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FRENIC 5000 SERIES POWER TRANSISTOR PWM TYPE VVVF INVERTER

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I. FOREWORD

With the development of a cheap transistor inverter, efficient, stepless variable speed operation of cheap and robust induction motors, which has long been a dream of variable speed equipment manufacturers and users, has become a reality. Since Fuji Electric developed its first transistor inverter variable speed drive equipment in 1977, we have broadened our capacity series and increased the type family to offer the best inverter for the load. In the initial stage, we started with the FRENIC 5000 G corresponding to a constant torque for applicability to all kinds of loads. For energy-saving operation for fans, pumps, and other square reduction torque loads, the FVR P Series and FRENIC 5000P Series, in which the functions were limited to a certain extent and higher cost/performance was pursued, were serialized. The FRENIC 5000 G Series was switched to sine-wave PWM and the low capacity range was separated as the FVR-G Series. Furthermore, for loads which require quick acceleration/deceleration performance, positioning control performance and other DC Leonard level control performances, the FRENIC 5000 V Series which uses TRANSVEKTOR control which controls the motor torque was serialized. In this way, an organization which can meet all demands from simple functions to complex functions was established.

Application to 400V circuits is one capacity extension. Regarding the FRENIC 5000 G and FRENIC 5000 P Series, serialization up to 120 kVA and 140 kVA, respectively, has been completed. Widening of the types applicable to 400 V and of the capacity is planned for the future.

II. INDUCTION MOTOR DRIVE BY VOLTAGE TYPE INVERTER

1. Volt/hertz ratio constant control

The following relationship is established at the speed N of an induction motor which is driven by an inverter and the flux ϕ generated in the induction motor at that time.

$$N = \frac{120}{P} f \times (1-s)\,(\text{rpm}) \quad \ldots\ldots (1)$$

$$\phi \fallingdotseq \frac{1}{f} \times v\,(\text{T}) \quad \ldots\ldots (2)$$

Where P: Number of poles
s: Slip
f: Impressed frequency (Hz)
v: Impressed voltage (V)

from Eqs. (1) and (2), by proportioning and changing the voltage type inverter output voltage (v) and output frequency (f), the speed (N) can be continuously changed while keeping the flux (ϕ) of the induction motor constant. This control method is also called V/F constant control and features comparatively simple control, the speed of the induction motor can be efficently varied, existing induction motors can be variable-speed operated without any changes, etc.

In the PWM type FRENIC 5000 Series, all models, except the FRENIC 5000 V, use this control system and microcomputer technology and PWM control technology have been introduced and control performance improved and size and weight reduced, etc. so that it is easier to use.

Fig. 1 shows the voltage and current waveforms of an induction motor which is driven by a sine wave modulation voltage type PWM inverter which performs volt/hertz ratio constant control.

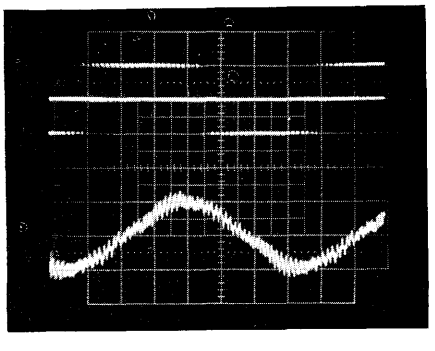


Fig. 1 Waveform of motor voltage and current

From the figure it can be seen that the motor current is near a sine wave and the lower harmonics are small. The motor efficiency is improved, the torque pulsations are reduced, and low noise is obtained by means of this.

2. TRANSVEKTOR control and its application

In the past, slip frequency control was widely used to control the generation torque of an induction motor. This method used the directly proportional relationship between the induction motor generation torque and the slip frequency in the range at which the slip frequency is low. However, since this relationship is established only in the steady state, in slip frequency control, good control of the transient generation torque of the induction motor was difficult.

TRANSVEKTOR control is proposed as a new control method to replace slip frequency control.

