HITACHI

UNI-TORQUE MOTOR

SERVICE MANUAL

No. 127

Contents

1. Outline of development

The signal-to-noise ratio, wow/flutter and other important characteristics of turntable which employ direct drive motor directly rely on the performance of the motor. This is because the platter and the motor are coupled directly.

Conventionally, multi-pole DC servomotors or cup type AC servomotors have been available for direct drive turntables, but each type has its merits and demerits. Hitachi set out to develop a high-performance direct drive motor which combines the merits of both systems, and the result of its endeavors was the flat, commutator-less DC servomotor. (A total of 15 patents have been applied for).

The construction of the new motor is completely different from that of conventional motors, and in theory, the torque is constant, there are few vibrations and it allows the platter to rotate smoothly. Hitachi called it the 'Uni-torque motor'. Its construction is shown in Fig. 1.

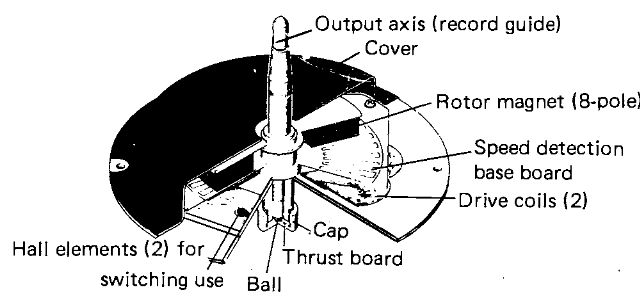


Fig. 1 Construction of main uni-torque motor unit

2. Features

(1)Excellent S/N and wow/flutter

Thanks to the new core-less, slot-less flat star-shaped coil construction, there is no slot phenomenon (whereby the platter does not rotate smoothly), and the output torque is constant so that there is very little vibration and the platter rotates smoothly. This makes for a superb signal-to-noise ratio and wow/flutter.

(2)High starting torque

Unlike the cup type AC motor, the new motor provides a high starting torque for its small size without slip.

(3)Simple construction, high reliability

The motor is composed of two core-less flat, star-shaped drive coils and a base board for speed detection, and also of a brush-less switching mechanism which contains two Hall elements for an overall simple construction. High reliability is yielded by the small number of parts used.

September 1977

(4)Very little rise in temperature

At start-up, the motor starts operating with its maximum torque provided by square waves, but when its speed has become constant, vibrations are prevented by sinusoidal waves. Furthermore, when locked together with the platter, the protection circuit is actuated to automatically reduce the drive current and safeguard against rises in temperature.

3. Comparisons with other types of motors

The table below compares the uni-torque motor with conventional multi-pole DC servomotors and cup type AC servomotors.

Performance required for direct drive motor	DC motors		AC motor	Uni-torque motor
	Brush	Brush-less		
Torque fluctuations	Poor	Poor	Good	Very good
Vibration	Good	Good	Poor	Very good
Temperature rise	Good	Good	Poor	Very good
Simple construction	Fair	Fair	Fair	Very good
Long service life	Poor	Good	Good	Good
Efficiency	Very good	Good	Poor	Good
Ease of control	Good	Good	Fair	Good

Comparison of performance of motors

4. Operating principle

Fig. 2 (a) shows a graphical representation of Fleming's Left Hand Rule. In a magnetic field, a conductor will be subjected to the force of wire motion at right angles to the direction of the current, and this diagram shows the basic operation of a rotating machine. According to this rule, the coil in Fig. 2 (b) will be subjected to the upward force. If the coil is fixed, a repelling force will be generated in the magnets and the direction of this force is shown by the dotted arrows, i.e. downward. If the length of the coil across the magnetic field is '1', then the relationship between this length and the force F, to which the coil is subjected, the magnetic flux density B and current I can be expressed by the following equation. $F = BI1$

Let us now consider two magnets which are bonded together with their polarities reversed, as shown in Fig. 3, with a V-shaped drive coil placed beneath them. The magnetic flux under the magnets go in opposite directions and so even when the direction of the current is the same, the forces on edge 'b' under the south pole and on edge 'a' under the north pole will be exerted in opposite directions. If these forces are Fa and Fb, and the component forces in the 'x' axis direction are fax and fbx, then the size of these component forces will be:

$$fax = fa \sin\theta$$
$$fbx = fb \sin\theta$$

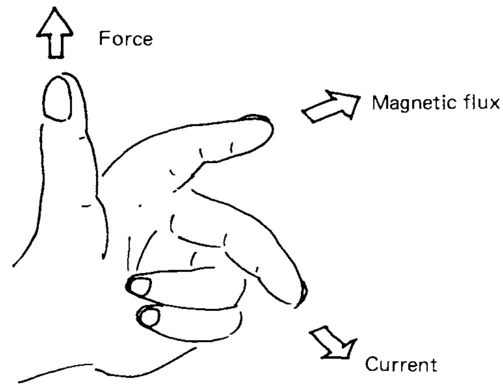


Fig. 2 (a) Fleming's Left Hand Rule

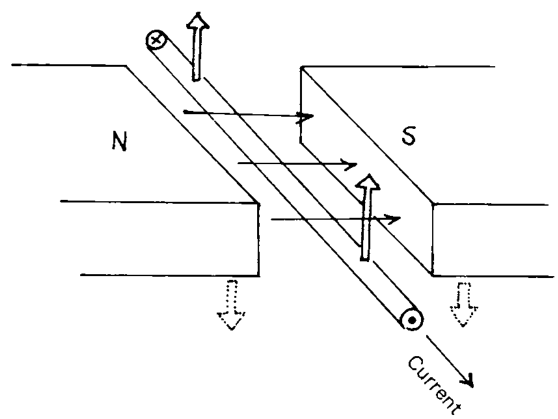


Fig. 2 (b)

If, as shown in Fig. 4 (a), the magnets are moved to the left in the direction of the 'x' axis, then the force to which the drive coil is subjected will be canceled out, since the forces on edges 'a' and 'b' under the north pole are applied in opposite directions, and force fx which is generated decreases.

