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DIGITAL INVERTER FRENIC 5000V3 FOR MACHINE TOOL SPINDLE DRIVE

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1. FOREWORD

Regarding modern machine tools, besides higher performance and more functions, the machining time is being shortened by multi spindle construction and polygon processing, rigid tapping, and other composite machining. Therefore, the demand for high response and more accurate spindle drive system has increased.

To meet this demand, Fuji Electric has undertaken control system DDC by using recent DSP (Digital Signal Processor) and other high-speed processing devices. The vector control AC spindle drive system FRENIC 5000V2 Series has already been developed for machining center and multi-function NC lathe spindle drive. The all-digital FRENIC 5000V3 Series has now been developed as a new series.

The specification and features of the FRENIC 5000V3 Series are outlined below.

2. SPECIFICATIONS AND FEATURES

Table 1 shows the standard specifications of the spindle motor and drive unit.

(1) Improved servo capabilities

An all-digital control section and high-speed microprocessor enable vector control over the entire speed range from low speed to high speed and provide faster speed control response and improve rigidness, and other servo capabilities in orientation control.

(2) Reduced torque ripple

Torque ripple is caused by current control system offset and mutual unbalance and on delay timer for switching element shorting prevention of main circuit. Therefore, the current control system offset and mutual unbalance were minimized and torque ripple was reduced to 1/5 that of the past by digitalizing the main control section including the current control system.

(3) Enhancement of man-machine interface

Since setting of the various control parameters is digitalized and can be performed by key operation while watching the numerics, adjustment mistake are prevented and operating time is shortened.

The operation status monitor display can display the torque command value, motor winding temperature, presence/absence of input/output signals, etc., in addition to motor speed.

When the inverter is tripped by an abnormality, besides ordinary cause classification display, the operation status and input/output signal status when the abnormality occurred are memorized and the memorized data is preserved even when the power is turned off so that diagnosis of abnormality tripping is easy.

(4) Miniaturization of drive unit

The base drive section was minaturized and standardized by using a high DC current gain and low loss power transistor and the size of the control board was reduced substantially by introducing surface mounting technology of PC board. As for the main circuit section, conversion to a resistance discharge system, especially in the small capacity range, was forecast and the switching loss was reduced and design of the cooling construction was optimized. The volume computed by outline dimensions was reduced an average of 54% for external cooling type and 37% for panel mounting type as compared to the old series.

(5) Drive unit construction

Two series of drive units were developed: panel mounting type and external cooling type with the main circuit cooling body outside the control panel. The allowable ambient temperature of the drive unit was made −10°C to 55°C and panel design was simplified. Since a construction which divides the interior of the drive unit into small blocks in function units is used, replacement of maintenance parts, etc. is easy.

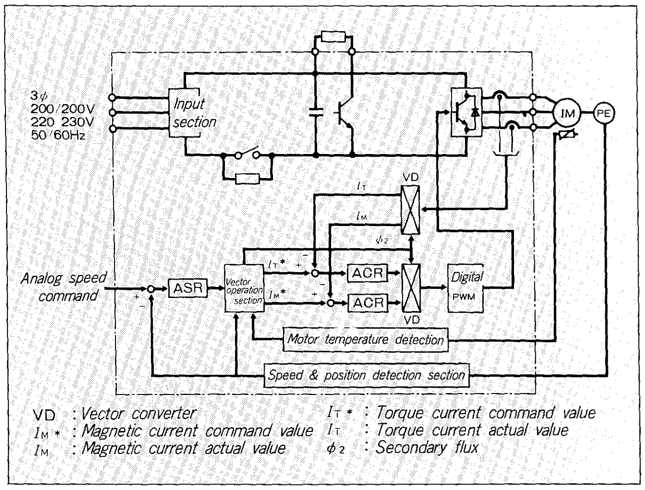
3. CIRCUIT COMPOSITION

Figure 1 is a block diagram which shows the entire circuit composition of the drive unit. The main circuit block is an example of a resistance discharge braking system with discharge circuit provided at the DC-link circuit. Systems in the 3.7/2.2kW and smaller ranges are limited to resistance discharge type and systems in the 22/18.5kW and larger range are limited to power regeneration type. However, in the medium capacity range, both types are available and can be selected freely.

