

FR-A500 : TECHNICAL DESCRIPTION OF NEW FEATURES

1 : ADVANCED MAGNETIC FLUX VECTOR CONTROL

The Advanced Magnetic flux vector control system has been developed in order to realize 0.5Hz with 150% torque and a speed control range with a ratio of 1 to 120 (from 0.5Hz to 60 Hz for a base frequency of 60Hz (ratio is 0 to 100 for a base frequency of 50Hz)).

Diagram 1 shows a block diagram of the advanced magnetic flux vector control system, where the output current of the inverter is detected and decomposed into the current i_d (the excitation phase) and the other current i_q (torque phase) on the axes d and q that rotate at the primary angle frequency ω_1 .

In the operating section for stabilizing compensating voltage, operation is performed for the compensating voltage V_{cd} on the axis d (excitation phase) and the compensating voltage V_{cq} on the axis q (torque phase) so that the primary flux of the induction motor may keep a stable specified value. Also, in the slip frequency operating section, operation is performed for the primary flux λ_d of the induction motor, and then operation is performed highly accurately for the slip frequency $\omega \sim s$ by using the primary flux λ_d operator, the current i_d in the excitation phase, and the current i_q in the torque phase.

Applying the expression given below, the primary voltage V_d and V_q on the axes d and q and the output frequency ω_1 are controlled by using the compensating voltages V_{cd} and V_{cq} on the axes d and q as well as the slip frequency $\omega \sim s$ that are operated as above.

Equations:

$$V_d = K_1 \times i_d + V_{cd}$$

$$V_q = K_2 \times i_q + V_{cq} + K_3 \times \omega_1 \quad \text{..... (equation 1)}$$

$$\omega_1 = \omega^* + \omega \sim s^* \quad \text{..... (equation 2)}$$

Where:

K1: Primary resistance compensating gain on axis d

K2: Primary resistance compensating gain on axis q

K3: Excitation voltage (V/f) gain

ω_1 : Output frequency

ω^* : Target frequency

The expression 1 (above) is used for controlling the output voltage so that a specified value may be applied to the primary flux of the motor. The expression 2 (above) is used for controlling the output frequency so that the actual rotational frequency of the induction motor may correspond to the target frequency.

Applying the advanced (magnetic) flux vector control system allows us to obtain a stable high torque in the range from low frequencies to high frequencies and eliminates the rotational deviation against the load (torque) fluctuation (i.e. obtains stability).

2 : AUTOMATIC TUNING

The off-line automatic tuning is a function which permits the inverter itself to automatically measure and memorize (store) the motor constants (see diagram 2, Motor Equivalent Circuit) required for operating with the advanced magnetic flux vector control.

This function allows us to realize a sufficient performance level by applying advanced magnetic flux vector control so that even a motor whose constants are unknown may be used.

The motor constants required for applying the advanced magnetic flux vector control vary depending on the motor temperature. In order to maintain stable control regardless of the change in motor constants, on-line automatic tuning has been developed for measuring motor constants automatically every time the motor is started and for compensating for those constants.

2.1 : Off-line Automatic Tuning

The off-line automatic tuning consists of the following three tuning elements:

- 1) Tuning for R1 (primary resistance)
- 2) Tuning for R2 (secondary resistance), I1 (primary leakage inductance), and I2 (secondary leakage inductance)
- 3) Tuning for L1 (primary inductance)

Conventionally, the primary resistance R1 was obtained through a resistance measuring test such as double-bridge or voltage drop method. For the inverter, however, such a resistance is obtained with the expression V/i by applying direct voltage V and detecting a current i. The values R2, I1, and I2 used to be obtained through a trapped flux test. For the inverter they are obtained by applying low, single-phase alternating voltage and a rated current for a short time. This method maximizes the slip value S, which makes the slip value equal to that obtained in a trapped flux test. The values R2, I1, and I2 are calculated with the power and voltage applied in this method. Generally, L1 is obtained through a test in which the motor is rotated at (approximately) the rated speed without a load. The value R2/S is made infinite by rotating the motor at a synchronous speed. In this state the current on the secondary side of the equivalent circuit becomes null and the voltage drop of the primary resistance becomes negligible because of the rated voltage being applied, thereby permitting the calculation of L1. For the inverter, L1

is obtained by adjusting M (excitation inductance) in such a manner that the error of the excitation current becomes null by rotating the motor at nearly synchronous speed with the advanced magnetic flux vector control.