If the magnets are moved further to the left, as in Fig. 4 (b), forces fa1x and fb2x are balanced, and the force generated is zero. Moving the magnets even further to the left means that the value of fb2x will increase more than that of fa1x, and that the direction of the force applied to the drive coil will be reversed and tend to the left. Fig. 5 shows the relationship between the distance moved by the magnets from the position in Fig. 3 and the forces which are applied to the drive coil.

Let us now proceed to extend the example by aligning four pairs of circular magnets, which were used in

Fig. 3, and by using a square-shaped drive coil such as the one in Fig. 6. There will now be eight magnets and each will exert a force on the drive coil. These forces are numbered F1 to F8.

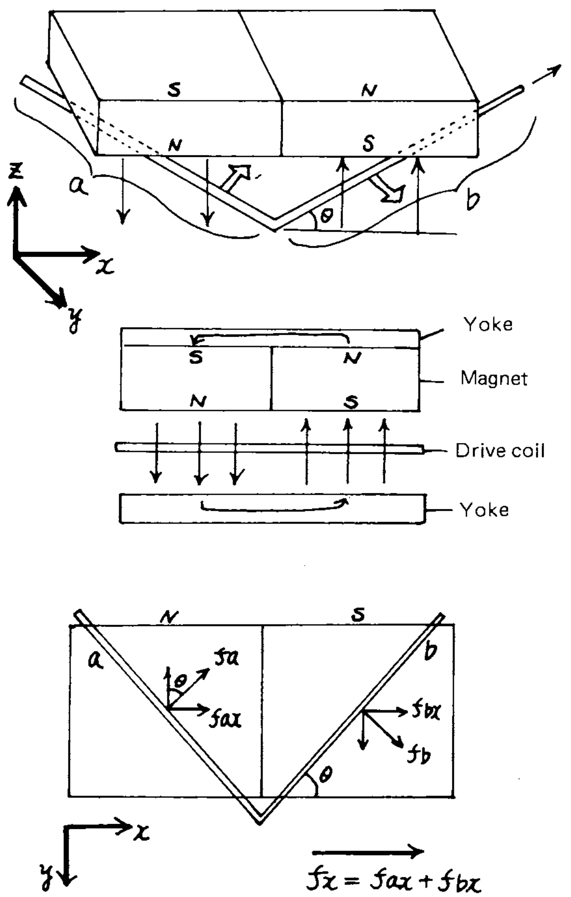


Fig. 3

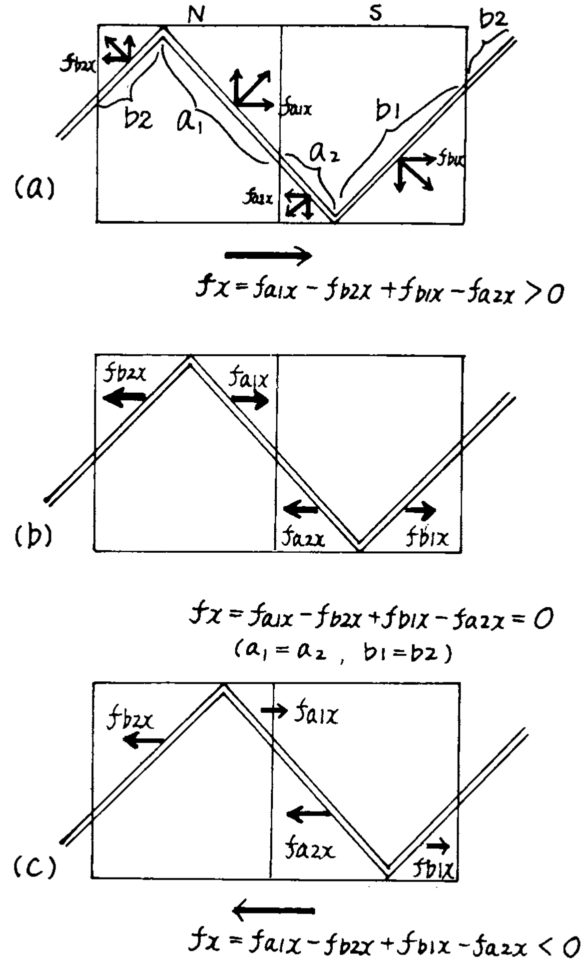


Fig. 4

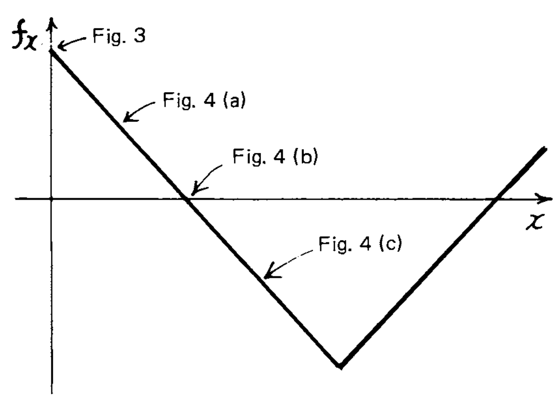


Fig. 5

Let us consider the forces in the direction across the diameter of the magnets and in the direction of the circumference. These are numbered Fr1 to Fr8, and Fθ1 to Fθ8, respectively. With forces Fr1 to Fr8, the value of the counterforces are the same, but their directions are reversed, and so they cancel one another out. This means that the force on the drive coil is the sum total of the eight forces (Fθ1 to Fθ8) applied in the direction of the circumference. If the torque with the sum total of forces Fθ1 to Fθ8 is 'T', then the relationship between T and the angle of the magnets' rotation θ will be repeated every 90°. This is expressed graphically in Fig. 7. As can be seen from the figure, there are periods during which a negative torque is generated and so if the direction of the current which flows to the drive coil during these periods is reversed, the torque represented by the dotted lines in Fig. 7 will also be reversed, and a positive torque will be generated.

