MEMOIRS OF THE SCHOOL OF ENGINEERING, OKAYAMA UNIVERSITY, Vol. 4, No. 1, SEPTEMBER 1969

On the Speed Control of a Three Phase Squirrel Cage Induction Motor Controlled by a Variable Frequency Three Phase Thyristor Inverter

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(Received June 10, 1969)

As one of the wide application of thyristor circuits, the inverter has a promising future and has been investigated vigorously. On the speed control of a squirrel cage induction motor by using a variable frequency thyristor inverter, although few papers have been presented, there seems to be many problems to be solved imminently. In this paper, the stability of performance of a thyristor inverter on this theme has been confirmed and some particular points with relation to practical use also have been discussed.

§ 1 Introduction

The speed control of an induction motor by using a variable frequency thyristor inverter, has distinctive merits such as compact size, easy maintenance and low cost over the method of d-c machinery. Also, compared with the conventional secondary resistor control of the wound-rotor induction motor, the speed control by a variable frequency thyristor inverter has higher efficiency, lower cost and need not a wound-rotor induction motor.

On the speed control of induction motors by thyristor inverters, few papers[1, 2)] have been presented. However, there seems to be many problems that should be solved to be put into practical use such that rectangular wave forms of the inverter result in the reduced efficiency ; that abrupt changes of load and of power factor affect the stability of operation ; that the failure of the inverter performance can be caused by outer noises ; and that noises generated by the inverter in turn will affect other installations.

Authors attempted to make clear the problems concomitant to driving a squirrel cage induction motor with a thyristor inverter. In this paper, experimental data and some considerations are presented. The adopted inverter is a type of thyristor three phase improved bridge inverter by Dr. Sato[3)]. The reversal of motor revolution was made by changing the phase sequence of the inverter. Also, the feedback of motor speed was added for the constant speed control.

§ 2. Circuit Configuration

2.1 Inverter Circuit

The thyristor three phase improved bridge inverter which was adopted, is showen in Fig. 1. This inverter has features that the peak of load voltage, when an inductive load, is restained within the source through the feedback of reactive energy and the high efficiency is kept for the load, the power factor of which varies in wide range.

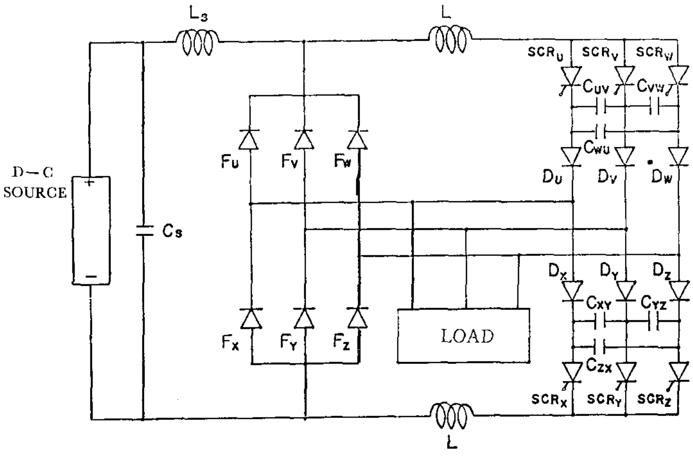


Fig. 1. Inverter circuit.

2.2 Auxiliary Circuit

The block diagram of auxiliary circuits, is indicated in Fig. 2. The pulses, generated by the UJT generator, are distributed by the thyristor ring counter to six pulse arrays each of which differs from 60 degrees and has a pulse width of 60 degrees. The logic circuit reverses the phase sequence of pulses which are fed to Royer generators. The Royer generators insulate the pulses in order to meet the requiring from the inverter. Then, the output pulses of the Royer generators about 7 kHz are converted by full-wave rectifying devices.

