UDC 621. 314. 63. 07

BASIC TECHNIQUE OF FUJI POWER THYRISTORS AND THEIR ASSEMBLIES

Harumoto Mori

Development Dept.

I. INTRODUCTION

Fuji Electric is now manufacturing power thyristors with repetitive peak forward voltages of up to 2500 v and mean forward currents of up to 400 amp. These thyristors are serving in a wide variety of industrial applications. This article will describe the construction and characteristics of these thyristors, as well as the construction of thyristor assemblies and protection systems.

II. CONSTRUCTION AND CHARACTERISTICS OF FUJI POWER THYRISTORS

1. Junction Design

Appropriate junction design is very important in high voltage/high current thyristors made from silicon wafers of limited diameters. If one of the thyristor characteristics is high (for example, the blocking voltage) the other characteristics (in this case, the forward voltage drop) must be increased disproportionately. For this reason, junction construction factors such as the carrier life time, base width, specific resistance, diffusion profile and distribution of the recombination center must be investigated carefully in relation to each of the thyristor characteristics and a junction design chosen in which all of the characteristics are evenly balanced. The relation between typical data used in junction design, in this case the specific resistance of the silicon crystal and the blocking voltage at various base widths, is shown in *Fig. 1*. When determining the junction design, it is naturally necessary to consider whether the design chosen will be difficult to manufacture or not.

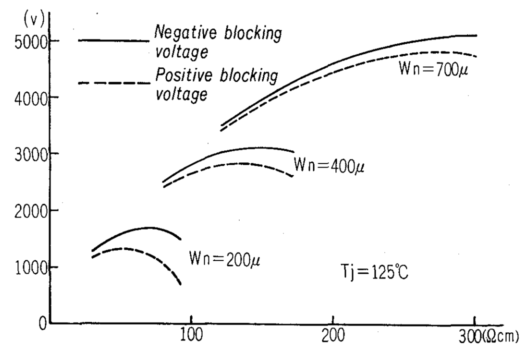


Fig. 1 Relations between resistivity and blocking voltage for various *n* base widths (W_n)

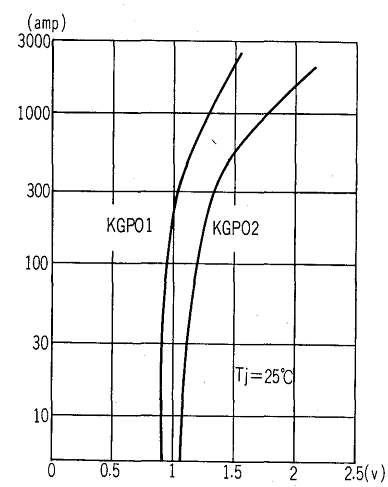


Fig. 2 Typical forward voltage drops of KGP01 and KGP02

2. Manufacturing Process

At present, most power thyristors are manufactured by the diffusion-alloy method which is carried out as follows.

(1) Diffusion process

In order to maintain the life time at a determined value or above, careful selection of materials as well as exacting atmospheric and process control are essential during the diffusion process. The diffusion process has a great influence on the on-state characteristics. The on-state characteristics obtained for KGP01 and KGP02 thyristors are shown in *Fig. 2*, while *Fig. 3* reveals the distribution of the forward voltage drop for the same types of thyristor.

For thyristors which must possess short turn-off times, doping using a life-time killer is performed during the diffusion process in order to decrease the life time.

(2) Alloying process

The cathode electrode of the thyristor is made by alloying a thin plate of gold-aluminum on the silicon