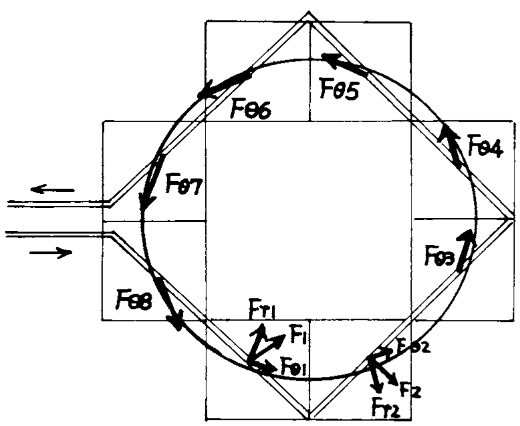


Fig. 6

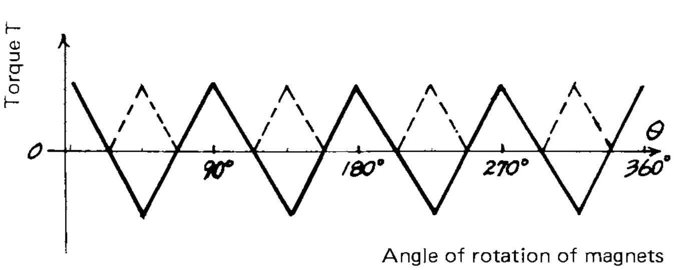


Fig. 7

In an actual motor, the magnets are shaped cylindrically in order to enhance the efficiency and the drive coil is shaped like a star, as is illustrated in Fig. 8.

When a constant current is passed to the drive coil, the relationship between the torque generated by the drive coil and the angle of rotation will materialize in the form of sine waves (see Fig. 9). The relationship between torque T and θ will be $T = Ki \cos 4\theta$ (K = constant). The dotted lines in Fig. 9 show what happens when the current which flows to the drive coil is reversed during the negative torque periods only.

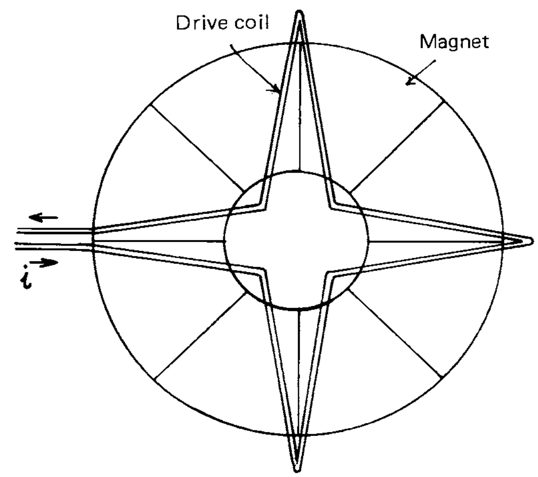


Fig. 8

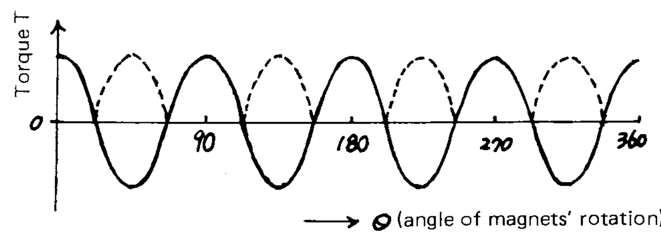


Fig. 9

5. Uni-torque

We looked into the principle behind the torque generation in section 4, and the last equation which we came up with was

$$T = Ki \cos 4\theta \quad \text{..........(1)}$$

Now, if the current flowing to the drive coil is based on sine waves, then:

$$i = I \cos 4\theta \quad \text{............(2)}$$

and so substituting equation (2) for equation (1), we arrive at:

$$T = KI \cos^2 4\theta \quad \text{.........(3)}$$

Let us now consider shifting the coil 22.5° and adding another drive coil: we shall call the first drive coil 'coil 1' and the second drive coil 'coil 2'. (Fig. 10)

First, the phase angle of the current flowing to both coil 1 and coil 2 is shifted 90°. The current flowing to coil 2 will be:

$$i_2 = KI \sin 4\theta$$

and the torque generated by coil 2 will be:

$$T_2 = KI \sin^2 4\theta \quad \text{.........(4)}$$

If T_0 is the sum of the torques (T_1 and T_2) generated in the two drive coils, then from equations (3) and (4), this will be:

$$T_0 = T_1 + T_2 = KI (\sin^2 4\theta + \cos^2 4\theta) = KI$$

Both K and I are constants, and so T_0 is constant regardless of the angle of rotation. (Fig. 11)

To allow a sine wave current which has been shifted 90° to flow to drive coil 1 and drive coil 2, the uni-torque motor employs two Hall elements.

We have now explained that the generated torque is constant. But how about the force which causes the platter to rotate?
The torque which causes the platter to rotate is the torque generated by the motor minus the loss torque. Included in the loss torque are the wear torque of the bearings, and the attractive torque generated by the magnets and yokes which pull against one another.
By raising the machining precision of the bearings and shaft, the fluctuations in the bearing wear torque can be eliminated. With the attractive torque, the slots in normal DC motors combine to produce large fluctuations depending on the rotation. However, with the uni-torque motor, the yokes are smoothed, and so the attractive torque is constant.
It will now have been gathered that even the generated torque and the loss torque will be constant regardless of the angle of rotation, and that the torque which causes the platter to rotate is also constant.
Fig. 12 shows the relationship between the torques in a conventional DC motor and a uni-torque motor. It can be seen that the fluctuations in the uni-torque are extremely low, and that there are few higher harmonic components. Therefore, the result is a low absolute wow & flutter. Also, higher harmonic components are not contained and the ultimate sound is clearer and crisper than the difference in the values of the two motors' wow & flutter.

