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HIGH-SPEED AC MOTOR INCLUDING THE FUNCTION OF A MAGNETIC FREQUENCY TRIPLER

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The new electric motor is the magnetic combination of a magnetic frequency multiplier and a AC motor which share the common magnetic yoke. The motor operates near the synchronous speed (10,800 rpm) by applied the single-phase commercial source at 60 Hz. The new machine is called "high-speed hybrid AC motor" because the combination of a motor and a frequency converter. This paper describes the structure and the operating characteristics of the new motor.

INTRODUCTION

The authors have developed the magnetic three times frequency multiplier(frequency tripler) with series-connected reactor circuit and the 3-legged core type tripler is suited to operate an electric motor at a high speed.[1,2] Since both the magnetic tripler and the motor have each magnetic circuit, the magnetic combination can simplify the structure. We call it "hybrid motor". In this paper we present the characteristics of the hybrid single-phase induction motor and the outline of the advanced two-phase type motor is described.

STRUCTURE OF A HIGH-SPEED INDUCTION MOTOR

The magnetic structure of the high-speed hybrid induction motor consists of a 3-legged core as shown in Fig.1.[3] One of the limbs is a salient pole in which a cage rotor is installed. The poles have shading coils. The capacitor C_2 are connected to the winding N_c at the output limb. The circuit enhances the third harmonic component and reduces the fundamental component and other harmonics. The left-hand limb with a gap (L) acts as a linear reactor and the right-hand limb with small section (SR) as a saturable reactor. Two limbs have the windings N_L and N_{SR} which are connected in opposite-series. The circuit (L_1, C_1) in the input side reduces the distortion of an input current and improve the power factor.
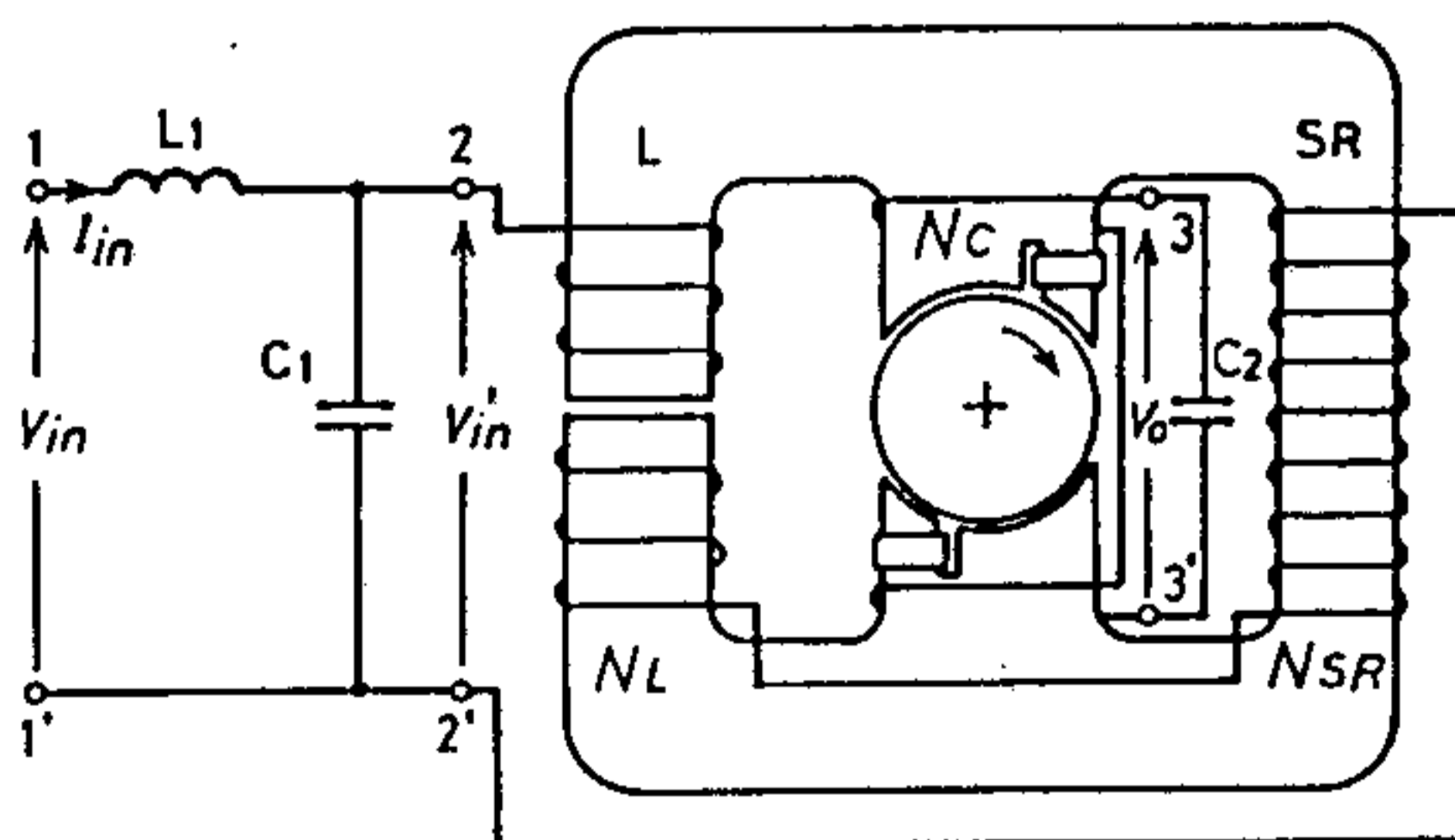