In TRANSVEKTOR control, the primary current (i_1) of the motor is separated into two components—a component (i_M) of the same direction as the flux (ϕ_2) and perpendicular direction component (i_T)—and the generation torque and flux of the motor are controlled independently by adjusting the current of each. By means of this, good control of the generation torque of an induction motor is regularly possible, of course, even in the transient state.

At Fuji Electric, the development of TRANSVEKTOR control was started early and many AC variable speed controller which performed TRANSVEKTOR control, including rolling mills which require high performance operation have been practicalized up to now.

In the FRENIC 5000V, TRANSVEKTOR controll which uses this experience and results is utilized and control performance equal to or better than that of DC machines can be obtained.

The circuit composition of the FRENIC 5000 V which uses TRANSVEKTOR control is shown in *Fig. 2*.

Small size was planned by using many LSI and MSI in the control circuit and from the speed commnads and position deviation signals to the primary current command is constructed with one CPU.

Concerning the operation excecution time, control performance, etc. which are actual problems when using a microcomputer, engineering studies covering control technology, inverter technology, microcomputer technology, and many other branches are conducted and the problems are solved by (1) software and hardware optimum load sharing, (2) suitable bit resolution and arithmetic execution time selection, (3) high-speed operation processing of the current command operation part by priority processing, (4) use of a high-speed CPU, (5) improvement of ROM table read technology for nonlinear functions, etc.

By means of this, accurate vector operation, high precision operation, etc. can be easily realized and, together with the fact that adjustment is unnecessary, high stability operation of a higher reliability is possible.

Moreover, at the current control section which is especially important in transvector control, Fuji Electric's unique instantaneous current control system is used.

The current command waveforms and the actual input current waveforms of the motor at starting and near the base speed are shown in *Fig. 3*.

The motor current follows the command value well and a low-distortion almost ideal pseudo sine wave current is continuously supplied to the motor.

By means of this, stable rotation from very low speed to high speed can be obtained, and a considerable reduction in motor torque ripple and magnetic noise and an improvement in motor efficiency are realized.

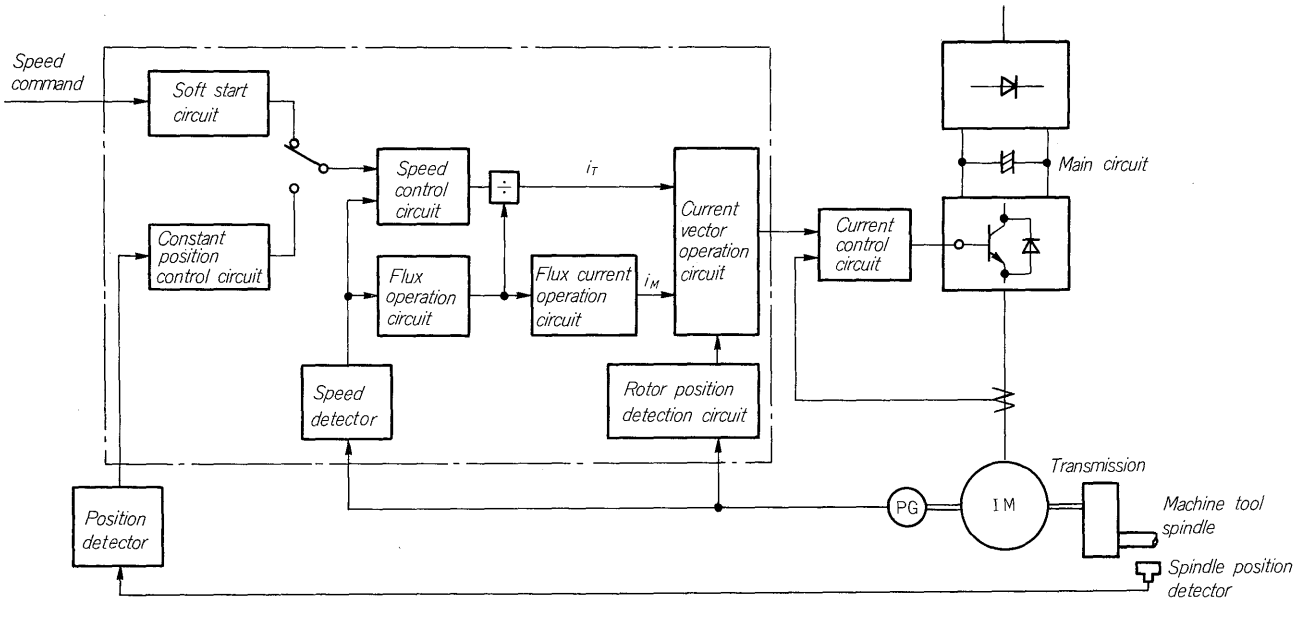
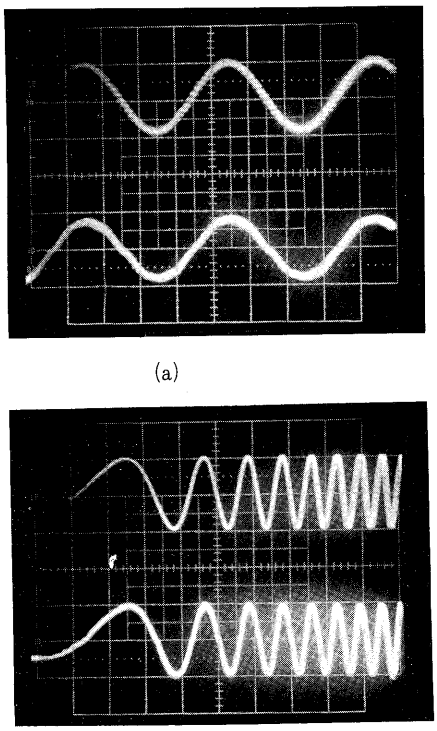


