UDC 621. 313. 2

AXLE GENERATING EQUIPMENT FOR TRAIN LIGHTING

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I. INTRODUCTION

Train power source equipment can be roughly divided into the centralized power source system and distributed power source system. Recently, the centralized power source system has become to be utilized in parts of express trains to install air conditioning equipments, or to increase lighting capacity. However, since there is a large amount of freedom in train composition, the distributed system is applicable to general passenger coaches and low capacity (2~3 kW) axle generating equipment is installed in each coach. Fuji Electric has produced large numbers of axle generating equipment for both the Japanese National Railways (JNR) and for export spanning many years.

II. OUTLINE OF THE EQUIPMENT

The axle generating equipment is composed of a generator, belt tension device, control device, and battery. When the train is stopped, power is supplied to the load from the battery and when the train is running, the generator supplies power to the load and at the same time charges the battery which was discharged when the train was stopped to maintain the battery in the fully charged state at all times.

The DC shunt generator formerly used has recently been replaced by a totally enclosed brushless AC generator, and little maintenance is required. The control equipment consists of silicon rectifiers to rectify the output of the AC generator, generator voltage regulator, and lamp voltage regulator.

The control equipment has been made a completely static type through the use of thyristors, diodes, transistors, and other semiconductor components throughout to make it as maintenance-free as the AC generator.

III. GENERATOR AND BELT TENSION DEVICE

As the generator is driven by the axle of the coach, it is installed under the floor of the coach. However, there are two types of mounting methods, mounting to the under frame of the coach (see *Fig. 1*) and mounting to the bogie frame. The shape of the generator and the type of belt tension device employed differs with the mounting methods.

1. Generator Specifications

Type: Inductor type
Cooling: Totally enclosed
Mounting: Under frame or bogie frame
Driving: Flat belt
Insulation: Class B

The exterior view of the generators which have been standardized as a series is shown in *Fig. 2* and their particulars are given in *Table 1*. The generator voltage and current are the values after rectification.

A cross sectional view of the Model KX7R is given in *Fig. 3* as a typical example. Since it is an inductor type and both the armature winding and field winding are at the stator side, the rotor is an iron block as shown in *Fig. 4* so that there are no accidents. Both the front and rear bearings are sealed bearings and maintenance and inspection of the generator are thus almost completely unnecessary.

2. Belt Tension Device

1) Spring type (for body-mount)

The generator is suspended from the under frame of the coach and driven by the flat belt from the axle pulley. In this system, the center distance of the pulleys during running is continuously varied by the relative operation of the coach body and the axle, and since the generator is attached to the under frame of the coach, the tension of the belt is not maintained constant. For this reason, a fairly constant belt tension is obtained by varying the generator suspension angle in accordance with the changes in the distance between the center of the pulleys and good combination of spring force and the weight of the generator. The belt tension characteristics are given in *Fig. 8* and the state in which the spring and generator are combined is shown in *Fig. 5*.

2) Rubber type (for bogie-mount)

The system in which the generator is mounted on the bogie differs from the above system in that since there are almost no changes in the distance between

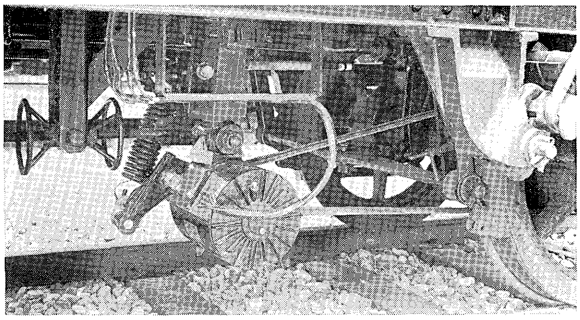

Fig. 1 Location of generator (body mount)

