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THYRISTOR CHOPPER CONTROLLER FOR TYPE 270 ELECTRIC CAR

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I. INTRODUCTION

The first work on the application of thyristor choppers in rolling stock was started in Japan around 1965. Thereafter, with the improvement on turn-off time, and capacities of thyristors and the advances in chopper control techniques, investigations were performed on coordination with existing facilities and equipment, field tests were carried out, application and manufacturing techniques for chopper equipment were improved and chopper controlled electric cars were realized[(1),(2),(3),(4)]. In the future, there will no doubt be qualitative improvements in chopper manufacturing technology including new thyristors and circuit systems; the equipment will become smaller, more lightweight and cheaper: improvements will be made in testing and maintenance techniques; and efforts will be made to show the advantages of chopper control equipment in practical fields such as operation. At present, a chopper controller has been installed in the Sanyo Electric Railway mainly for the collection of actual field data. It is now in operation on the line and an outline will be given here.

II. PRINCIPAL PARTICULARS OF TYPE 270 ELECTRIC CARS

The chopper control equipment is attached to the middle car of three motor cars. The other two cars have cam controllers. The properties and handling of all three cars, however, are completely the same. *Table 1* shows the principal ratings of the chopper car.

III. MAIN CIRCUIT CONSTRUCTION AND CONTROL SYSTEMS

1. Main Circuit Construction

Fig. 1 shows the connections of the main circuits. One chopper is connected in series to each motor cascade connection and the main circuit connection is composed of the two phase separate type in which two groups of choppers operate with a phase difference of 180°. This type of circuit construction requires

Table 1 Principal ratings of type 270 chopper controlled car

(1) Source voltage	
Overhead line voltage	1,500 V (900～1,650 V)
Arrester limit voltage	(Sparkover voltage)≦5,500 V (Limit voltage) 4,500 V (at 2,000 A sparkover current)
Control voltage	(MG) DC 100 V AC 200 V 120 Hz 2ϕ
(2) Control air pressure	5 kg/cm^2
(3) Car data	
Weight	Empty 36,5 ton, loaded 54.3 ton
Acceleration	Empty 2.1 km/h/sec Loaded 1.4 km/h/sec
Brake	Air brake
(4) Motor	
Connections	2S×2G
Rated capacity	52.2 kW (750 V 82 A)
Rated speed	825 rpm
Weak field	1 stage 60% field
Pulsation rate	≦10%
(5) Chopper controller	
Connections	2 phase separate
Rated voltage	1,500 V (900～1,650 V)
Rated current	115 A
Max. commutation current	154 A
Fundamental frequency	200 Hz (100 Hz at start)
Resultant frequency	400 Hz (200 Hz at start)
Commutation system	Half cycle oscillation
Control system	Constant frequency conduction angle control, current average value control
Type of element	Thyristor KGP 22-13 Diode KSP 03-30
Ambient temperature	−10°C～+40°C
Cooling system	Forced air cooling
Commutation capacitor	12 μF
Commutation reactor	40 μH
(6) Main smoothing reactor	
Inductance	80 mH (115 A)
Rated current	82 A
(7) Filter	
Filter capacitor	500 μF×2 P
Filter reactor	10 mH 164 A
Resonance frequency	50 Hz
(8) Electronic discharger	
Discharge voltage	2,500 V
Discharge resistance	5 Ω