Fig. 2 Circuit composition of FRENIC 5000 V



(a)

(b)

Fig. 3 Motor current waveforms

III. OVERVIEW OF VVVF INVERTER FRENIC 5000 SERIES

1. Features

The FRENIC 5000 Series transistor inverter has the following features:

1) Abundant models and capacities.
Since the degree of model selection and capacity selection freedom is large, a VVVF inverter having the best functions and capacity for the load can be economically selected. Besides, in small plants, configuration with a common transistor inverter which handles most of the variable speed devices is possible.
2) Complete protection functions.
Since the special features of the power transistor are fully utilized and high speed detection and high speed tripping against various abnormalities are used as a basic protection system, positive protection is possible.
3) High reliability
Because the number of parts has been reduced by using compounded insulated modules as the main circuit elements and using a microprocessor, highly integrated module elements, etc. as the control circuit, reliability es extremely high.
4) High efficiency.
Needless to say here, regarding conversion to high efficiency by variable frequency operation, high efficiency operation is reached by reducing the power transistor switching loss, reducing the motor loss by waveform improvement, etc.

2. Introduction to Series

1) FRENIC 5000FVR-P

This series is a functional and small version of the FVR-F series previously commercialized by Fuji Electric.

The FVR-P series was mainly devloped for fans, pumps, and other square reduction torque loads at motor outputs of 7.5 kW or less, and has the following features:

(1) Can be easily used without the need for complex relay sequences and magnetic contactors.
(2) The V/F ratio is variable and the V/F ratio is weakened to the load characteristic and makes the motor quieter.
(3) The equipment was made smaller by using module transistors by Fuji Electric semiconductor technology and by integrating the control circuit.

2) FRENIC 5000FVR-G

The FVR-G Series are sine wave modulated inverters developed for constant torque loads. Three types of 1.5 kVA, 3 kVA, and 5 kVA have been serialized. This series has the features described below.

(1) Small size obtained by concentrating the following functions which conventionally consist of individual ICs in a microcomputer by using a small, high performance dedicated inverter custom microcomputer by microcomputer control and, at the same time, high performance was achieved by high precision operation inside the microcomputer.
   ① Sine wave PWM pulse generation function.
   ② Softstart function (0.35 – 100 secs)
   ③ Fault protection, suppression function (stall prevention, overvoltage suppression, etc.)
   ④ Forward/reverse operation switching function
   ⑤ AVR function
   ⑥ V/F pattern setting function (9 kinds)
(2) Wide variable speed range and low pulsating torque by sine wave modulation.

