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OPERATIONAL RESULT OF SILICON DIODES FOR ELECTROLYSIS SERVICE

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I. FOREWORD

Since the beginning of the operation of Fuji Electric's first large capacity silicon rectifier dc 220 v 20 ka at the Kambara Works of the Nippon Light Metal Co., Ltd. in October of 1959, the total output capacity of the silicon rectifiers for electrolysis service up to the present time have reached over 660 Mw and 2.3 million amperes. And the total number of silicon diodes used in these facilities have reached approximately 30,000 pieces. Ever since the appearance of silicon diodes, the expectations were that their reliabilities are extremely high as observed through the theoretical and structural properties or from the results of aging tests, but the reports on the statistical data regarding their practical running results are limited. With the elapsed period of more than 7 years since the operation of the silicon rectifier No. 1 first began, Fuji Electric had decided to contact each of the users for their cooperation in order to conduct an investigation concerning the operation and problems relative to all of the delivered silicon rectifiers and centering on their diodes in order to obtain the statistical results of their actual operation and to use them as data for the future technical improvements. The results have been compiled and the outline will be introduced at this time.

II. SUBJECT OF INVESTIGATIONS

1. Scope of Investigations

The investigation covered the classification of the failures on rectifier diodes used for all of the electrolysis service rectifiers with outputs over 1000 kw with varying applications such as for caustic soda, chloride acid soda, hydrogen peroxide, water, aluminum, magnesium, copper, zinc, etc. Those with maximum period of usage reached full 7 years while the most recent ones were those with approximately 6 months usage. The number of investigated users were 30 with the total output of 661,959 kw and the number of silicon diodes used totaled 29,849 pieces.

2. Construction of Rectifier Assembly

The construction of Fuji's silicon rectifiers used for electrolysis services have been introduced from time to time in the past[1], while those which were subjected to this investigation are classified into three constructions as follows:

1) Open forced air cooled type (cooling air is drawn in from the bottom and released to the top of housing by the internally mounted blower) .....89 units
2) Forced air cooled type (cubicle is sealed, the cooling air is circulated internally and the air is cooled by the water cooled heat exchanger) .....96 units
3) Direct system S-former (silicon diodes are screwed directly on the tank side wall of the rectifier transformer and directly cooled with the transformer oil) ..... 5 units

Those employing the system of forced cooling with pure water or insulation oil were not subjected to the investigation since they were recently delivered.

3. Rectifier Diodes

The types and the quantity of the rectifier diodes used in the subject investigations are listed in *Table 1*. The outer views of these diodes are shown in *Fig. 1*. The diode type Si 150 is the first power diode to be produced domestically for the first by Fuji Electric through the technical tie-up with Siemens Co. and has been used for many types of applicatsons in a long period of time. However,

***Table 1* Ratings of Silicon Diodes**

Name of Diode	Average Forward Current (amp)	Permissible Junction Temperature (°C)	Internal Construction	Delivered quantity	Period
Si 150	200	140	Soft soldered	26,903	1959 and after
Si 250.1	240	150	Hard soldered	384	Only 1964
Si 250.3	280	160	Pressure contact	2562	1964 and after