6. Servo control circuit

(1)Speed detection circuit

A newly developed magnetic induction detection circuit (patent pending) is used to detect the rotation speed of the motor.
The principle behind this is as follows. When there is a conductor in a magnetic field and the magnetic flux of the field changes, an electromotive force whose size varies in accordance with the changes is generated in the conductor. If this is expressed as an equation, we arrive at:

$$v = -d\Phi/dt$$

Therefore, a conductor which is located beneath one pole of a magnet will not vary the magnetic flux even if the magnet is rotated, and so no voltage will be generated. However, voltage will be generated with a conductor located on the dividing area between the north and south poles. As shown in Fig. 13, nine conductors are placed under one pole for a total of 72 conductors all round the circumference of the magnet. If we give these conductors numbers ranging from 1 to 72, a voltage is generated at conductor no. 1, 10, 19, 28, 37, 46, 55, and 64, or at the first conductor under every pole. The direction of the voltage is reversed for each of these conductors in line. However, the conductors are wired in reverse for each, and so the direction of the eight voltages becomes the same,

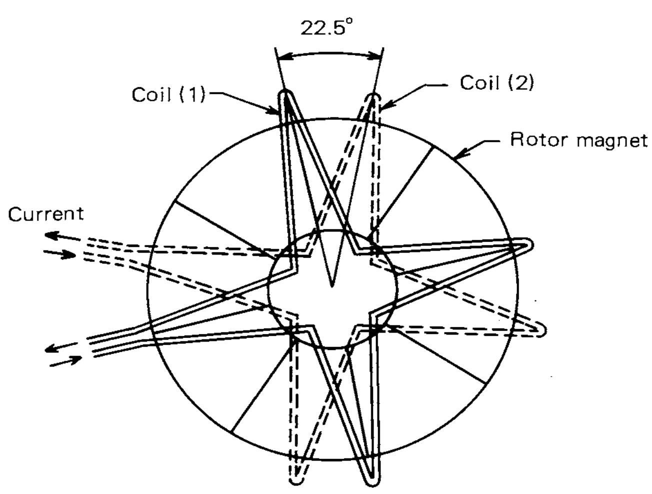


Fig. 10 Coil shape and rotor magnet

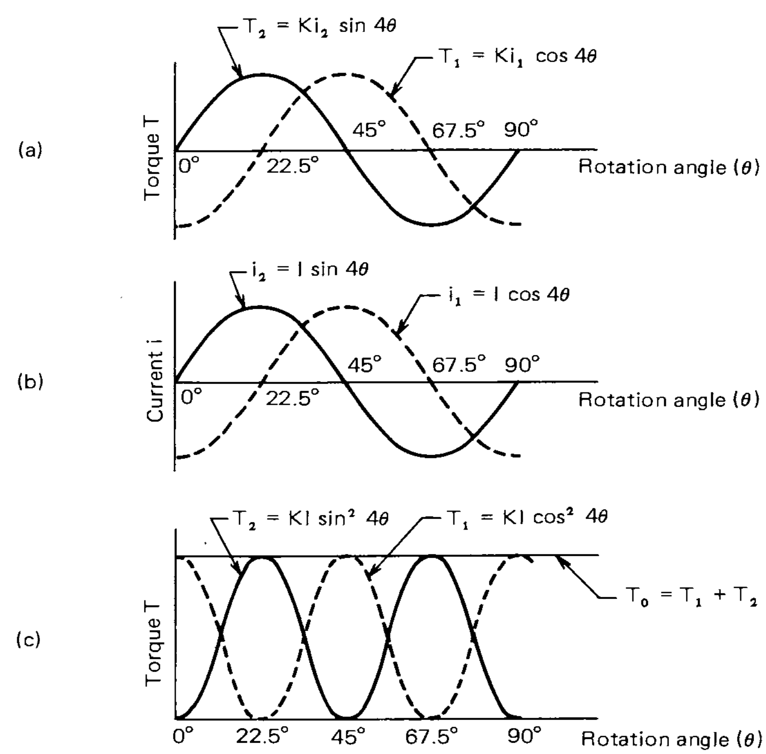


Fig. 11 Torque and rotation angle

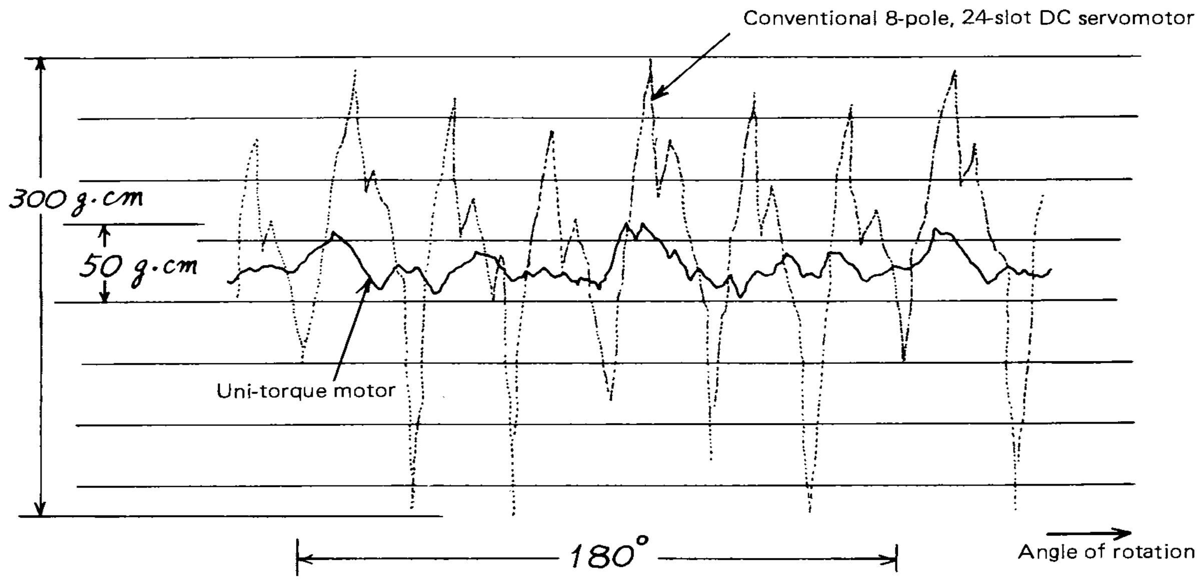


Fig. 12

and the eight voltages combine to form a single voltage. In other words, a signal is provided which reverses the rotation of the magnet 72 times. This signal is used to detect the voltages at the eight locations and so it is a high-precision and constant output signal at all times even if there are fluctuations in the magnet or eccentricity. These conductors are actually made with high-precision print patterns. The detection frequency for 33-1/3 rpm is 20Hz, and 27Hz for 45 rpm.

(2)Limiter amplifier, waveform shaper

The speed detection signal has a low level and still contains AM components, and so it will produce an error if it is not amplified. Therefore, it is amplified in an excess saturation by the high-gain amplifier and then by the waveform shaper, and it becomes a square wave signal. This means that the AM components are limited and the error eliminated.

