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TRANSISTORIZED AUXILIARY POWER SUPPLY FOR ROLLINGSTOCK

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I. FOREWORD

Various systems are used as the auxiliary power supply of rollingstock, depending on the type of car.

In the case of electric cars, a system in which electric power is obtained from the overhead line, the same as the driving electric power, is the most popular. Depending on the kind of load, the electric power from the overhead line is used either directly or by converting to low voltage AC power through a converter.

In the case of disel cars, a system which drives an auxiliary generator by means of the drive engine and a system which drives the alternator by means of a special auxiliary engine are available.

In the case of passenger cars, there is an axle driven alternator system which obtains power from the axle, a system using an engine generator, a system which obtains electric power from the overhead line by means of a pantograph, the same as electric cars, when the passenger cars are used on an electrified railway, and a system that provides electric power from the locomotive.

In brake vans, an axle driven alternator or an engine driven alternator is generally used as the auxiliary power supply.

Many semiconductors are applied in power equipments and service equipment for the rollingstock, and especially the applications of transistors are gradually expanding with the development of higher capacity and higher withstand voltage power transistors in recent years.

We have manufactured auxiliary power supplies for rolling stock for many years, and have large achievements and are making constant efforts in their improvement.

II. AUXILIARY POWER SYSTEM FOR ROLLINGSTOCK AND APPLICATION OF TRANSISTOR

The current relationship between auxiliary power supply system and loads used by the world's railways and the fields of application of power transistors are outlined in *Table 1.*

If the system composition of a passenger car using an axle alternator were diagrammed from these, it would appear as shown in *Fig. 1.* The main apparatus are the axle alternator, rectifier, alternator voltage regulator, lamp voltage regulator and inverter for fluorescent lamp.

Of these, transistorized apparatus, such as the new alternator voltage regulator, lamp voltage regulator and inverter, will be introduced, centered around the application of transistors.

III. TRANSISTORIZED AUXILIARY POWER SUPPLY FOR ROLLINGSTOCK

The alternator voltage regulator, lamp voltage regulator, and inverter will be introduced below as transistorized auxiliary power supply for rollingstock.

1. Alternator voltage regulator

1) Outline

The alternator voltage regulator is used to regulate the output voltage of an alternator driven from the axle of the car by a belt or gear, and is provided with two output characteristics, constant voltage and constant current. That is, up to a certain load current, a constant voltage is maintained without regard to the speed of the alternator and the

