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DISK TYPE SILICON POWER DIODE

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I. INTRODUCTION

The so-called stud structure with a stud-equipped base and flexible lead is the most widely used type of construction for medium and large capacity silicon power diodes. Hardly any other type of construction is in use, although this construction is not necessarily the most logical when very important factors in the construction of silicon diodes, such as cooling effect, mechanical strength, lightness and compactness, reversibility of polarity and cost of materials are taken into consideration. Rather, considerable sacrifice of rationality occurs because of restrictions in the manufacturing process, such as soldering the silicon pellet to the base and facilitating replacement of the diodes.

Today, when pressure-contact type silicon diodes have been developed that have done away with problems concerning electrode soldering and when manufacturing techniques of diodes have vastly improved and the high reliability of the majority of diodes has been proven over lengthy periods of use, the time has come to fundamentally restudy construction of power diodes with the object of making them more economical in weight, volume, and cost.

Disk type silicon power diodes retain advantages of pressure-contact type silicon diodes and at the same time eliminate the structural faults of previous stud type diodes and indicate the tendency of future construction of silicon power diodes.

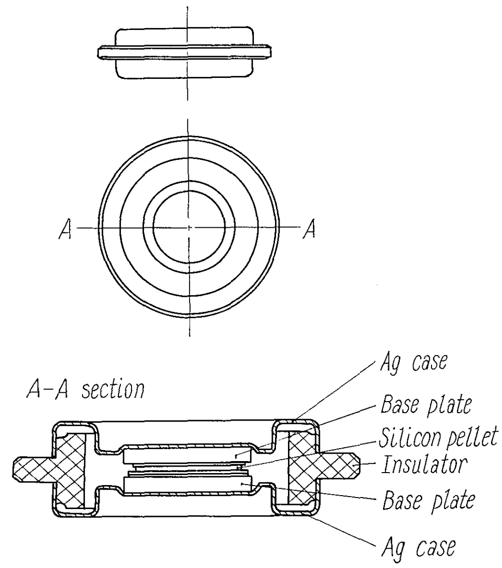


Fig. 1 Construction of disk type silicon power diode

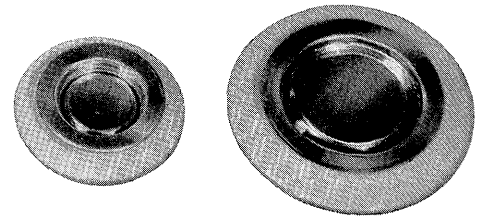


Fig. 2 Disk type silicon power diode

II. CONSTRUCTION

1. Outline of Construction of Disk Type Silicon Power Diode

The construction of the disk type silicon power diode is shown in *Fig. 1*. Base plates that have a coefficient of expansion approximately the same as the silicon pellet are bonded at both sides of silicon pellet. These elements are contained in a thin silver case. The silver case and the base pltaes are not bonded together with hard solder, but are kept in contact by externally exerted pressure. The silver case on each side acts as an electrode and is insulated from the base by a ring-shaped ceramic insulator.

2. Decrease of Internal Thermal Impedance due to Thermal Conduction from Both Sides of Disk

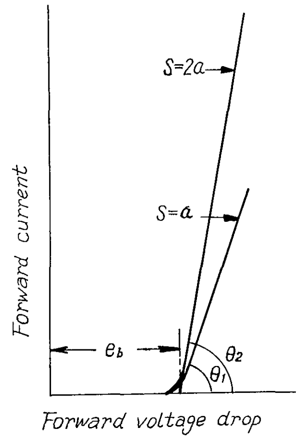
The first problem that occurs when miniaturizing the size of a silicon diode is how to heighten its current carrying capacity. The current carrying capacity of a silicon element is determined mainly by the three following factors:

(1) Allowable temperature of the junction.

(2) Forward characteristics and forward losses that are determined by the load current.

(3) Thermal impedance between junction and base and between base and cooling medium.