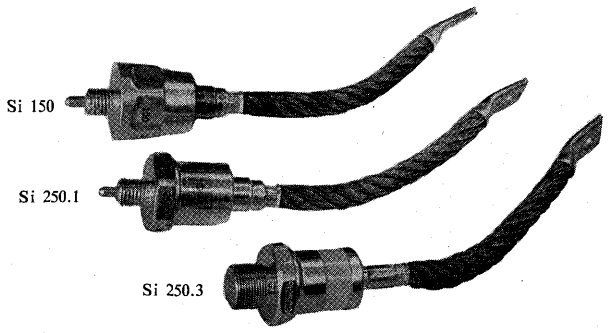

Fig. 1 Outer view of silicon diodes

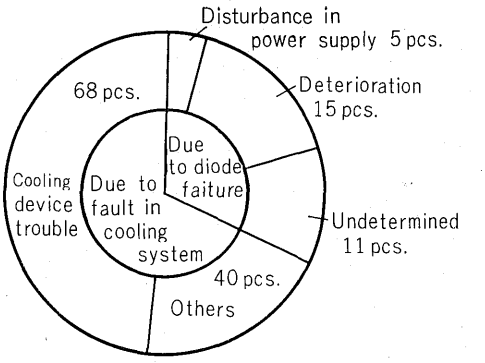

Fig. 2 Fault diodes classified according to the causes

since the silicon pellet is attached to the copper case through soft soldering, in order to use this diode for the railway rolling stock, especially the Tokaido's new super-express trains, the concern was given in the transformation of the soft soldered portions by the heat cycle. In order to eliminate this defect which presents no problem for electrolysis use, the hard soldered diode type Si 250.1 was first developed followed by the epochal mechanical pressure contact type Si 250.3 and this type Si 250.3 is being applied as the standard type of power diodes by this company.

III. INVESTIGATION RESULTS

1. Number of Trouble Occurrences

The results of researches per user have been listed in *Table 2*. The annual delivery records to each customer from 1959 to 1966 are indicated with the output kw and the number of diodes being used respectively and the number of diodes causing troubles are indicated inside the box per cause in the same Table.

According to these results, the number of troubles which caused damages to the silicon diodes were recorded in 21 cases while the number of damaged diodes totaled to 139 pieces.

This number does not include those damaged by the misoperation while conducting the tests and adjustments nor does it include those damaged mechanically as well as electrically during the erroneous inspection and cleaning operations.

2. Trouble Content

The classification of the damaged 139 diodes are shown in *Fig. 2*. The major cause of trouble was due to the overheated operation caused by the troubles in the cooling device or in its control and protection devices. 108 pieces (78% of the total faulty diodes) were found to be damaged through only 4 conditions. These included those where the drive belt for the blowers were cut and stacked with trouble in the ventilation monitoring apparatus as well as in the defects of the protective control circuit which is supposed to function when trouble exist in the cooling devices.

There were 15 pieces which were determined to have been caused by the deterioration in the diodes themselves, 11 pieces with cause unknown and 5 pieces assumed to have been punctured by the surge voltage, for the total of 31 pieces.

IV. COUNTERMEASURES FOR COOLING SYSTEM TROUBLES

All of the troubles due to cooling devices as previously mentioned were generated only in the forced-air-water cooled system rectifiers. Furthermore, they were not circumstantial to the essence of this system but is deeply reflected that the troubles were caused through the fault in the trouble detection and protection systems. From the results of these troubles, the ventilation monitoring device as well as the protection and control circuits have been re-investigated and improved.

V. FAILURE RATE OF SILICON DIODES

1. Deteriorated Diode Causes

The result of dividing the number of damaged diodes by the product of the number of operating diodes and the operating time is called the diode failure rate. Generally, the relationship between the running time and the diode failure rate will show the progress such as that in *Fig. 3* and this can be separated into three periods which definitely shows difference in the tendencies such as the initial failure period, accidental occurrence period and end of life expectancy. *Fig. 4* shows the elapsed period after delivery (operation) when the failures were generated in the diodes themselves aside from those caused by the cooling devices. The number of years operated until the time of diode failure is recorded horizontally according to the causes while the number ofdamaged diodes are recorded vertically. The silicon diodes having actual operational records of over 3 years out of all those normal diodes presently being used