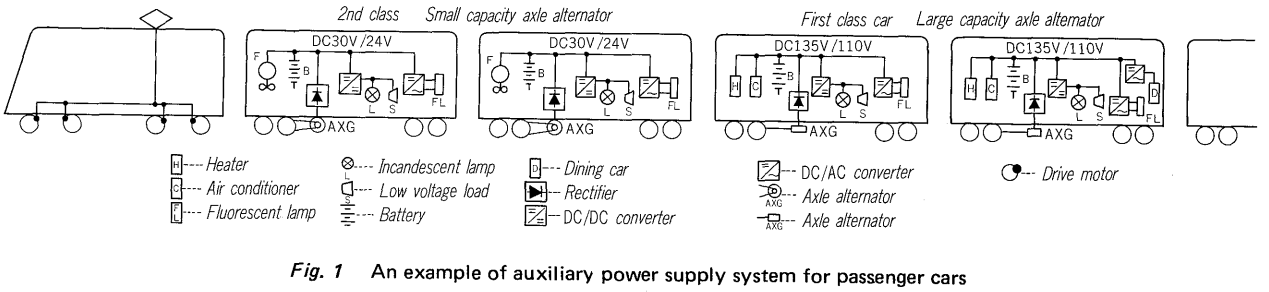


Fig. 1 An example of auxiliary power supply system for passenger cars

Table 1 Auxiliary power supply for rollingstock

	Type	Power source	Type of auxiliary power supply			Load	Application field of transistor
1	Electric car	Overhead line DC 600, 750, 1,500, 3,000V 1φ AC 20, 25kV, 60/50Hz 15kV, 16-2/3Hz (Stepped down by transformer)	Direct from overhead line DC 600, 750, 1,500, 3,000V			Heating, cooling (direct drive by DC motor	Speed regulator for motor-generator Generator voltage regulator Inverter Light dimmer Battery charger Fan speed regulator
			Direct from transformer 1φ, AC 60, 50, 16-2/3Hz			Heating	
			MG (brush-less MG)	2φ, AC 100V, 60/50Hz		Lighting, fan, control, battery charger	
				3φ, AC 220/440V, 60/50Hz		Heating, cooling, lighting, control, battery charger, fan, kitchen load, motor load	
			Inverter	1φ, AC 100V, 60/50Hz		Lighting, fan, control, battery charger	
				3φ, AC 220/440V, 60/50Hz		Heating, cooling, lighting, control, battery charger, fan, kitchen load, motor load	
2	Diesel car	Drive engine	Auxiliary generator	AC direct 3φ VVVF		Motor load (radiator, fan, etc.)	Generator voltage regulator Inverter Light dimmer Battery charger Fan speed regulator
				Rectified DC constant voltage 24/100V		Lighting, fan, control, battery charger, heating, cooling	
			Aux. generator (+) inverter	1φ, AC 100V, 60/50Hz		Lighting (fluorescent lamp), fan, control, kitchen load	
				3φ, AC 220/440V, 60/50Hz		Heating, cooling, lighting, control, fan, kitchen load, motor load	
		Auxiliary engine	Engine generator 3φ, AC 220/440V, 60/50Hz			Heating, cooling, lighting, control, battery charging, fan, kitchen load, motor load	
3	Passen-ger car	Axle	Axle alternator (+) battery	DC 24/100V		Battery charging, lighting, control, fan, heating, cooling	Speed regulator for motor-generator Generator voltage regulator Inverter Light dimmer Lamp voltage regulator Battery charger Fan speed regulator
				(+) inverter	1φ, AC 100V 60/50Hz	Lighting (fluorescent lamp), control, fan, kitchen load	
					3φ, AC 220/440V 60/50Hz	Heating, cooling, lighting, control, fan, kitchen load, motor load	
		Auxiliary engine	Engine generator same as the case of diesel car			Same as case of diesel car	
		Overhand line (pantagraph)	Same as case of electric car			Same as case of electric car	
		DC 1500, 3000V from locomotive Transformer, motor generator, inverter	Direct			Heating	
			1φ, AC 60, 50, 16-2/3Hz			Heating	
			Motor-generator, inverter 3φ, AC 220/440V, 60/50Hz			Heating, cooling, lighting, control, fan, battery charging, kitchen load, motor load	
4	Freight car	Axle	Axle alternator (+) battery, Same as case of passenger car			Same as case of passenger car	Inverter, Generator voltage regulator, Light dimmer, Battery charger, Fan speed regulator
		Auxiliary engine	Engine generator, same as case of passenger car			Same as case of diesel car or passenger car	

magnitude of the load, but when the load has increased to above this, the alternator voltage is suddenly dropped and the current is limited to an almost constant value. This constant current control prevents the alternator current from becoming excessive when the battery is overdischarged, etc.

The alternator voltage is controlled by regulating the field current by turning on and off a power transistor connected in series with the field. Instantaneous value control is used in voltage and current control. A block diagram of the axle generating equipment is shown in *Fig. 2.*

2) Specifications of alternator voltage regulator

The main specifications of the alternator voltage regulator for JNR 50 Series passenger coaches are given below as an example:

Rated output voltage: DC30V

Rated output current: DC144A

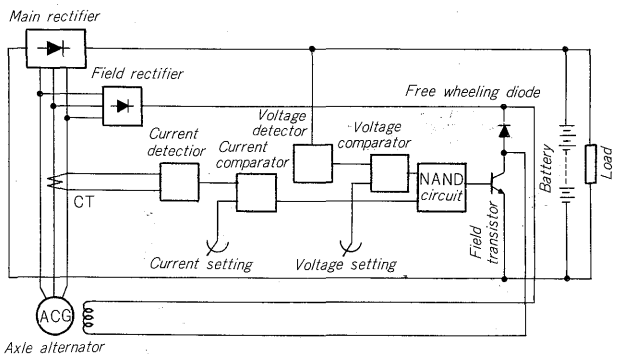


Fig. 2 Block diagram of axle generating equipment

Voltage variation: ±5% or less

Current limiting: Limited to within 115% load

Maximum field current: DC13A

3) Characteristics

The speed characteristics are shown in *Fig. 3* and the load characteristics are shown in *Fig. 4*. For rising of the charging efficiency of the axle alternator to the battery, the alternator voltage should by established from the lowest speed possible. Therefore, a circuit such as that shown in *Fig. 5* is employed at the field transistor base drive circuit. In other words, suficient current to turn the transistor on flows from the battery at all times.