2.3 Constant Speed Regulation Circuit

The regulation of constant speed, if errors exist, is achieved by adjusting the inverter frequency to the reference speed. In Fig. 3, the difference of voltage between that of reference and of tachometer-generator $2E_0-E_s=E_0+(E_0-E_s)$ applies to the emitter-base of a transistor Q. At equilibrium, the voltage ΔE

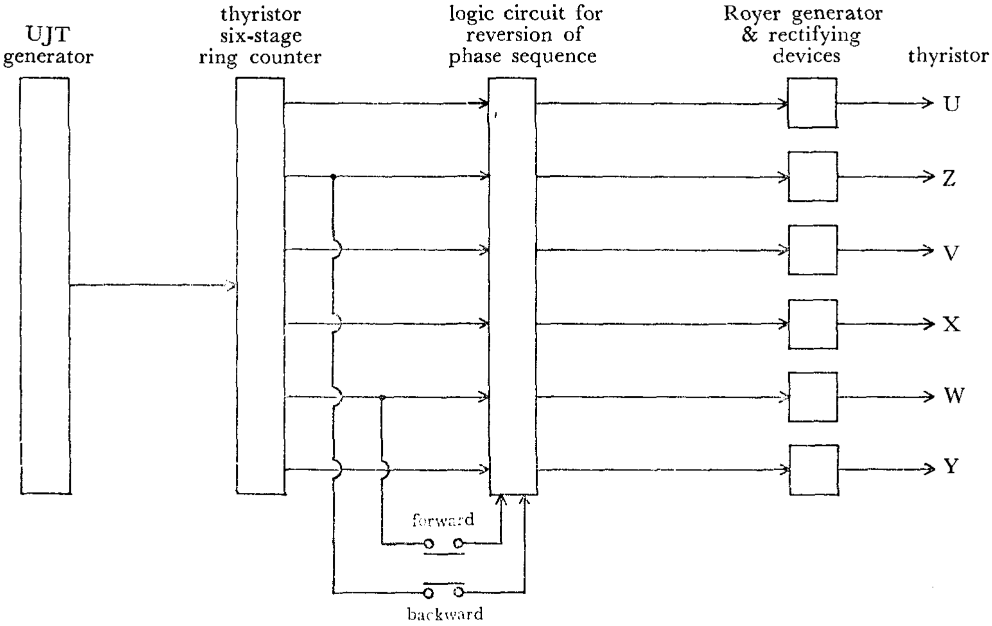


Fig. 2. Block diagram of auxiliary circuit.