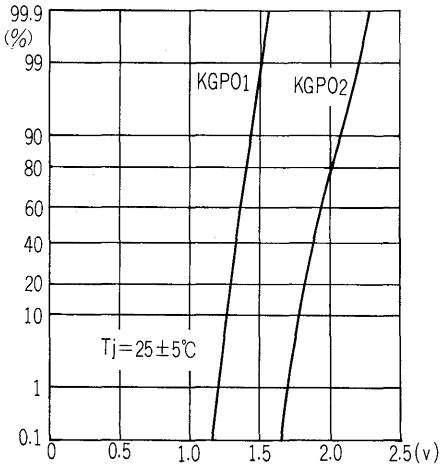


Fig. 3 Distribution of forward voltage drop KGP01 : 1500 amp, KGP02 : 1250 amp

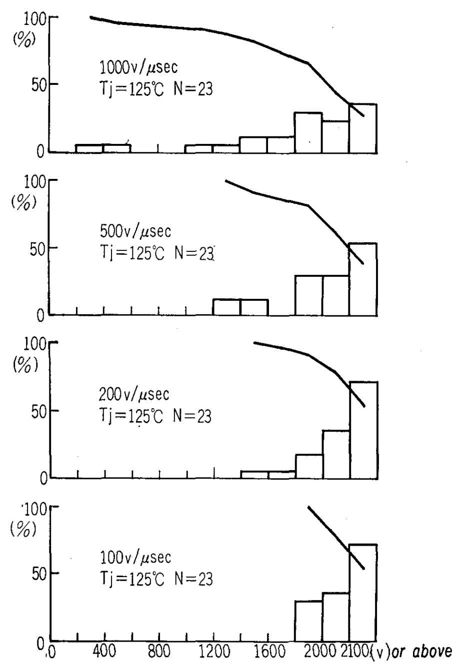


Fig. 4 Forward blocking voltage of KGP02 for various dv/dt

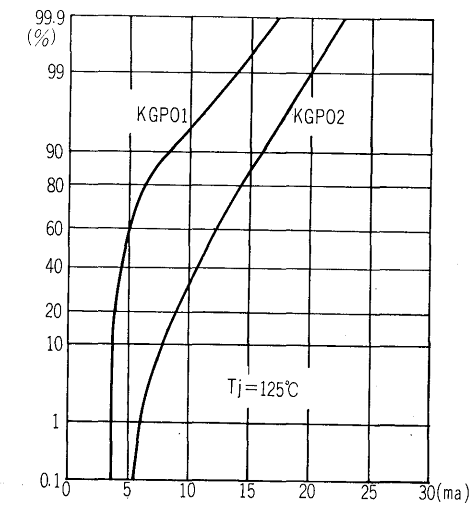


Fig. 5 Distribution of forward leakage current KGP01-12, KGP02-25

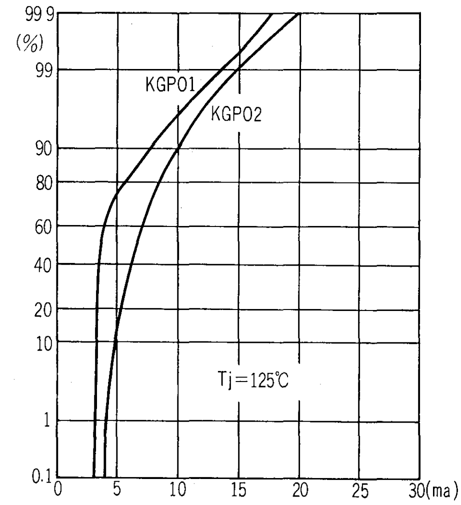


Fig. 6 Distribution of reverse leakage current KGP01-12, KGP02-25

wafer. By this process, a pn junction is created by the donor used in the doping. The uniformity of this junction has a considerable influence on the blocking characteristics, rate of rise of on-state voltage, rate of rise of forward current and surge current of the thyristor. The following steps must be performed carefully when alloying junctions with large surface areas: compounding of the Au-Sb alloy, treatment of the materials, pressing during the alloying process and temperature process control. Fuji Electric has made improvements in each of these steps. *Fig. 4* shows dv/dt values for the KGP02 thyristor.

(3) Treatment of silicon surface

The field intensity on the thyristor surface is kept at maximum of 5×10^4v/cm or below. The etching process employs a device by which the anode electrode metal is dissolved in the etching solvent so that it never comes into contact with the junction surface. As shown in *Figs. 5* and 6 respectively, the forward leakage current and reverse blocking current are distributed in low value regions.

3. Construction

External dimensions and views of the GTN type thyristors are shown in *Figs. 7* and *8* respectively and those for the KGP types are shown in *Figs. 9* and *10* respectively. In the interior of the GTN type thyristors, a copper stud and silicon pellet are brought into contact under pressure by means of a spring. In the KGP type, both sides of the thyristor electrode are pressed against the heat sink by means of an external spring. The construction features of Fuji power thyristors are as follows.

(1) Since pressure contacts are used, there is no thermal fatigue. There is also no internal contamination since no soldering is required during assembly.

(2) Since heat transfer takes place from both sides in the KGP type, the thermal resistance is low

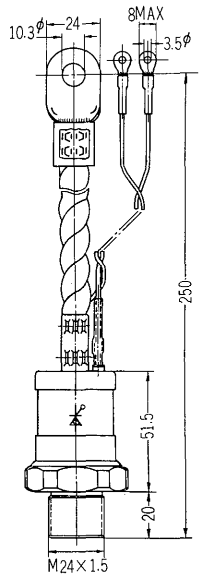


Fig. 7 Dimensions of thyristors GTN01, GTN02 and GTN21

Fig. 8 Outer view of thyristors GTN01, GTN02 and GTN21

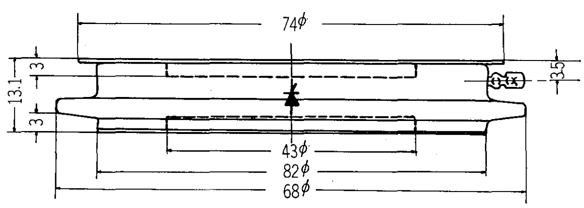


Fig. 9 Dimensions of thyristors KGP01, KGP02, KGP03 and KGP21

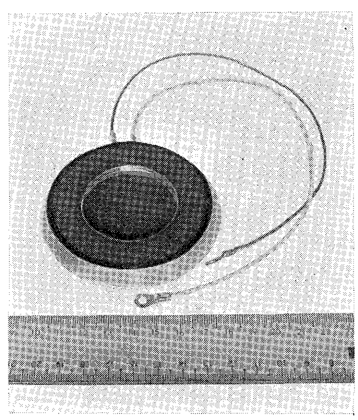


Fig. 10 Outer view of thyristor KGP01, KG02, KGP03 and KGP21

as can be seen from *Fig. 11.* When the flat-packaged type thyristors are assembled, the polarity can be changed and the most suitable of various cooling systems can be adopted, as will be explained later.

(3) Both the GTN and KGP types employ ceramic insulators which provide sufficient creepage.

4. Ratings and Charactecristics

1) Ratings of Fuji power thyristors

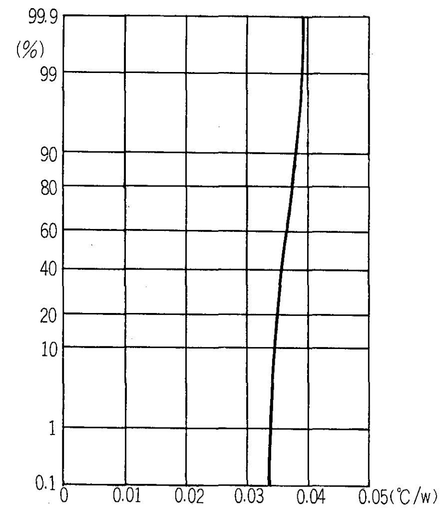


Fig. 11 Thermal resistance between junction and specified inner point of cooling fins of P thyristors