The allowable junction temperature is determined by the reverse leakage current at high temperature, the protection given to the junction surface to pre-



$\text{Cot } \theta_1 = r_1$
$\text{Cot } \theta_2 = r_2$
$r_1 = 2r_2$

Fig. 3 **Forward characteristics of silicon power diode**

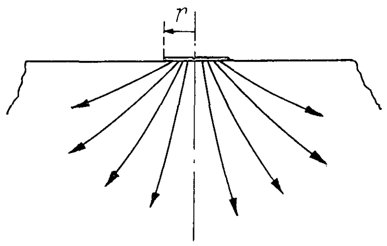


Fig. 5 **Thermal conduction from disk to hemisphere**

vent deterioration and the thermal fatigue of the bonded part of the diode. These factors may be improved by improving the method of constructing the p–n junction, improving the method of treating the surface, and using a pressure-contact construction. Increasing the p–n junction area is the main factor in improving forward characteristics. As shown in *Fig. 3*, differential resistance r is in inverse proportion to the area s of the p–n junction. But in the forward voltage drop there is barrier potential e_b that has no relation to current density. This e_b takes a large part in total forward voltage drop within normal load current values and even if area s is made larger the forward voltage drop for the same current does not decrease much, and therefore forward losses do not drop in proportion to the area.

The thermal impedance R_{jb} between junction and base will naturally drop when the junction area is increased. The greater part of heat dissipation of the stud type diode occurs from the base side and that from the lead side is negligible. R_{jb} may be approximated from the radial thermal impedance resulting from a disk thermal source of radius r with its heat being dissipated to an infinitely large hemisphere. The radial thermal impedance R_V is in inverse proportion to the radius of the disk type thermal source, or is the square root of its area.

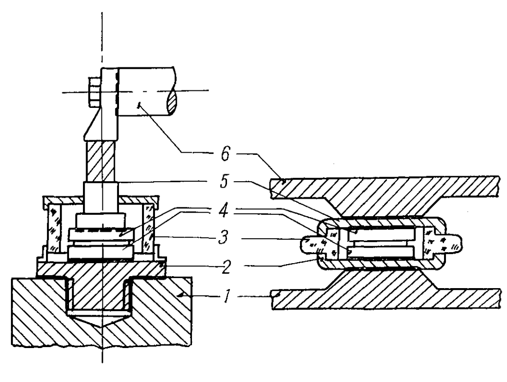
$$R_V = \frac{1}{4\lambda r}$$

λ: Thermal conductivity of infinite hemisphere

The actual construction of the diode differs from an infinite hemisphere and foreign material is interposed between the pellet and the copper base. Therefore, this theoretical equation is not exactly true. However, the relation between internal thermal impedance and junction area of exsisting stud type diodes also support the relation $R_{jb} \propto 1/\sqrt{F}$ (See *Fig. 6*).

The thermal impedance R_{ba} between the base and cooling medium is determined mainly by the construction of the cooling body and method of cooling. R_{ba} will decrease if the cooling body is enlarged and if forced air, water, or oil cooling is used, but the shape, weight, cost, and balance with R_{jb} will be problems and so R_{ba} alone cannot be drastically reduced. The thermal capacity of the silicon pellet is extremely small compared to the base and cooling body, and so if $R_{jb} \gg R_{ba}$ then a short overcurrent will cause the temperature difference between the junction and the case to become large and the allowable junction temperature will be surpassed in a very short time and the diodes' overcurrent capacity will diminish drastically. Therefore, the following relation generally holds true for usual diodes:

$$R_{jl} \leqq R_{ba}$$



(a) Stud type diode
1. Heat sink
3. Insulator
5. Upper electrode

(b) Disk type diode
2. Lower electrode
4. Rectifying element
6. Terminal, this also acts as the heat sink in (b)