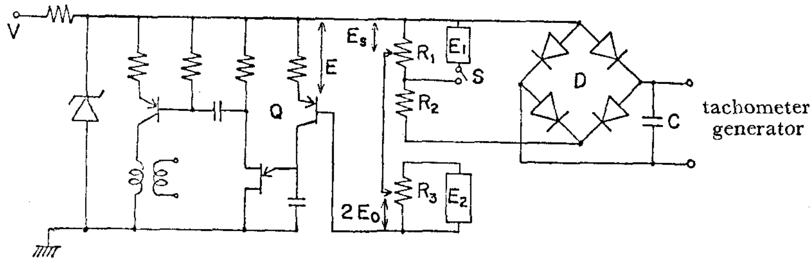


Fig. 3. Constant speed control circuit. $E_1=18(V)$, $E_2=18(V)$

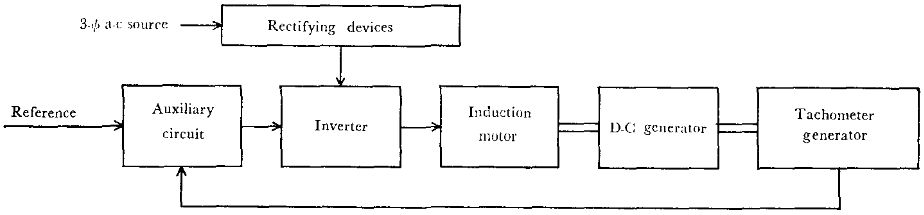
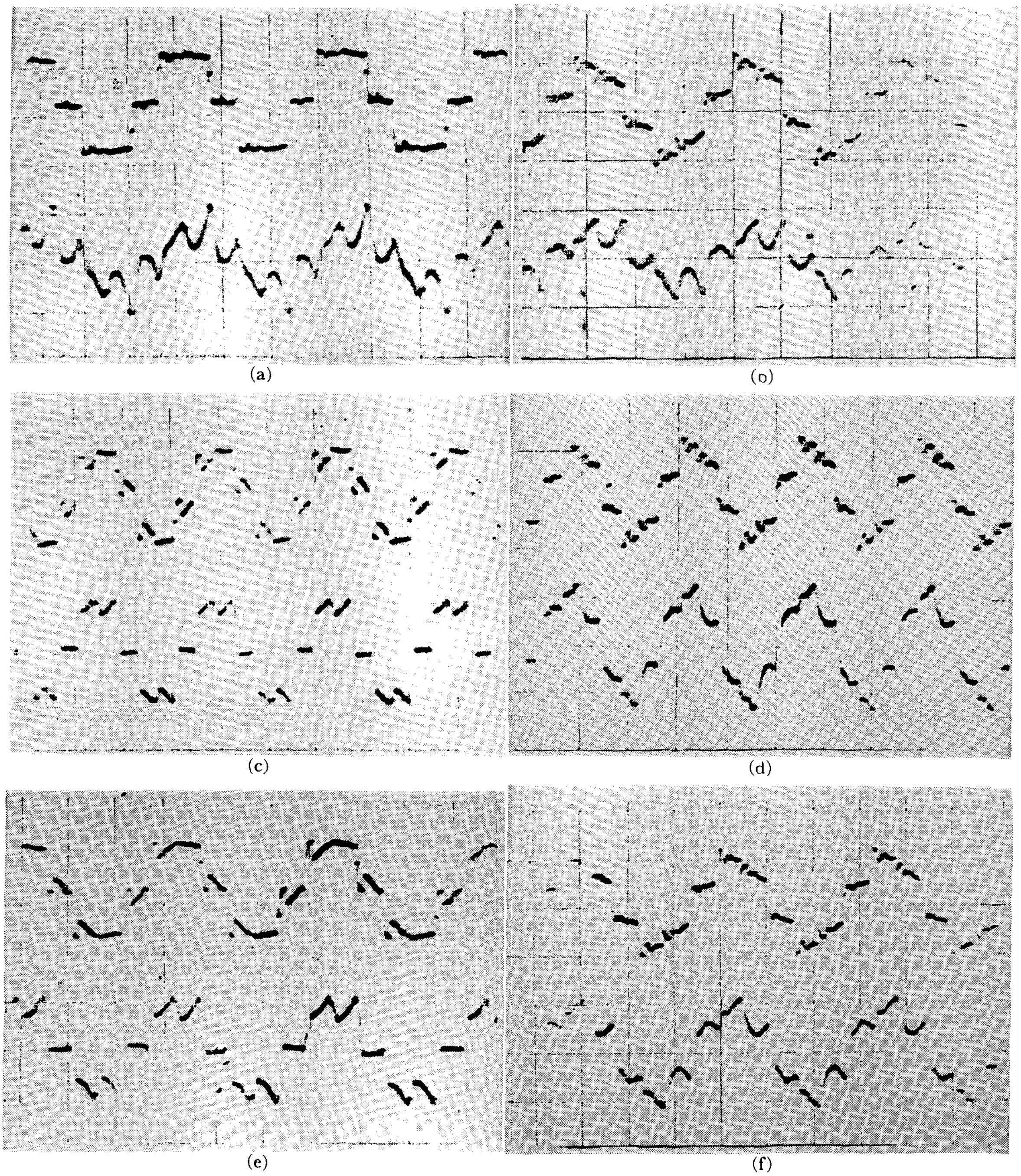


Fig. 4. Block diagram of constant speed control.



(a) (b)

(c) (d)

(e) (f)

Fig. 5. Wave forms of load voltages and currents.

Upper traces: load current (vertical scale: 100V/cm, horizontal scale: 5 msec/cm)

Lower traces: load current (vertical scale: 1 A/cm, horizontal scale: 5 msec/cm)

Input voltage: 100 (V)

(a) operation at 60 Hz, wtih no capacitor and motor with no load.

(b) operation at 60 Hz, with capacitor and motor with no load.

(c) operation at 60 Hz, with no capacitor and motor with load.

(d) operation at 60 Hz, with capacitor and motor with load.

(e) operation at 80 Hz, with no capacitor and motor with load.

(f) operation at 80 Hz, with capacitor and motor with load.

is equal to zero. If the voltage of the tachometer-generator rises, ΔE shifts to minus and the frequency of UJT oscillation diminishes, and vice versa.

2.4 Block Diagram

The block diagram of the constant speed regulation of an induction motor is shown in Fig. 4.

§ 3. Driving Characteristics of Induction Motor

3.1 Wave Forms

The wave forms of inverter output are rectangular and includes the fifth harmonics component as the lowest harmonics. In order to decrease the distortion rate of wave forms, the filter is needed. But, here, the only capacitance was connected to improve the performance stability of the inverter.