Because the output waveform of the FVR-G is sine wave PWM, the motor torque ripple is small even in the low speed range and it can be used in almost all applications spanning a wide range from high speed to low speed.

(3) Quick stopping is possible by built-in braking resistor.
Since a braking resistor is installed internally, a braking

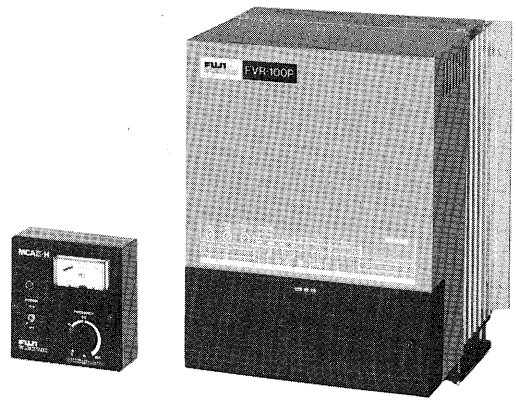


Fig. 4 FRENIC 500 FVR-P

Table 1 Specifications of FVR-P

Applicable motor output (kW)		0.4	0.75	1.5	2.2	3.7	5.5	7.5
Inverter model		FVR-015P		FVR-030P		FVR-050P	FVR-057P	FVR-100P
Inverter capacity (kVA)		1.5		3		5	7.5	10
Inverter rated current (A)		4.5		9		15	23	30
Power requirement	Voltage, frequency	3-phase, 200/220 V, 50/60 Hz						
	Allowable variation	Voltage ±10 %, frequency ±5 %						
Output	Maximum voltage, frequency	50 Hz, 200 V and 60 Hz, 200 V switching						
	Control range	17 ~ 50 Hz and 20 ~ 60 Hz switching (Maximum frequency is adjustable up to +5 %).						
	Control precision	±0.5 % of maximum frequency (at 25°C ± 10°C)						
Control system	Applicable load	Square reduction torque load						
	Control system	PWM system						
	Voltage/frequency ratio (V/F)	V/F constant and V/F weak switching						
Overcurrent strength		120 % of rated current for 1 min.						
Operating system		One direction operation						
Soft start/stop function		1 ~ 6 secs and 6 ~ 60 secs switching						
Protection functions	Stall prevention	Control by overcurrent suppression and overvoltage suppression functions so motor does not stall.						
	Inverter stop	Undervoltage protection, inverter overload protection (including when overcurrent limited operation continues), overvoltage protection.						
	Momentary power interruption protection	If there is an operation command after recovery from a power interruption, operation continues.						
	Alarm lamps	Capacitor charge voltage present (LD 1), inverter overload and overvoltage (LD 2), no operation command lamp display (LD 3) Make contact of relay x 1 (250 V, 7.5 A), on at inverter overload and overvoltage protection operation.						

Table 2 Specifications of FVR-G

Inverter model		FVR-015G (FVR-015GS)		FVR-030G (FVR-030GS)		FVR-050G (FVR-050GS)	
Applicable motor output (kW)		0.4	0.75	1.5	2.2	3.7	
Inverter capacity (kVA)		1.5		3		5	
Inverter rated current (A)		4.5		9		15	
Input	Voltage and frequency	3-phase 50/60 Hz, 200/200 · 220 V					
	Allowable variation	Voltage: 180~242 V, frequency: ±3 Hz					
Output	Voltage	3-phase 200/220 V (at 200 V input voltage)					
	Frequency	50, 60, 100, 120 Hz switching					
Control system		Sine wave PWM					
Variable frequency range		1 : 40 (3 ~ 120 Hz)					
Frequency precision		±0.5 % of maximum frequency					
Voltage/frequency ratio		V/F constant and V/F strong, weak					
Overcurrent strength		150% of rated current for 1 min.					
Soft start/stop		Approx. 0.35 ~ 100 secs adjustable, acceleration time and deceleration time independent setting					
Braking		Braking circuit built-in, brake torque 40 ~ 100 % (brake torque up possible as an option)					
Operating system		Forward/reverse operation possible by 1c contacts.					
Protection functions	Stall prevention	Such that motor does not stall at overcurrent and overvoltage suppression.					
	Inverter stopping	Inverter is stopped (individual LED display) and a signal is output by contacts by overcurrent, overvoltage, overload, cooling fan overheating, motor overload, and braking resistor overheating.					
	Momentary power interruption	Stopped by power interruption. If there is an operation command after the power recovers, operation continued.					
	Others	Setting signal present LED display, external fault LED display.					