(3)Differentiation circuit, multiplier

The servo loop response frequency is determined by the speed detection frequency, and the higher the response frequency, the faster the system's response and the higher the stability with regard to disturbances. This is why the speed detection frequency is multiplied and the response is accelerated. The signals which are differentiated by C03, R08, C04 and R09 resemble those illustrated in Fig. 14, although only the downward pulse is added by diodes CR02 and 03, the pulse intervals are halved and the frequency doubled.

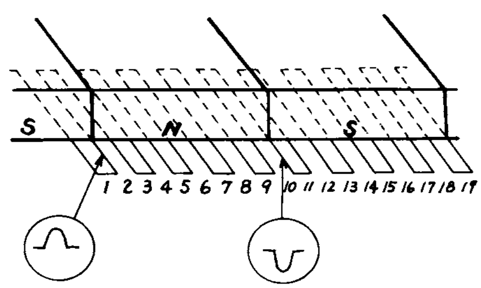


Fig. 13

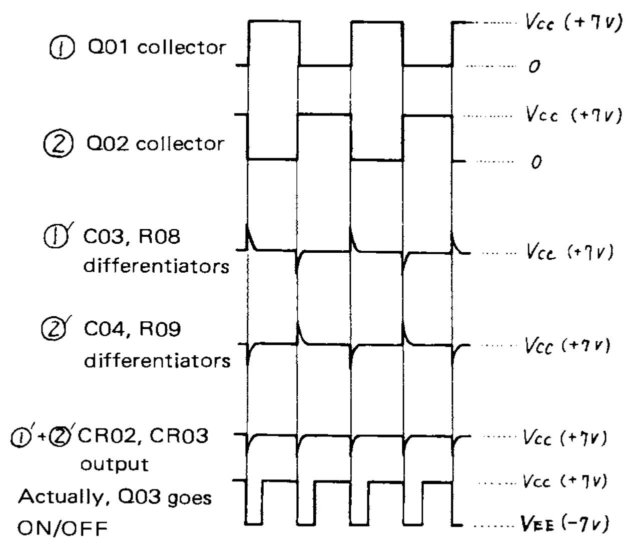


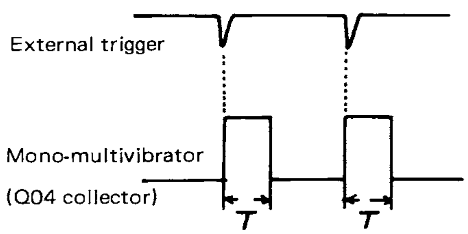
Fig. 14

(4)Mono-multivibrator

The Uni-torque motor employs a mono-multivibrator to convert the frequency variations of the speed detection signal into DC variations. The mono-multivibrator is designed so that it is synchronized with an external trigger, reversed and then returned to its original position after a certain time period. Refer to Fig. 15.

When the speed changes, the output of the mono-multivibrator resembles the graphic representation in Fig. 16.

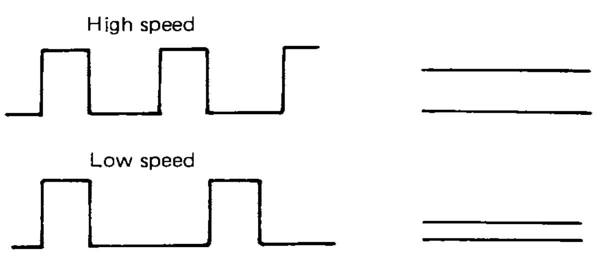
When the speed increases, the duty ratio of the mono-multivibrator also increases, and if this is smoothed through the low-pass filter, the DC voltage increases. Conversely, if the speed decreases, the mono-multivibrator's duty ratio decreases, and the DC voltage also decreases (the duty ratio is the ratio between the operation and non-operation times).



T: Time constant determined by circuit constant. The speed is selected when the time constant is changed.

Fig. 15

The accuracy of the speed is determined by the precision of the circuit which determines the time constant, and so metal-film resistors and film capacitors are employed in the circuitry.



(a) Mono-multivibrator output (b) Low-pass filter output

Fig. 16

(5)Low-pass filter

The mono-multivibrator output contains a large amount of ripple components and so the low-pass filter attenuates the ripple. The filter features a quadratic construction and provides an attenuation of −60dB.