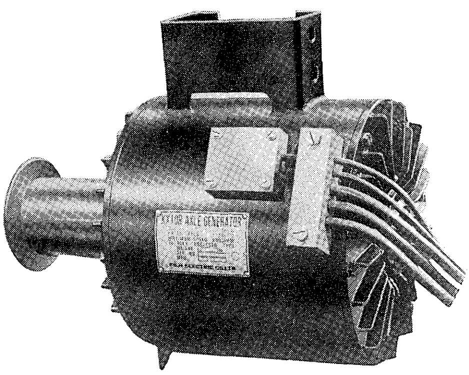

Fig. 2 Outerview of KX10R generator

Table 1 **Particulars of axle generator**

Type	No. of revolution (rpm)		Output (kW)	Voltage (V)	Current (A)
	Rating	Maximum			
KX3	800	3,600	0.8	30	26.7
KX3R	800	3,600	0.8	30	26.7
KX7	1,100	4,000	2.1	30	70
KX7R	1,100	4,000	2.1	30	70
KX10	1,100	4,000	3.0	30	100
KX10R	1,100	4,000	3.0	30	100

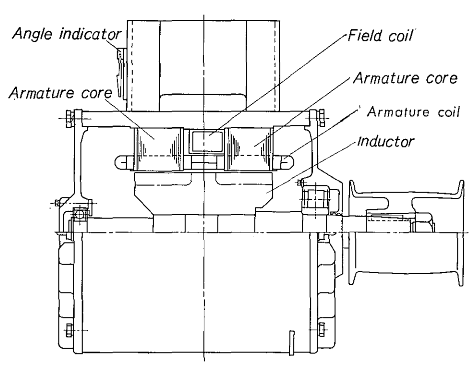

Fig. 3 Sectional view of KX7R generator

the pulleys and elongation has very little effects for short length of belt, a construction utilizing the twisting repulsion force of the tension rubber is employed. Three types matched to the model of the generator are available. The same torsion rubbers are applied

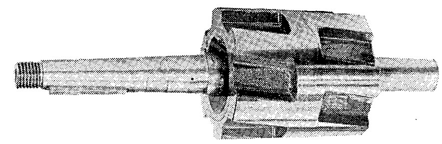

Fig. 4 Outerview of rotor

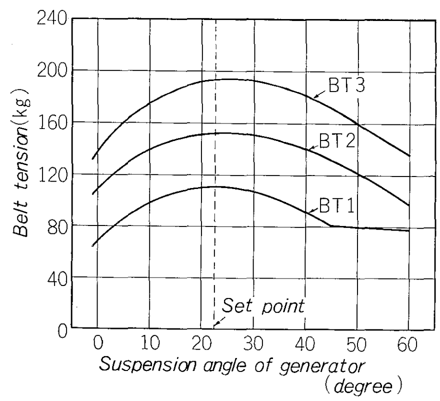

Fig. 5 Characteristics of belt tension (spring type)

in common but the numbers of this rubber are altered to adjust the belt tension. An exterior view of the Model BTR3 for KX10R is shown in *Fig. 7*. Characteristics of belt tension are illustrated in *Fig. 6*. The tension varies with the generator suspension angle, but working range is within the 0°~10° and does not propose serious problems as a practical matter.

Combinations are given in *Table 2*, and the related dimensions are given in *Figs. 8* and *9*.

IV. CONTROL DEVICE

The two vital functions demanded in axle generating equipment for train lighting can be given as:

(1) Maintenance of a constant lamp voltage.
(2) Complete charging of the battery when the train is running.

These two functions must be amply displayed even when the following conditions change.

(1) Speed and direction of rotation of the generator
(2) Load
(3) Train running pattern
(4) Train composition
(5) Seasonal and geographical temperature changes

In order to satisfy the above conditions, the control device is roughly composed of the following three devices.

(1) Rectifying device
(2) Generator voltage regulator
(3) Lamp voltage regulator

The block diagram of standard axle generating equipment is given in *Fig. 10*.

1. Rectifying Device

Rectifying device is composed of silicon rectifiers and surge absobers and is constructed compactly.

