	0.57 to 33 kVA	44 to 132 kVA	11 to 29 kVA	44 to 158 kVA
		400V series	1.1 to 34 kVA	46 to 316 kVA	12.5 to 33.5 kVA	46 to 400 kVA
	Voltage	200V series	Three-phase, 200V/50Hz, 200V, 220V, 230V/60Hz			
		400V series	Three-phase, 380V, 400V/50Hz, 380V, 400V, 440V, 460V/60Hz			
	Rated output frequency		50Hz, 60Hz			
	Overload capacity		150%–1min		120%–1min	
			200%–0.5s	180%–0.5s		
Input	Rated voltage/ frequency	200V series three-phase	200 to 230V 50/60Hz	200 to 210V/50Hz 220 to 230V/50Hz 200 to 230V/60Hz	200 to 230V 50/60Hz	200 to 210V/50Hz 220 to 230V/50Hz 200 to 230V/60Hz
		400V series three-phase	380 to 480V 50/60Hz	380 to 420V/50Hz 380 to 480V/60Hz	380 to 480V 50/60Hz	380 to 420V/50Hz 380 to 480V/60Hz
	Variation		Voltage : +10 to –15%, Frequency: +5 to –5%			
Control	Control method		Sinusoidal PWM control (Torque vector control)			
	Carrier frequency		2 to 15kHz (depending on inverter capacity)			
	Output frequency range		0.2 to 400Hz			
	Output frequency accuracy		Analog setting: ±0.2% of maximum frequency (25 ±10℃) Digital setting: ±0.01% of maximum frequency (–10 to +50℃)			
	Frequency setting resolution		Analog setting: 1/3,000 of maximum frequency Digital setting: 0.01Hz (less than 99.99Hz) 0.1Hz (110Hz and higher)			
	Torque boost		Automatic torque boost, Manual torque boost			
	Starting torque		More than 150% (torque vector)		More than 50% (torque vector)	
	Braking torque		more than 100% (7.5kW and less) more than 20% (22kW and less) 10 to 15% (30kW and more)		more than 20% (22kW and less) 10 to 15% (30kW and more)	
Enclosure			IP40	IP00	IP40	IP00
Cooling method			Natural cooling (0.75kW and less) Forced cooling (1.5kW and more)		Forced cooling	

4. Control Method

To meet the market demands for higher torque at low speeds, Fuji Electric has developed the "torque vector control" aimed at substantially improving the torque characteristics. Also, slip compensation control has suppressed fluctuations in rotation speed as well as remarkably improving response to load fluctuations. The control method applied to the FRENIC5000G9S/