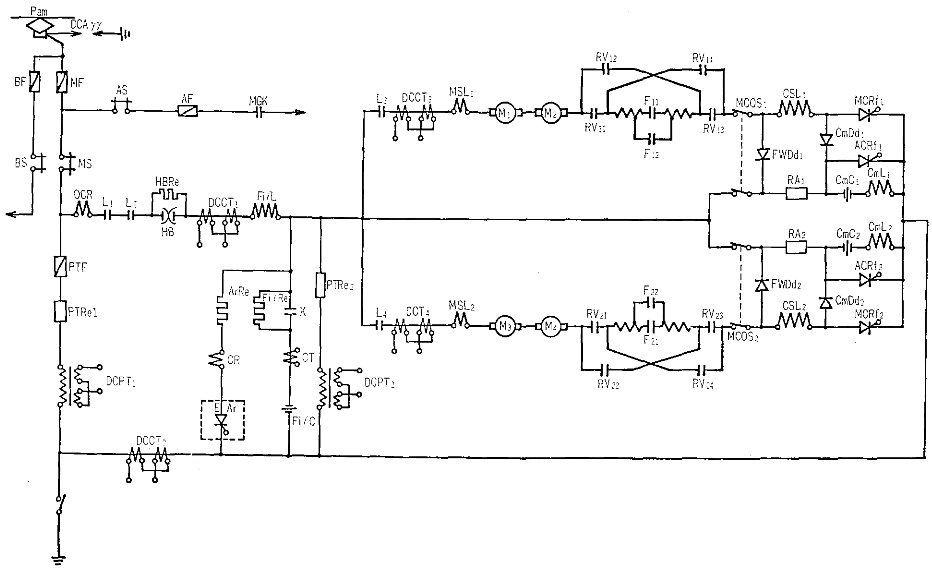


Fig. 1 Main circuit diagram

a larger smoothing reactor (MSL) to suppress pulsation of the motor current than is needed in the 2 phase duplex system. However, each of motor circuits including the majority of the chopper gate control circuits are more simple and independent so that reliability is greater and disconnection of the defective motor circuit is simpler. If motors with high pulsation rates are used, the MSL value required for limiting the chopper peak current from the standpoint of the chopper commutation capacity becomes larger than the MSL value required to smoothen the motor current. This causes the advantages of multiplicity decrease. The effects of minimizing the harmonic components of the overhead line current are exactly the same as those of the phase duplex system. In conjunction with the input L-C filter the value of harmonic components is reduced sufficiently so as to do no harm.

The filter capacitors are divided into two equal groups. The balance condition of the current of the each group is monitored as a precaution against faults such as broken wires or deterioration of the capacitors. An electronic discharger is also employed for chopper overvoltage protection as well as to know the amplitude and frequency of external surges.

The chopper is used especially for powering and since there are no braking duty, the half cycle oscillation method is used for the commutation circuits as can be seen in the circuit diagram (*Fig. 1*). This makes the equipment more compact.

2. Control Systems

Fig. 2 shows the notching curves, *Fig 3.* a block diagram of the control systems and *Fig. 4* the control flow chart. Since the chopper controlled car is connected to cars with the previous rheostatic control system, it is necessary to provide the same operation and starting acceleration functions as well as final characteristics for each notch. It is also necessary to perform constant motor current control, setting of the current value for each notch and limiting of the chopper conductance ratio. The chopper employs a constant frequency conduction angle control system which is effective in suppressing harmonic disturbances.

The operational instruction include master controller notches (1 : starting, 2 : series, and 3 : parallel), and the weak field and notch advance of selection switches. With the first notch, the operation is at a chopper frequency of 100 Hz. When advanced to the second notch, the chopper performs conduction angle control and the chopper frequency skips from 100 to 200 Hz. At this time, the conductance ratio is reduced in order to suppress any current surges. The same control is also used at the time of weak field advances in order to reduce