(6)Reference voltage circuit

The mono-multivibrator output is compared with the reference voltage and the difference between the two voltages is amplified and fed to the Hall elements. The reference voltage acts as the standard for the speed, and so it is essential that it be stable. The reference voltage is produced through the 2-stage stabilizing circuit. Fluctuations in the reference voltage from changes in the temperature and other factors are canceled out with ±2 power sources. Furthermore, any fluctuations caused by the temperature of the mono-multivibrator output are canceled out using the temperature characteristics of the diodes. No problems are posed from a practical viewpoint with a speed fluctuation of 0.2% across a temperature range of 5°C – 35°C.

(7)Phase compensator

If the loop gain is increased with a view to raising stability with respect to the load with servomotors, oscillations are generated, and this results in instability. This is why a phase comparator is inserted into the system to prevent such oscillations from arising. R24, C09, R25, and C10 are used for this purpose. The system is designed to yield an inertia moment of 200kg/cm^2 (value of the PS-48 turntable) which is regarded as optimum. Therefore, if the inertia moment of the turntable is reduced, the speed of the turntable is adversely affected by a click motion. This is called hunting in the servo system.

(8)Hall elements

The Uni-torque motor is driven by sine wave signals, and two Hall elements are adopted for the switching.

The output voltage (V_H) of the Hall elements is proportionate to their current I_H and strength B of the magnetic field. If the proportional constant is K, then:

$$V_H = KBI_H$$

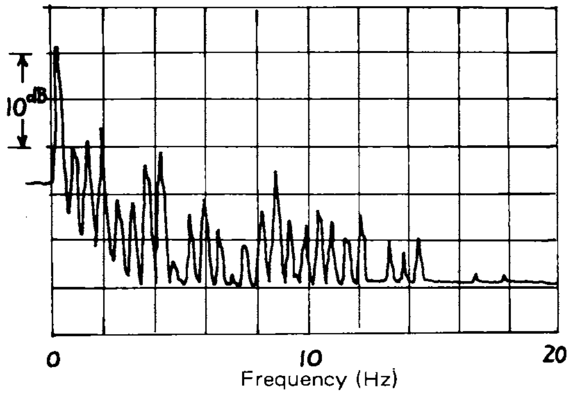
The magnetic distribution is a sine wave distribution at the outside of the magnet, and so the Hall elements are placed below and a sine wave output is provided. Also, the speed is proportionate to the size of the output voltage, and so current I_H is varied and the speed of rotation controlled. In other words, the mono-multivibrator output increases and exceeds the value of the reference voltage if the rotation speed is increased. Therefore, the error voltage increases on the negative side and the I_H decreases. This means that the V_H decreases and the rotation speed returns to its original value. Conversely, the mono-multivibrator output decreases and falls below the reference voltage when the rotation speed drops, and the error voltage increases on the positive side. I_H increases and the rotation speed accelerates.

(9)Drive amplifier

The output of the Hall elements is too low to be able to drive the motor, and so it is amplified by the drive amplifier.

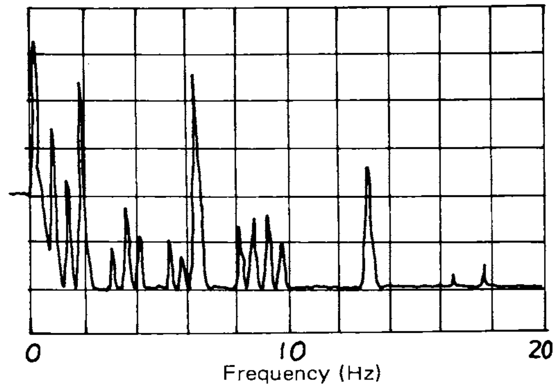
If the motor is left locked for a prolonged period of time, the current will become excessive, the temperature will rise and the motor's service life will be shortened. That is why this motor incorporates a protection circuit which halves the current and safeguards against rises in temperature when the motor is locked. More specifically, it provides the drive amplifier with frequency characteristics, and when the platter comes to rest, the gain is reduced and it reaches its maximum value if the platter is turned even a fraction. During start-up, the gain increases only during the CR's time constant intervals and so the speed increases and the torque is always keep at its maximum value.