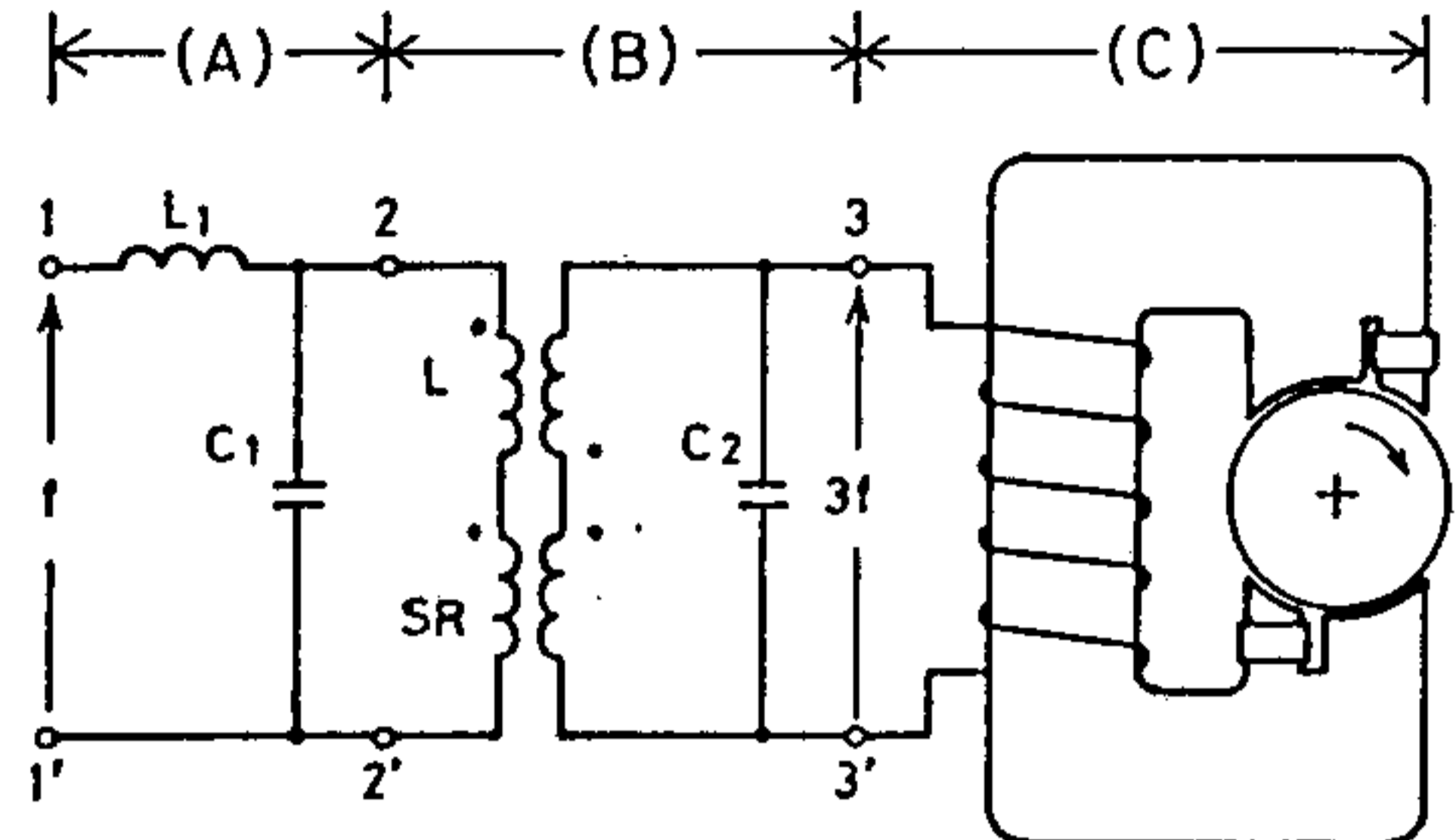Fig.1 High-speed single-phase induction motor

Fig.2 Equivalent circuit

FUNDAMENTAL CHARACTERISTICS

The simplified equivalent circuit of the hybrid induction motor in Fig.1 is illustrated in Fig.2. The circuit consists of three parts. The part (A) is a filter circuit, the part (B) a three-times frequency and the part (C) a single-phase induction motor. In the part (B), a linear reactor and a saturated reactor are connected in series and the secondary windings in opposite-series. We call the circuit "series-connected reactor circuit".

The basic frequency conversion of a series-connected reactor circuit can be explained by approximating the characteristics of linear and saturated reactors as shown in Fig.3(a). When a sinusoidal voltage with the rms value V_{in} and the angular frequency ω is applied, waveforms in the circuit are shown in Fig.3(b). The saturated reactor SR is saturated over the flux linkage λ_k for the periods $\theta_{sl} < \omega t < \pi - \theta_{sl}$ and $\theta_{sl} + \pi < \omega t < 2\pi - \theta_{sl}$. As the waveform of the secondary voltage is represented by the Fourier series, the rms value of the fundamental and (2n+1) order harmonics are expressed as

$$V_{o(f)} = \frac{1}{\pi} \{ \frac{2}{\alpha+1}(2\theta_{sl} \cdot \sin 2\theta_{sl}) - \pi \} \cdot V_{in} \qquad \ldots (1)$$

$$V_{o(2n+1)f} = \frac{2}{\pi(\alpha+1)} \{ \frac{\sin 2\theta_{sl}}{n} - \frac{\sin 2(n+1)\theta_{sl}}{n+1} \} \cdot V_{in} \qquad \ldots (2)$$

where the phase angle θ_{sl} is given as,

$$\theta_{sl} = \cos^{-1} (\frac{\omega \lambda_k}{\sqrt{2} V_{in}}) \qquad \ldots (3)$$