torque of approximately 30% (5 kVA)–100% (1.5 kVA) can be obtained and quick stopping is possible. Furthermore, an external installation braking resistor is available for when a large braking torque is necessary.

(4) High reliability obtained by advanced protection functions

The protection functions have been made more advanced and reliable by building in the protection functions

shown below so that the FVR-G operates safely no matter how it is used.

(1) Overcurrent protection (transistor, motor)
(2) Overvoltage protection (transistor)
(3) Cooling fan overheating protection
(4) Braking resistor overheating protection
(5) Output terminals short-circuit protection

Moreover,when these protection circuits operate they are individually displayed so that troubleshooting is easy.

(5) Easy handling and safety

Since the FVR-G is often handled as a general purpose electric part because of the nature of the product, its handling characteristics were amply studied and the installation of nameplate to prevent input terminals and output terminals mistakes and the provision of signal lamps which indicate the presence and absence of the frequency setting signal, etc. were considered. Moreover, the provision of a signal lamp which indicates the residual voltage of the internal capacitor and other considerations were also given as regards safety. *Fig. 5* is an outside view of the FVR-G.

3) FRENIC 5000P

This series is for fans, pumps, and other square reduction torque loads. There are two series: one for 200V power supply and another for 400V power supply as shown in *Table 2*.

The FRENIC 5000P series is a high level series of the FVR-P series and has the following features:

(1) The torque pulsations are made small and smooth variable speed operation is be performed by using Fuji Electric's unique sine wave PWM.

Table 3 Specifications of FRENIC 5000P

200V series	Applicable motor output (kW)		5.5	7.5	11	15	18.5	22	30	37	45	55
	Inverter capacity (kW)		8	10	15	20	24	30	37	47	57	70
	Inverter rated current (A)		22	29	42	56	70	86	106	135	164	200
	Power requirement	Voltage and frequency	3-phase 200/220V, 50/60Hz									
		Allowable variation	Voltage 180 ~ 253V, frequency ±5%									
		Maximum voltage and frequency	50Hz, 200V and 60Hz, 200V switching									
	Output	Control range	17 ~ 50Hz and 20 ~ 60Hz switching (Maximum frequency can be adjusted up to ±5%)									
		Control precision	±0.5% of maximum frequency (at 25 °C ±10 °C)									
400V series	Applicable motor output (kW)		5.5	7.5	11	15	18.5	22	30	37	45	55	75	90	110
	Inverter capacity (kVA)		10		24		47		70		95	140	
	Inverter rated current (A)		15		35		68		100		137	200	
	Power requirement	Voltage and frequency	3-phase 400/440V, 50/60Hz									
		Allowable variation	Voltage 360 ~ 484V, frequency ±5%									
	Output	Maximum voltage and frequency	50Hz, 400V and 60Hz, 440V switching (However, input voltage must be the output voltage or greater.)									
		Control range	27 ~ 50Hz and 29 ~ 60Hz switching (Maximum frequency can be adjusted up to +5%.)									
	Control system	Control precision	±0.5% of maximum frequency (at 25 °C ±10 °C)									
		Applicable load	Square reduction torque load									
		Control system	Sine wave PWM system									
		Voltage/frequency ratio (V/F)	V/F constant and V/F weak switching									
Common specification	Overcurrent strength		120% of rated current for 1 min.									
	Operating system		One direction operation									
	Soft start/stop function		2 ~ 20 secs and 20 ~ 200 secs switching, soft start time and soft stop time can be adjusted individually.									
	Protection function	Stall prevention	Controlled by overcurrent suppression and overvoltage suppression function so that motor does not stall.									
		Inverter stopping	Overcurrent protection, overvoltage protection, inverter overload protection, cooling fan overheating protection, motor overload protection, undervoltage protection.									
		Momentary power interruption protection	Stopped by power interruption. When there is an operation command after the power recovers, operation continues.									
		Alarm lamp	Individual lamp display when each protection function operation is performed.									
		Alarm contacts	Relay c contacts x 1 (250V, 7.5A), on when protection function other than undervoltage protection operates.									