When even a small alternator voltage is generated by the residual magnetism of the alternator, current begins to flow in the transistor and the alternator quickly establishes a voltage by means of its self-excitation. After alternator voltage establishment, the output voltage is detected as shown in the block diagram of *Fig. 2*, compared with the standard by a comparator instantaneously, and if the output voltage is high, the transistor is turned off, the field current is reduced, and the output voltage is dropped. If the output voltage is lower than the standard voltage, the transistor is turned on, the field current is increased, and the output voltage is increased. The transistor control stage

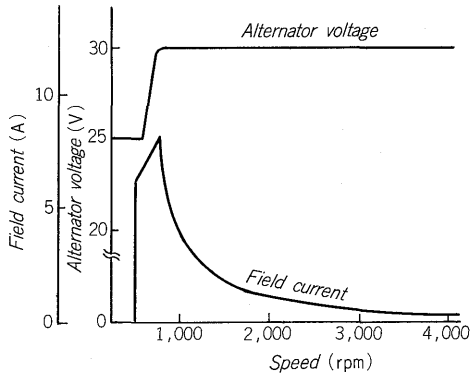


Fig. 3 Speed characteristics

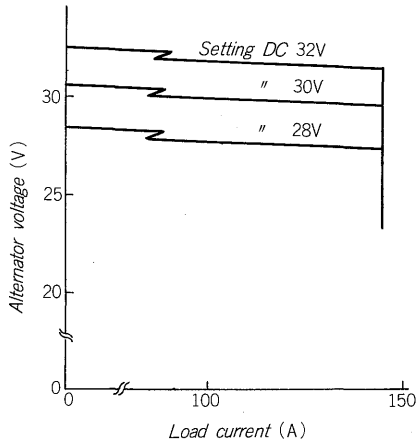


Fig. 4 Load characteristics

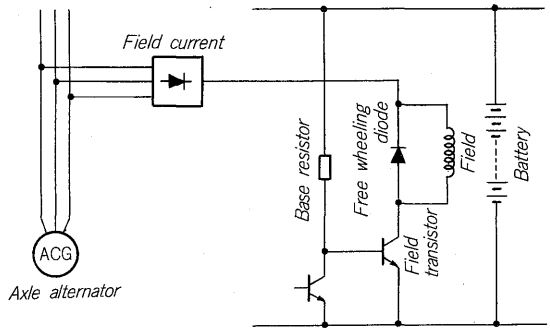


Fig. 5 Base drive circuit of field transistor

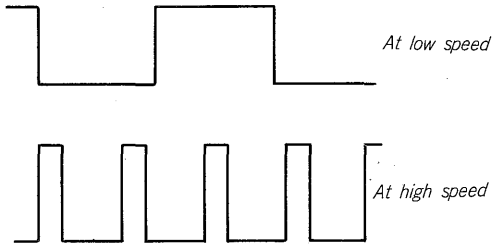


Fig. 6 Waveforms of field voltage

at this time is shown by the voltage waveforms of *Fig. 6*.

Moreover, the AC current of the alternator is detected by CT, compared with the current standard value by a comparator, and if the current is large, the transistor is turned off, the field current is reduced and the output voltage is dropped, without regard to the output of the voltage control comparator.

The use of a power transistor as the field switching element has the following merits. That is, since the transistor can turn itself off, synchronizing switching with the frequency of an external circuit is unnecessary, instantaneous control is possible, the control circuit can be simplified, and good response, wide range field control is possible.

2. Lamp voltage regulator

1) Outline

As previously mentioned, while the car is running, the battery is charged by a constant voltage from the alternator, but when the car is stopped, the battery is in the discharging state and its terminal voltage becomes lower than that while the car is running. Therefore, the load voltage also varies according to battery variations. In this state, when the lamps are connected to the load, their brightness will vary considerably, and the life of the lamps will also be effected. The lamp voltage regulator supplies a constant voltage to the lamp load whether the car is running or stopped. As shown in the block diagram of *Fig. 7*, the lamp voltage regulator consists of a transistor chopper. From *Fig. 8*, the chopper output voltage average value is given by the following equation:

$$Eave = \frac{T_{ON}}{T} Es$$

Eave: Chopper output voltage average value

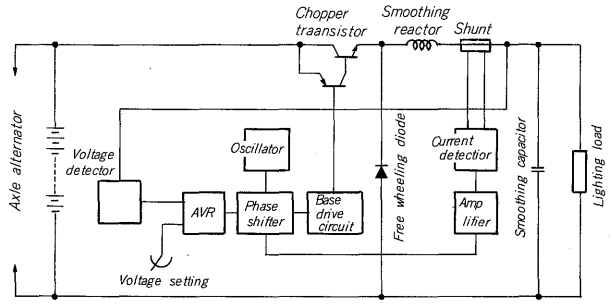


Fig. 7 Block diagram of lighting voltage regulator

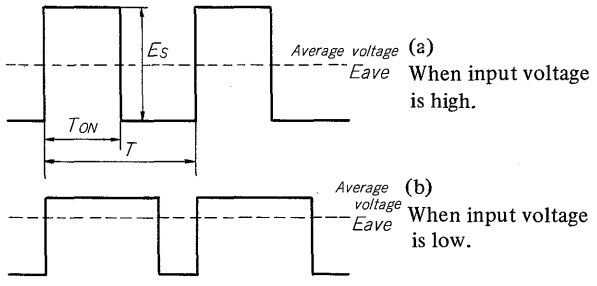


Fig. 8 Output voltage of chopper

Es: Chopper input voltage

T: Chopping period

T_{ON}: Chopper on time

In other words, the output voltage can freely control from 0 to 100% of the input voltage by changing the proportion of the transistor turn on time T_{ON} in one period *T*.

If the value of T_{ON} is controled for *T* according to variations of the battery voltage, the average value of the lighting voltage can be made constant without regard to the magnitude of the input voltage. Moreover, since the chopper output voltage is a square wave, the voltage is smoothed by using a free wheeling diode, smoothing reactor and smoothing capacitor.

2) Specifications of lamp voltage regulator

The specifications of the lamp voltage regulator for the JNR 50 series passenger coach are given below as an example.

Rated input voltage: DC30V (20~32V)
Rated output voltage: DC24V
Voltage variation (when running): ±5% or less
Rated output current: DC100A
Current limiting: Limited to within 115% load
Chopper frequency: 1kHz
Voltage drop (when stopped): 2V or less

3) Characteristics

A simple description of the voltage control method will be given in accordance with the block diagram of *Fig. 7*. The difference between the output voltage detected value and the set voltage standard value is amplified by a PI regulator. The conducting time within one period of the output transistor is controlled by a phase shifter operated at a constant frequency set by an oscillator and is proportional to the output signal of the PI regulator, and a transistor on signal is given to the base drive circuit. Moreover, the output current is detected by a shunt and the detected signal is amplified and sent to the phase shifter. When the output current exceeds a certain current value, the detected signal takes priority over the signal from the PI controller, the phase shifter is controlled by this signal and the output current is limited. The input voltage characteristics are given in *Fig. 9* and the load characteristics are given in *Fig. 10*. Moreover, this equipment is such that the battery is the only power source while the car is stopped and all the chopper transistors conduct and the voltage drop between the input and output is minimized.

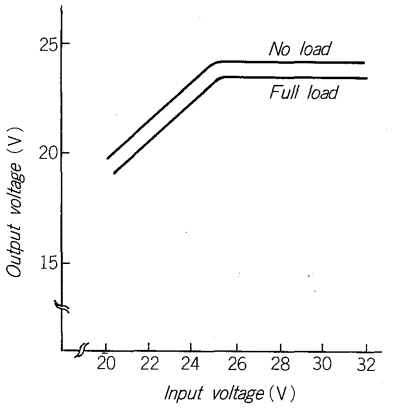


Fig. 9 Input voltage characteristics

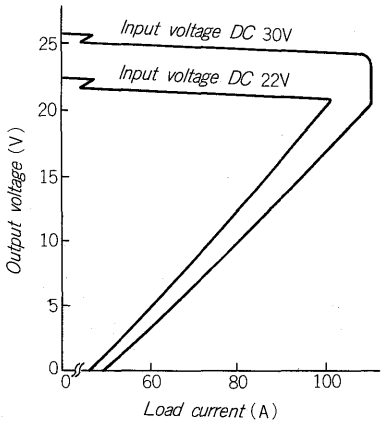


Fig. 10 Load characteristics

A photograph of the control box for the JNR 50 series passenger coaches housing the alternator voltage regulator described in item **1** and this lamp voltage regulator and the exterior dimensions are given in *Fig. 11* and *Fig. 12*. (In *Fig. 11*, the alternator voltage regulator is at the left and the lamp voltage regulator is at the right.)