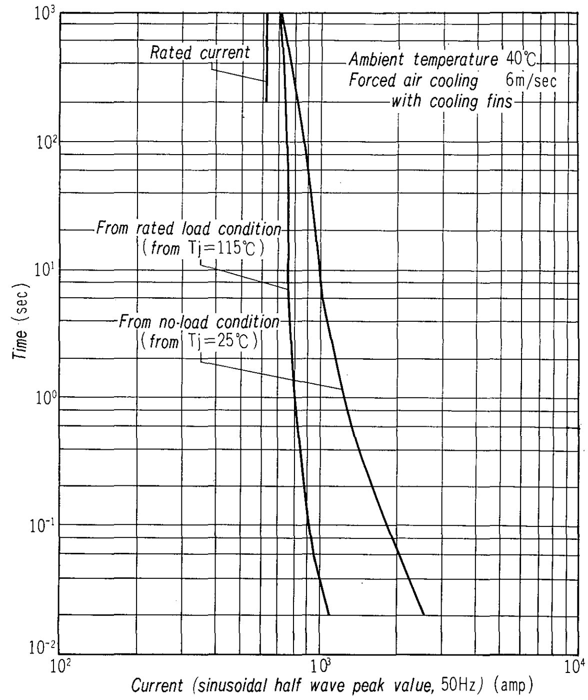


Fig. 12 Overcurrent withstand capacity (GTN02)

Ratings and characteristics of the various types of GTN and KGP thyristors are shown in *Tables 1*, 2 and *3*. Overcurrent capacities for these two types are as shown in *Figs. 12* and *13* respectively. The turn-off time characteristics of the short turn-off time thyristor KGP21 are shown in *Figs. 14* and *15.*

2) Dynamic thyristor characteristics

When thyristors are used as circuit elements in converters, the thyristor is subjected to dynamic stress, and therefore, the dynamic behaviour of the thyristor assumes considerable importance.

(1) Dv/dt characteristics

The dv/dt values represent the critical rate of rise of the off-state voltage. This value tends to decrease as the junction temperature and the final off-state

Table 1 **Ratings and Characteristics of Thyristors GTN01 and GTN02**

Item	GTN01				GTN02
	08	10	12	13	16
Rated peak reverse voltage	800 v	1000 v	1200 v	1300 v	1600 v
Rated peak forward voltage	800 v	1000 v	1200 v	1300 v	1600 v
Critical rate of rise of off-state voltage	100 v/μs (1/1.5×PFV)				200 v/μs (1/1.5×PFV)
Forward voltage drop	≦1.5 v (25°C, 600 amp)				
Rated mean forward current	200 amp (sinusoidal half wave, conduction angle 180°, T_c=80°C				
Critical rate of rise of on-state current	50 amp/μs				
Permissible surge current	6300 amp (1 cycle of 50 Hz)				
I^2t value	240,000 amp²-sec				
Holding current	≦180 ma (25°C)				
Reverse current	≦10 ma (at rated peak reverse voltage)				
Off-state current	≦10 ma (at rated peak forward voltage)				
Continuous permissible junction temperature	−40°C∼+125°C				
Thermal resistance between junction base	≦0.17 deg/w				
Gate trigger current	≦300 ma (25°C)				
Gate trigger voltage	≦2.0 v (25°C)				
Gate non-trigger voltage	≧0.2 v (125°C)				
Rated mean gate loss	<2.0 w				
Rated peak gate loss	<20 w (pulse width ≦100 μs)				
Rated gate reverse voltage	<2.0v				
Standard fastening torque	5.5 kg•m with compound, 8.0 kg-m without compound				
Weight	Approx. 550 g				

Table 2 **Ratings and Characteristics of Thyristors KGP01 and KGP02**

Item	KGP01		KGP02	
	08	12	20	25
Rated peak reverse voltage	800 v	1200 v	2000 v	2500 v
Rated peak forward voltage	800 v	1200 v	2000 v	2500 v
Critical rate of rise off-state voltage (dv/dt)	100 v/μs $\left(\frac{1}{1.5}\times \text{PFV}\right)$		100 v/μs $\left(\frac{1}{1.5}\times \text{PFV}\right)$	
Forward voltage drop	≦1.6 v (25°C, 1500 amp)		≦2.3 v (25°C, 1250 amp)	
Rated mean forward current, sinusoidal half wave, conduction angle 180°	500 amp T_c=80°C		400 amp T_c=80°C	
Critical rate of rise of on-state current (di/dt)	50 amp/μs		50 amp/μs	
Permissible surge current	10,000 amp (1 cycle of 50 Hz)		7000 amp (1 cycle of 50 Hz)	
I^2t value	410,000 amp²-sec		200,000 amp²-sec	
Holding current	≦400 ma (25°C)		≦400 ma (25°C)	
Reverse current	≦20 ma (at V_{R0})		≦30 ma (at V_{R0})	
Off-state current	≦20 ma (at V_{F0})		≦30 ma (at V_{F0})	
Permissible continuous junction temperature	−40°C∼+125°C		−40°C∼+125°C	
Thermal resistance between junction and base	≦0.04 deg/w		≦0.037 deg/w	
Gate trigger current	≦300 ma (25°C)		≦300 ma (25°C)	
Gate trigger voltage	≦2.0 v (25°C)		≦2.0 v (25°C)	
Gate non-trigger voltage	≦0.2 v (125°C)		≦0.2 v (125°C)	
Rated mean gate loss	4.0 w		4.0 w	
Rated peak gate loss	70 w (pulse width ≦100 μs)		70 w pulse width ≦100 μs)	
Rated gate reverse voltage	5.0 v		5.0 v	
Standard fastening pressure	1000^{+200}_{-100} kg		1000^{+200}_{-100} kg	
Weight	Approx. 240 g		Approx. 190 g	