2.2 : On-Line Automatic Tuning

For on-line automatic tuning motor constants are obtained by applying dc excitation when operation using the advanced magnetic flux vector control is started. Then, a temperature compensation is made for the motor constants which were obtained in the off-line automatic tuning.

The time required for on-line automatic tuning is between 50ms (minimum time) and 500ms (maximum time) however it varies depending upon the motor.

Figure 1 shows a block diagram of the on-line automatic tuning. As shown in the configuration chart (Figure 1), R1 (primary resistance) and R2 (secondary resistance) are simultaneously determined with a voltage error which is given by comparing the actual voltage V obtained when dc excitation is applied by a step function at the start to another which is obtained when calculated with a current i and a mathematical motor model (estimated model) This is done by the main RISC CPU of the inverter.

Applying these R1 and R2 values to the advanced magnetic flux vector control allows us to make a temperature compensation for the R1 and R2, thereby realizing a highly accurate operation which will not be affected by motor temperature as well as large torque and stable operation even at an ultra-low speeds.

3 : SMART DRIVER

The Smart Driver (Mitsubishi's newly developed, original ASIC) has been developed so as to directly monitor the condition of the main circuit and control the output waveform of an inverter. The smart driver has improved the rotational fluctuation at low speeds by double (0.5Hz or less), in comparison to that of previous (FR-A200E) models manufactured by Mitsubishi.

In conventional general-purpose inverters the IGBT drive signals were created by insulating the PWM signals that had been created in the control circuit. In order to prevent the upper and lower IGBT drive signals from shorting with each other the PWM signals must be provided with a period (short-circuit prevention period) which turns off both the upper and lower IGBTs. Since the output voltage fluctuates according the load current during such a short-circuit prevention period, the motor rotation could become unstable due to a failure to obtain voltage which has been designated previously. Low-noise type inverters (high-frequency inverters) are notably affected by such a failure, where the PWM signals conventionally were compensated based on the load current. However, it was difficult to eliminate all of

the influence with this compensation. Therefore, the LSI (Smart Driver) for creating PWM signals has been developed exclusively for operations with the potential (voltage levels) in the main circuit. This LSI creates PWM signals according to the voltage command of the CPU in the control circuit and compensates the PWM signals by feeding back the output voltage so as to keep the motor from rotating in an unstable manner.

4 : RESULTS OF PERFORMANCE TESTS

1. SPEED vs. TORQUE Characteristics

Figure 5 shows the characteristics of the relationship between speed and torque at when advanced magnetic flux vector control is employed. In this example, the torque obtained (stable) is in the range (1 to 120) for 0.5Hz to 60 Hz and the fluctuation of the rotational speed relative to the torque is remarkably small.

2. Effects of On-line Automatic Tuning

Figure 6 depicts the effects of the on-line automatic tuning.

Figure 6 depicts the effects of the on-line automatic tuning, showing the performance of repeated start and stop actions of a motor with a speed of 300rpm.

In the case where the on-line automatic tuning is employed the rotational speed does not decrease as time passes, however the motor temperature goes up from about 20°C to 100°C. On the other hand, in the case where the on-line tuning is not employed the rotational speed decreases because of a presumed error of a slip frequency which was obtained by slip compensation. This is caused by failure to compensate for motor constants which result in a large amount of error between the motor constants used internally of the inverter and the actual motor constants.

It can be said that the on-line automatic tuning is effective to applications where start and stop actions are performed repeatedly, since it employs a method which detects a motor constant in a short time at a start of operation.

3. Rotational Fluctuation

Figure 7 depicts the comparison data of the rotational fluctuation. Compared to that of conventional models, the rotational fluctuation at low speeds has been reduced owing to the effects of the smart driver. (1/2 or less in comparison to that of conventional models.)