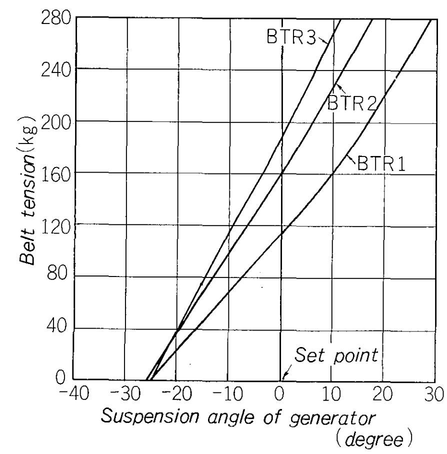

Fig. 6 Characteristics of belt tension (rubber type)

2. Generator Voltage Regurator

This device has both the constant voltage characteristics and constant current characteristics demanded by the charging use generator. In other words, a constant voltage is maintained up to a certain load current without regard to the speed and load of the generator and the generator voltage is abruptly dropped relative to a load above this value. Therefore, constant current charging is performed at a fixed current limit value at the start of charging (this protects the generator against overcurrent) and

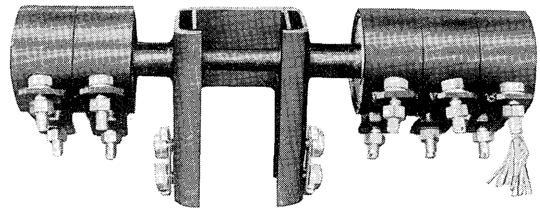

Fig. 7 Outerview of BTR3 belt tension device

then shift to constant voltage charging as charging progresses to prevent overcharging of the battery. This generator voltage regulator is capable of regulating the generator voltage (this is also the battery charging voltage) over the 28～32 V range as required so that the battery is amply charged with respect to changes in the state of the battery due to the type of train or seasonal or geographical temperature changes.

Generator voltage control is a field thyristor firing phase control system. The field use thyristor is connected in two phases of V and W in order to perform field control over a wide range.

In order to increase the charging efficiency of the battery, it is desirable to build up the generator voltage from the lowest speed possible. For this reason, an auxiliary circuit is provided in this equipment to provide gate current to the field thyristor from the battery when the train is stopped.

Consequently when the generator is started and

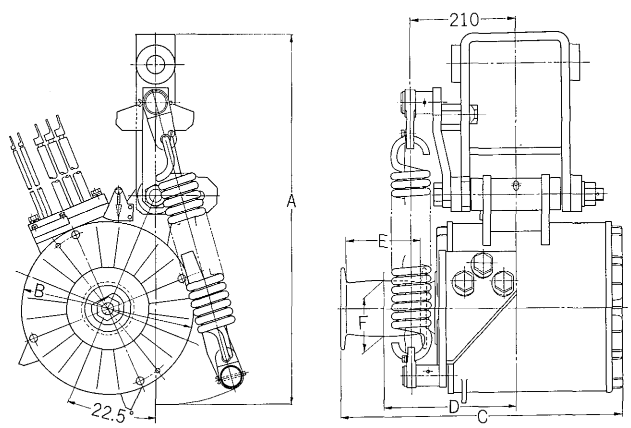

Fig. 8 Axle generator for underframe mount

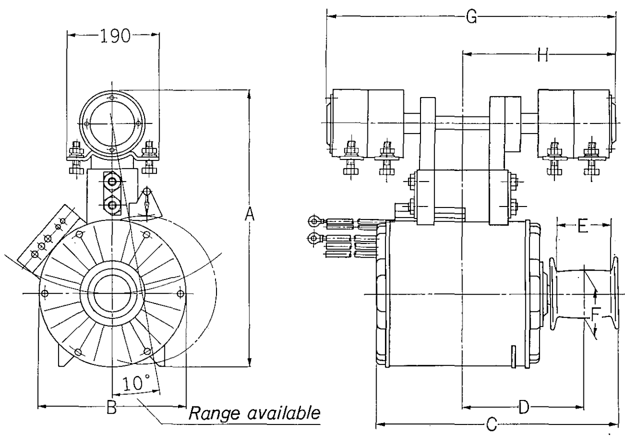

Fig. 9 Axle generator for bogie mount

Table 2 **Combination of generator and belt tension device**

Monuting	Type of generator	Type of belt tension device	Refer to	Dimensions							
				A	B	C	D	E	F	G	H
Under frame	KX3	BT1	Fig. 8	685	240	410	210	90	80/100/115	—	—
	KX7	BT2		740	305	500	250	125		—	—
	KX10	BT3		740	345	560	265	150		—	—
Bogie frame	KX3R	BTR1	Fig. 9	505	240	410	210	90		520	312
	KX7R	BTR2		572	305	500	250	125		594	312
	KX10R	BTR3		617	345	560	265	150		685	388