Table 3 Ratings and Characteristics of Short Turn-Off Time Thyristors

Item	GTN21			KGP21
	03	06	12	13
Rated peak reverse voltage	300 v	600 v	1200 v	1300 v
Rated peak forward voltage	300 v	600 v	1200 v	1300 v
Critical rate of rise of off-state voltage (dv/dt)	50 v/μs $\left(\frac{1}{1.5}\times \text{PFV}\right)$			100 v/μs $\left(\frac{1}{1.5}\times \text{PFV}\right)$
Forward voltage drop	≦1.9 v (25°C, 600 amp)			≦2.0 v (25°C, 1250 amp)
Rated mean forward current, sinusoidal half wave, conduction angle: 180°	160 amp T_c=80°C			400 amp T_c=80°C
Critical rate of rise of on-state current (di/dt)	100 amp/μs			100 amp/μs
Permissible surge current	5500 amp (1 cycle of 50 Hz)			8000 amp (1 cycle of 50 Hz)
I^2t value	150,000 amp^2-sec			260,000 amp^2-sec
Holding current	≦180 ma (25°C)			≦400 ma (25°C)
Reverse current	≦10 ma (at V_{R0})			≦30 ma (at V_{R0})
Off-state current	≦10 ma (at V_{R0})			≦30 ma (at V_{F0})
Permissible junction temperature	−40°C～+120°C			−40°C～+115°C
Thermal resistance between junction and base	≦0.15 deg/w			≦0.04 deg/w
Turn-on time	≦3.0 μs (25°C)			≦5.0 μs (25°C)
Turn-off time	≦50 μs (120°C)			≦50 μs (115°C)
Gate trigger current	≦300 ma (25°C)			≦300 ma (25°C)
Gate trigger voltage	≦2.0 v (2.0 v (25°C)			≦2.0 v (25°C)
Gate non-trigger voltage	≧0.2 v (125°C)			≧0.2 v (115°C)
Rated mean gate loss	2.0 w			4.0 w
Rated peak gate loss	20 w (pulse width ≦100 μs)			70 w (pulse width ≦100 μs)
Rated gate reverse voltage	2.0 v			5.0 v
Fastening torque and pressure	5.5 kg-m (with compound)			1000^{+200}_{-100} kg

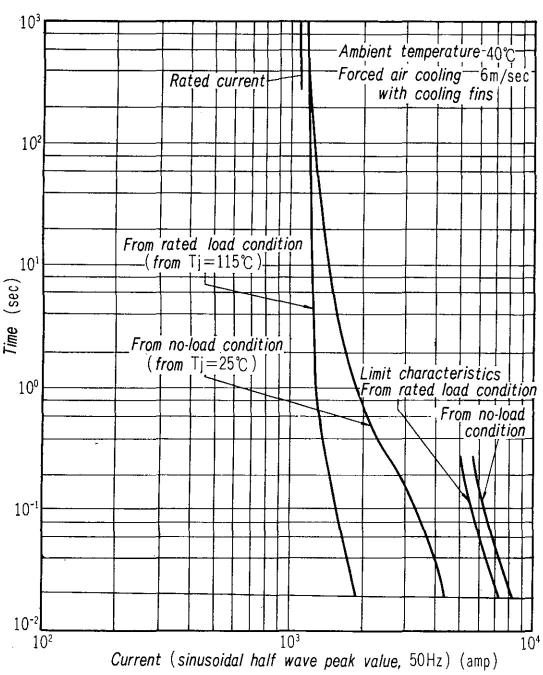


Fig. 13 **Overcurrent withstand capacity (KGP02)**

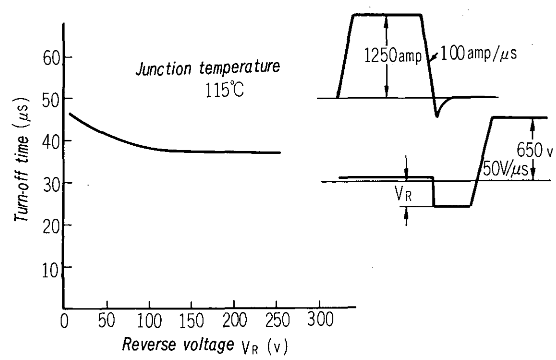


Fig. 14 **Dependence of applied reverse voltage on turn-off time**

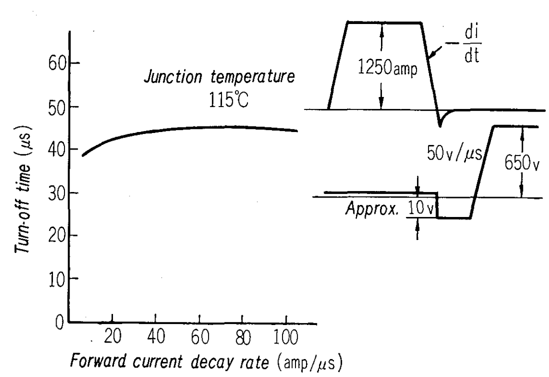


Fig. 15 **Dependence of forward current decay rate on turn-off time**

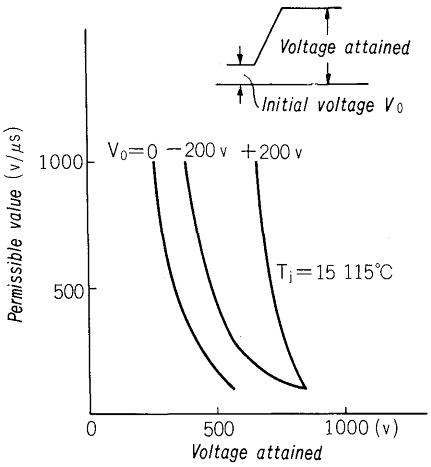


Fig. 16 Typical dv/dt capability

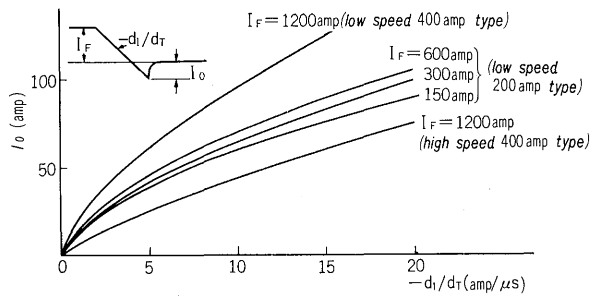


Fig. 19 Typical reverse recovery current of thyristor

voltage increase. When the initial off-state voltage is present, the dv/dt value is high. The dv/dv characteristics of the GTN01 thyristor are shown in *Fig. 16.*

(2) Di/dt characteristics

The di/dt values represent the critical rate of rise of the forward current. This value is limited according to the di/dt of the commutating current in converters. When the thyristor is employed in a parallel connected R-C filter as shown in *Fig. 17*, the di/dt value is also limited by the discharge current from the capacitor.