Fig. 4 **Current and heat path of silicon power diode**

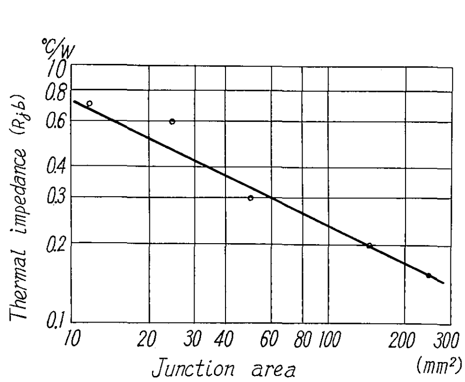
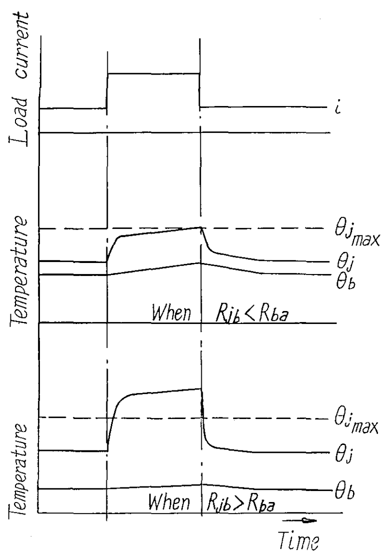


Fig. 6 **Relationship between junction area and thermal impedance**



θ_j max.: Max. allowable junction temperature
θ_j : Junction temperature
θ_b : Base temperature

Fig. 7 Junction temperature due to short overcurrent

From the above observations it is noted that in the case of stud type diodes, even if the junction area is enlarged and the element made large-sized, the current load capacity does not increase in proportion, and so it becomes uneconomical to attempt to do this.

It may be readily estimated from the thermal dissipation route of a double-sided heat radiating construction, such as shown in *Fig. 4* (b), that R_{jb} is about ½ of that of a stud type diode, when junction area is the same. In this case even if forward losses do not decrease it is possible to make up for this by the decrease in R_{jb}. Also it will be possible to rectify large currents through a small junction area by lowering R_{ba} by utilizing large cooling bodies, water or oil cooling, so that it is in proportion to the decrease in R_{jb}.

3. Mechanical Strength and Weight

Semiconductor diodes are extremely superior in mechanical strength and vibration withstanding properties compared to present vacuum tubes and mercury rectifiers, but as diodes are used in wider and wider fields demands on these characteristics have become more and more stringent. For example, there are many instances when they are required to withstand long periods of continuous vibration, centrifugal acceleration of several thousand G's, and also sharp shocks. The weakness of stud type diodes in cases like this is that the lead wires are apt to break from long lasting and intense vibration. Stud type diodes need a considerably mechanical strength, because the stud is screwed into the cooling body, and so thick copper base must be used. Consequently its total weight becomes fairly heavy.

Disk type diodes require no lead wires or thick copper bases. The silicon element is clamped firmly by heat dissipating bodies on both sides, with a thin silver plate interposed, and therefore is less than 1/10 of the weight of present diodes, and its vibration-proof, shock-proof, and centrifugal force-resistant characteristics are greatly superior.

4. Insulation

The surface of the insulator between the anode and cathode becomes dirty when forced air cooling is used in an atmosphere which contains dust, noxious gases, and salt, consequently, insulation between anode and cathode becomes poor. Therefore there is need to make the length of the leakage path as long as possible.

The height or diameter of a stud type diode must be made large to increase its leakage path length, and in either case this has a great effect on the shape of the diode and stack, its weight and exchangeability of cells and is not a simple matter.

For the disk type, it is possible to use a ring type insulator, as shown in *Fig. 1*, and both sides of protruding part form a leakage path that is more than double that of other types of diodes with the same outer diameter. Also, the outer diameter of the ring has little effect on the size of the stack and so the leakage path may be made as large as desired within reasonable limits.