4. Environmental Compliance : Soft-PWM Control

When an inverter drives a motor, a noise caused the carrier frequency is generated by that motor.

When the carrier frequency is as low as 1kHz, the motor makes a metallic, unpleasant magnetic noise. In order to reduce such a magnetic noise a carrier frequency from 10kHz to 14.5kHz was applied to conventional models, where the magnetic noise was transferred into the inaudible frequency range.

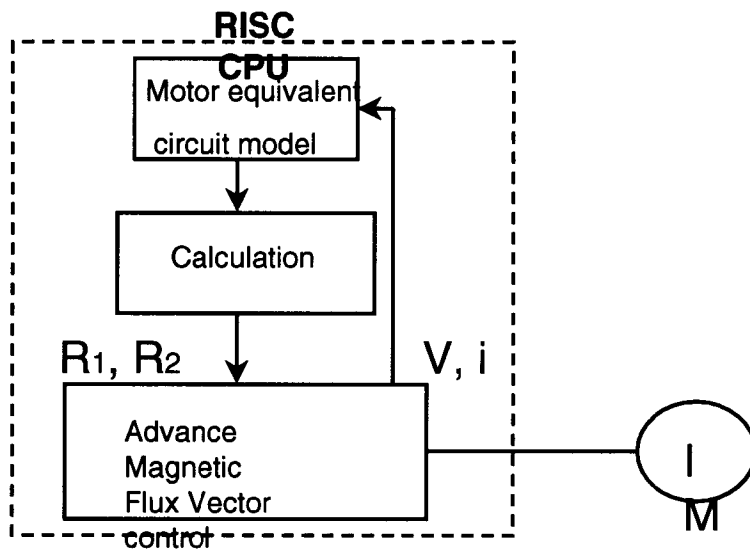
However, while a good result was obtained by employing high carrier frequencies in terms of noise (acoustic) reduction, an increase in electric noise occurred which could cause undesired effects on other devices as well as an increase in leakage current, both were problems to be solved. Therefore, Soft-PWM control was developed to try to reduce this motor noise, in which the components of magnetic noise are diffused without increasing the carrier frequency thereby making the noise a gentle sound to human ears.

Triangular wave comparison is a method to realize the PWM control for a three-phase inverter. Figure 4 shows the switching timing for each phase for the triangular wave comparison, where the command voltage is set to a specified value. As shown in Figure 4, the voltage at point N (N terminal of inverter) on the negative side of the dc bus line in each phase and the line-to-line voltage, that are obtained by triangular wave comparison, are the pulse voltage. The mean time value obtained by applying these pulse-like voltages becomes equal to the line-to-line voltage of the command voltage. What determines the line-to-line voltage here, in the case of voltage V_{u-v} between U and V for example, is the pulse width t_0 . The output voltage remains unchanged however the output timing of this pulse voltage is changed.

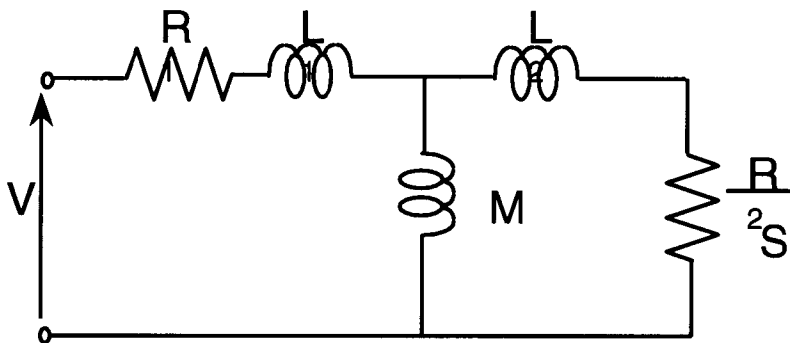
Soft-PWM control is a system where the output timing of this pulse is changed with respect to time, i.e. the distribution of t_{11} and t_{12} is varied according to the change of time while keeping the time value of the t_{11} and t_{12} . This system permits to diffuse the excitation noise generated by the motor.