(2) V/F ratio is 50/60 Hz switchable. Moreover V/F ratio weak switching is also possible and selection matched to the load characteristic is possible.
(3) Complete protection functions. Especially, overcurrent limiting operation by frequency tracking control, overvoltage suppression operation, and other operating safety are considered.
(4) The design is such that the equipment has been made smaller and more reliable by changing the semiconductors into module and making the more integrated. An example of the equipment is shown in *Fig. 6*. The specifications of the FRENIC 5000 P 200 V series and 400 V series are shown in *Table 3*.

4) FRENIC 5000G

This series is for general variable speed applications and is the FRENIC 5000 G series previously commercialized by Fuji Electric with more advanced functions and makes smaller. There are two series: one for 200 V power supply and another for 400 V power supply as shown in *Table 4*.

The FRENIC 5000 G series is equipped with the following functions besides the features of the 5000 P series previously described.

Fig. 5 FRENIC 5000 FVR-G

(1) Reversible operation is possible. Moreover, four quadrant operation is possible by using a braking unit (option).
(2) Consideration has been given so that sensor operation,

Table 4 Specifications of FRENIC 5000G

200V series	Applicable motor output (kW)		5.5	7.5	11	15	22	30	37	45
	Inverter capacity (kVA)		8	11	15	20	30	40	50	60
	Rated output current (A)		23	32	44	57	86	115	142	175
	Input	Voltage and frequency	3-phase, 3-wire 200/220V, 50/60Hz							
		Allowable variation	Voltage: 180 ~ 253V, frequency ±5%							
	Output	Voltage	3-phase, 3-wire 200V							
		Frequency	50, 60, 100, 120Hz switching							
400V series	Applicable motor output (kW)		5.5	7.5	11	15	18.5	22	30	37	45	55	75	90
	Inverter capacity (kVA)		10	20		40			60			80	120	
	Rated output current (A)		15	29		58			87			115	173	
	Input	Voltage and frequency	3-phase, 3-wire 400/440V, 50/60Hz											
		Allowable variation	Voltage: 360V ~ 484V, frequency ±5%											
	Output	Voltage	3-phase, 3-wire 400V (at 400V input) or 440V (at 440V input)											
		Frequency	50Hz/400V, 60Hz/440V, 100Hz/400V, 120Hz/440V											
Common specifications	Control system		Sine wave PWM											
	Frequency control range		1 : 20 (rated output range 1 : 2)											
	Frequency precision		±0.5% of maximum frequency (at 25 °C ±10 °C)											
	Voltage/frequency ratio		V/F constant and V/F strong switching											
	Overcurrent strength		150% for 1 min											
	Soft start/stop		2 ~ 20 secs, 20 ~ 200 secs switching (start and stop times can be adjusted independently)											
	Operation system		Forward and reverse operation											
	Converter efficiency		95% or greater											
	Protection functions	Stall prevention	Countermeasures taken so that motor does not stall at overcurrent and overvoltage suppression.											
		Inverter tripping	The inverter is stopped and a signal is output by contact (1c, 250V, 7.5A) by overcurrent, overvoltage, overload, cooling fan overheating, motor overload, and braking resistor overheating (LED individual display).											
		Momentary power interruption	Stopped by a power interruption. When there is an operation command when the power recovers, operation continues.											