7. Specifications



W & F : 0.025 % WRMS

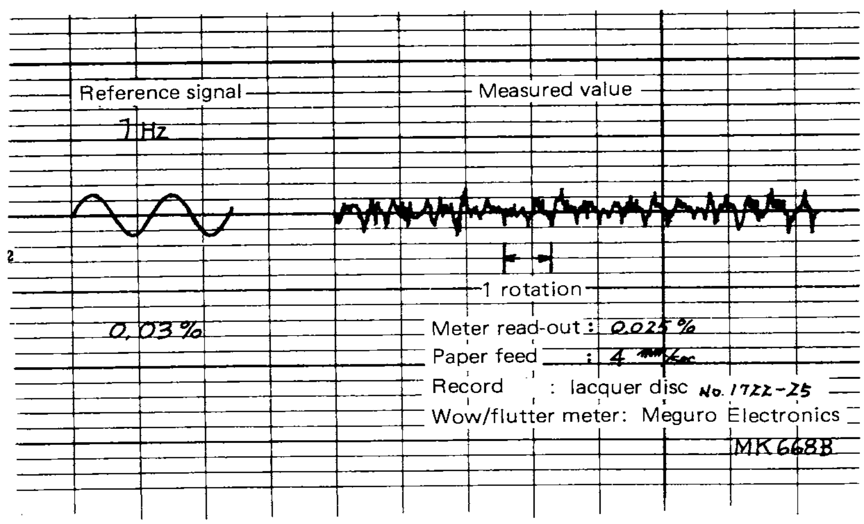
Uni-torque motor



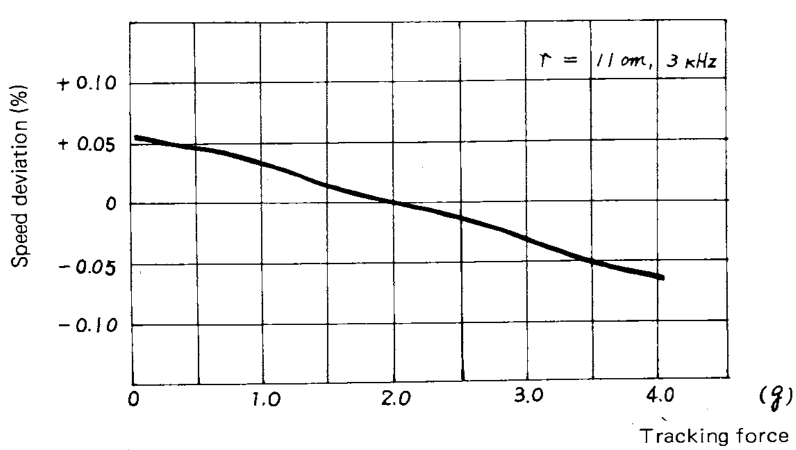
W & F : 0.040 % WRMS

Conventional 8-pole, 24-slot
DC servomotor

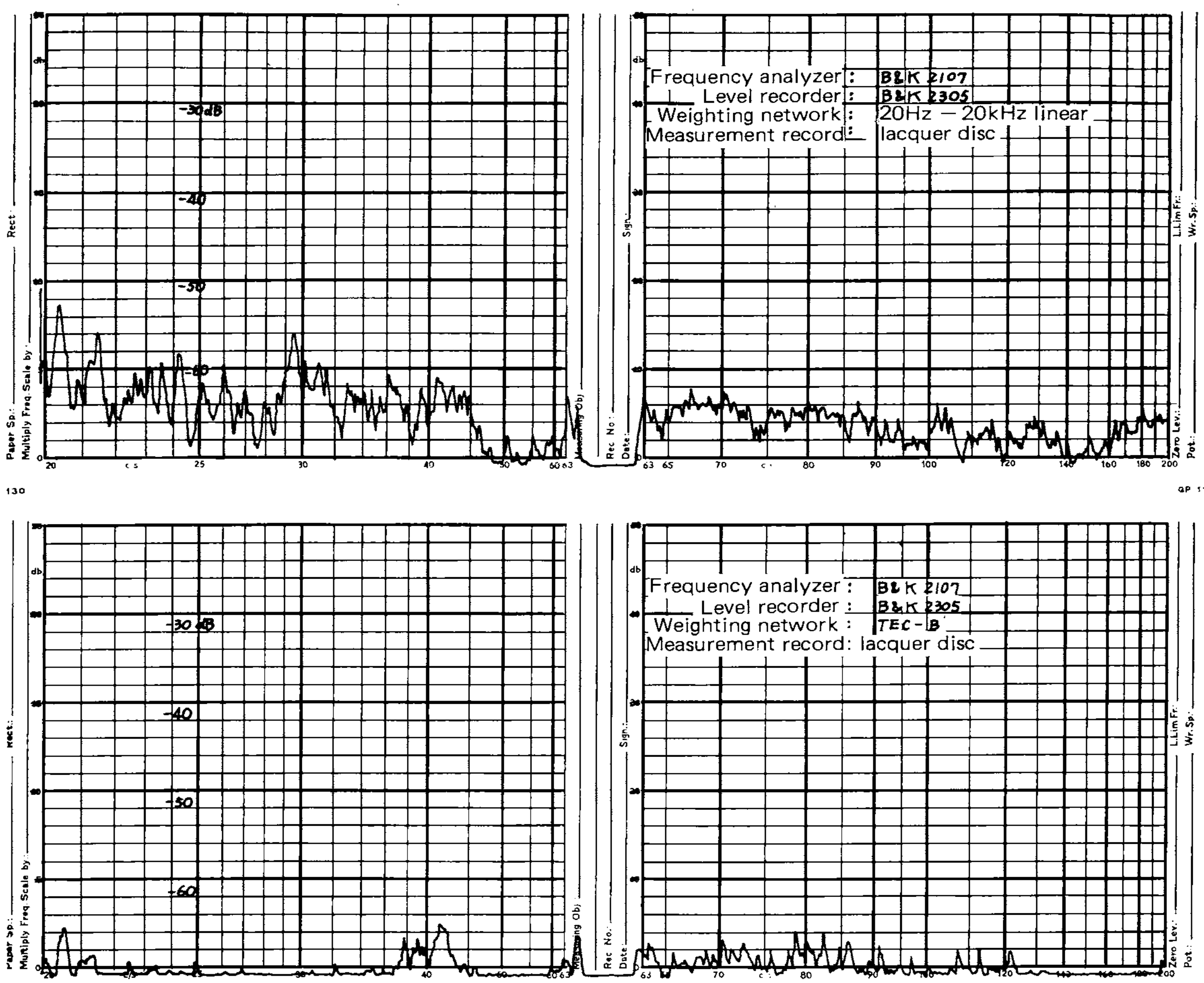
Wow/flutter (frequency analysis)