(3) Reverse recovery current

The reverse recovery current flows temporarily just after the foward current stops since there is no reverse blocking capability in the reverse direction. When the reverse recovery current decreases, a reverse voltage appears in the thyristor. However, if the reverse recovery current decreases rapidly, the inductance present in the circuit induces a large voltage. After commutation is finished, a transient voltage arises which is known as the initial reverse voltage. In order to keep this initial reverse voltage low, a capacitor is connected in parallel with the thyristor as shown in *Fig. 17.* The anode current and anode voltage during turn-off are as shown in *Fig. 18.* The reverse recovery current depends on the anode current (I_F) and the anode current decrease rate (di/dt). *Fig. 19* shows the peak values of the reverse recovery current (I_0).

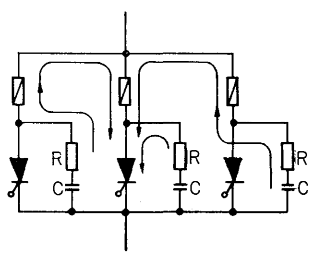


Fig. 17 Connection of R-C filter

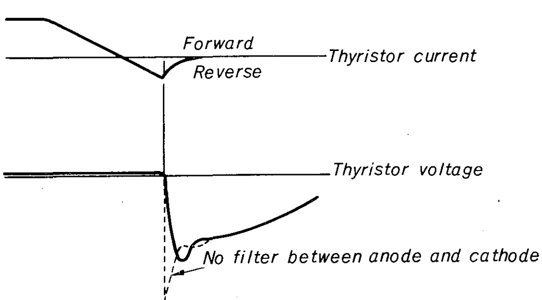


Fig. 18 Transient waveforms of thyristor current and voltage at turn-off

(4) Turn-on time

The turn-on time is the time required for the turn-on process, and consists of the delay time and the rise time. When the series and parallel connection method is used, the difference in the turn-on times for each thyristor must be kept to a minimum so that the stress can be shared evenly among the thyristors. For this reason, the gate trigger current is large. The rise time of one of the thyristor arms in the converter circuit affects the dv/dt stress of the other thyristor arms.

(5) Turn-off time

The turn-off time is the time required for recovery of the forward blocking capability. This time is determined the phase control angle of advance in externally commutated converters and the capacity of the commutating device in self-commutated converters. The maximum operating frequency of the converter is limited in accordance with the turn-off time.

The dynamic stress to which the thyristor is subjected during converter operation is described in section IV.

III. CONSTRUCTION OF THYRISTOR ASSEMBLIES

1) Air-cooled thyristor unit

The thyristor is accommodated in a converter along with a cooling fin, fuse, R-C filter, and gate trigger pulse transfer circuit. The thyristor element and these accessories are mechanically and electrically connected beforehand. This connection is as shown in *Fig. 20* and an external view of thyristor units is shown in *Figs. 21* and *22.* The number of thyristor units required for the converter capacity in question are inserted in a standard cubicle containing a cooling fan.

In this way converters with various ratings can be

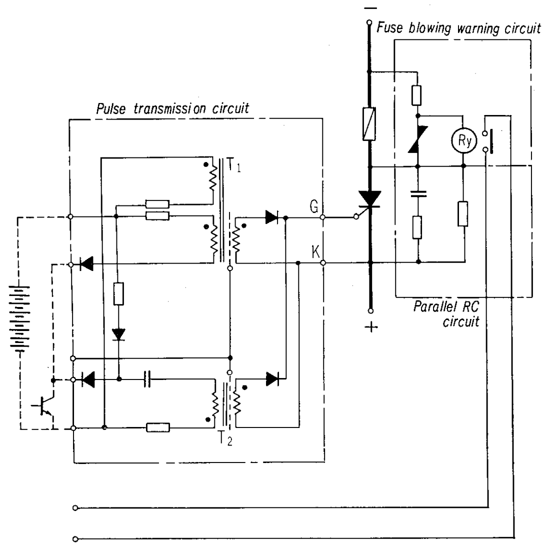


Fig. 20 Connection diagram of thyristor unit

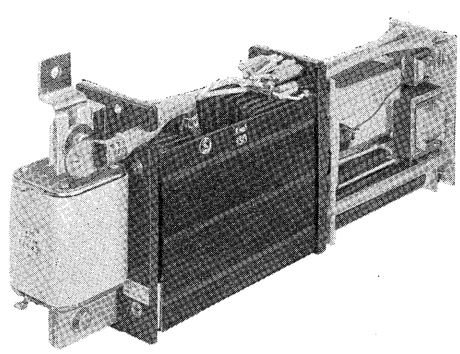


Fig. 21 Thyristor unit (Type BAS-GN02)

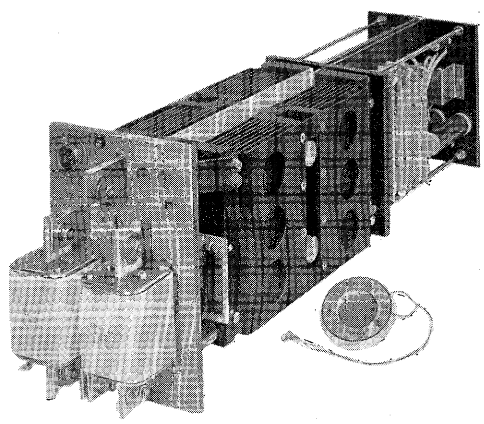


Fig. 22 Thyristor unit and flat-packaged thyristor KGP02

standardized. *Table 4* lists the specifications of the thyristor units. As can be seen from *Fig. 20*, the gate trigger pulse transfer circuit contains two pulse transformers, T_1 and T_2. T_2 generates the rapid rise peak pulse while T_1 is used to transfer the width pulse. The R–C filter is intended to absorb the carrier storage effect due to overvoltages. When the fuse is blown, a warning signal is given on the exterior by a relay.