Fig. 2 Basic circuit configuration

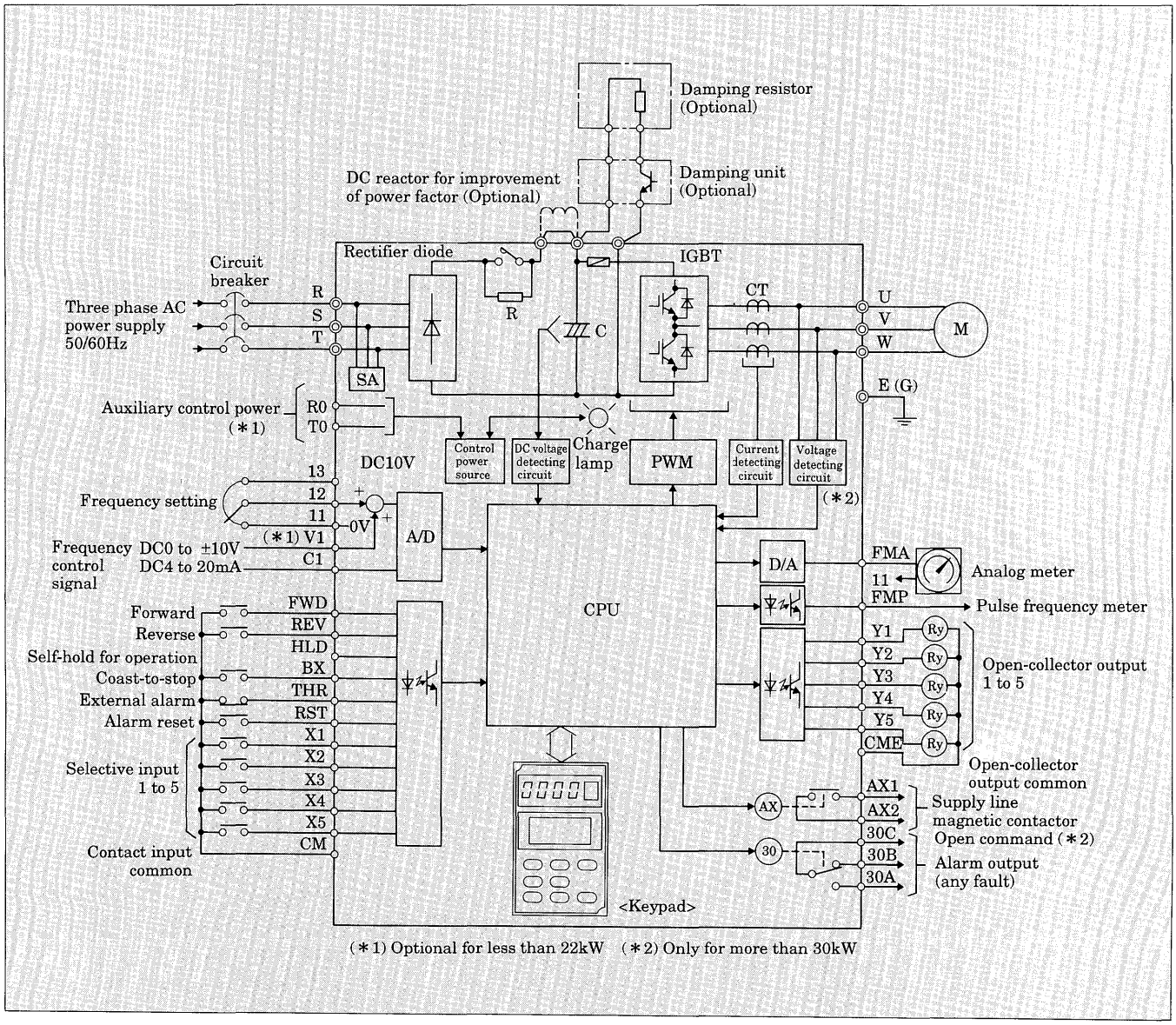
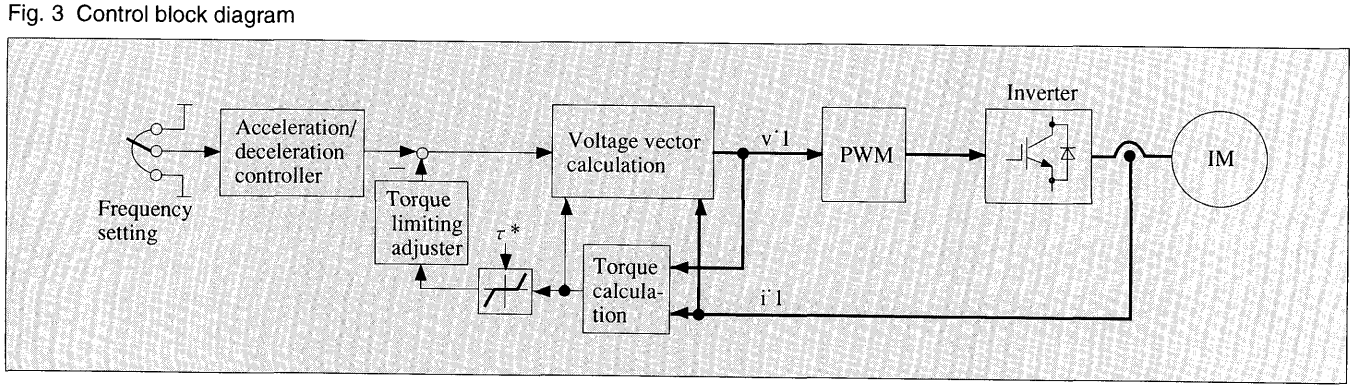


Fig. 3 Control block diagram



P9S is introduced below, together with its operation characteristics.