***Table 2* Results of Researches**

Names of Users \ Placed in Service	1959	'60	'61	'62	'63	'64	'65	'66
Nikkei Kako Co., Ltd.	4400 kw 144 pcs.						2420 kw 96 pcs.	
Nippon Carbide Industries Co., Ltd.	3600 kw 192 pcs.					2550 kw 192 pcs.		
Kanegafuchi Chemical Industries Co. Ltd.		3780 kw 192 pcs.		[1] 1 pc.	6300 kw 288 pcs.		[3] 38 pcs.	
Tsurumi Soda Co., Ltd.		3000 kw 192 pcs.			3000 kw 192 pcs.	3000 kw 96 pcs.		
Toyo Soda Mfg. Co., Ltd.		6000 kw 288 pcs.	15,000 kw 768 pcs.		[2] 1 pc.	8400 kw 384 pcs.	[3] 26 pcs.	
Shin-etsu Chemical Industry Co., Ltd.		6480 kw 288 pcs.	4320 kw 192 pcs.		[2] 3 pcs.	2160 kw 96 pcs. [4] 2 pcs.		
Kureha Chemical Industry Co., Ltd.		12,960 kw 768 pcs.				26,300 kw 1006 pcs.	[1] 1 pc.	
Hokuriku Salt & Chemical Co., Ltd.		2640 kw 96 pcs.						
Sumitomo Chemical Insustry Co., Ltd.		4375 kw 192 pcs.			8750 kw 384 pcs.	[2] 2 pcs.	[2] 1 pc. [4] 1 pc.	[2] 2 pcs.
Kanto Electrochemical Industry Co., Ltd.			7920 kw 504 pcs.	3360 kw 192 pcs.		7920 kw 264 pcs. [4] 2 pcs.	18,000 kw 1152 pcs.	[4] 3 pcs.
Yee Fong Chemical & Industries Co. Ltd. (Formosa)			1800 kw 96 pcs.				6000 kw 192 pcs.	
Taiwan Alkali Co., Ltd. (Formosa)				3800 kw 192 pcs.				
Hodogaya Chemical Co., Ltd.				6500 kw 384 pcs.	2200 kw 72 pcs. [3] 30 pcs.			
Asahi Chemical Industry Co., Ltd.					5500 kw 215 pcs.	14,000 kw 768 pcs.		
Showa Electro-Industry Co., Ltd.						24,000 kw 1152 pcs.		[4] 1 pc.
National Rayon Corp. (India)						9225 kw 360 pcs.		
Nippon Soda Co., Ltd.						1800 kw 96 pcs.		
Dawood Corp. (Pakistan)						3354 kw 336 pcs.		
Central Chemical Industry Co., Ltd.						22,000 kw 768 pcs.		
Asahi Chemical Industry Co., Ltd.						21,000 kw 960 pcs.	[3] 14 pcs.	
Formosa Plastic Corp. (Formosa)							11,250 kw 384 pcs.	
Hokkaido Soda Co., Ltd.								4520 kw 144 pcs.
The Chemical Industries of Pakistan Ltd.								2400 kw 120 pcs.
Above are caustic soda and chloride acid soda electrolysis service								
Sumitomo Chemical Industry Co., Ltd.			78,000 kw 4608 pcs.					
Nippon Light Metal Co., Ltd.			40,350 kw 1728 pcs. [1] 1 pc.	43,410 kw 1392 pcs. [4] 2 pcs.	19,500 kw 768 pcs.	78,000 kw 3072 pcs.	27,600 kw 1152 pcs. [1] 1 pc.	45,000 kw 1440 pcs. [1] 1 pc.
Sumitomo Metal Mining Co., Ltd.			3720 kw 192 pcs.			2100 kw 120 pcs.	[2] 6 pcs.	1320 kw 42 pcs.
Dowa Mining Co., Ltd.						1500 kw 96 pcs.		6000 kw 132 pcs.
Toho Titanium Co., Ltd.							1125 kw 36 pcs.	
Above are the Metallic (aluminum, magnesium) electrolysis service								
Tokai Electrochemical Co., Ltd.		1800 kw 96 pcs.	1980 kw 96 pcs.			3960 kw 192 pcs.		
Above are the hydrogen peroxide electrolysis service								
Kao Soap Co., Ltd.		2640 kw 120 pcs.	2640 kw 120 pcs.					
Total	Above are the water electrolysis service							
661,959 kw 29,849 pcs. [1] 5 pcs. [2] 15 pcs. [3] 108 pcs. [4] 11 pcs.	8000 kw 336 pcs.	43,675 kw 2232 pcs.	155,730 kw 8304 pcs. [1] 1 pc.	57,070 kw 2160 pcs. [1] 1 pc. [4] 2 pcs.	45,250 kw 1919 pcs. [2] 4 pcs. [3] 30 pcs.	225,599 kw 10,008 pcs. [2] 2 pcs. [4] 4 pcs.	66,395 kw 3012 pcs. [1] 2 pcs. [2] 7 pcs. [3] 78 pcs. [4] 1 pc.	60,240 kw 1878 pcs. [1] 1 pc. [2] 2 pcs. [4] 1 pc.