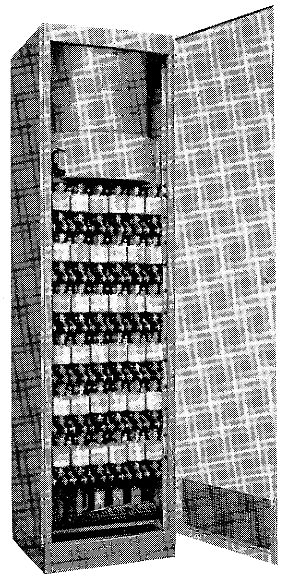


Fig. 23 Standard cubicle for N-unit

2) Standard cubicles for thyristor units.

The GTN 01 and GTN 02 stud type thyristors are accommodated in the standard cubicle shown in *Fig. 23*. One cubicle is capable of holding 36 units. The dimensions are 600 mm (W) × 800 mm (D) × 2350 mm (H). Converter circuit connections are made at the rear of the converter. The cooling air flows from the bottom to the top.

The KGP01 and KGP02 flat-packaged type thyristors are accommodated in the standard cubicle shown in *Fig. 24* which can accommodate 18 units. For large capacity converters, several cubicles are collected to make up a single converter.

In special cases, an air-to-water recooler is used for circulation of the cooling air as shown in *Fig. 25*. When the converter capacity is small, the thyristor units along with the gate control equipment and the regulator etc. can be accommodated in a single cubicle as shown in *Fig. 26*.

3) Construction of thyristor assemblies with liquid cooling systems

The cooling effect with liquid cooling is superior to that obtained with air-cooling, but it requires a recooler and accessories. Among the cooling mediums there are water, transformer oil and liquid chemicals. When the thyristor assembly is water cooled, a