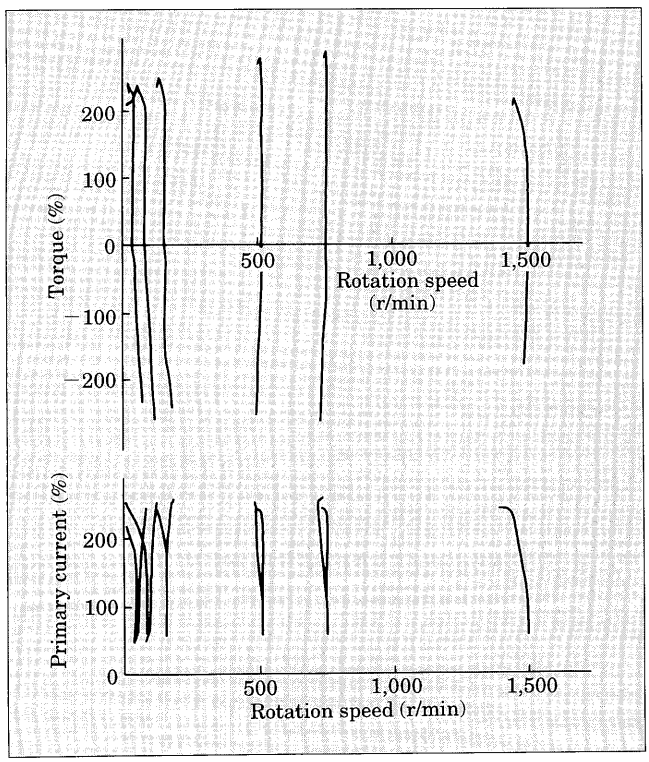
4.1 Torque vector control

Improvement of torque characteristics in the previous V/f control was made by changing only the amplitude of the motor terminal voltage. However, separation of the primary current into a flux and a torque component was difficult, and satisfactory torque characteristics could not be obtained using this method.

Fuji Electric has developed its own "torque vector control" method to improve the torque characteristics. This was achieved by applying the concept of the vector control method, also known as a high performance control method for induction motors, to control systems for general-purpose inverters. This new torque control method regulates a voltage vector to produce a suitable current vector based on the generated torque. This is precisely calculated from the motor current and voltage, using motor constants (primary resistance, etc.). Figure 3 shows the block diagram of this new method, and its features are described below.

(1) Improvement of starting characteristics-the starting torque was increased to 150% of rated torque
(2) Realization of an automatic torque boost over the entire control frequency range depending on load
(3) Stability enhancement of rotation at sudden load changes
(4) Suppression of rotation fluctuations without the use of a speed sensor (improvement of the slip compensation characteristic)
(5) Remarkable improvement in torque response time, approximately 1/10 of the previous model

Fig. 4 Speed-torque characteristics



4.2 Automatic torque boost

Formerly in V/f control systems, a torque boost was used to compensate for the torque deficit at low speeds (starting torque deficit) caused by the motor's primary resistance, etc. There was a problem, however, of overexcitation at light loads if the torque boost value was used to achieve sufficient torque. With the present control method, overexcitation has been suppressed at low speeds, and initial torque of more than 150% of rated torque was obtained by adjusting the output voltage. The output voltage adjustment is based on the torque value computed from the output voltage and the output current. Figure 4 shows the speed-torque characteristics, speed-primary current characteristics.

4.3 Slip compensation control and other characteristics

Speed characteristics related to load fluctuations have been greatly improved by slip compensation control based on the computed torque values. Figure 5 shows the static characteristics of the slip compensation control, and Figure 6 shows its dynamic characteristics. From these figures we find that the speed fluctuation at 100% load is less than 1%, and the speed regulation with a 100% change in load is minimal and recovers in a short period of time. These characteristics are suitable for operating equipment in such places as