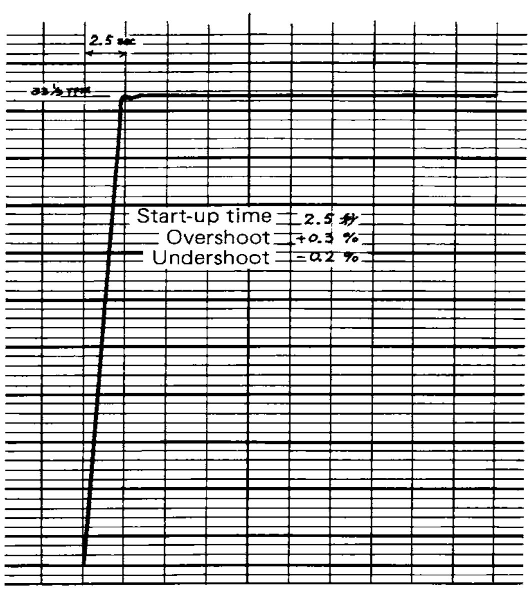
Wow/flutter characteristics



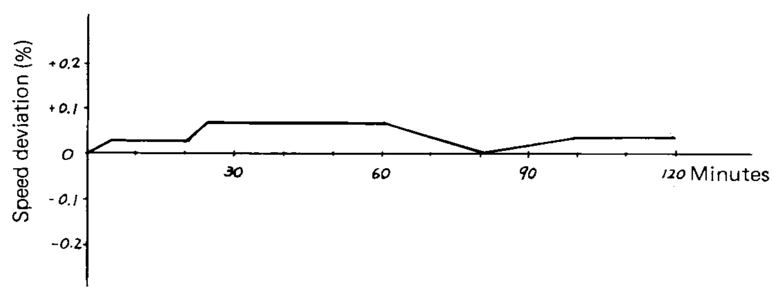
Load characteristics



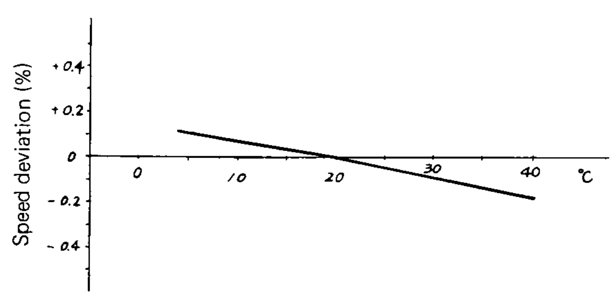
S/N ratio



Start-up characteristics

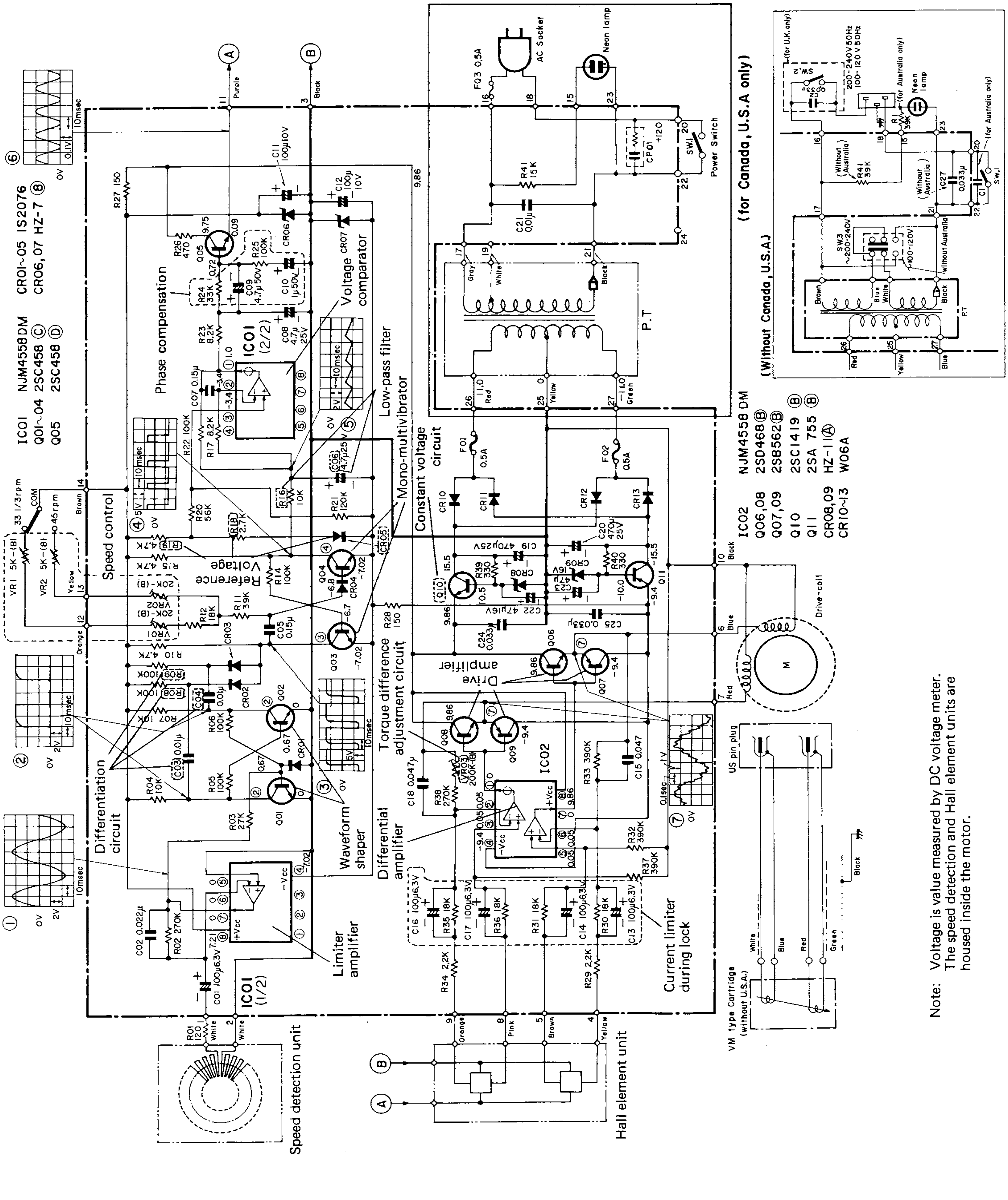


Time characteristics



Temperature characteristics

8. Circuit diagram



Hitachi, Ltd. Tokyo Japan

Head Office	:	5-1, 1-chome, Marunouchi, Chiyoda-ku, Tokyo
Tel.	:	Tokyo (212) 1111 (80 lines)
Cable Address	:	"HITACHY" TOKYO

Printed in Japan (H)