Without capacitors, as illustrated in Fig. 5, the wave forms are decisively affected upon varying load conditions. With capacitors, however, the variation of wave forms is hardly recognizable between with and without load. Figs. 5 (e) and (f) display that this holds true on different frequencies.

3.2 Constant Speed Regulation

The characteristics of constant speed regulation are given in Fig. 6. The speed variation ratio with and without the feedback is expressed as functions of load current. Where, the variation ratio is denoted by

$$\zeta=\frac{N_0-N}{N_0}\times 100 \text{ [percent]}$$

N_0 : speed with no load (rpm)
N : actual speed (rpm)

The d-c source voltage, however, was not regulated proportionally to the frequencies of the inverter. The curves in Fig. 6 shows that the deviation of motor speed with speed control is very small. The difference of the vari-

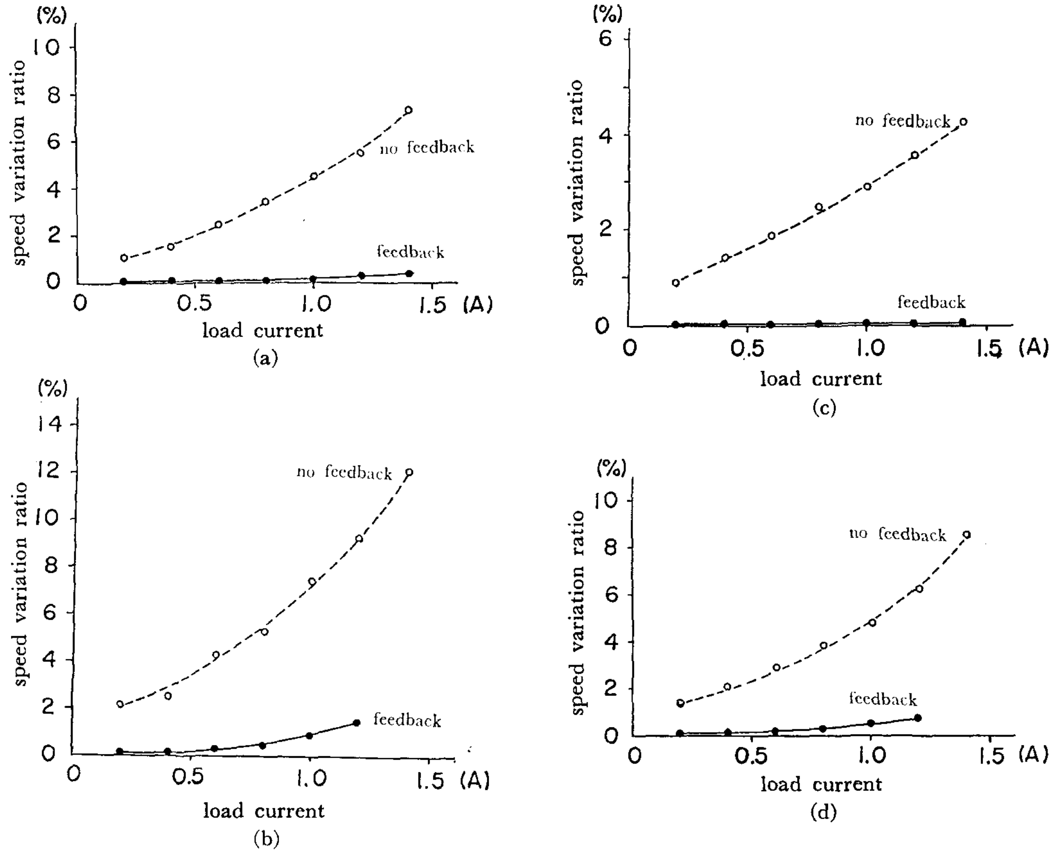


Fig. 6. Control characteristics of constant speed regulation.

(a) N_0 : 1500 (rpm) ; d-c input voltage : 70 (V)
(b) N_0 : 1800 (rpm) ; d-c input voltage : 70 (V)
(c) N_0 : 2100 (rpm) ; d-c input voltage : 100 (V)
(d) N_0 : 2800 (rpm) ; d-c input voltage : 100 (V)

ation ratio from a reference speed due to the magnetic saturation of the induction motor and the nonlinear characteristics of the detecting tachometer-generator.