Equation (1) indicates that the fundamental component vanishes in the condition as,

$$\frac{2}{\alpha+1}(2\theta_{sl} - \sin 2\theta_{sl}) = \pi \qquad \ldots (4)$$

Then the output voltage has the odd-order harmonics including the three times frequency voltage as a prime component. Figure 4 is obtained by using Eqs.(1) and (2). The torque of the hybrid motor is calculated by the sum of torque which each harmonic component generates.
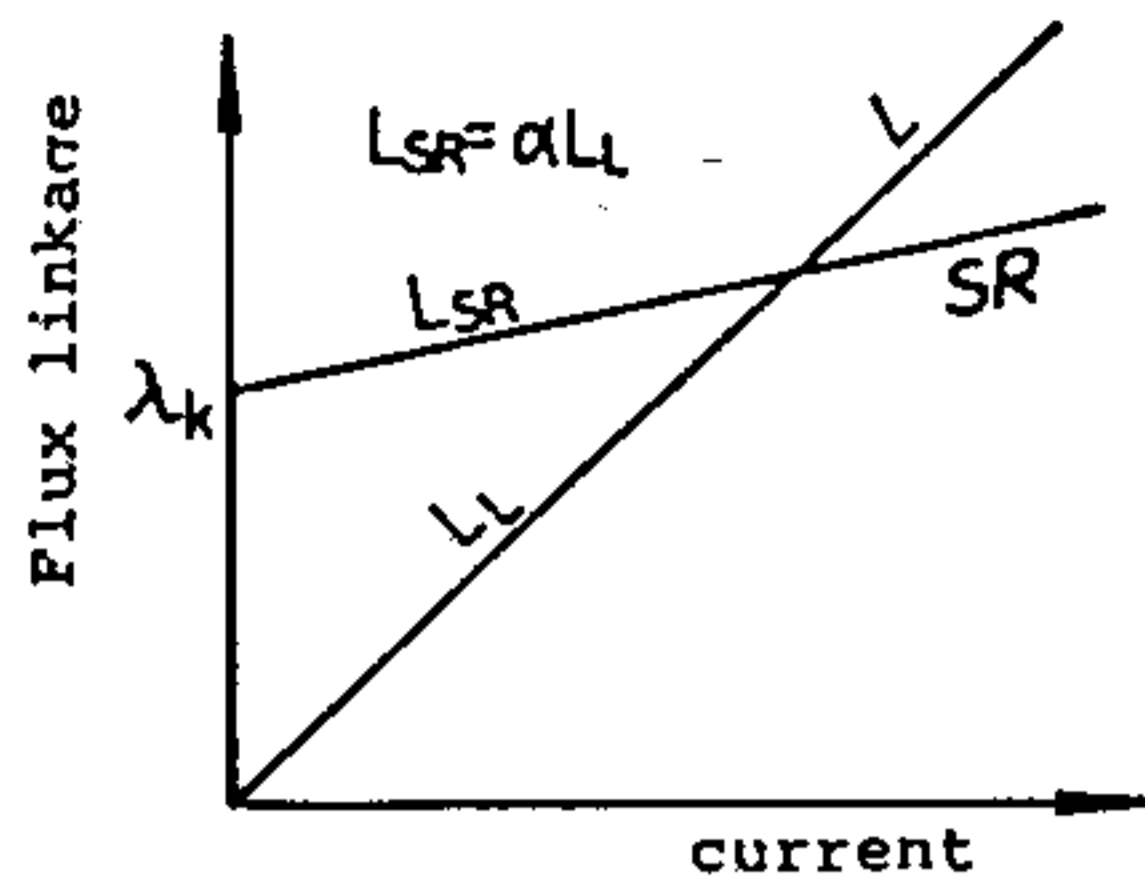
(a) Idealized flux linkage curves(SR, L)
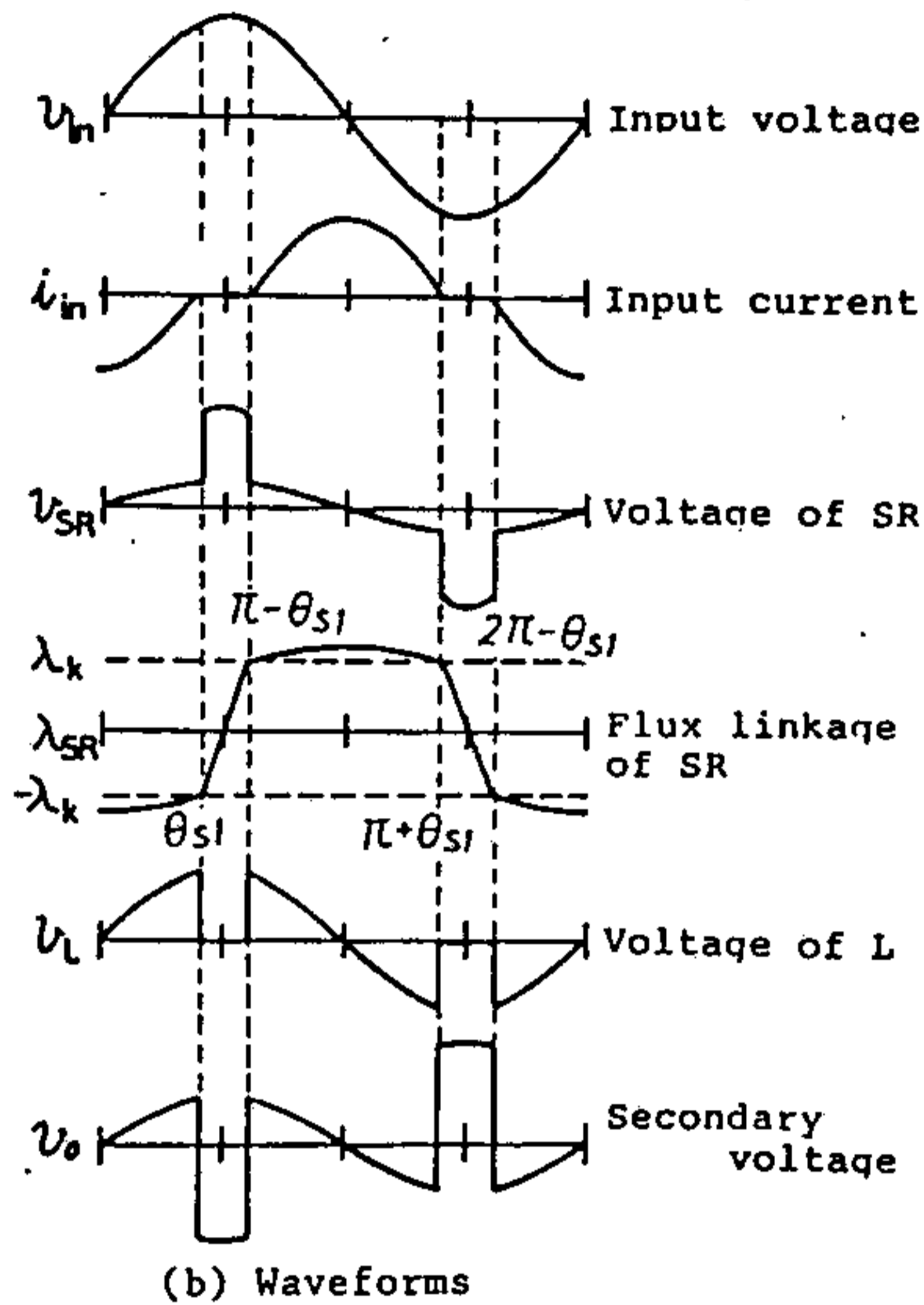
(b) Waveforms