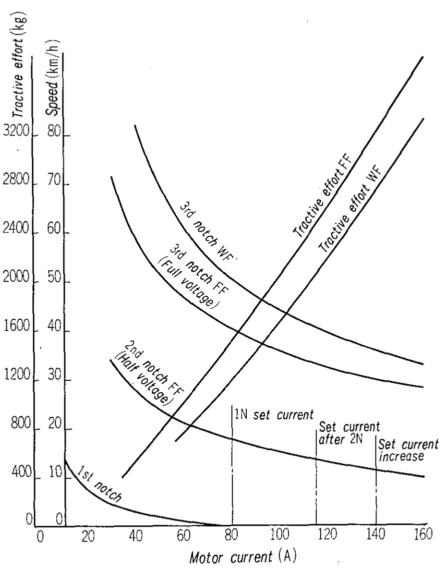


Fig. 2 Powering notching curve

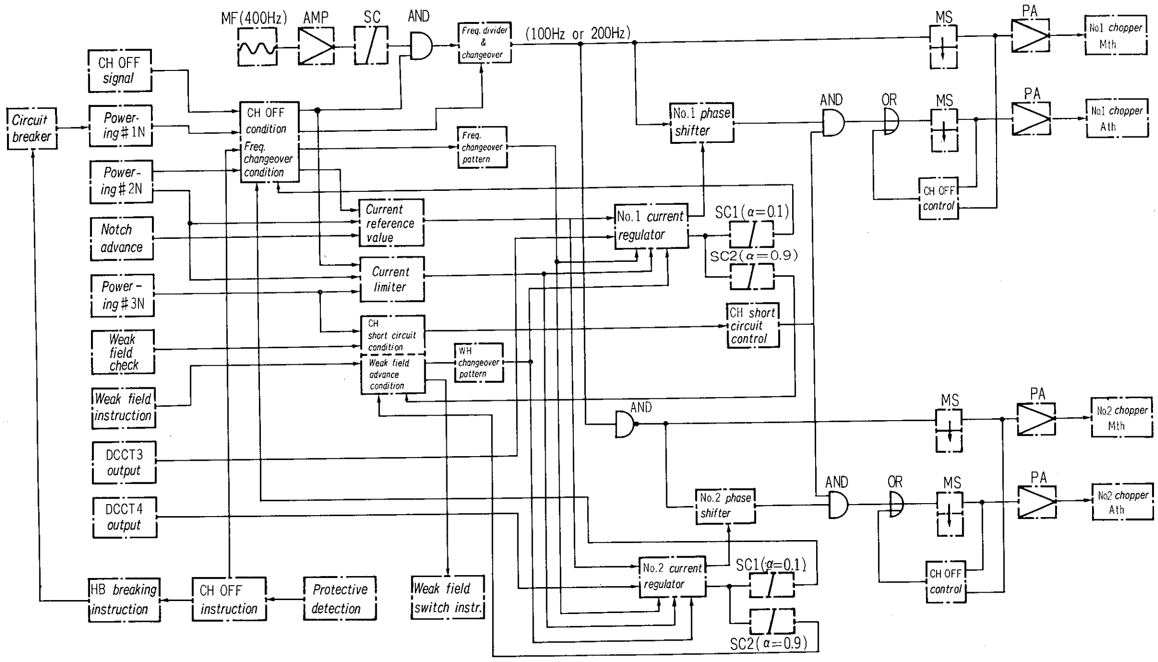


Fig. 3 Block diagram of control system

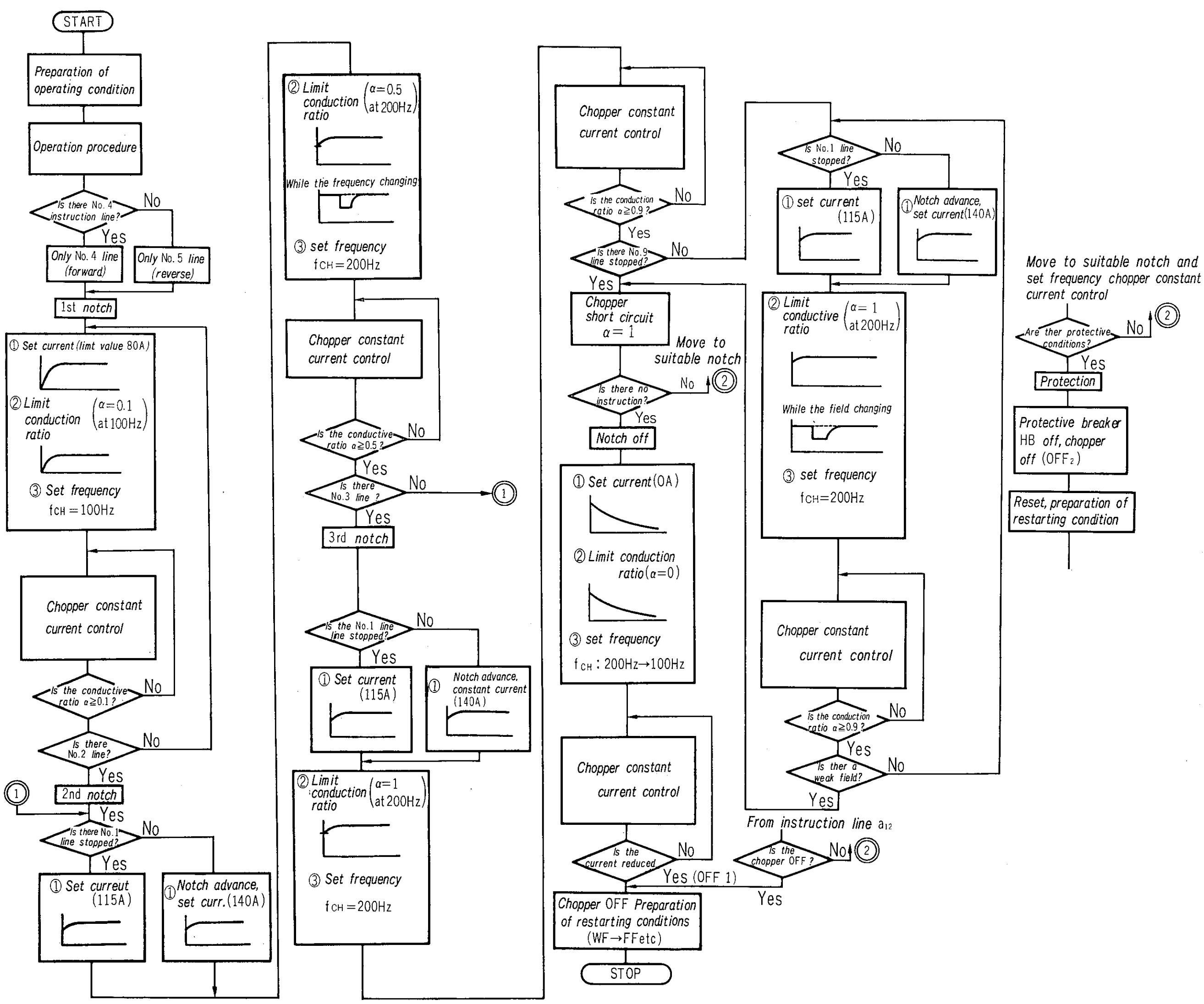


Fig. 4 Flow chart of control system

shocks. When the conductive ratio reaches a maximum value in the final notch, the off pulse is locked and the chopper is short circuited in order to keep the chopper loss low. At this time, the chopper is maintained in such as state that it can resume chopping in accordance with sudden changes in the overhead line voltage. The current setting value is increased with notch advances in order to coordinate with the operation of the cam control equipment.

IV. MAIN ELECTRICAL COMPONENTS

1. Chopper Control Equipment

Fig. 5 shows an outerview of the chopper control equipment (two boxes). Since flat type elements with sufficient current capacity margins are used, the element cooling fin is small and four thyristors (or diodes) can be accomodated in one stack. Each stack is in the form of a tray depending on function and the equipment is arranged so that the cooling wind tunnel is provided at the same time as the equipment is installed. The commutation circuit devices are arranged on the rear of the trays to make the construction more compact.

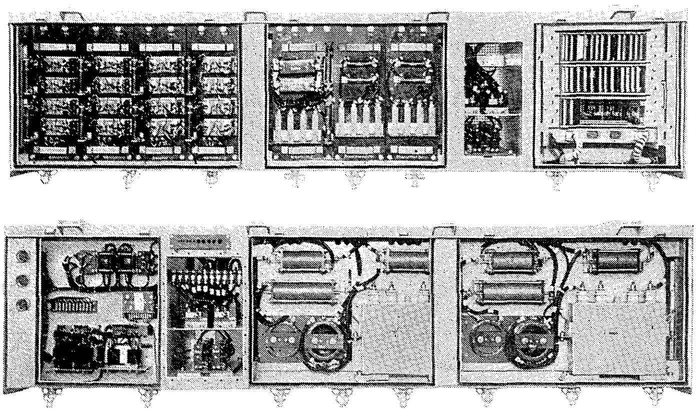


Fig. 5 Chopper control equipment

2. Gate Control Equipment

The gate control equipment is inserted in the chopper equipment and if it is connected to the cannon plug, it can be operated. This equipment is a very important component since it controls the chopper gate signal and also serves as protective equipment. In order to imporve reliability and make the equipment more compact and lightweight, digital and analog IC's are used in all parts. Each unit is separated according to function and system in order to prevent noise and facilitate maintenance and inspection.