Figure 8 show the comparison of the Soft-PWM Control System to a conventional system. It can be noted in Figure 8 that the motor noise is remarkably high, the frequency of which is twice the carrier frequency. The Soft-PWM Control in Figure 8 shows that the motor noise is diffused when it reaches this peak value, the difference can easily be seen.

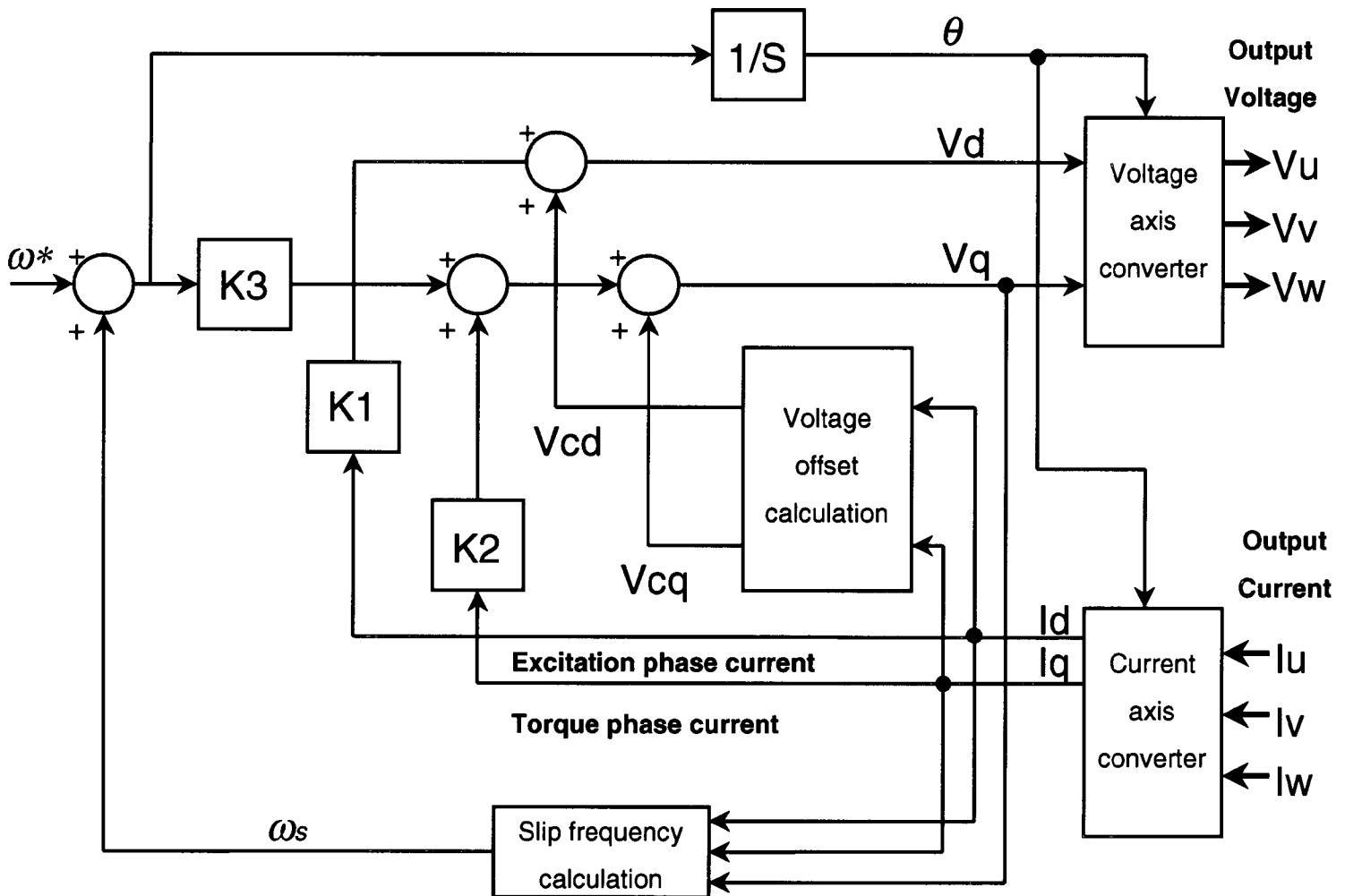
1 : "ONLINE" AUTOTUNING BLOCK DIAGRAM



2 : MOTOR EQUIVALENT CIRCUIT