Under the same condition, the transient response has been examined and is indicated in Fig. 7. The maximum speed deviation is suppressed to 10 rpm with feedback, compared with 140 rpm deviation without a feedback. The response time is about two seconds.

3.3 Efficiency and Power Factor

The measured efficiency of the inverter driving the induction motor, is shown in Fig. 8 with frequency as parameter. The output voltages of the inverter were constrained to 150 V. The efficiencies were calculated with

$$\eta=\frac{W}{EI}\times 100\ [\text{percent}]$$

where,

E : input voltage of inverter
I : input current of inverter
W: output of inverter

The high efficiency is obtained with low frequencies even in the range of heavy load current.

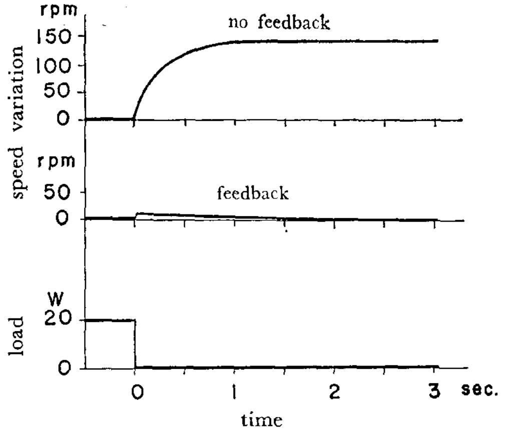


Fig. 7. Response.

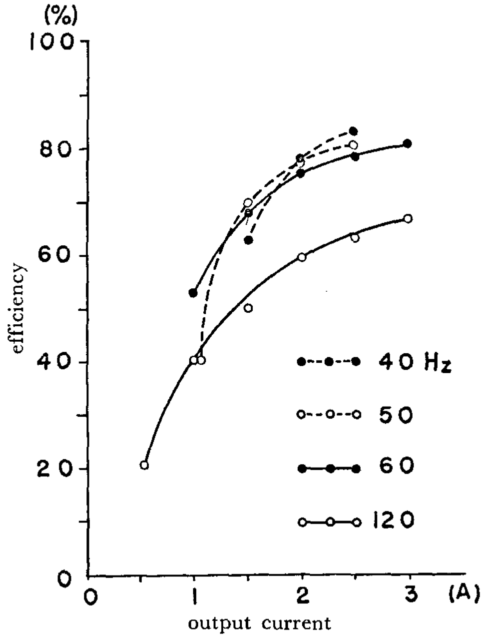


Fig. 8. Efficiency.

The power factor decreases, if wave forms of voltage differs from those of current. The measured curves of power factor of the inverter with the induction motor are shown in Fig. 9 as functions of load current with frequency as parameter. The power factor advances high with the increased frequency for relatively small currents, but reverses for heavy currents.

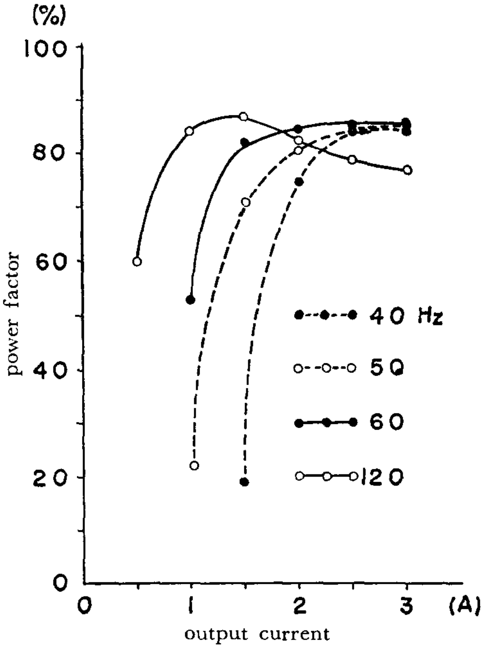


Fig. 9. Power factor.