3. Electronic Discharger

In order to prevent abnormal increases in the voltage V_C of the filter capacitor C_F in the car containing the chopper and the electrical locomotive in any of the following cases:

(1) entry of surges from the power supply
(2) sudden interruption of loads connected to the chopper
(3) sudden loss of the load during regeneration

An electronic discharger has long been used[5]. There have also been reports and analysis of its surge suppressing action[6], [7]. An electronic discharger consisting of voltage detector VD (with trigger device), thyristor TH_{Arr} and discharge current suppressing resistor R_{Arr} as shown in *Fig. 6(a)* has been provided in this equipment mainly for suppression of surge voltages from the overhead lines. This electronic sischarger should not be operated when the notches are off and the set value of the operation voltage has been selected as 2,500 V. *Fig. 6 (b)* shows the voltage waveforms (calculated values) of the pantograph voltage V_S and the filter capacitor voltage V_C in the case of an impulse surge with a peak value of 5,000V, 0.1 × 4ms comes from the overhead lines during operation at a power source voltage of 1,650 V and a load current of 310 A and the discharger operates. As can be seen from the figure, the filter capacitor voltage V_C is kept below 2,500V and because of the discharger, the chopper can be operatees with a sufficient voltage margin and high reliability is maintained.

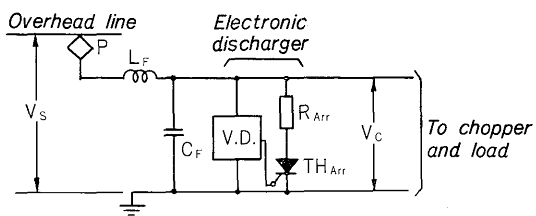


Fig. 6 (a) Schematic diagram of electronic discharger

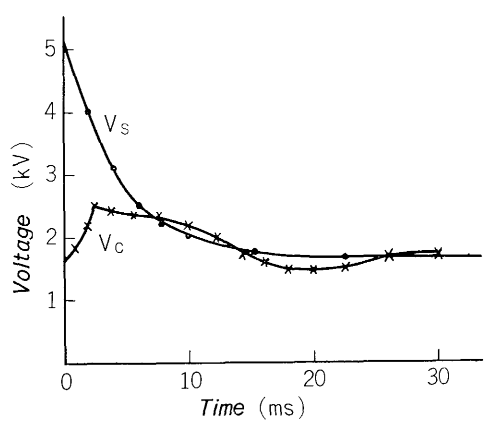
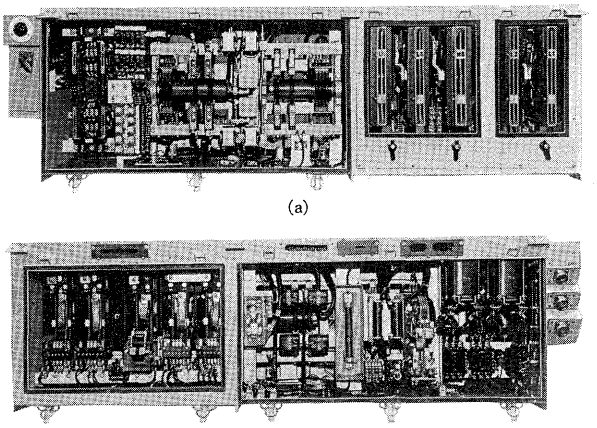


Fig. 6 (b) Voltage wave form

4. Line Breaker and Changeover Switch Box

As shown in *Fig. 7* this box is intended to accomodate movable parts such as the high speed breaker



(a)

(b)

Fig. 7 Breaker and reverser box

for chopper control equipment protection, the unit switches, the reversers and the weak field contacts. It also contains parts which require maintenance such as the main circuit, control circuits, relays and targets.

5. Other Components

In addition to the above, the main components include the filter capacitor box and the reactor box (containing MSL. Fil. L.).