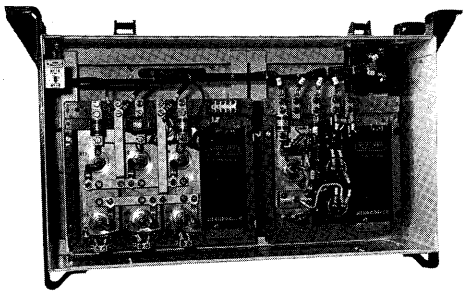


Fig. 11 Control box of axle generating equipment for 50 series passenger car

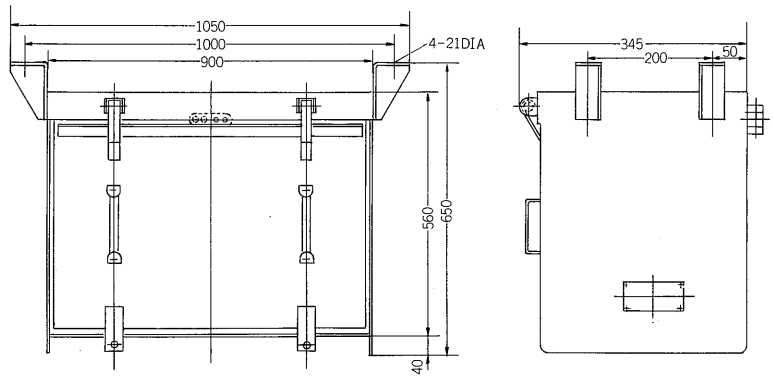


Fig. 12 Control box of 50 series passenger car

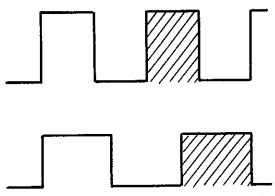
3. Transistor inverter for fluorescent lamp

1) Outline

The transistor inverter for fluorescent lamp converts the DC voltage of the battery charged by the axle altnerator to an AC voltage and supplies this AC voltage to the fluorescent lamps of the passenger cars.

Since the load of this inverter is the fluorescent lamps, so a constant voltage, constant frequency characteristic is not necessary, it is controlled so that the voltage-time product of a half-cycle of the AC output becomes constant as shown in *Fig. 13.*

That is, as described in the lamp voltage regulator item the battery voltage is different when the car is running and when the car is stopped, and a VVVF system which detects the voltage and changes the output frequency in direct proportion to it is employed.



(a) When input voltage is high

(b) When input voltage is low (area of hatched part is the same)

Fig. 13 Output voltage of inverter

2) Specifications of transistor inverter fluorescent lamp

The specifications of the transistor inverter delivered the Burma Railways Corporation are given below as an example.

Input voltage: DC24V (22~32V)
Output capacity: 1kVA
Output voltage: AC130V, single-phase
Output frequency: 400Hz

3) Characteristics

A simple discription of the operation of the inverter will be given in accordance with the transistor inverter block diagram shown in *Fig. 14.*

The output transformer employs a center tap system, and a square wave AC voltage is generated at the secondary