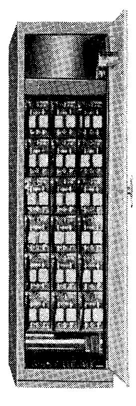


Fig. 24 Cubicle for P-unit

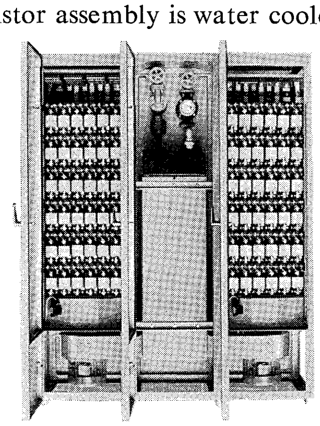


Fig. 25 Enclosed dust-proof type cubicle

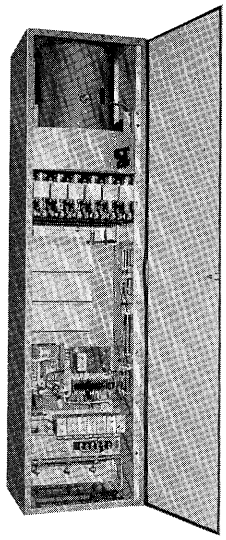


Fig. 26 Converter accommodated in single cubicle

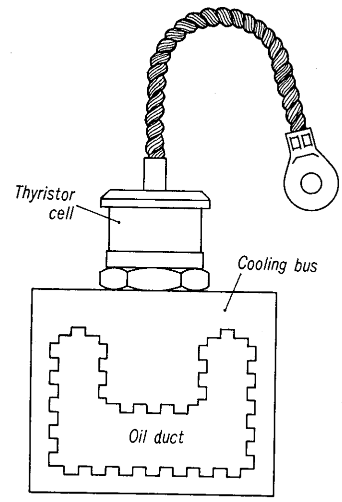


Fig. 28 Cooling unit for oil-cooled rectifier

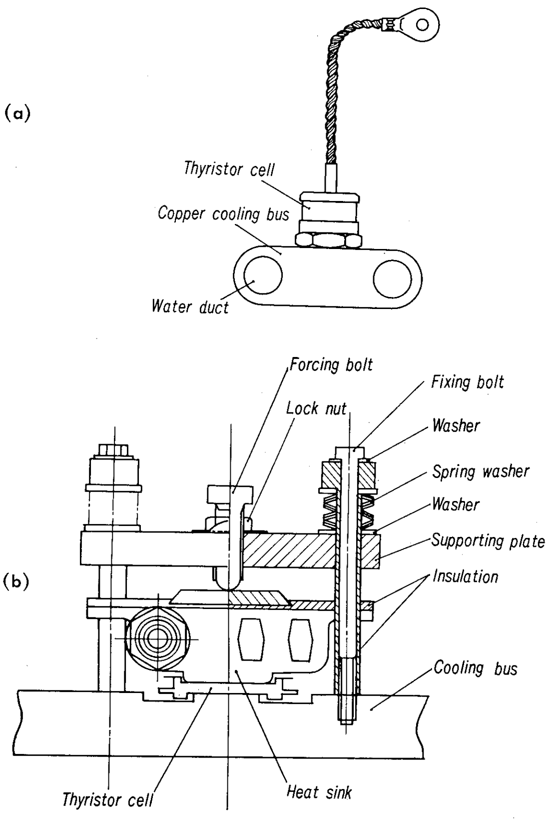


Fig. 27 Cooling unit for water-cooled rectifier

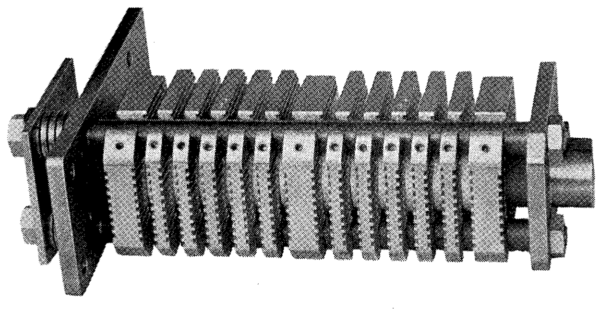


Fig. 29 Outer view of oil-immersed rectifier stack

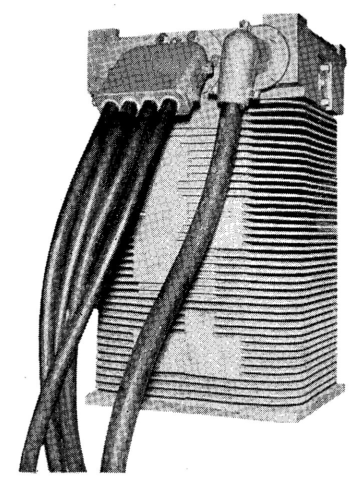


Fig. 30 Outer view of oil-immersed rectifier unit

copper cooling bar as shown in *Fig. 27* (*a*) for stud type elements and in *Fig. 27* (*b*) for flat-packaged type elements is employed. Practical examples of the use of water-cooled thyristor rectifiers have been described in detail elsewhere[(1), (2)]. For oil cooling, the cooling bar is made of aluminum with the shape shown in *Fig. 28*. The construction of this type of rectifier has also been described elsewhere[(3)]. When oil cooling is used, the thyristor elements can be immersed directly in the oil and the flat-packaged type thyristors can be combined with their cooling fins in stack type construction as shown in *Fig. 29* and inserted in a tank in which the oil circulates. *Fig. 30* is an external view of an oil-immersed rectifier unit manufactured by Fuji Electric for railway use. Ideal chemical liquid coolants which have the same heat transfer coefficient as water and the same dielectric strength as oil are expensive. Thus it is difficult to get good results from the conventional methods where heat transfer is performed by liquid flow. However, if a method is used in which heat transfer is effected by means of latent heat of boiling liquid, a heat transfer coefficient 3～4 times the usual value can be obtained. A Freon boiling cooled rectifier has been constructed using a 600 v, 2000 amp thyristor set. Details are given elsewhere[(4) (5)].

The type of cooling system to be used is determined by careful consideration of the equipment location, capacity and load fluctuations.

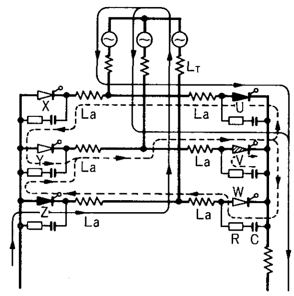
IV. PROTECTION OF THYRISTOR CONVERTERS

When compared with other electrical equipment, the operating voltage of ordinary semi-conductor devices is very close to the permissible limit voltage and since the thermal capacity is small, the overcurrent capability is also small. With thyristors, there is also a limiting value in respect to the dynamic characteristics, dv/dt and di/dt. As the voltage and capacity of the converter equipment increases, the stress on the individual thyristor elements becomes more severe. This section will describe the overcurrent, overvoltage dv/dt stress and di/dt stress which occur in external commutated converters and also explain the protection methods adopted.

In large capacity converters, the 3-phase bridge connection is generally used. This type of connection subjects the thyristor to more severe dynamic stress than other converter connections. The phenomena brought about by this connection are as follows.

1) Phenomena associated with thyristor turn-on

Fig. 31 shows the arm voltage waveform for a 3-phase bridge connection for a typical control angle consisting of a delay angle of $\alpha=90°$ and an advance angle of $\gamma=60°$. As was described previously, the anode current which flows into the gate-triggered thyristor consists of the commutating current and the capacitor discharge current, both of which reach a maximum at $\alpha=90°$. In order to prevent this rush-in current, an anode reactor is inserted in each arm as shown in *Fig. 32* and a resistor (*R*) is connected in series with a capacitor (*C'*).



Arm v: Turn on
Solid line: Main load commutation current
Broken line: Current passing through R-C filter
(When La is large, current also flows to power source)

Fig. 32 Current path at thyristor turn-on

As shown in *Fig. 31*, the arm voltage is rapidly changed by the turn-off and turn-on of other arms. When excess dv/dt is applied to the thyristor during forward blocking, break-over occurs. The dv/dt stress becomes most severe when $\gamma=60°$, and as shown in *Fig. 31*, this dv/dt stress is applied right from the zero initial voltage. The value of dv/dt at this time is determined according to the rise times of the thyristors in the other arms, but it can be suppressed by wiring inductance in the converter of the arm reactor, a parallel capacitor etc.