V. PRACTICAL TEST RESULTS

The chopper controlled car underwent trial operation in the Higashifutami shops of the Sañyo Line and also at night on the line. The required functions were confirmed and the car went into actual commercial operation from August, 1972. In the trial operation, investigations were made concerning the performance of the chopper controlled car, and influences of outside disturbances on the car, particularly signal disturbances.

1. Performance of the Chopper Controlled Car

Fig. 8 shows an oscillogram of the chopper controlled car and *Fig. 9* an oscillogram comparing the cam controlled and chopper controlled cars. In both cases, all of the controllers in the train were operated. The speed changing performance showed no abnormalities of any kind since the motor was the same as in the cam controlled car so that operation was coordinated and braking was by means of an air brake. From *Fig. 9*, it can be seen that the motor currents of the cam controlled and chopper controlled cars were well balanced and the load distribution was good in both cases. The cam controlled car showed a tendency to start somewhat quicker but the chopper controlled car was more comfortable than the cam controlled car since there was no sensation of starting. Performance conditions can be satisfied sufficiently.

2. Power Consumption

When comparing the power consumption only for the current limited acceleration period, the chopper controlled car consumed only about 78% of the power consumed by the cam controlled car. Since the series/parallel connection is used for the motors in the cam controlled car, about 25% of the power is consumed by the resistor but almost all of this consumption is avoided in the chopper controlled car.

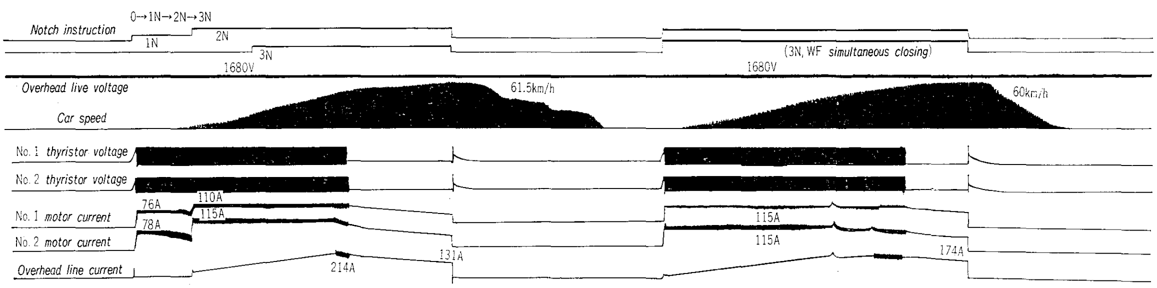


Fig. 8 Oscillogram of chopper controlled car

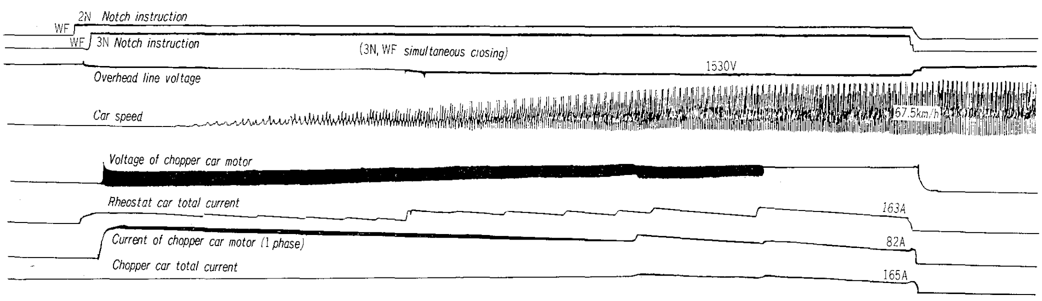


Fig. 9 Oscillogram of chopper controlled car and cam controlled car

3. Noise

A test was performed in which a resistor was connected in place of the motor, the chopper was operated in a stationary position and the noise was investigated. It was found that the noise from the blower used for reactor cooling was somewhat loud but the chopper magnetic noise was so small as not to be any problem at all.

4. Harmonic Current in Overhead Lines

In the investigations made previously using chopper controlled cars, careful studies were made concerning the harmonic components of the overhead line current which might cause inductive disturbances. In order to reduce these harmonic components to a level would cause no practical harm, a power supply filter was used, the chopper frequency was carefully selected, the number of chopper phases was increased or some similar measure was taken. In this trial operation, a harmonic analysis was performed on the overhead line current and JP measurements were made but the overhead line current was small and harmonics presented no problem.