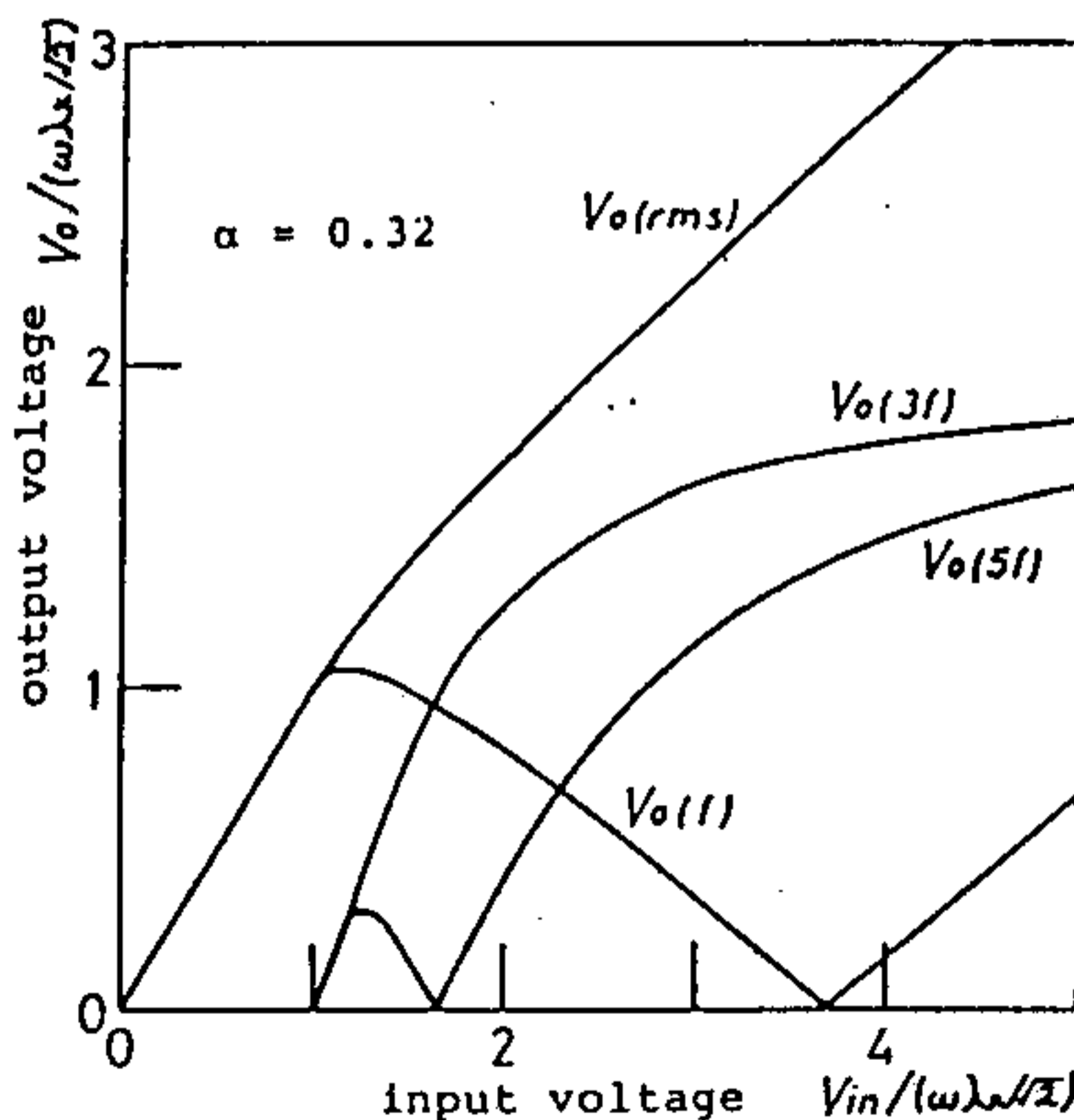Fig.3 Waveformes in series-connected reactor circuit

Fig.4 Characteristics of series-connected reactor circuit

SINGLE-PHASE HYBRID INDUCTION MOTOR

Structure

The configuration of the single-phase hybrid induction motor made for test is illustrated in Fig.5. The yoke is made of Fe-Si plate with a thickness 0.35 mm and a squirrel-cage rotor is used. The windings N_L, N_{SR} and N_c are 75, 26 and 400 turns, and the constants of elements are $L_1 = 32.9$ mH, $C_1 = 900$ F and $C_2 = 4$-$10\mu F$ respectively. A single-phase commercial source at 60 Hz is supplied to the motor.

Input characteristics

As the hybrid motor has a saturated reactor for frequency changer, an inductive input current flows and the power factor becomes low. Therefore, a capacitor C_1 is connected parallel to input terminals for the improvement of power factor. And to obtain a high-speed rotation in the wide range of input voltage, a linear reactor L_1 is connected to it in series. The voltage between 2-2' terminals keeps constant for the fluctuation of an input voltage because of the function of a constant voltage regulator.