3.4 Transient Behavior

The reversal of motor revolution is achieved by changing the phase sequence of inverter output, which provides the motor a plugging and makes much loss result in the rotor. The dissipation of loss can be expressed by

$$\frac{3}{2}J\omega^2\ (\text{Joule})$$

which should be within the ratings of the motor at continuous operation. Figs. 10 and 11 indicate the transient performance of the motor reversal. At 60 Hz, as shown in Fig. 11, the period to a standstill is about 0.17 seconds and that to a reversal reference speed is about 0.5 seconds. On the other hand, at 40 Hz, the period to a standstill is about 0.08 seconds, and about 0.25 seconds were necessary to the reversal reference speed from standstill. The

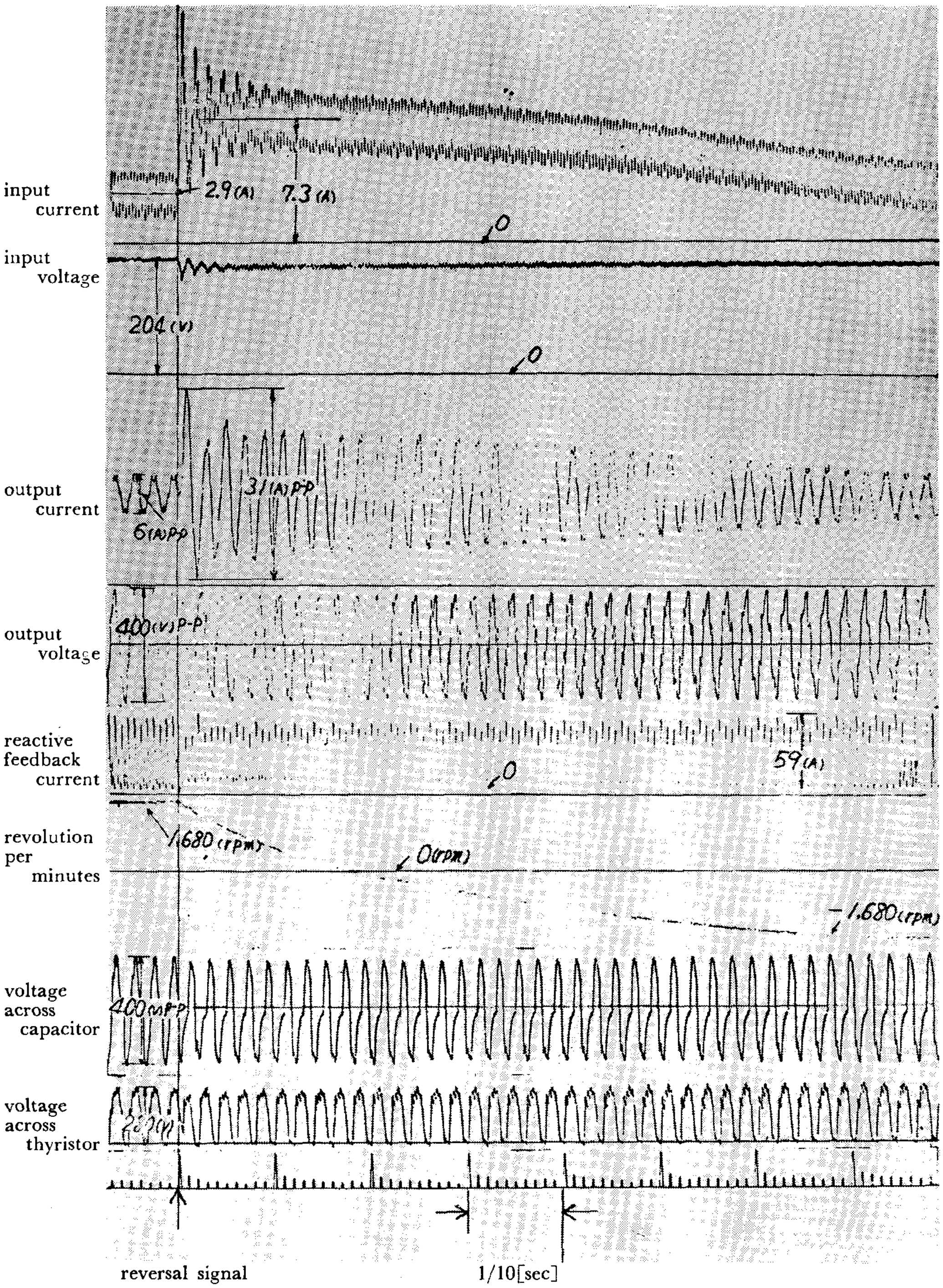


Fig. 10. Transient response of the reversal of an induction motor, operation at 60 Hz.

time of the completion of reversal at 60 Hz is around two times to 40 Hz. It should be noted that rush currents flow at the instant of reversing. From the inspection of Figs. 10 and 11, the peak value which must be within the ratings of thyristors and diode devices, is six times over the normal value.

