NEW TYPE POWER FUSE "HH FUSE" HF 337, HF 338

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I. INTRODUCTION

Recently, the rapid increase of demand of the electric power requires the further development of extreme high capacity power fuses.

As the results of the many tests and researches, our Company have completed the new type current limitting power fuses, type HF 337, HF 338.

The arc quenching medium and the construction of our previous type power fuse have been improved in this new type HF 337, HF 338, so as to enlarge extremely the breaking capacity, to lower the over voltage which would occur at the instant of sudden melting of fuse wire, and to get wider range of application of the rated voltage and current.

This new type power fuses are excellent protecting device of the high voltage circuits from overload current and short-circuit current, whose quick breaking characteristic can not be expected by the circuit breakers or the expulsion type power fuses.

II. MERITS

The HH fuses, HF 337 and HF 338, have the following merits:

1) Short circuit current can be broken by limitting under the crest value of current wave.
2) Without the jetting action of ionized gas, short-circuit current and overload current can be interrupted.
3) Although it is generally difficult to interrupt a small magnitude of over-load current, this new type HH fuses have the ability of interrupting of the small overload current, and, moreover, the un-limited interrupting capacity for short-circuit current.
4) At the interruption of the short-circuit current, the induce of dangerous over voltage can be prevented by providing the special fuse wires described hereinafter.
5) Ageing of the time-current characteristic caused by corona or oxidation of a fuse wire will not occur.
6) The time-current characteristics of all products are uniform, and so the HH fuse is favourable to cooperate with other overload protecting devices or fuses.

Fundamental principles and general outline of the new HH fuse, HF 337, HF 338 will be described as follows.

III. BREAKING PHENOMENA

The main parts of the HH fuse are fuse wires of pure silver and the arc-quenching meduim of quartz sand, filled tightly around fuse wires.

By the short-circuit current, fuse wires are melted and vaporized, and the current is interrupted on the way of rising up to the crest value.

Assumed that all section of fuse wire has been melted and vaporized at the same time, and the gas is ideal gas, and the temperature of gas is boiling temperature 1930°C, the relation between gas volume and gas pressure at just boiled instant per each one gram would be given as follows.

Formula of ideal gas is:

$$p \cdot v = R \cdot T$$

where $R = \frac{1}{M} \cdot 8.313 \cdot 10^7$ erg/°C

M (atomic weight of silver) $= 107.88$

T (absolute boiling temperature of silver) $= 273 + 1930$ (°K)

when for each one gr. of silver

$$p = 1730/v$$

where

v: silver gas volume after just vaporized (cm^3)

p: silver gas pressure after just vaporized (kg/cm^2)

The arc-quenching medium filled tightly around the fuse wire would be slightly forced out by this extremely high pressure. But in our HH fuses, the hollow gap generated by the above mentioned high pressure is suppressed in extremely small degree, on account of tightness of fillers, and so the arc induced after the vaporization of fuse wire can be cooled rapidly and extinguished at the small gaps between the sand. The silver gas generated by vaporization is cooled and solidified sporadically on the surface of filler grains, as shown in Fig. 1, microphotograph.

Fig. 1. Particles of filler, partially covered by metal foil of vaporized fuse wire material (×80 enlarged)

The X-ray photograph Fig. 2 shows the inside of a fuse after circuit breaking action. Part (a) in

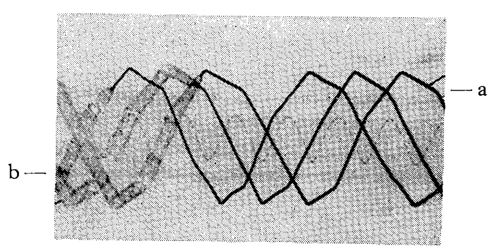
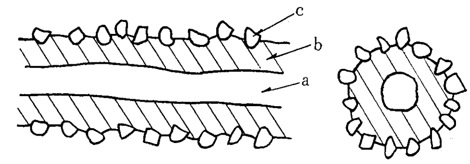


Fig. 2. X-ray photograph, showing inside of a fuse after circuit breaking action

this photograph shows the un-melted portion of fuse wire near the end of fuse tube, and part (b) shows one part of the long melted fuse wire changed into non-conductor. The part (b) is the sintered substance " Schmelzraupe ", which is the consolidated filler grains, each surface of which was consolidated slightly with each other by heat energy of arc and partially covered by solidified silver foils. In order to suppress the leak current, the length of a fuse wire are designed suitably for its rated voltage.