3 : BLOCK DIAGRAM OF ADVANCED MAGNETIC FLUX VECTOR CONTROL

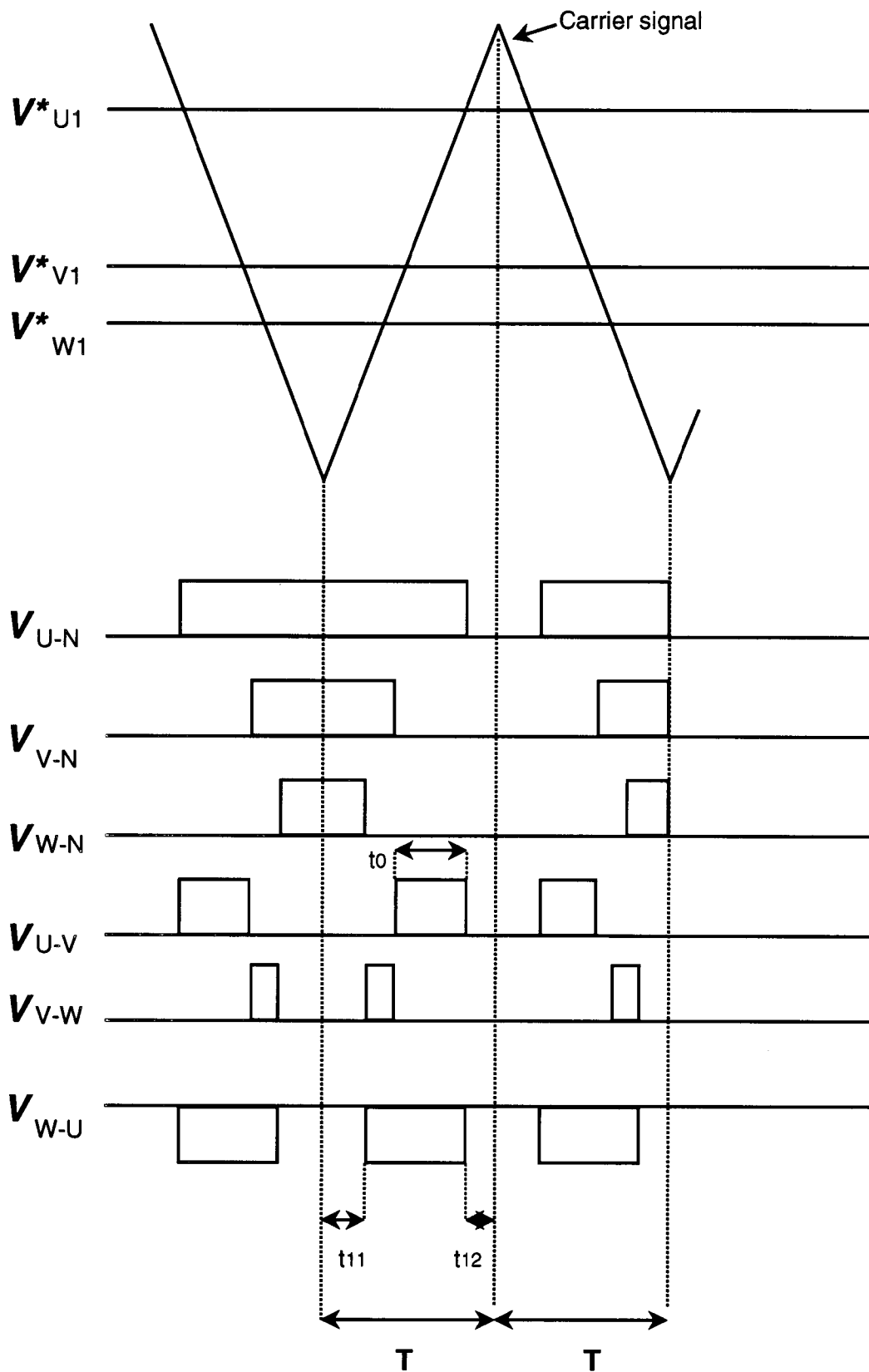


K1 : d phase primary resistance comparison gain

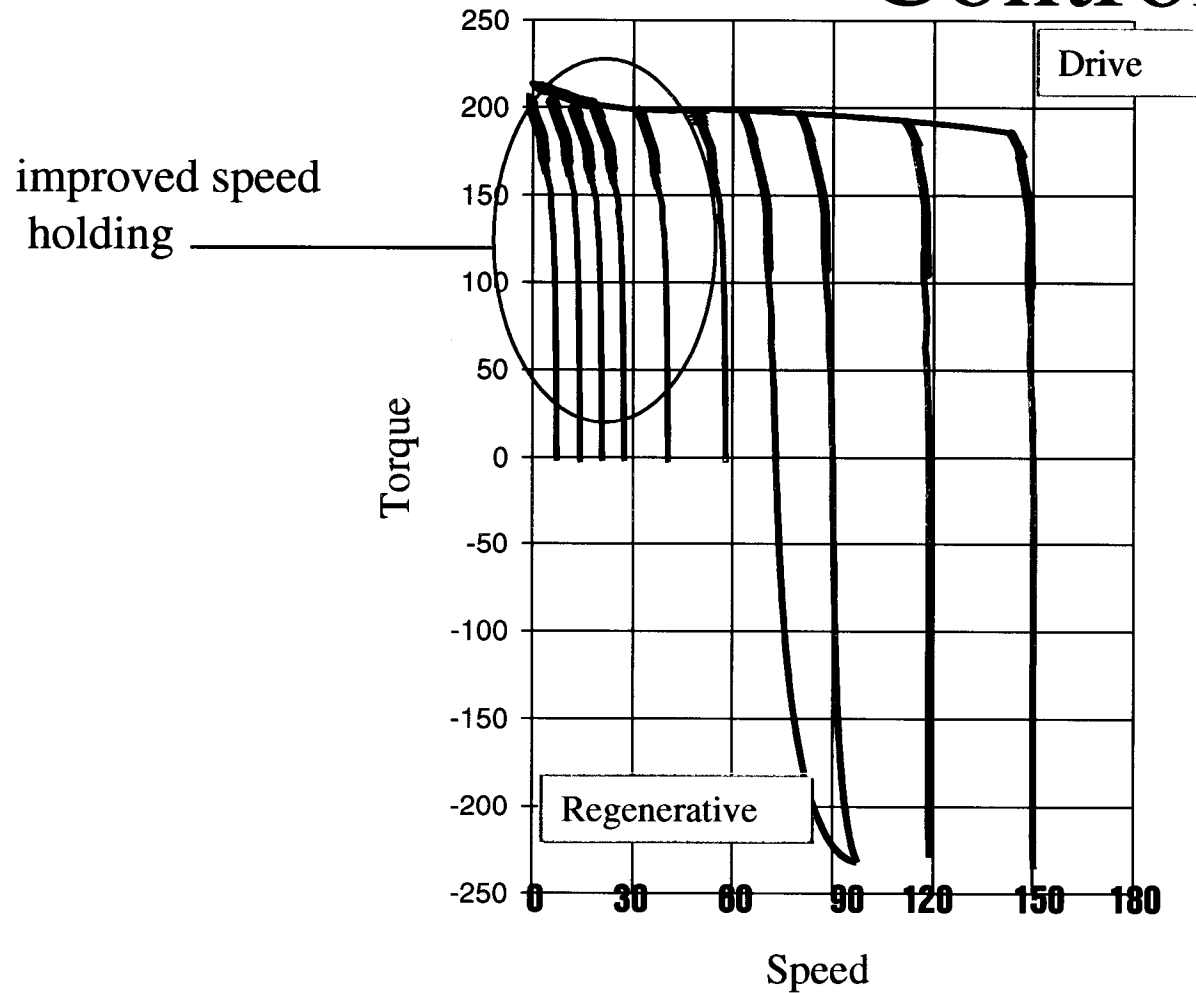
K2 : q phase primary resistance comparison gain