Figure 6 shows the steady-state characteristics 'as a function of an input voltage on the tested motor. The high-speed rotation can be obtained in wide range of an input voltage and the power factor is 0.78 at an input voltage 130 V.
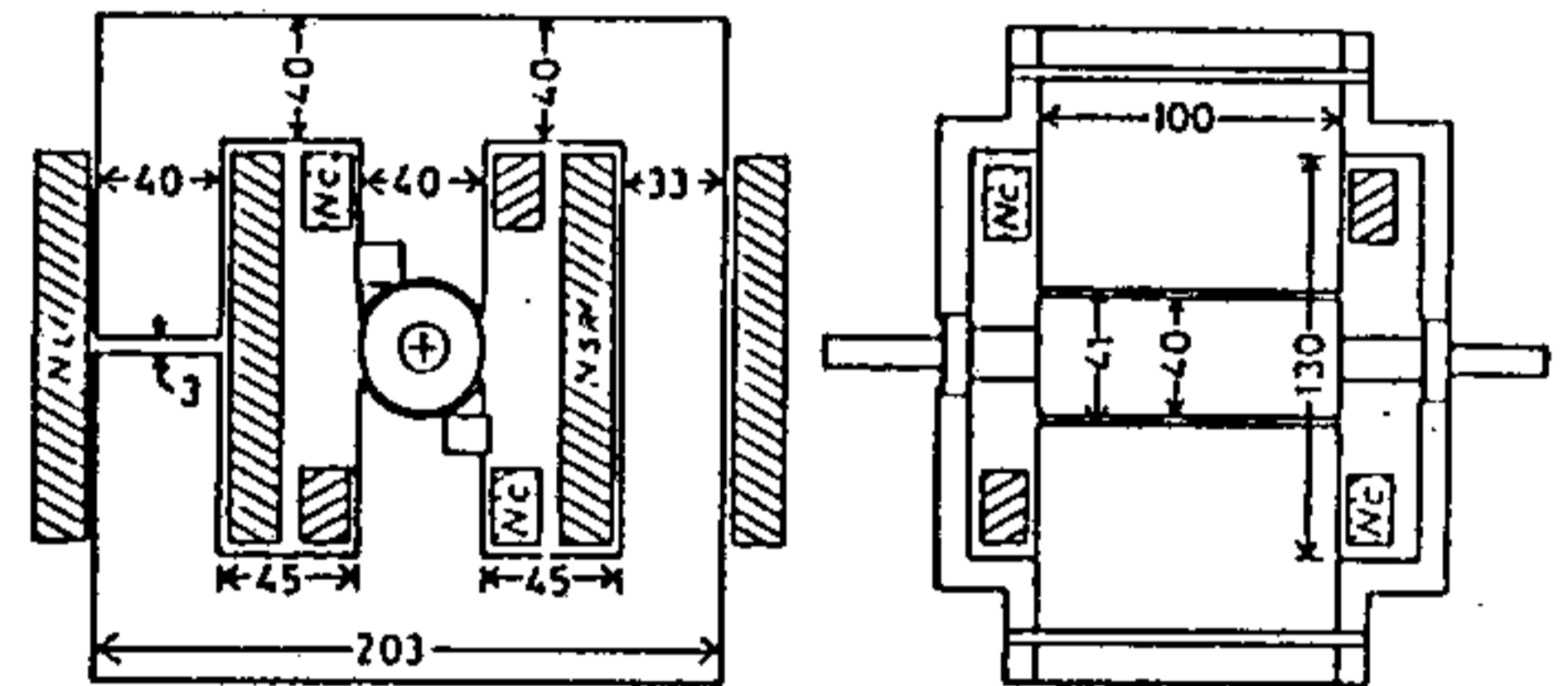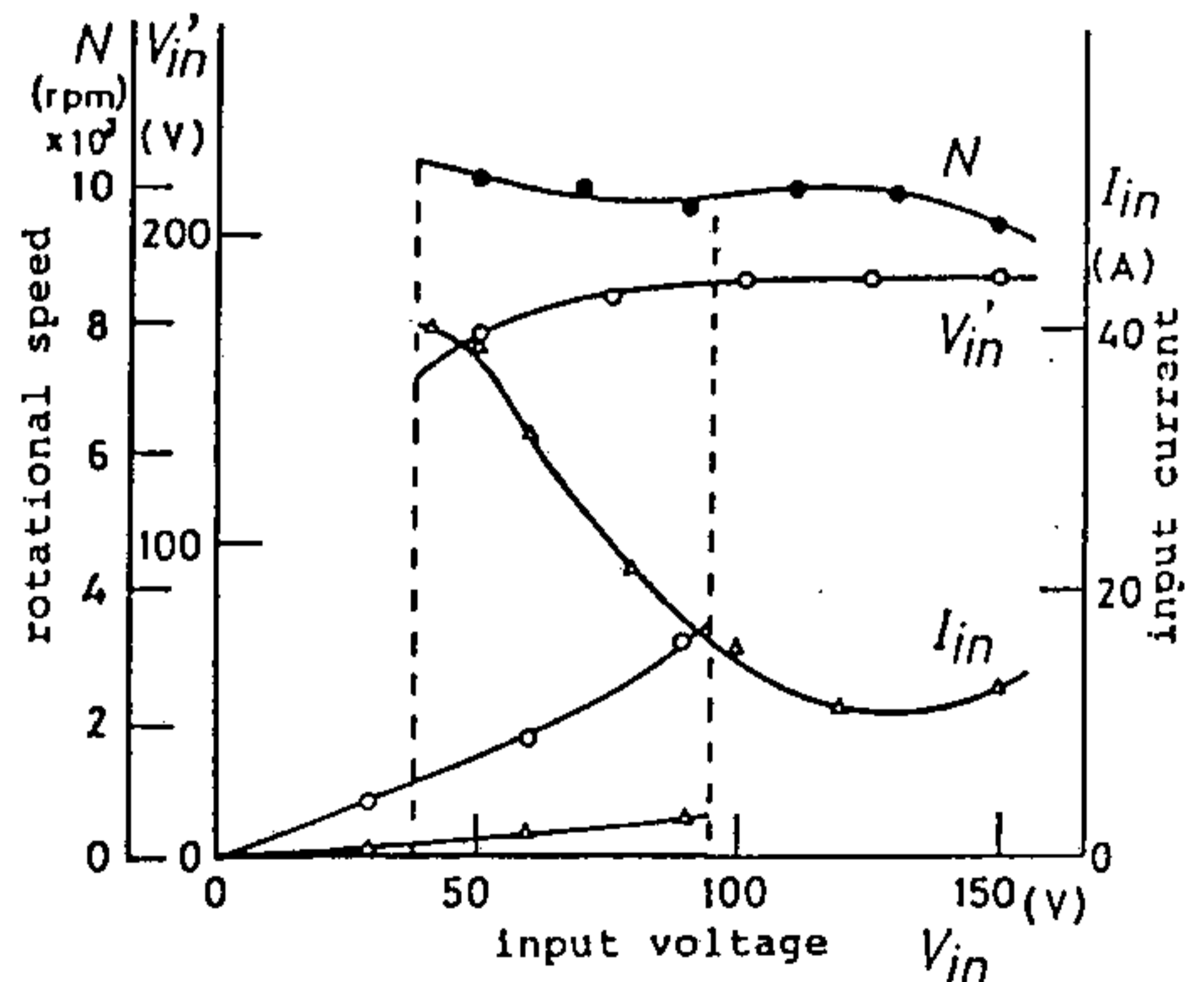