The HH fuse which has interrupted successfully the over current, remains " Schmelzraupe " inside of it, which was mentioned above, but the HH fuse which has failed in the breaking test on account of defect of the arc quenching medium or manufacturing process, remains in the fuse tube the substance shown in Fig. 3.

That is, the grain of quartz sand around the silver wire, when the arc failed to be broken, is changed into quartz tube containing silver silicate by arc energy, and because the quartz tube would be electrically conductive at high temperature, the heat caused by the current flown through the quartz tube would help to melt the grain of quartz sand around that, so that the breaking would not be carried out.



a : hollow part caused by vaporizing of fuse wire
b : quartz tube containing silver silicate produced by complete melting of quartz sand
c : clogging of grain of quartz sand

Fig. 3. Sintered quartz tube in fuse, failed to break circuit

Now, the breaking phenomena is explained here by dividing abnormal current to be interrupted into two figures, i.e., short circuit current and over load current.

1. Interruption of Short-Circuit Current

By the short-circuit current, the fuse wire will melt and vaporize on the way of rising up of the current, as the current is too heavy compared to the rated current of the fuse, then, the short-circuit current will be broken by chopping of the rising up current. Fig. 4, oscillograph, and Fig. 6 show this figures.

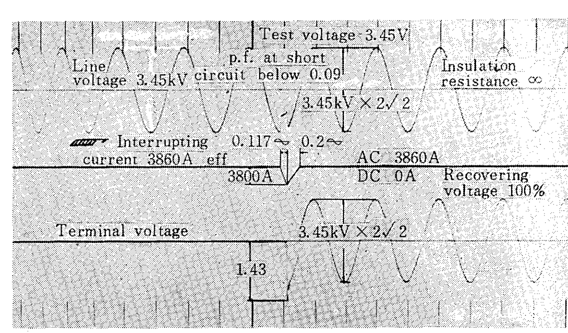


Fig. 4. Breaking phenomana of short-circuit by HH fuse, 3.45 kV, 40 A rating, short-circuit current 3,860 A rms

Fig. 5 and 6 show equivalent electric circuit and the short-circuit current limitted by HH fuse.

When short-circuit has occured in the electric circuit, as shown in Fig. 5, the fuse terminal voltage $i \cdot r$ can be described as follows.

$$i \cdot r = E \sin(\omega t + \varphi) - L\frac{di}{dt}$$

At the current limitting point, Fig. 6, the high

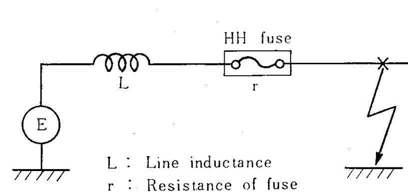


Fig. 5. Equivalent-electric circuit

over voltage is induced suddenly as shown in Fig. 4, on acount of the high internal resistance of fuse.

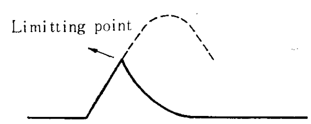


Fig. 6. Limited short-circuit current by HH fuse

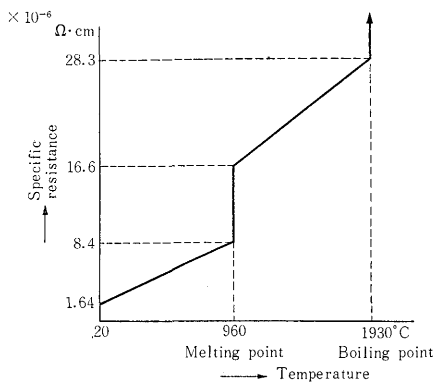


Fig. 7. Temperature specific resistance curve of silver

Fig. 7 shows the temperature—specific resistance curve of the silver fuse wire. At the vaporized instant, the silver gas is non-conductor, because the gas is not ionized at the boiling point, but owing to the induced high voltage the arc current is ignited and then the arc current is extinguished rapidly by the arc quenching medium.