Table 1 Standard specifications

	Item \ System name	FSD-2B	FSD-3B	FSD-5B	FSD-7B	FSD-11B	FSD-15B	FSD-18B	FSD-22B	FSD-30B	FSD-37B	FSD-45B
Output	50%ED rating (kW)	2.2	3.7	5.5	7.5	11	15	18.5	22	30	37	45
	Continuous rating (kW)	1.5	2.2	3.7	5.5	7.5	11	15	18.5	22	30	37
Spindle motor	Base speed (rpm)	1,500									1,150	
	Maximum speed (rpm)	8,000		6,000							4,500	
	Type	MPF 002V3	MPF 003V3	MPF 005V3	MPF 007V3	MPF 011V3	MPF 015V3	MPF 018V3	MPF 022V3	MPF 030V3	MPF 037V3	MPF 045V3
	Overload Allowable	120% of 50%ED rating for 1 minute										100% of 50%ED rating for 30 minutes
	Vibration	V5									V10	
	Noise [dB(A)]	70					75				80	
Drive unit	Type	FRN 002V3 -21S, C	FRN 003V3 -21S, C	FRN 005V3 -21S, C	FRN 007V3 -21S, C	FRN 011V3 -21S, C	FRN 015V3 -21S, C	FRN 018V3 -21S, C	FRN 022V3 -21S, C	FRN 030V3 -21S, C	FRN 037V3 -21S, C	FRN 045V3 -21S, C
	Power supply (voltage/ frequency)	3-phase, 200/200, 220, 230V +10%, −15%, 50/60Hz±5% (operation guaranteed), voltage unbalanced 3% max.										
	Main circuit system	Transistor sine wave PWM type VVVF inverter										
	Control system	All-digital vector control with speed feedback by magnetic encoder										
	Operating system	Variable four quadrant operation										
	Braking system	Regenerative braking (resistance discharge)							–			
		–		Regenerative braking (power regeneration)								
	Speed control range	30~8000rpm		30~6000rpm					30~4,500rpm			
	Speed control accuracy	0.1% or less of maximum speed (load fluctuation 10 to 100%)										
	Speed command input	Analog: DC+10V/forward & reverse maximum speed, DC±10V/forward & reverse maximum speed Digital: 12 bits binary, BCD 2 digits										
	Acceleration/deceleration system	Torque current limiting acceleration or soft start/stop (0.1 to 120.0s)										
	Data parameters setting system	Digital setting by key switch										
	Check display function	I/O signal, current value, motor speed, trouble, etc. (by 5-digit, 7-segment LED)										
	Construction	Panel mounting type unit, external cooling type unit										
	Ambient temperature	−10 to +55°C (unit ambient temperature)										

Fig. 1 Drive unit block diagram



The main part of the control circuit section is digital control centered about software operation. It features ACR (Auto Current Regulator) control by the DC amount obtained by coordinate conversion of the AC voltage and current and detection of the winding temperature by NTC thermistor buried in the winding and continuous secondary resistance compensation.

4. OPERATION CHARACTERISTICS

(1) Fast speed control response

Speed control system operation was speeded up using a DSP capable of processing one step in one machine cycle (200ns) as a high-speed microprocessor and shortening the processing time of the speed regulator and vector operation section which govern the speed control response. Furthermore, a speed control response frequency of 40Hz was realized by building a small delay speed detection circuit. Good dynamic characteristics and excellent response even to impact loads was obtained by means of this. The impact load response characteristics are shown in *Fig.2*.

(2) Torque characteristics

Figure 3 shows the output torque temperature change characteristic. The output torque limit value was set to the 50%ED rated value and the unit was operated continuously and the output torque and winding temperature relationship was obtained by the process by which the motor raises the temperature. Since the horizontal temperature is not