Fig. 5 Slip compensation characteristics

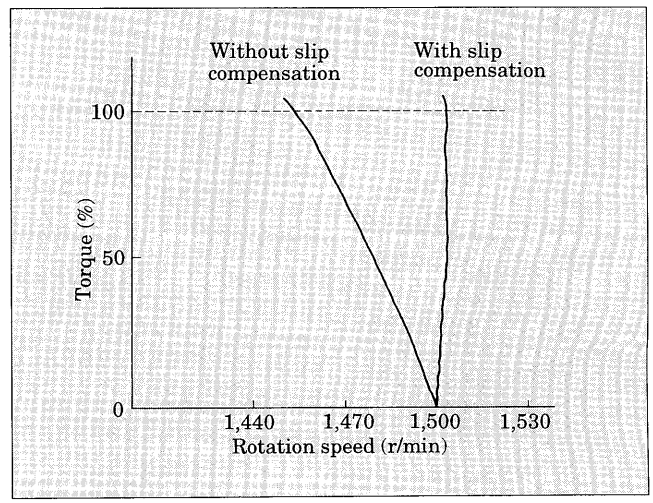


Fig. 6 Dynamic characteristics at slip compensation

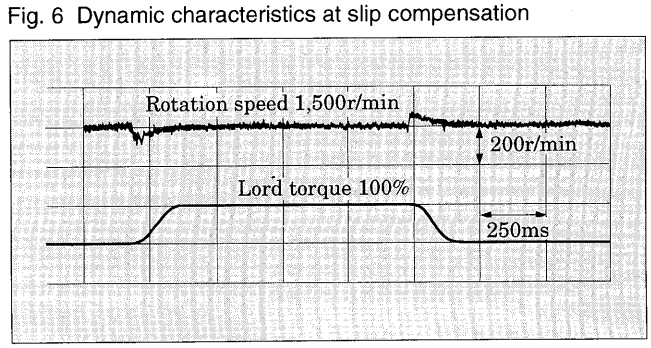
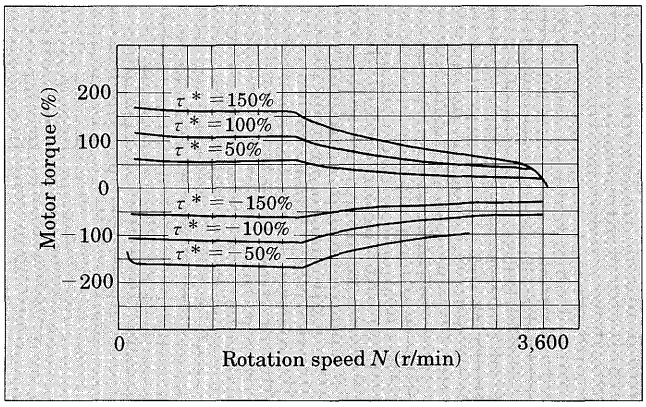


Fig. 7 Torque limiting characteristics



multi-storied parking garages, where the load fluctuates greatly but speed stability is required.

This new product series comes with a torque limiting function which limits the generated torque based on computed torque values. Figure 7 shows the torque limiting characteristics.

4.4 Automatic tuning

FRENIC5000G9S has the motor constants of Fuji's general-purpose motors as the factory setting values. Since general-purpose inverters are applied to many types of motors, an automatic tuning function is normally provided to recognize the motor constants essential for torque vector control. A feature of this system allows for tuning without rotating the motor. During automatic tuning, the breaking of a wire can also be detected. Automatic tuning provides satisfactory operation of torque vector control.

5. Keypad Panel

Figure 8 shows the external view of the keypad panel. Its design is based on the concept of user-friendliness and facilitated operation.

5.1 Features

The main features of the keypad are described below.

(1) LCD monitor

A large LCD is adopted for the monitor, and more information can be displayed by increasing the number of characters displayed on the screen. As a result, an operation guide can be displayed on a representative screen. Units, setting range, present and altered values of a function, operation comments, etc. can all be displayed on a function setting screen so that operation can be done without a manual. In addition, ease of operation was enhanced by the introduction of a scrolling function on the selection screen.

(2) Simple key operation

Key operation is simple because the number of keys has been reduced to 8, and key operation differs little from the existing FVR series.