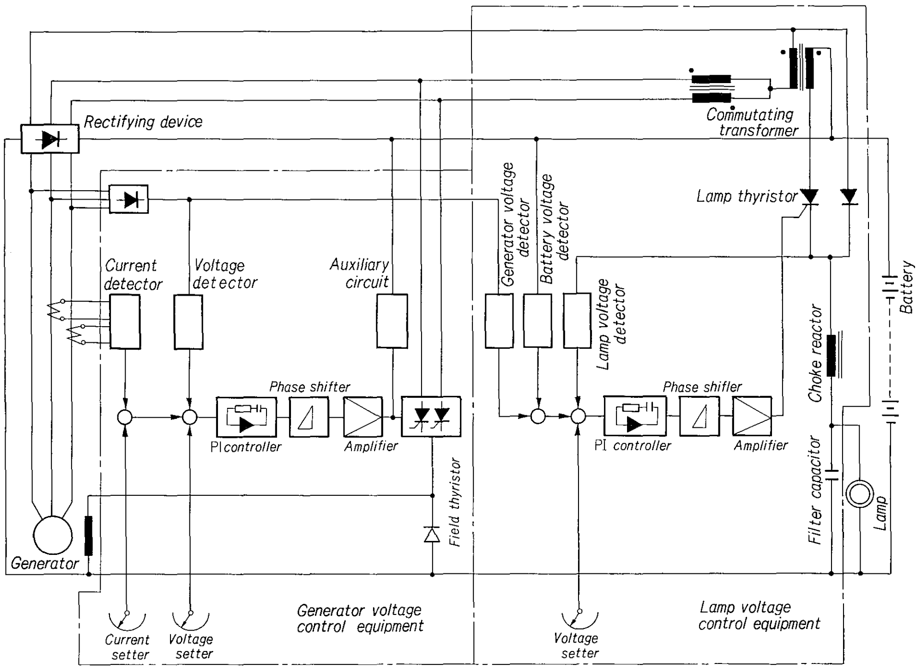

Fig. 10 Block diagram of train lighting system

even the smallest generator voltage is produced by residual magnetism, the thyristor is turned on and the voltage is quickly built up by the self-excitation action of the generator. This auxiliary circuit is simultaneously disconnected with built-up of the generator voltage and operation is shifted to phase control.

3. Lamp Voltage Regulator

The lamp voltage when the train is stopped is almost equal to the discharge voltage of the battery. On the other hand, when the train is running, the battery is in the charged state and its terminal voltage is higher than that when the train is stopped. Therefore, some means must be used to maintain the the lighting voltage at an almost constant value whether the train is stopped or running in order to provide pleasant lighting. For this reason, the lamp voltage regulator is indispensable with axle generating equipment. The lamp voltage control employs a thyristor firing phase control system. Ripple is removed by a smoothing circuit.

The AC voltage of the generator is utilized for lighting thyristor commutation. For this reason, a special commutating circuit such as that used in general DC circuit is not required and an extremely simple method can be used to meet the purpose. A theoretical diagram is given in *Fig. 11*. Firing of thyristor CRf is performed at phases V and W and interruption is performed by phase U. Now making phase rotation sequence UVW, CRf can be assumed to fire at a certain phase of phase V or W. Soon thereafter the voltage of phase W is attenuated and the voltage of phase U increases. Then when the voltage of phase U becomes higher than the voltage of phase W, its voltage is applied to the cathode of CRf through diode Rf_7. On the other hand, since a voltage such as that shown by the arrow is produced at the secondary of transformer Tr_2 at this time, a counter emf corresponding to this voltage is impressed between the anode and cathode of CRf. Transformers Tr_1 and Tr_2 employs a Scott connection so that the secondary voltage of Tr has the same relationship as phases V and W even when the phase rotation varies with forward and reverse rotation of the generator.