Fig.5 The tested single-phase hybrid induction motor

Fig.6 Characteristics as the function of an input voltage

Torque-slip characteristics

Figure 7 shows the torque-slip characteristics of the single-phase induction motor. The torque-slip curve is similar to that of the conventional single-phase induction motor. But the negative torque of the fundamental component affects the torque-slip curve at 4,000 rpm and the crawling effect can be observed. The efficiency of the motor was 7.2 % as a rotational speed is 9,000 rpm.

OUTLINE OF TWO-PHASE INDUCTION MOTOR

The single-phase induction motor has unavoidable defects, starting torque and efficiency. In order to remove these defects, we propose the rotating-field type hybrid motor.

Figure 8 shows the three-phase to two-phase magnetic frequency tripler circuit. In the figure, two triplers shown in Fig.2 are connected in Scott-connection. Therefore an input voltages at each tripler is shifted at 90 degree. The three-times output voltages have the phase difference of 270 degree.

Two-phase hybrid induction motor is illustrated in Fig.9. Each pole has the magnetic frequency tripler and the third harmonic flux flows through the rotor and the yoke.

CONCLUSION

The new high-speed motor with the combination of a magnetic frequency tripler and an AC motor have been proposed. The structure of motor is simple and does not need the semiconductor device. The principle of operation have been reported briefly. And it has been indicate that the characteristics include the function both of a magnetic frequency tripler and of an AC motor.
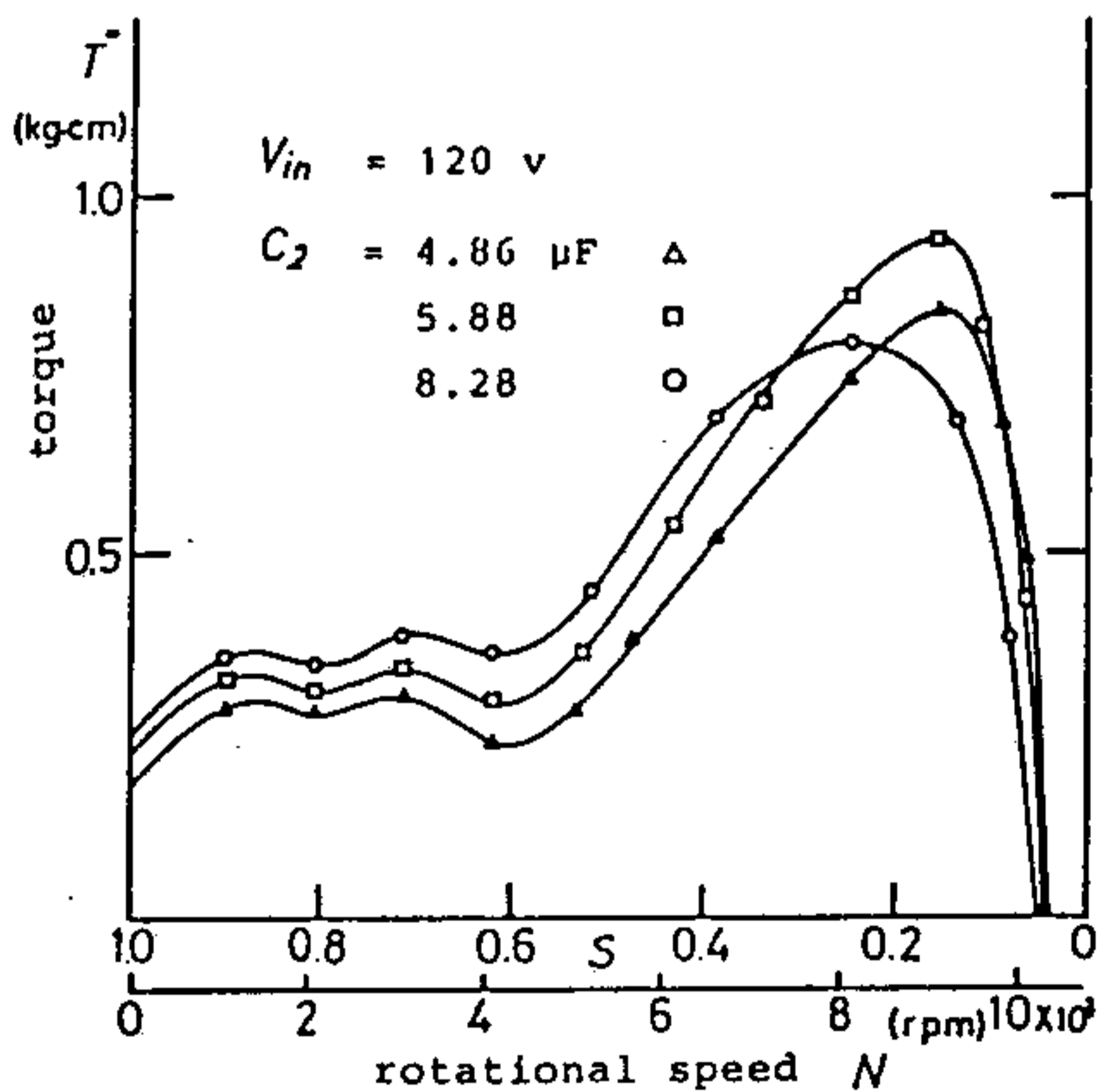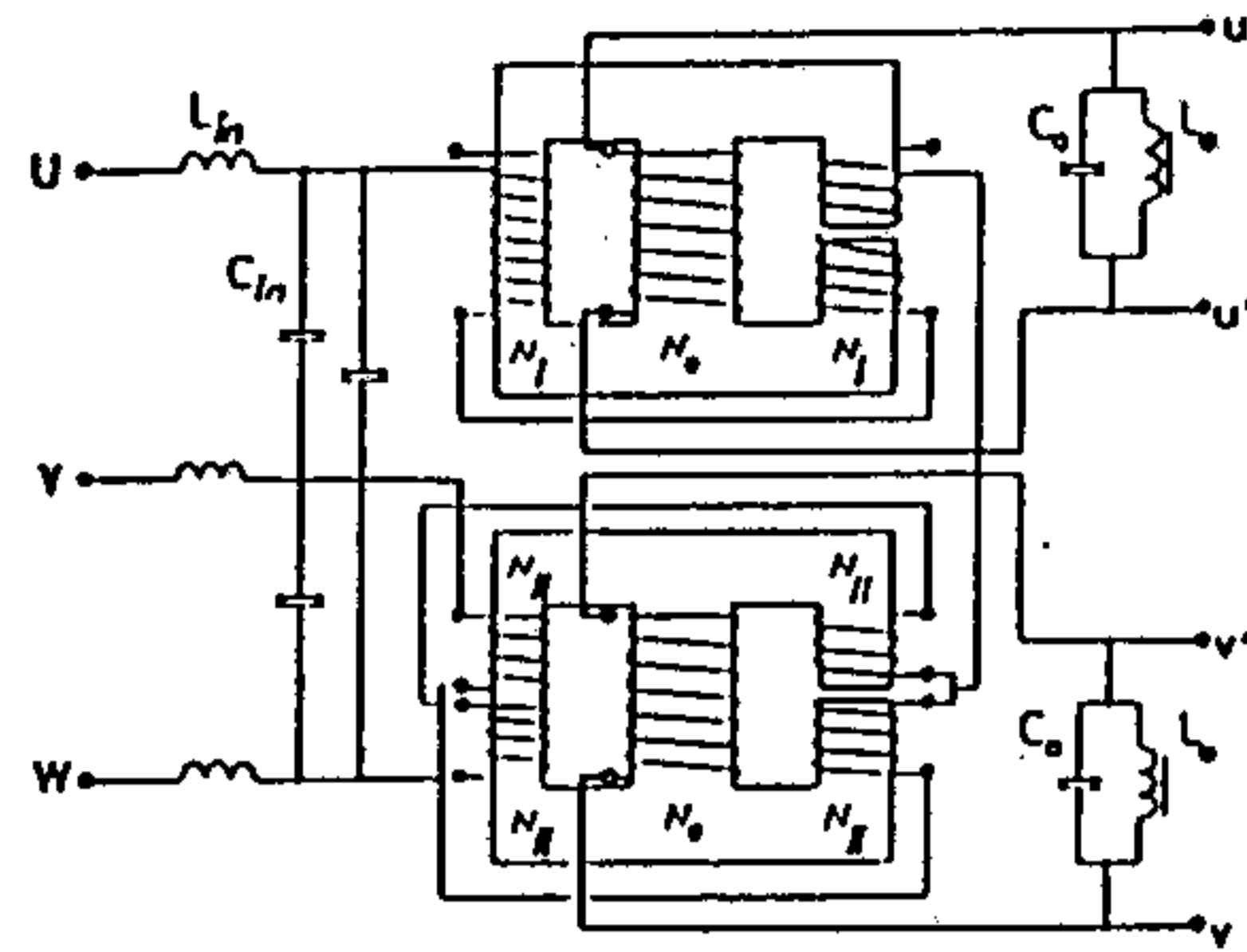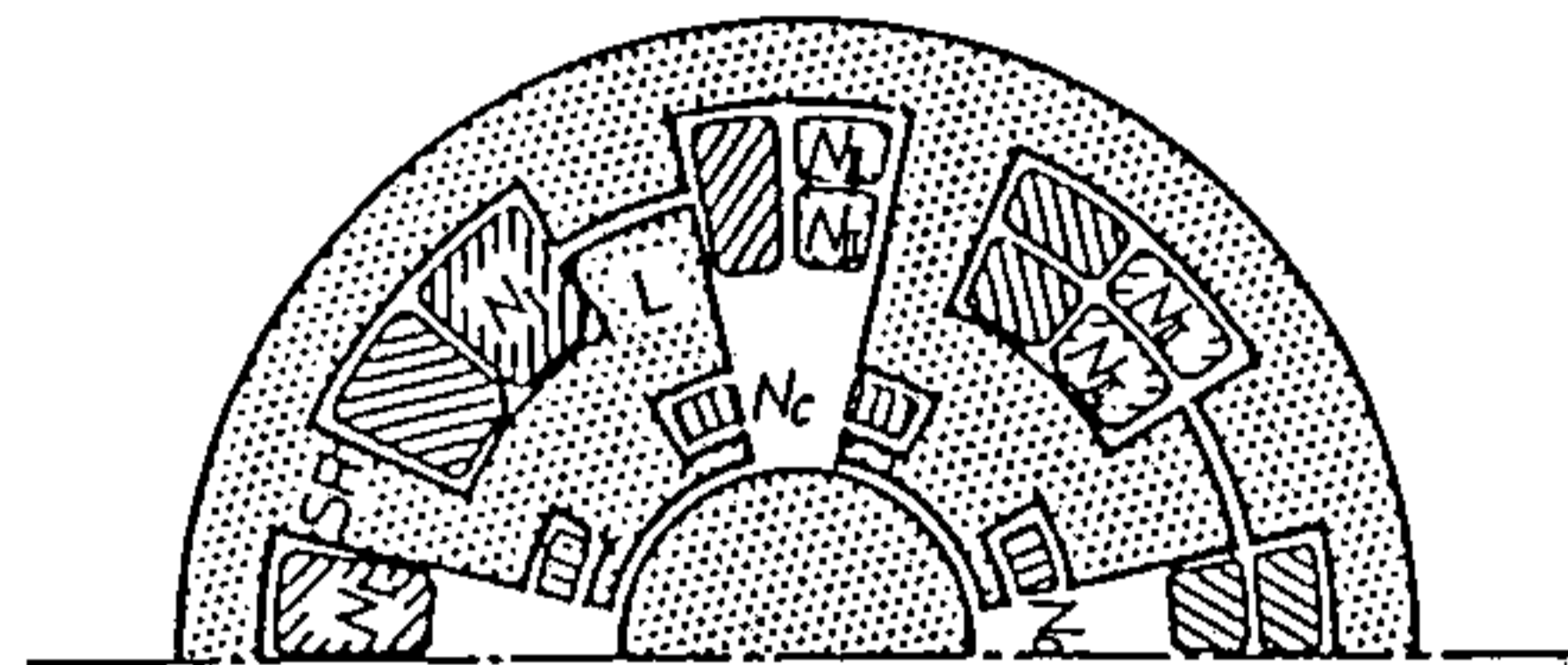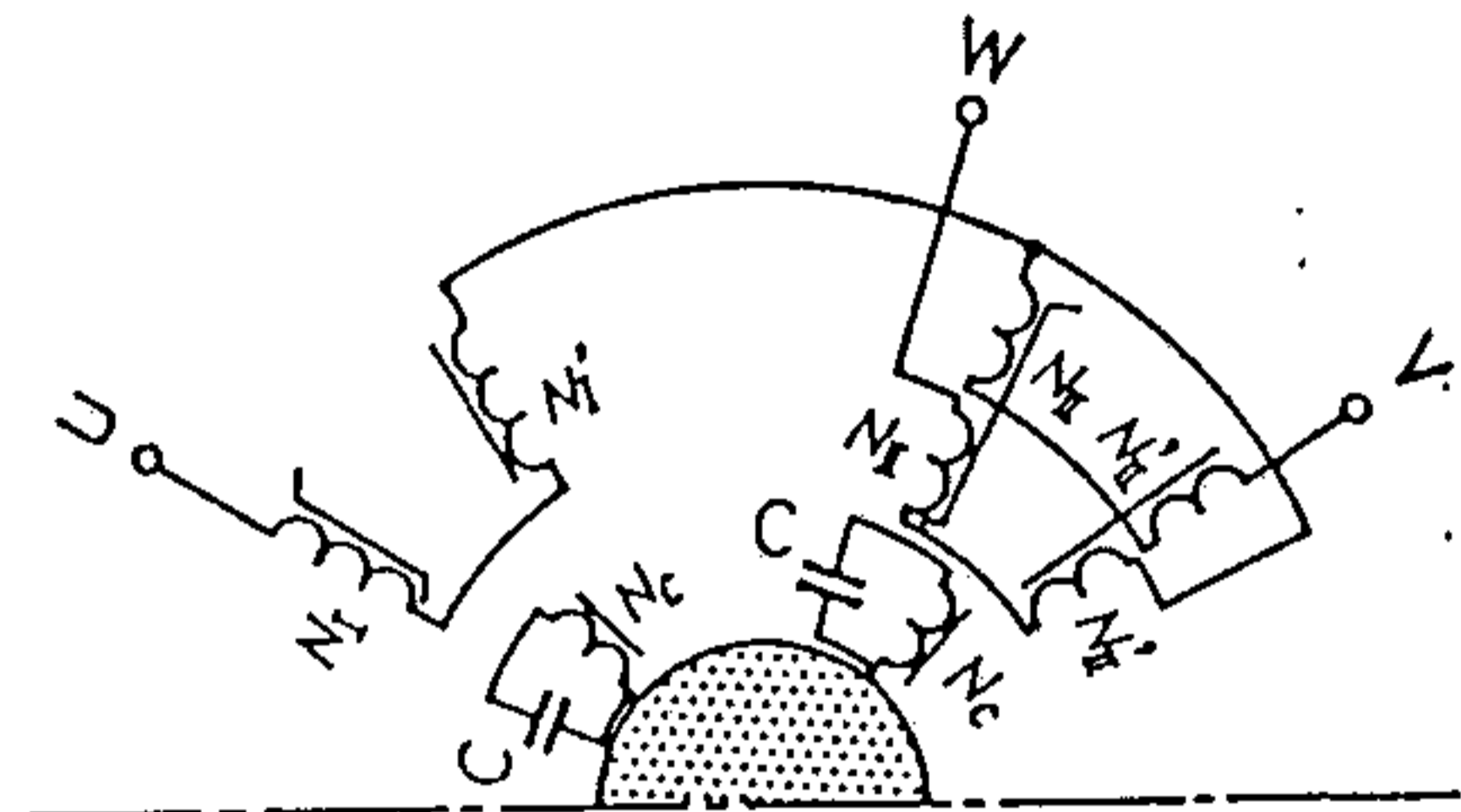

Fig.7 Torque-slip curve

Fig.8 Two-phase frequency tripler

(a) Cross section

(b) Connection

Fig.9 Two-phase hybrid induction motor

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