Fig. 8 Keypad panel

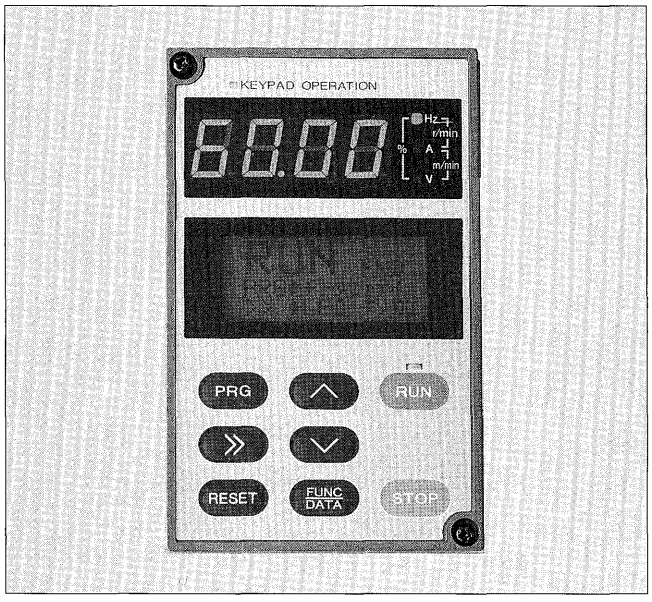


Fig. 9 Japanese/English display

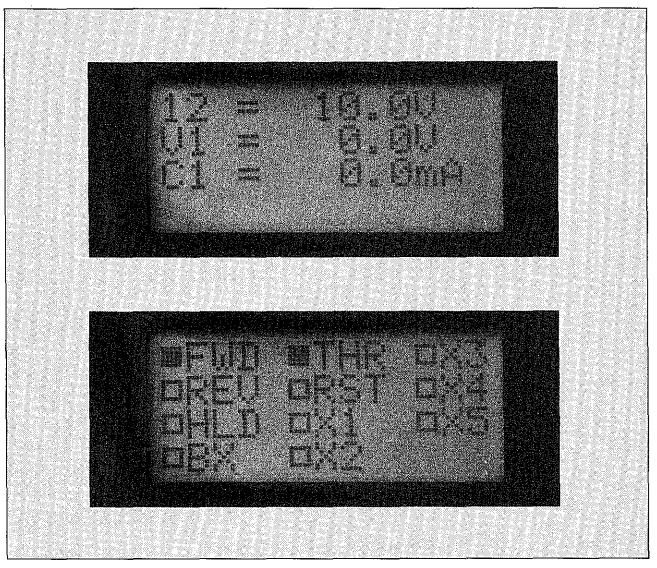
(3) LED display

The LED display consists of an LED monitor with 7 segments of 4 figures, a unit display LED, an operation mode display LED and a RUN display LED. The LED monitor can display 9 types of information including set frequency, output frequency, output current and voltage, line speed, and computed torque value. In addition, the operator can check and judge operating conditions with a single glance by using the operation mode and RUN displays.

(4) Facilitated function selection

Although the number of functions has increased to 95, only the 30 most frequently used functions are usually displayed. Therefore, a simple application requires partial alteration to only one of the 30 functions. A special application requires setting specific functions, which are displayed. Thus, the conflict between simple

Fig. 10 Display example of keypad panel (I/O check mode)



operation and multiple functions was resolved.

(5) Language

The system displays in either Japanese or English (Fig. 9). German, French, Spanish or Italian are also available as option.

5.2 Useful functions

(1) Data confirmation

Data can be confirmed by displaying only the function's number and data, not the function name.

(2) I/O check (tester function)

The operator can easily check for faults such as an improper connection at the input terminal or wire breakage, since the keypad panel is equipped with a function to display the presence of a digital control input/output signal and a tester function to display the magnitudes of such analogue signals as frequency settings and meter outputs. Furthermore, cumulative operating time can be confirmed, which is helpful in maintenance and history management of the system (Fig. 10).

(3) Fault analysis

Even after resetting after a fault, the fault information can be investigated as long as the power source is kept alive. Included in the fault analysis are various data such as output frequency and current at the time of the fault, operating conditions, conditions at input/output terminals and past analysis history.

(4) Fault factor

Possible factor of every fault are displayed on the keypad as a troubleshooting aide, improving analysis at the time of a fault and fault confirmation, described above.

6. International Markets

The inverter market is expanding worldwide to include Asia, America and Europe. To meet this trend, the FRENIC5000G9S/P9S has the following features:

(1) The approval of UL /CSA

Fuji Electric has acquired the approval of UL /CSA for the series as a whole.

(2) Multiple languages of keypad

Any of four languages can be displayed.

(3) Overseas power supply

The 400V series can meet 380-480V.

(4) Control interface for European units

An input voltage control interface is provided for European units.

7. Conclusion

An outline of the newly marketed, general-purpose inverter FRENIC5000G9S/P9S has been introduced in this paper. It is clear that demands for improved performance and functionality will hereafter increase, and we are determined to do our very best to develop and commercialize general-purpose inverters capable of meeting these market demands.