Fig. 2 Inverter impact response characteristics

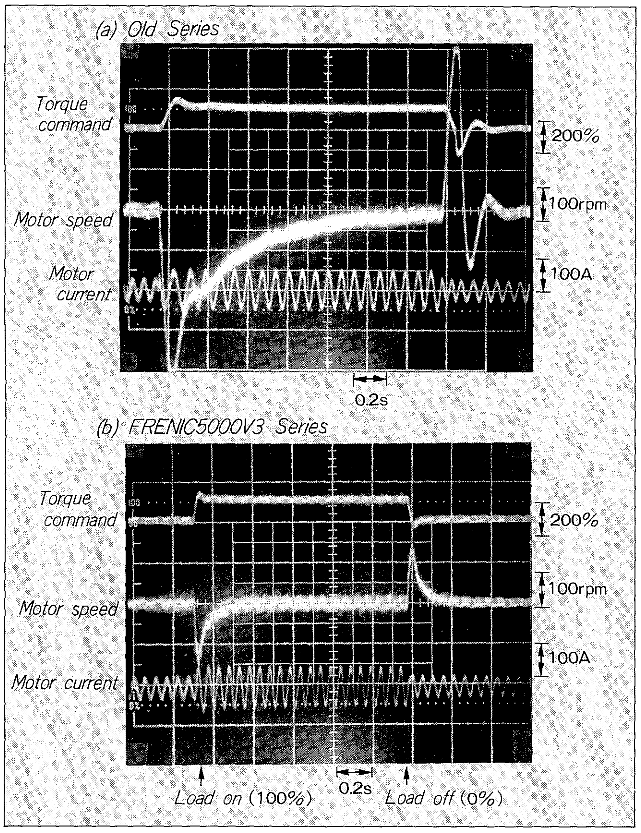
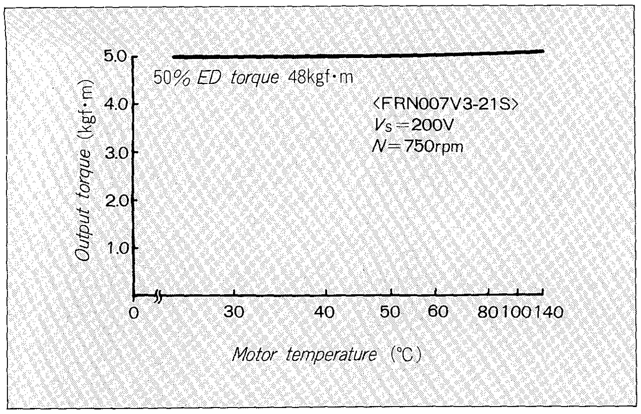


Fig. 3 Output torque winding temperature dependence characteristic



equally divided due to the affects of the thermistor characteristics, the typical value of several points is plotted. The dependency of the output torque value on the winding temperature is very stable and shows that the temperature compensation circuit is effective.

Figure 4 shows the maximum output torque (1 minute rated value) speed dependency characteristic. The characteristics of the new and old series are compared. For the old series, the torque tends to decrease in the high-speed range and tends to increase in the low-speed range. This is caused by the AC ACR. In the high-speed range, the phase delay of the ACR is affected. The circuit which compensates for this has an affect on the low-speed range. The new series (V3)

Fig. 4 Maximum output torque speed dependence characteristic

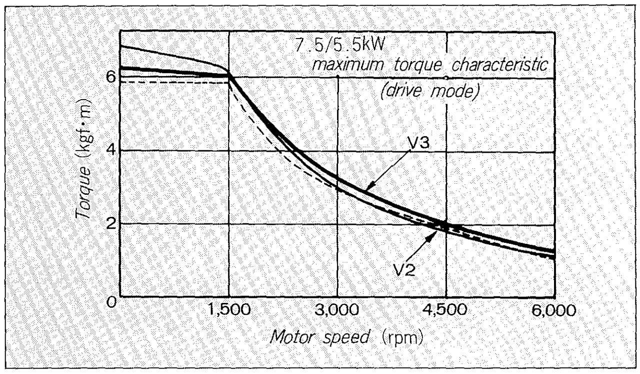
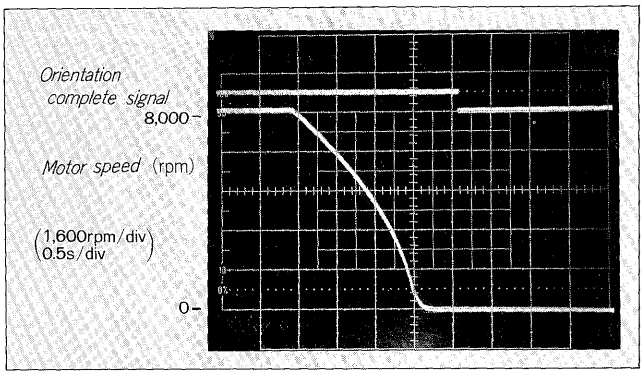


Fig. 5 Pulse encoder system orientation operation waveform



uses DC ACR control so that a stable output is obtained over the entire speed range.