5. Communication and Signal Disturbances

A survey was conducted under actual operating conditions using noise measurements, electrical field strength measurements, concerning disturbances of commercial telephone lines, and disturbances of radio, television, inductive wireless and broadcasting devices inside the cars, but no problems were encountered. There was some noise only when there was no synchronization with an amplitude modulation receiver.

There were also absolutely no disturbances in respect to equipment operating by track current or electric field such as track signals, automatic train controllers, crossing controllers, or due to harmonic components of the overhead line current.

VI. MAINTENANCE

One of the reasons for the advances of thyristor equipment in the field of DC electric car drive is that the maintenance required for the contacts which was a major part of the maintenance work former in rolling stock is greatly reduced. By full utilization of the stepless control functions of the chopper, the contacts of the main circuits can be minimized and even when contacts which can not be omitted such as the unit switches for the line breakers, the cam switch for the P-B changeover and the cam switches for forward-reverse changeover are operated, it is possible to greatly reduce contact wear by currentless switching of the main circuit contacts through utilization of the current interrupting functions of the chopper. However the control section which is to be built into the chopper equipment has more small electronic components and the circuit construction is more complex than in former equipment. Therefore, in order to insure reliability, it is necessary not only to selected parts very strictly, perform screening and sufficient debugging, and consider processing controls, but also to have easy maintenance and inspection. Considering these requirements, Fuji Electric has adopted the following concepts concerning the maintenance and inspection of general chopper control equipment.

(1) Chopping part

All of the thyristors and diodes, in the chopping part are arranged in trays and all of the terminals requiring maintenance and inspection protrude from the front surface.

(2) Control part

The control part consists of a section made up of relays with contacts and a section consisting of IC's etc. arranged on printed boards. However, this part contains automatic testing equipment developed to check the entire parts. *Fig. 10* shows the outerview and the inner construction of the automatic tester. This testeı is a type of simulator of chopper controlled cars from a dummy master controller to a dummy chopper. This tester and the test terminals of the control equipment of the chopper controlled car to be tested are connected mutually to a cannon plug and the four printed boards for the test are inserted into the chopper control equipment. With this simple procedure, it is possible to perform a sham notch test utilizing the dummy master controller in tester. In the sham notch test, the tester can distinguish and indicate which printed board is defective which is the chopper does not operate correctly in respect to the various operation modes from the dummy master controller. The tester can also check the operating levels of various protective circuits and detection circuits.

The equipment manufactured at this time has operation of each notch performed by test personnel using the dummy master controller. It is difficult to say that the tester is completely automatic be-

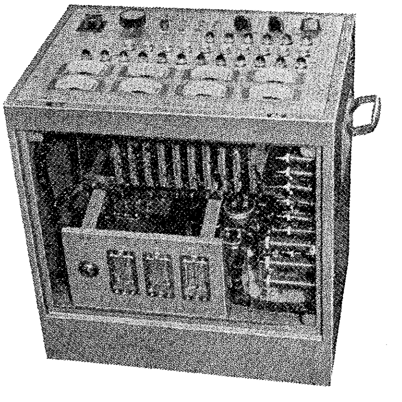


Fig. 10 Automatic tester for chopper controller

cause the test results including those indicated by the tester were recorded by the test personnel. However, compared to the formerly used synchroscopes and videographs where only one printed board was measured at a time, this tester greatly reduces the man power required for maintenance. With this test system using the simulator we are confident that a step has been made in achieving the desired goal.

Complete automation including operation of each notch and test results is possible but the decision concerning the degree of automation should be made from economic considerations.

This equipment has already undergone complete practical tests related to car performance, inductive disturbances, and is now being used for regular commercial operation. However, even more practical tests are to be performed in the future. We intend to concentrate our efforts on producing an even more practical chopper controlled car based mainly on field data.

Finally the authors wish to thank all of those persons from the Sanyo Railway for their kind guidance in the design, manufacture and testing of this thyristor chopper control equipment.

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