2) Phenomena associated with thyristor turn-off

Immediately after the thyristor is turned off, reverse

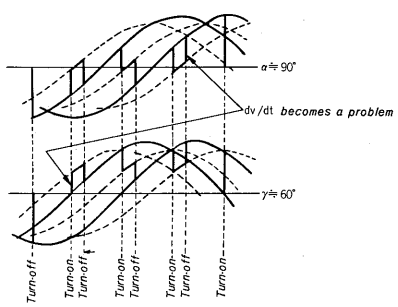


Fig. 31 Voltage waveforms of blocking thyristor in 3-phase bridge connection

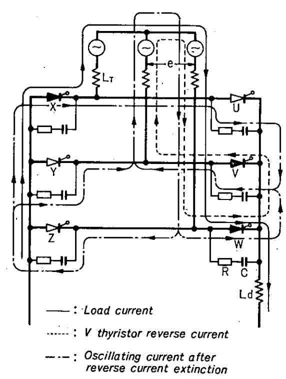
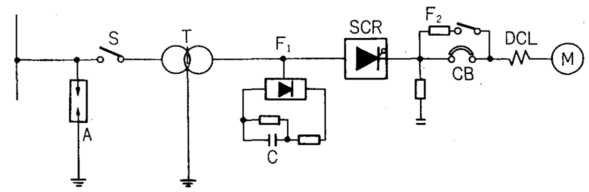


Fig. 33 Current path at arm *V* turn-off

Table 4 **Specifications of thyristor unit and diode unit**

Type	Thyristor Unit					Diod Unit		
	BAS-GN0108	BAS-GN0112	BAS-GN0216	BAK-GP0220	BAK-GP0225	BAS-SN0108	BAS-SN0112	BAS-SN0320
Element	GTN0108	GTN0112	GTN0216	KGP0220	KGP0225	SIN0108	SIN0112	SIN0320
PFV PRV	800 v	1200 v	1600 v	2000 v	2500 v	800 v	1200 v	2000 v
Rated current	200 amp (air-cooled 6 m/sec, T_a=40°C) 90 amp (self-cooled T_a=40°C)			365 amp (air-cooled 6 m/sec, T_a=40°C) 170 amp (self-cooled T_a=40°C)		200 amp (air-cooled 6m/sec, T_a=40°C) 90 amp (self-cooled T_a=40°C)		
Fuse	RF1233 f-350B	RF1244-3/350		RF 1244-3/350 (double parallel)		RF1233 f-350 B	RF1244-3/350	
Coolant	AN01			KT01		AN01		
Dielectric strength	Main circuit—earth 3.5 kv 1 min, arcing circuit—earth 1.5 kv 1 min							
Permissible temperature	−20°C∼+50°C (operation)							



A: Lightning arrester
T: Transformer
F_1: Ac side surge absorber
SRC: Thyristor
F_2: Dc side surge absorber
CB: High speed dc circuit breaker
DCL: Dc reactor
M: Dc motor

Fig. 34 Overvoltage protection system for thyristor converter

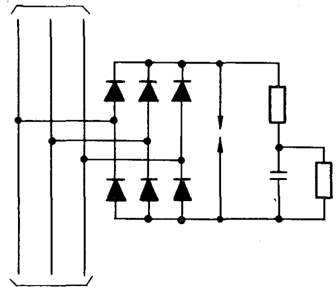


Fig. 35 Connection diagram of ac surge absorber with dc arrester

recovery current quenching occurs, followed by the occurrence of the initial reverse voltage. This initial voltage must be within the permissible limits for the thyristor and causes rapid changes in the anode voltage for other arms which are in the blocking state. The most severe case occurs when $\alpha = 90°$. *Fig. 33* shows the path of the oscillating current which flows just after thyristor quenching in arm *V*. The reverse current flowing in the thyristor of arm *V* passes through phase windings *V* and *W* of the transformer. Just after thyristor reverse recovery, the current remaining in transformer windings *V* and *W* oscillates through the path shown in *Fig. 33*. The initial reverse voltage at this time is determined according to the operating voltage, leakage inductance of the transformer and the values of *R* and *C*.

3) Overvoltage protection

Fig. 34 shown a typical overvoltage protection system for the thyristor converter. Overvoltages include lightning surges from the ac source, switching surges, and static transfer surges of the step-down transformer. Arrester *A* suppresses surge voltages from the ac source. The ac side surge absorber F_1 absorbs the energy of switching surges and suppressed external surges. To protect against static voltage transfers from the ac source, a shield plate is provided between the transformer windings and a capacitor is connected between the transformer valve winding and ground. When one portion of the overvoltage which arises during operation of the dc circuit breaker is applied to the converter, the dc side filter F_2 is connected. In order to prevent the discharge current from the capacitor in the ac side filter from rushing into the thyristor when the thyristor is turned on, this discharge is prevented by a diode bridge as shown in *Fig. 35*.

4) Overcurrent protection

The causes of overcurrents arising in converter thyristors include the following: reverse breakdowns, break-through missing, conduction through, dc short-circuits, decreases and losses in the ac source voltage, load rush currents, and irregular gate triggering.

Means of protection against such overcurrents are as follows.

(1) Load current limiting by gate control

One example of this method is current limiting by means of feedback control in respect to rush currents which occur when the motor starts or accelerates.

(2) Gate pulse shift

With this method, fault currents are eliminated by shifting converter operation to the inverter zone when faults occur.

(3) Fuse

Each thyristor contains a quick-acting fuse connected in series. These fuses cut off the current mainly in cases of element failure. Fuse operation is coordinated with that of the circuit breaker.

(4) High speed circuit breaker

In converters containing many thyristors connected in parallel, it is undesirable if all the fuses are blown during a dc short. If this happens, a circuit breaker is provided on the dc side to protect the converter.

The surge voltage which occurs when the fuses and circuit breaker interrupt a short-circuit does not become excessive in respect to the thyristors.

V. CONCLUSION

This article has given an outline of the power thyristors and thyristor assemblies produced by Fuji Electric. The stress to which thyristors are subjected in converters is rathers complex. The relation between transient phenomena in the circuit and stress on thyristors has been described for typical converter connections and the means of protection have been listed. This article is intended to serve as a basic reference in relation to the thyristor application articles in this issue.

References:

(1) Electrical Review, 16 May, 1969, p. 718
(2) Proceedings of conference on power thyristors and their applications, May 1969, IEE, p. 225
(3) Fuji Electric Review Vol. 15 No. 3 (1969) p. 59
(4) Fuji Electric Review Vol. 15 No. 3 (1969) p. 88
(5) Proceedings of conference on power thyristors and their applications, May 1969, IEE, p. 79