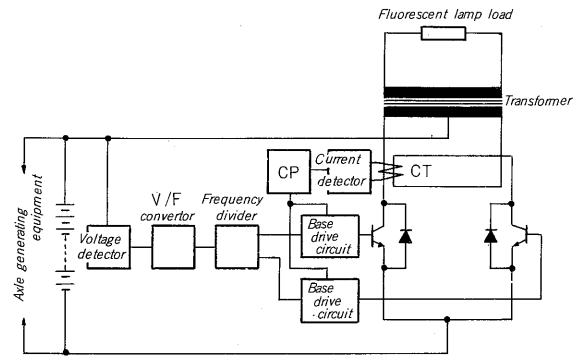


Fig. 14 Block diagram of transistor inverter for fluorescent lamp

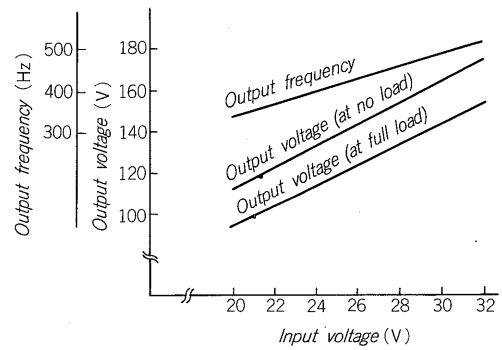


Fig. 15 Input voltage characteristics of inverter

winding of the transformer by passing the current in the reverse direction in each winding of the primary side by turning the two transistors on alternately. At the control circuit, first, the input voltage is detected and its pulse is applied to a frequency divider by means of a V/F converter, the frequency is divided to 1/2 and the duty of pulse is changed to about 1/2 and alternately applied to the two transistors as the base signal. Moreover, current detection is performed by means of an AC CT. When a certain current value is exceeded, the comparator is operated, the base circuit is opened, the inverter is turned off and the tran-

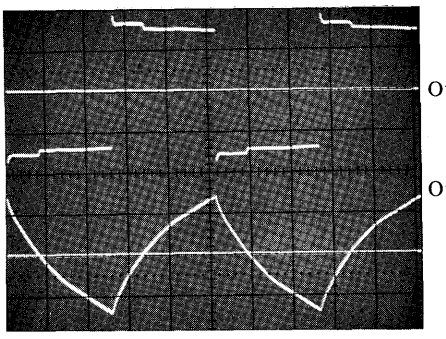


Fig. 16 Waveforms of output voltage and current

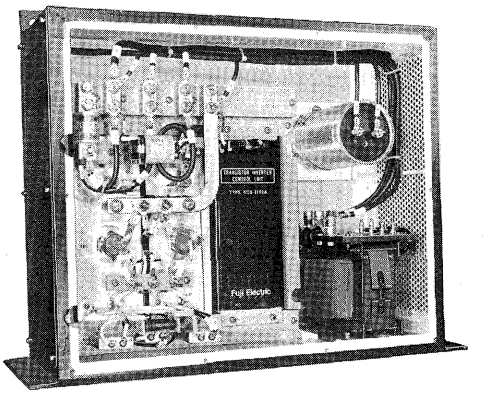


Fig. 17 Transistor inverter for Burma Railways Corporation

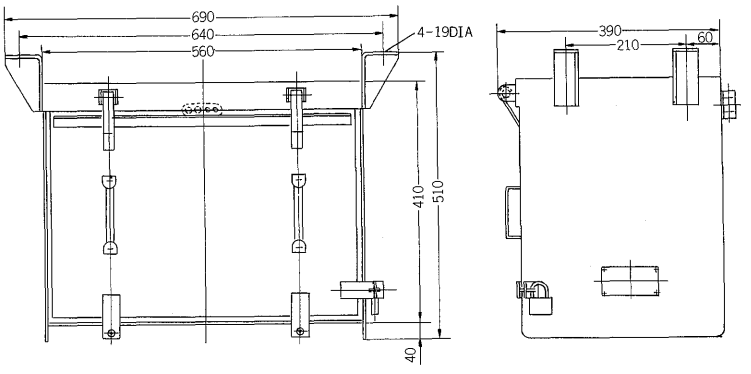


Fig. 18 Transistor inverter box for Burma Railways Corporation

sistors, transformer, etc. are protected against an overcurrent.

The input voltage characteristics are shown in *Fig. 15.* At these characteristics, at no load and full load, the output frequency is proportional to the input voltage and is the same characteristic, but load compensation is not performed, so the variation of the output voltage caused by the load is fairly large. The inverter output voltage and current waveforms when a fluorescent lamp is made the load are shown in *Fig. 16.*

A photograph of the transistor inverter for Burma Railways Corporation is shown in *Fig. 17* and the exterior dimensions of underframe type box are shown in *Fig. 18.*

IV. CONCLUSION

One application of transistors to an auxiliary power supply for rollingstock has been described in the above.

We have supplied axle generating equipment for passenger cars for many year and, fortunately, they have been acclaimed by all users and a large achievements has been obtained with the railways of other countries, as well as with the JNR. A new series using transistors has recently been developed but this will be discussed at another time. Finally, the authors wish to express they gratitude to the JNR Rollingstock design Office and rollingstock manufacturers for they helpful assistance and guidance.