Figures contained within [ ] are the trouble classification and the number of pieces concerned
Trouble classification: 1) Power disturbance 2) Diode deterioration 3) Cooler trouble 4) Undetermined

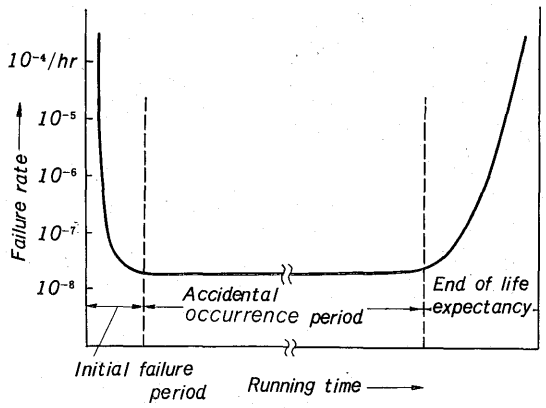

Fig. 3 Relation between failure rate and running time

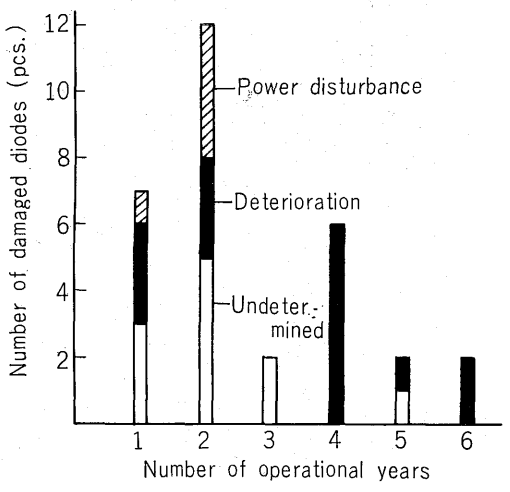

Fig. 4 Relation between number of damaged diodes and running time

consist of approximately 55% of the total number of diodes (28,849 pieces) while the remaining 45% have not passed the full three year usage and the accurate forecast cannot be made. However, the number of diode troubles are extremely small and it can be concluded that they will fall into the category of accidental occurrence period according to the figure. The damaged diodes which are categorized in this period are normal diodes without any special defect in the material, construction nor in the testing process. There are diodes which are relatively easy to deteriorate and those which are difficult to deteriorate or in other words, diodes with weak constitution and strong constitution according to the production lot or the individual diode characteristics.

It is said that troubles are caused in almost a fixed rate gradually from the diodes with weak constitution. The failure rate in this period decreases through the material of better quality, sturdy construction, logical production process and marginal ratings.

2. Failure Rate of Silicon Diodes

The following is the result obtained when calculated for failure rate of diodes due to the faults in the diodes themselves or deterioration while operating with respect to the results of the present researches. The 26 pieces of damaged diodes aside from those which were caused by the cooling system or power surges will temporarily be assumed to have had the causes in the diodes themselves. If divided by the product of the number of operating diodes up until the day of investigation and the conduction time, or in other words, by the total operating time (10.3×10^8) of the diodes, the

$$\text{failure rate} = \frac{26}{10.3 \times 10^8} = 2.5 \times 10^{-8}/\text{hour}$$
$$= 2.2 \text{ pieces}/10{,}000 \text{ pieces} \cdot \text{year}$$

VI. CONCLUSION

The combination of extremely high reliability in the Fuji's diodes, the efforts on the part of the personnel connected in the development of those diodes and the severe quality controlling of the production process have resulted in obtaining the failure rate of less than 10^{-8} as shown through the forced breakdown-tests conducted during the inital stages of the development of the products and this has been actually proven by the results obtained in the recent researches. An appreciation is hereby expressed to each of the users for his acceptance and constant application of our rectifiers and for the cooperation received during this research in spite of the busy schedules. At the same time, we hope to fully utilize the results obtained as data for future technical imprvements and continue to satisfy your expectations.

References

(1) T. Mizushima, T. Shimizu and others: "The Progress of the Large Current Silicon Rectifiers for Electrolysis Service," *Fuji Electric Review:* Vol. 12 No. 6 (1966)