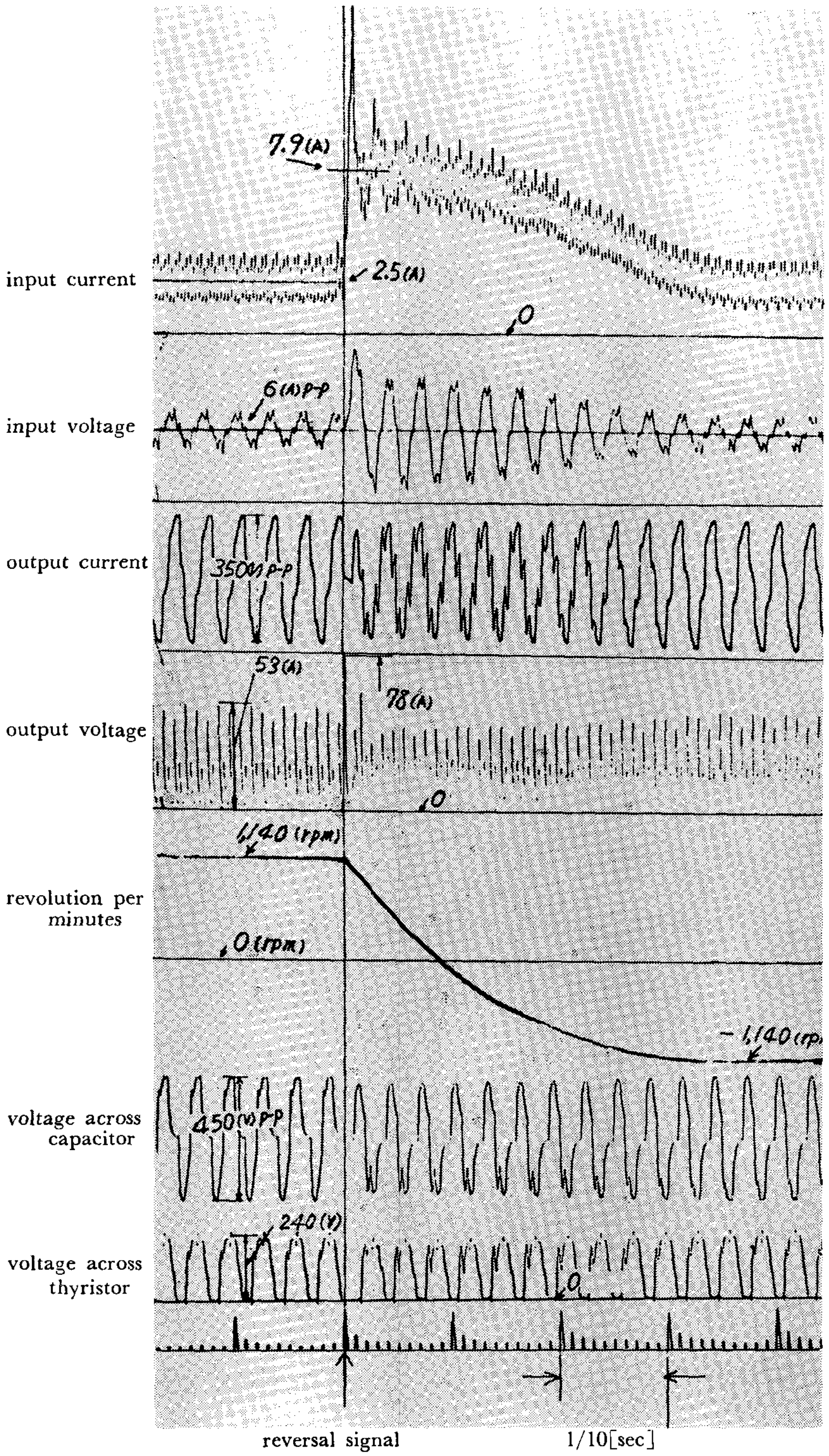
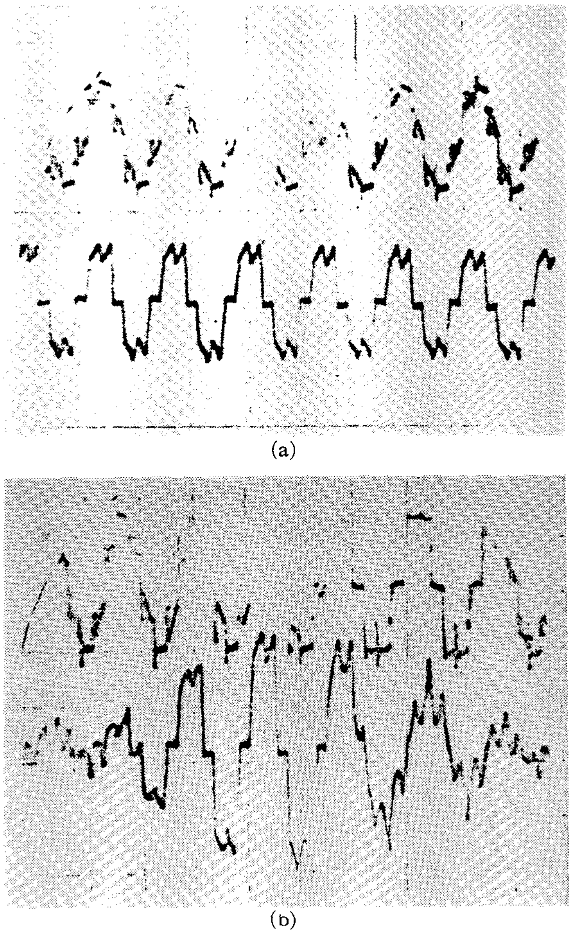