5. Pressure Contact Structure

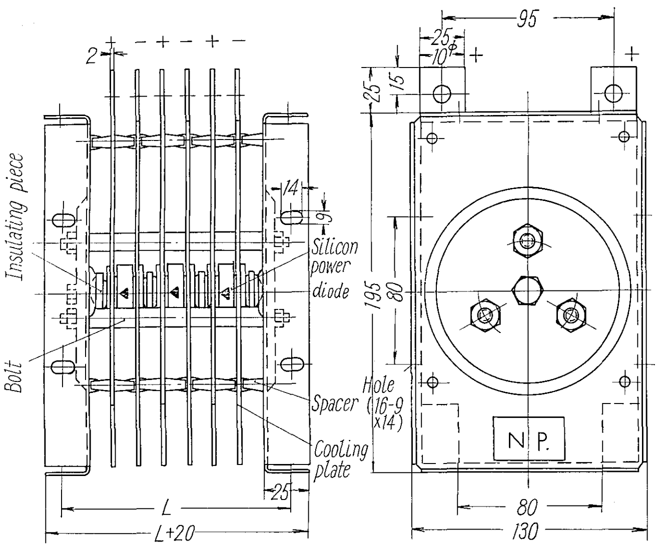
No soft or hard solder is interposed between the case and base plate of the disk type diode, and they are kept in contact by pressure exerted on them externally. Therefore there is no need for concern over thermal fatigue of the bonding material caused by temperature cycles as is true in the case of pressure contact type diodes.

Pressure need not be exerted on individual disk type diodes as is required in the case of pressure contact type diodes Si 250.3, and therefore only a single pressure structure is required for a stack of disk type diodes, making construction very much simplier.

6. Construction of Rectifier Stack

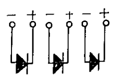
The construction of a basic rectifier stack is shown in *Fig. 8*.

Cooling plates with attached contact plates are placed on both sides of the disk type and form one unit. Several of these units are stacked together with supporting plates placed at each end of the stack. Three bolts covered with insulating piping are used to tighten the supporting plates and designed so that clamping force is nearly even and constant. The disk type diodes and both sides of the contact plates are processed so that sufficient parallelism is obtained, but when a great many units are stacked together there is some danger that parallelism may suffer somewhat and result in the pressure on the contact



This fig. is an example at using KS110 . . . 3PJ2

Dimensions of disk type silicon rectifier stack



Connection KS110..3PJ

Model	Dimension (L)
KS110....2PJ2	98
KS110....2PJ3	154
KS110....3PJ2	126
KS110....3PJ3	210
KS110....4PJ2	154
KS110....4PJ3	266
KS110....6PJ2	210
KS110....6PJ3	378

Fig. 8 Outline of disk type silicon rectifier stack

surface of the diode being uneven with consequent poor thermal impedance. Therefore, a convex insulator is placed between each unit, and the convex plane equalizes the pressure to solve this problem. Each diode is insulated from the others by these convex insulators and so connections are made externally as a rule. However, a convex conductor may be used to put the stack in series for connection internally, or other rectifier circuit connections may be accomplished by these means. The fact that the polarity of the diodes may be changed easily is extremely convenient. The supporting plates are designed so that they construct a part of the air cooling channel. Terminal holes are bored at one end of the cooling plates so that they may be connected to external lead wires.

Disk type diodes are constructed like thin plates and it is simple to narrow the space between cooling plates within an extent that the circulation of the cooling medium is not obstructed, and the cooling surface area may be increased. Flat plates arranged in parallel are ideal heat dissipators whether for air or oil cooling systems, and they have large heat transfer coefficients and enable uniform cooling.

It is possible to lessen significantly the weight and space taken up by the stack by this vast improvement in the heat dissipation efficiency of the diode and stack. A comparison of stacks using stud type diodes in general use currently and disk type diodes, of about the same output, is shown in *Table 1*.