(3) Orientation control

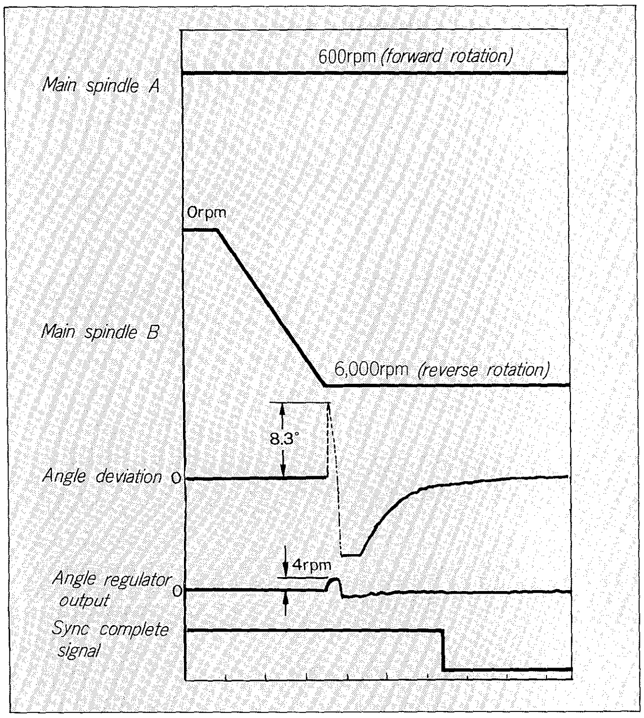
This system make it possible to raise the gain of the position regulation system at orientation control operation to increase the response of the speed control system. As a result, repeated positioning accuracy can be improved. An accuracy of $\pm 0.05°$ or less is realized for a magnetic sensor orientation system and an accuracy of $\pm 0.1°$ or less is realized for a pulse encoder orientation system.

When the spindle is stopped by orientation control, conventionally, the speed command switches to creeping speed and after the motor speed reaches the creeping speed, the motor is stopped by switching to positioning control near the target stop position and, therefore, orientation take a long time. Since a machining center performs the orientation operation each time ATC (Automatic Tool Change) is performed, the orientation time must be minimized. The orientation time can be shortened considerably by using an algorithm system which can widen the orientation control range ($\pm 360°$) and increase the creeping speed considerably and can also generate a speed patern which decelerates from the creeping spped to near the target stop position in the shortest time. The pulse encoder system orientation operation by this sytem is shown in *Fig. 5.*

(4) Synchronous controller

A synchronous controller was provided as a now option. This synchronous controller can be used with lathes with a tool spindle and which perform polygon processing,

Fig. 6 Synchronous controller control characteristics



dual spindle lathes, etc. and receives the signal from sensors (pulse encoder) installed to the main spindel and tool spindle or to two mainspindles and performs angle synchronous control between two axes.

Besides 1:1 synchronous operation, 1:2 and 1:3 ratio synchronous operation is possible. Various polygon processing can also be performed by combining with multiple tools. Ratio selection is performed by external signal.

When two main spindles angle synchronous operation is performed, since both axes are mechanically coupled through the chuck and work at the completion of synchronization, angle control alone is insufficient. Therefore, torque balance control is added so that twisting torque is not applied to the work.

There are two operation modes: a mode which accelerates both axes by position synchronous control after both axes have been preset to the synchronization position and the work chucked and a mode which chucks the work in the rotating state after accelerating one of the axes to that speed and synchronizes it with the set angle. Multi angle work can be chucked by the chuck in both modes. *Figure 6* is an oscillogram which shows the control characteristics of the synchronous controller. Synchronous control was performed by accelerating stopped axis B relative to rotating axis A.

Recently, a compound lathe with two main spindles and two tool spindles has been practicalized and the application of the synchronous controller is expected to increase steadily in the future.

5. CONCLUSION

The vector control digital AC spindle drive system FRENIC 5000V3 Series and its option were outlined above. In the future, series with a constant output over a wide range, etc. will be developed and will progress as products with satisfying performances and functions as electrical parts for developing machine tools.