This axle generating equipment can not only be used as the lighting power source but also as the control power source for electrical equipments and as the train intercommunications power source. Therefore, its ripple must be reduced to a permissible value relative to the electrical equipment. The smoothing circuit consists of a choke reactor and capacitor. Flickering of the lamp poses a problem when the load is switches from thyristor phase control when the train is running to the battery when the train is stopped (and vice versa). As can be seen from the commutating circuit of *Fig. 11*, when the generator voltage in this system becomes lower than the battery voltage, the counter emf applied to the lighting thyristor is interrupted and flickering is produced by the thyristor commutation failure. For this reason, the generator voltage and battery voltage are compared, and when the commutation limit is reached, the thyristor firing phase is advanced by the regulator and switching is performed after the lamp voltage reaches the battery voltage. When switching from the battery to phase control when the train is started,

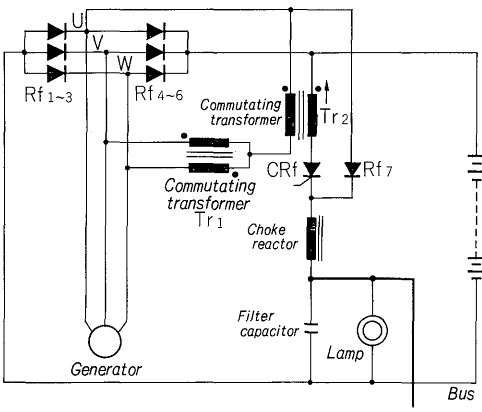

Fig. 11 **Communication circuit for lighting thyristor**

continuous switching is performed by the opposite operation. If the load is connected even through the train is stopped, the thyristor must be fired. For this reason, a signal is applied to the gate of the thyristor at all times even when the train is stopped.

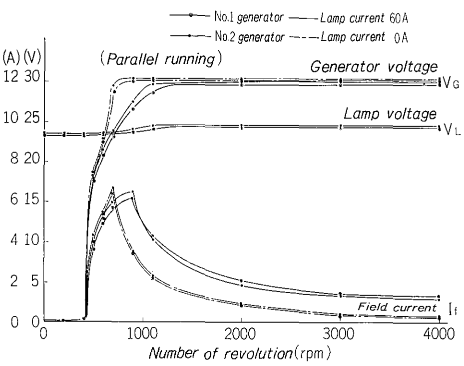

Fig. 12 **Build-up vs. speed characteristics**

4. Characteristics

Characteristics of the generator voltage and lamp voltage against the revolving speed of generator are given in *Figs. 12* and *13*. The generator build-up speed characteristics are given in *Fig. 12* and the speed characteristics at each setting voltage are given in *Fig. 13*. The load characteristics are given in *Fig. 14*. The current limiting characteristics are given in *Fig. 15*.