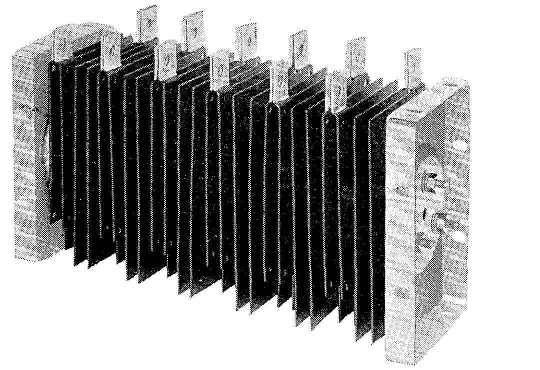
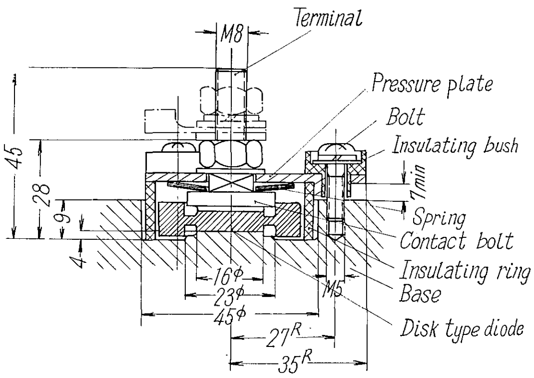


Fig. 9 Disk type silicon rectifier stack



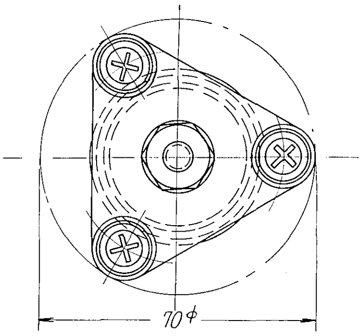


Fig. 10 Mounting construction of disk type diode

An example of mounting on rotors or stators of generators is shown in *Fig. 10*. In this case heat dissipation will be mainly from one side only but as the diode is constructed of thin plates it has the advantage that the space taken up is relatively small and its mechanical strength far surpasses that of a stud type diode.

Table 1 **Comparison in Weight and Volume of Rectifier Stack**

Rect. Stack Model	KS 110 H 6PJ2	Si 50 F-T 6/1
Dc Output	500 v 350 amp 175 kw	500 v 250 amp 125 kw
Weight	6.7 kg	15 kg
Space Occupied	230×220×130 mm 6600 cm^3	290×270×285 mm 22,300 cm^3
Weight per kw	38.3 g	120 g
Ratio of Above	1	3.13
Space Occupied per kw	37.7 cm^3	179 cm^3
Ratio of Above	1	4.75

III. CHARACTERISTICS

1. Rating and Characteristics

Rating and characteristics of disk type silicon power diodes KS 110 H and KS 250 H are shown in *Table 2*.

The rating of a standard stack using disk type silicon power diodes KS 110 H is shown in *Table 3*.

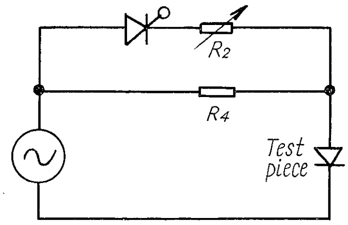
2. Test Results of Characteristics

1) Overcurrent test

The schematic circuit shown in *Fig. 11* was used to test KS 250 H starting with rated load and then passing an overcurrent through it for a period of time previously determined, its peak value raised in stages to find its destruction value. The results are shown in *Fig. 12*.

2) Temperature cycle test

KS 250 H was used for the test. First it was thrown in boiling water (100°C) for one minute and then in cold water (0°C) for one minute. This temperature cycle was repeated 10,000 times. During this test the variation in thermal impedance between junction and case was measured and the airtightness of the diode tested before and after the test by a helium leak tester. Variations in thermal impedance are shown in *Fig. 13*, and as may be seen, remained within the range of testing errors. Absolutely no abnormality in airtightness was found.