K3 : Excitation voltage (V/f) gain

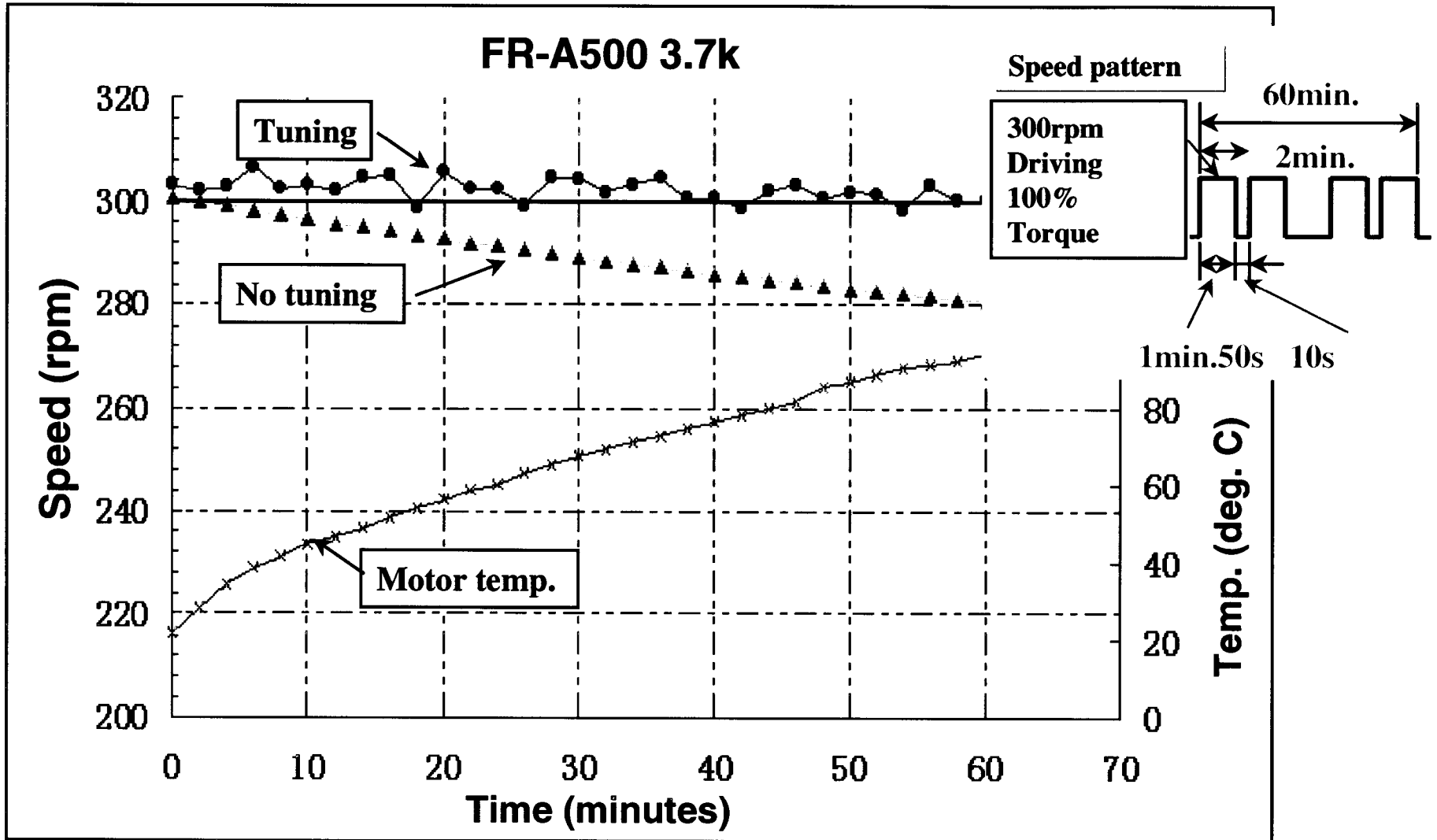
4 : SOFT-PWM : TIMING/OPERATION CHART



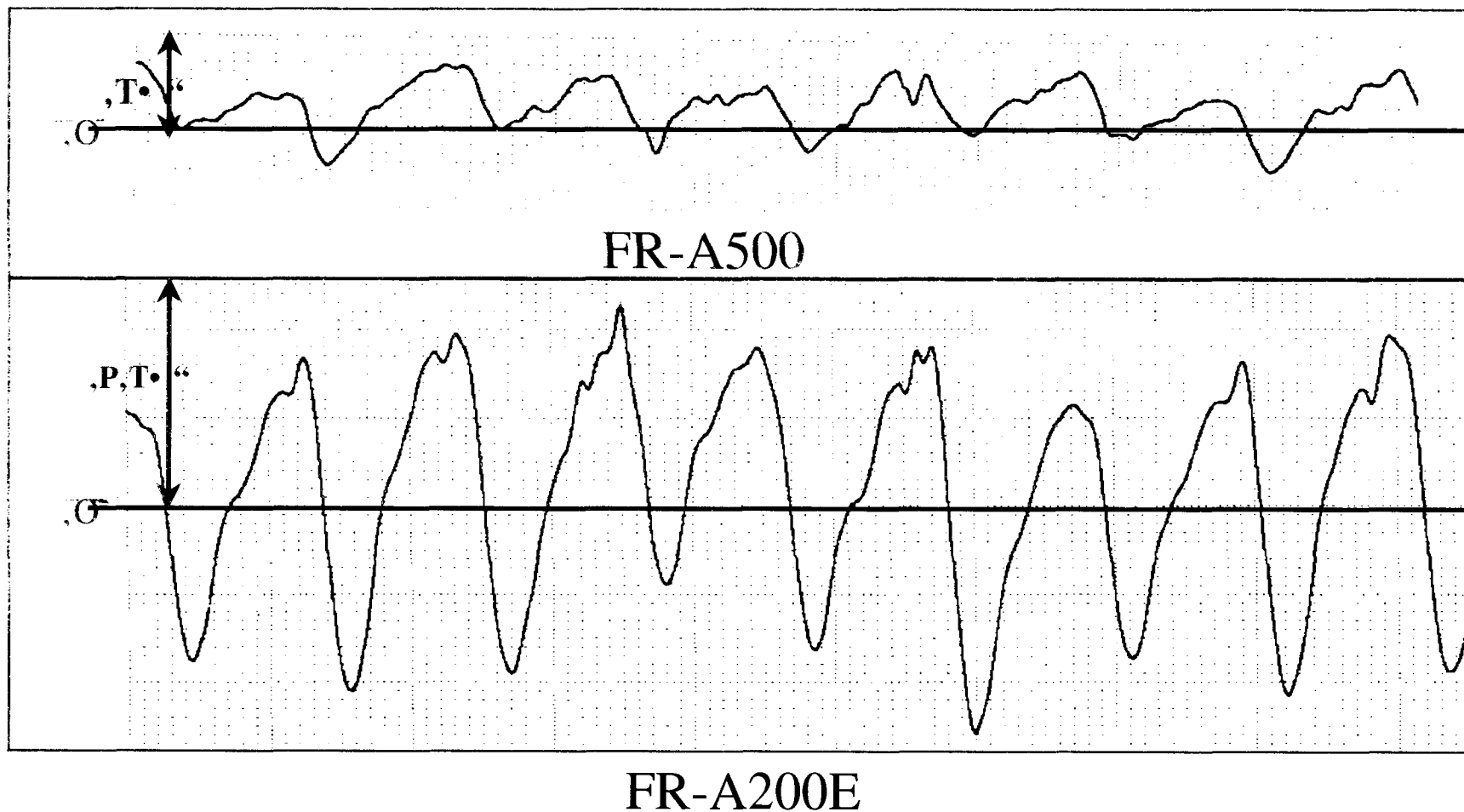
Advanced Vector Control



6 : EFFECTS OF AUTOMATIC TUNING



7 : ROTATIONAL FLUCTUATION COMPARISON



8 : SOFT PWM COMPARISON

Motor data

(Operating freq. 3Hz, carrier freq. 2kHz, 3.7kW 4P motor)

Soft-PWM

Without Soft-PWM