Fig. 11. Transient response of the reversal of an induction motor, operation at 40 Hz.

§ 4. Discussion

(1) Magnetic Saturation of Induction Motor

For the purpose of driving a motor, the d-c source voltage should be regulated proportionally to the performance frequency of an inverter, unless the magnetic saturation of the motor causes load current to increase with the decreased frequency. This current in turn causes the "irregular revolution" of the motor. Wave forms of voltages and currents were presented in Fig. 12, compared with those of normal operation. In order to avoid the magnetic saturation, it will be most convenient method to utilize thyristor rectifying circuits or thyristor d-c chopper control circuits to regulate d-c input voltage proportional to the frequency of the inverter.


(a)

(b)

Fig. 12. Operation of irregular revolution at 2100(rpm).

Upper traces: voltage (vertical scale: 100V/cm, horizontal scale: 100 msec/cm)

Lower traces: voltage (vertical scale: 1 A/cm, horizontal scale: 100 msec/cm)

(a) normal operation at d-c input 85 (V)

(b) irregular revolution at d-c input 110 (V)

(2) Noise Prevention

The radio frequency interference[4] results from the turn-on and turn-off switching performance of thyristors and is not particular phenomenon subsequent to the performance of thyristor inverters. RFI is conveyed through both electric conduction and radiation. To prevent the RFI, the following methods will be very effective.

(i) add small inductance to suppress the abrupt rise of current.

(ii) add high frequency filter to input and output line.

(iii) screen the installations with electrostatic shielding.

Disturbances to the inverter are divided into two kinds: that is, one to the auxiliary circuit and the other to d-c source. The false conduction of thyristors originating from disturbances to the source line occurs when the voltage exceeds over the breakover value of thyristors or its dv/dt surpasses allowance ratings. This kind of disturbances can be suppressed considerably by connecting the anode-cathode of the thyristor with a R-C filter. Disturbances to auxiliary circuits induce the noise voltage in gate wires and disturb the performance of inverter or sometimes leads to a complete malfunction. To prevent the influence of noise voltages, the selection of an auxiliary circuit configuration must be stressed to the stability of performance. Noise voltages can be bypassed fairly well by connecting a resistor-capactor in parallel across the gata-cathode of the thyristor.

§ 5. Conclusion

The stability of operation was confirmed with relation to the speed control of a squirrel cage induction motor controlled by a variable frequency three phase thyristor inverter. Some particular points of the thyristor inverter associated with a practical use were discussed.

The authors are indebted to Mr. K. Kawashima, Mr. T. Yoshida, Mr. M. Okada and Mr. K. Moriwake for their assistance in the experiments and the preparation of Figures and photographs.

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