R_1: Resistance for normal rated load current
R_2: Resistance for over-current

Fig. 11 Test circuit for overcurrent characteristic

3) Equivalent load test

The equivalent load test circuit shown in *Fig. 14* was used to test a large number of diodes for long periods of time. Variations in reverse leakage current were measured mainly and the result confirmed their

Table 2 Ratings and Characteristics of Disk Type Diodes

Model	KS 110 H	KS 250 H
Peak Repetitive Inverse Voltage (v peak)	1200	1200
Peak Nonrepetitive Inverse Voltage (v peak)	>1500	>1500
Inverse Leakage Current (ma mean) 1200 v peak Sine half-wave inverse voltage 25°C	≤3	≤5
160°C	≤12	≤20
Max. Ac Input Voltage (v eff)	420	420
Rated Ac Input Voltage (v eff)	380	380
Dc Blocking Voltage (v)	540	540
Foward Voltage Drop (v)	≤1.1 at dc 200 amp	≤1.0 at dc 300 amp
Rated Mean Forward Current (amp mean) Case temp. 120°C, 1φ, half wave connection	180	280
Half Cycle Surge Current (amp peak) 50 cps, sine half wave, from rated load	3300	7500
Allowable I^2t Value from Rated Road	27,000	140,000
Allowable Frequency (cps)	15~2000	15~2000
Allowable Continuous Junction Temp. (°C)	160	160
Allowable Continuous Case Temp. (°C) at rated load	120	120
Thermal Imp. between Junction and Case (°C/w) Anode side	≤0.28	≤0.14
Thermal Imp. between Junction and Case (°C/w) Cathode side	≤0.40	≤0.20
Diode Weight (g)	20	40

Table 3 Ratings of Disk Type Rectifier Stacks

Ac Input Voltage (v eff)	Connection	Dc Output Voltage (v)	Dc Output Current (amp)	Stack Model	No. of Diodes	Heat Sink	Weight (kg)
380	C	170	110 (250)	KS 110 H 2PJ2	2	PJ2	3.2
	C	170	170 (360)	KS 110 H 2PJ3	2	PJ3	5.0
	B	340	110 (250)	KS 110 H 4PJ2	4	PJ2	5.0
	B	340	170 (360)	KS 110 H 4PJ3	4	PJ3	8.7
	S	250	150 (350)	KS 110 H 3PJ2	3	PJ2	4.1
	S	250	240 (500)	KS 110 H 3PJ3	3	PJ3	6.7
	T	505	150 (350)	KS 110 H 6PJ2	6	PJ2	6.7
	T	505	240 (500)	KS 110 H 6PJ3	6	PJ3	12.2

Note : Dc output current in brackets are values for forced air cooling (velocity of wind 6 m/s)

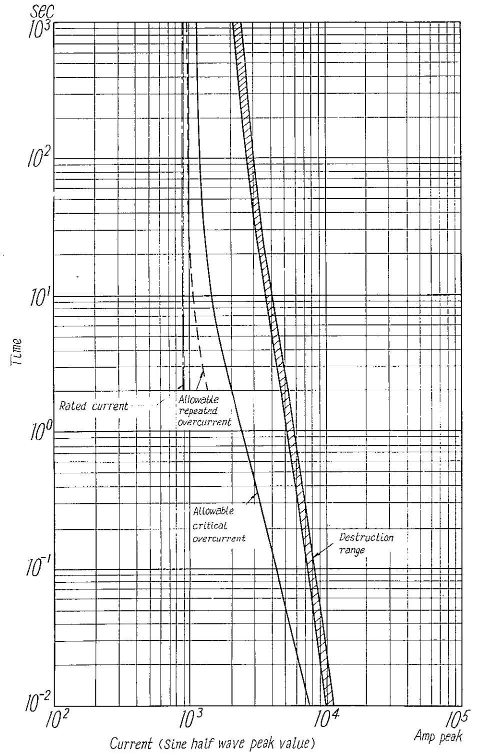
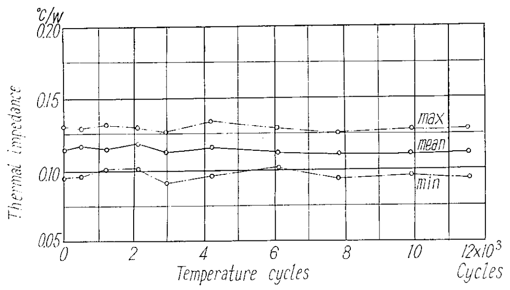
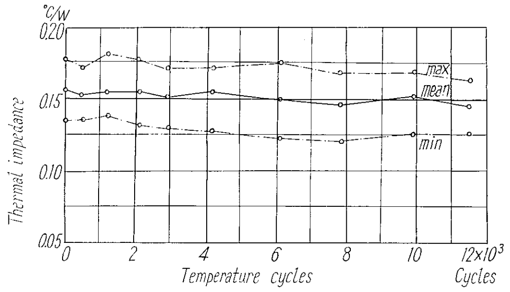