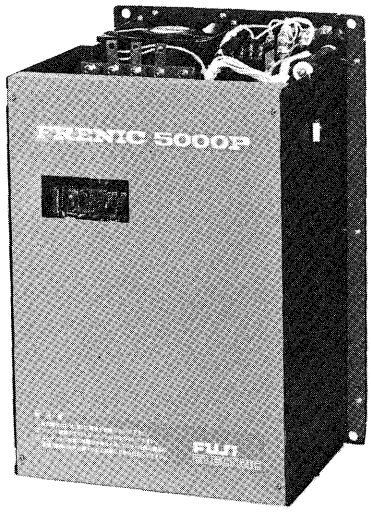


Fig. 6 FRENIC 5000 P

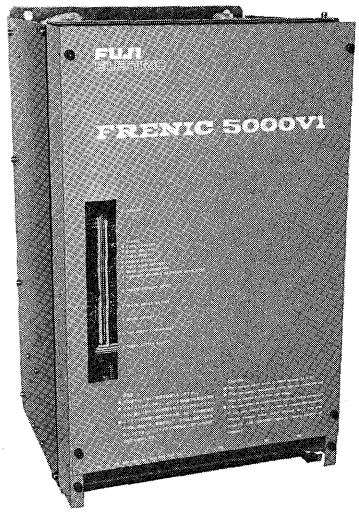


Fig. 7 FRENIC 5000 V

ratio setting, and other options can be easily built-in, and a wide range of applications is possible.

(3) Variable speed operation over a wide frequency control range of 1:20 is possible.

5) FRENIC 5000 V

This series was developed and commercialized as drive equipment having performances equal to or greater than direct current leonard by applying microprocesser applied TRANSVEKTOR control to an induction motor for NC machine tool spindle drive equipment.

It features a wide speed control range, quick response, smooth low speed operation characteristic, environment resistance through the use of a totally-enclosed squirrel-cage motor, good maintainability, etc. Moreover, an electric orientation control function is also available (option). An outside view is shown in *Fig. 7* and the series specifications are shown in *Table 5*. A high-speed type having a maximum speed of more than 10,000 rpm is required for machine tool spindle drive, and commercialization of it is also being promoted.

Table 5 Specifications of FRENIC 5000V

Rated output (continuous/30 mins)		3.7/5.5kW ~ 7.5/11kW		11/15kW ~ 30/37kW	
Speed control range		45 ~ 6000rpm (1 : 133)		45 ~ 4500rpm (1 : 100)	
Rated output range		1500 ~ 6000rpm (1 : 4)		1500 ~ 4500rpm (1 : 3)	
Speed control precision		±0.5% or less (at maximum speed)			
Overload strength		120% of 30 mins rating for 1 min			
Control system		Speed control by vector control (with current control)			
Modulation system		Sine wave PWM system			
Power requirement		AC200/220, 230V, 50/60Hz, 3 ϕ			
Standard functions		Zero speed detection Speed reached detection Arbitrary speed detection Torque limiting Speedometer output Loadmeter output Soft start Override Maximum speed fine adjustment			
Option functions		Electric orientation [Magnetic sensor type pulse encoder type] Speed setting D/A conversion function			
Protection functions		Overcurrent Overvoltage Overspeed Undervoltage Motor overheating Inverter overload Braking resistance overload			
Dimensions		3.7/5.5kW 5.5/7.5kW	7.5/11kW 11/15kW	15/18.5kW 18.5/25kW	22/30kW 30/37kW
	W	300	300	300	590
	H	500	680	860	860
	D	290	290	290	290
Braking system		Intermediate circuit regenerative braking		Power supply regenerative braking	

IV. CONCLUSION

The Fuji Electric transistor VVVF inverter was introduced above. We are confident that these families can cover a fairly wide range and understand that there are also many needs which are not covered. The transistor VVVF inverter is a product which has been raised so that the series of models has been extended up to here, and can meet diverse needs. In the future, we will put our efforts in the development of new models and expansion of the capacity range toward the ideal variable speed equipment and ask for the opinions and guidance of all users.