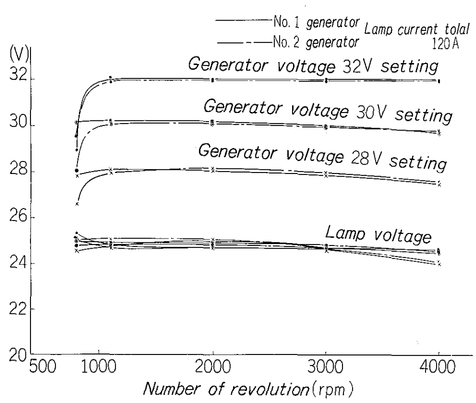

Fig. 13 **Speed characteristics**

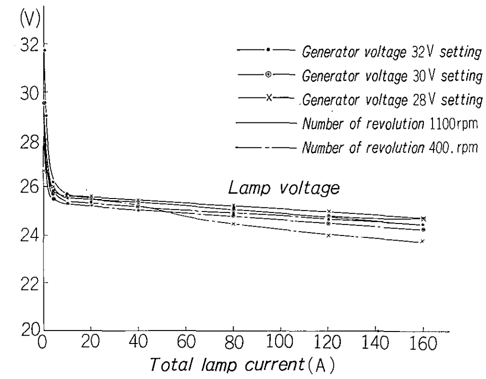

Fig. 14 **Load characteristics**

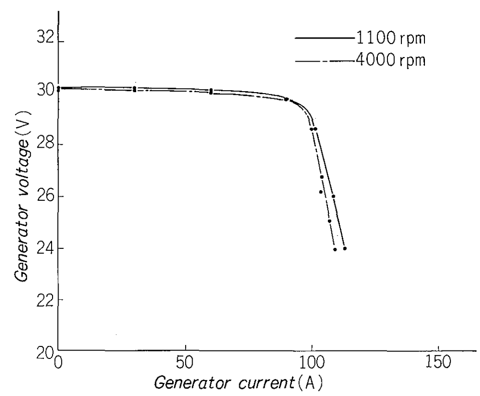

Fig. 15 **Current limit characteristics**

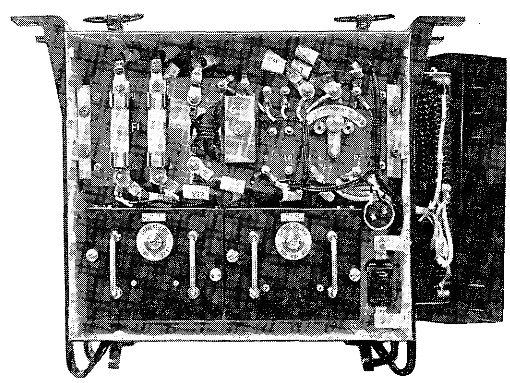

Fig. 16 **Outerview of KB12G-5R-2LS control equipment**

Table 3 **Standard series of control equipments**

Type of control equipments	Form	Rated com'tation output	Rated lamp output	Generator
KB12G-5R-2LS- KP12G-5R-2LS-	Box type Panel type	50 A	20 A	KX3/ KX3R
KB12G-10R-4LS- KP12G-10R-4LS-	Box type Panel type	100 A	40 A	KX7/ KX7R
KB12G-12R-8LS- KP12G-12R-8LS-	Box type Panel type	120 A	80 A	KX10/ KX10R

5. Standard Series of Control Equipment

There are three generator and control equipment combinations in accordance with capacity. Each is roughly divided into a under-frame suspension box type and an panel type which is mounted to the wall inside the coach. The combinations of the standard types are given in *Table 3*. An outerview of the KB12G–5R–2LS is given in *Fig. 16*.

Table 4 **Supply list of recent 3 years**

Delivery	Type	Output (kW)	No. of rev'tion (rpm)	Q'ty	Type of car	Delivery
JNR	KS0N	0.8	800	478	Brake ban	1969
JNR	KS0Nb	0.8	800	20	Brake ban	1969
JNR	KS2N	2.1	1,100	69	Passenger coach	1969
JNR	KS3N	3.0	1,100	188	Passenger coa.	1969
Korea	KX10	3.0	1,100	45	Passenger coa.	1969
Thailand	KX7	2.1	1,100	45	Passenger coa.	1969
Australia	KX7–T	1.5	800	1	Brake ban	1969
Formosa	KX10R	3.0	1,100	52	Passenger coa.	1969
Ceylon	KX3R	0.8	800	6	Passenger coa	1969
Congo	KX10	2.1	770	103	Passenger coa.	1970
Thailand	KX10	3.0	1,100	10	Dining car	1970
Formosa	KX10R	3.0	1,100	100	Passenger coa.	1970
New Zealand	KX10	2.1	770	20	Passenger coa.	1970
JNR	KS0N	0.8	800	26	Brake ban	1970
JNR	KS2N	2.1	1,100	151	Passenger coa.	1970
JNR	KS0Nb	0.8	800	3	Brake ban	1970
JNR	KS3N	3.0	1,100	315	Passenger coa.	1970
Formosa	KX3	0.8	800	32	Brake ban	1971
Australia	KX10–S	3.0	1,100	11	Passenger coa.	1971
Formosa	KX7R	1.05	550	6	Special car	1971
Formosa	KX10R	3.0	1,100	117	Passenger coa.	1971
Korea	KX10	3.0	1,100	180	Passenger coa.	1971
Formosa	KX7R	2.1	1,100	16	Passenger coa.	1971
JNR	KS0N	0.8	800	35	Brake ban	1971
JNR	KS2N	2.1	1,100	347	Passenger coa.	1971
JNR	KS2Nb	2.1	1,100	278	Passenger coa.	1971
JNR	KS3N	3.0	1,100	54	Passenger coa.	1971

V. CONCLUSION

This equipment is being widely used and highly praised both by the Japanese National Railways and around the world. Our production record for the past 3 years is given in *Table 4*.

We wish to express our gratitude to the Japanese National Railways Design Office for its invaluable assistance in the redesign of the regulating equipment in order to improve its performance.