Fig. 12 **Relationship between overcurrent and time of KS250**



(a) Anode side



(b) Cathode side

Fig. 13 **Test result of thermal impedance for temperature cycles**

reliability. An example of the result of one test is shown in *Fig. 15*.

IV. FIELDS OF APPLICATION

Disk type silicon power diodes may be used in nearly every field where stud type power diodes are being used because they have a nearly ideal construction, as described above. They may also be used in

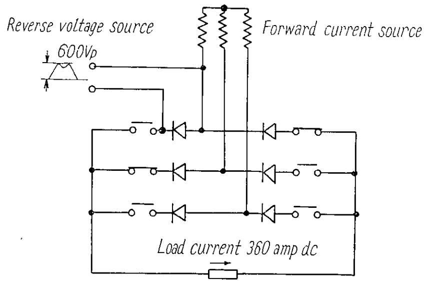


Fig. 14 **Equivalent load test circuit**

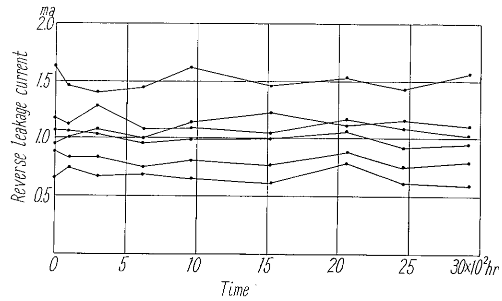


Fig. 15 **Reverse current during equivalent load test**

places where previous diodes were difficult to use. Epochal progress in the cooling methods and construction methods of silicon rectifiers is anticipated by use of disk type silicon diodes.

The following are the main applicable fields that may be considered for the present:

(1) They will make rectifier stack construction for small and medium capacities such as several hundred or several thousand amperes compact and lightweight. They are especially applicable to dc arc welders and exciter rectifiers for self-excited ac generators.

(2) For substations of electric railways where existent air-cooled stacks are unsuitable because, for example, of the need for minimizing noise, providing complete unattended operation, and reducing concern over deterioration of insulating material from noxious gases. In these cases disk type power diodes using oil self-cooling or oil-filled forced air-cooling systems are advantageous.

(3) Silicon rectifiers for railway coaches where existent air-cooled stack insulating properties decrease greatly from infiltration of rain water, snow and dust. Also in very cold climates where the air intake filters become clogged and frozen over with snow and minimum air intake volume becomes a problem. In these cases it is ideal to use an oil-filled, air-cooled rectifier and immerse the entire high voltage section in an oil tank.

(4) Silicon diodes are assembled onto the rotors of brushless ac generators and these diodes must withstand centrifugal forces of several thousand G's and must be able to withstand shocks. Disk type silicon power diodes have ample mechanical strength to meet these requirements.