2. Interruption of Over Load Current

For over load current breaking, as shown in Fig. 8, oscillograph, this figure differs greatly from the previous short-circuit current breaking, several cycles to several ten cycles are required for melting a fuse wire, besides, short-circuit current is extremely heavy compared to the rated current, so the whole fuse wire is melted instantly in a very short time, that is, below several ms. On the contrary, for over load current, the hottest part in the fuse wire will melt partially and there the arc is ignited, and extend up to high resistance arc according to the circuit voltage, which is sufficient to break a circuit, then, several cycles are required to break a circuit from the partial melting instant of the fuse wire. During this, the arc-quenching medium is exposed to high temperature of arc, so, it can be said that, duty of arc-quenching medium for cooling and quenching is very severe for over load breaking.

In spite of this heavy duty, it is verified by many tests that HH fuse's arc-quenching medium can break also the over load current successfully. And as, Fig. 8, oscillograph shows, it is a different point from the arc which is in free air as shown in Fig. 9 (b), that the arc in the filler grain shows the arc voltage-current characteristic as shown in Fig. 9 (a).

In multi-parallel connected fuse wires, because the arc characteristic in the grains of filler is not negative, the arc current is not accumulated in one path, and the current is divided equally into parallel paths, and so the duty of the arc quenching medium is lightened.

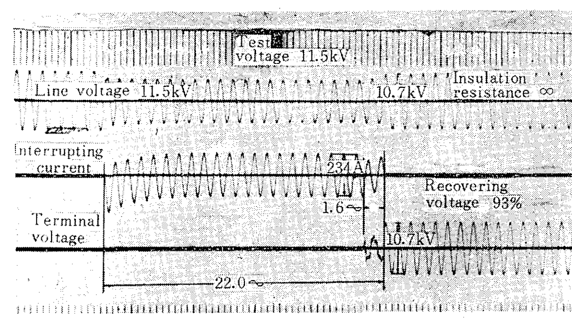


Fig. 8. Breaking phenomena of overload current by HH fuse, 115 kV 50 A rating. Overload cunrrent 234 A rms.

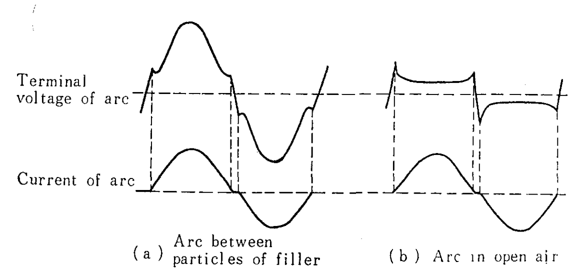


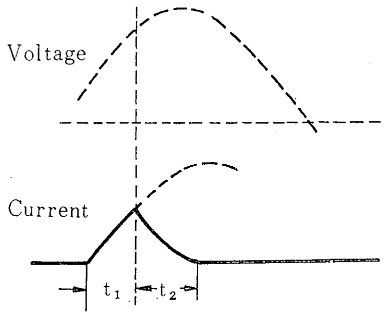
Fig. 9. Difference between arc characteristics in HH fuse and that in open air

If we assume the arc characteristic is negative, the terminal voltage or arc resistance will decrease with the increasing of the arc current. In the case, of the multi-parallel arc, the arc current in the path of the smallest resistance will increase, or accordingly, the arc resistance becomes smaller and smaller, then this arc current accumulating into one arc, becomes greater. This will make it increasingly difficult to break the circuit.

IV. BREAKING CAPACITY

For conventional power fuses, the breaking of an overload current, equivalent to several times the rated current is very difficult as has been previously mentioned. Otherwise, it is also difficult to interrupt the short-circuit current, by which the fuse wires has been melted at the point, 10° to 30° in electric angle before the peak point of the source voltage, in other word the fuse wires have been melted at such phase angle, as during the arc time, the source voltage wave rise up to the crest value as shown in Fig. 10.

When fuse wire of enclosed current limiting type



t_1 : melting time, t_2 : arcing time

Fig. 10. Most severe case of melting phase angle of fuse wire, for breaking circuit

HH fuse melts at the phase angle, at which the arc current is most severe to be broken as mentioned above, the short-circuit current of such magnitude as following described, is most difficult to be broken and larger the current grows than this range, easier the interruption of the current becomes on the contrary. This has been borne out by extensive testing at our research laboratories.

Fig. 11 shows a curve of breaking test data of short-circuit current on the HH fuse HF 338/20/20 of rated 23 kV, 20 A. This curve shows us that the arc energy is approximately maximum at the prospective short-circuit current 1,100 A, and for the heavier current, the arc energy has a tendency to be smaller.

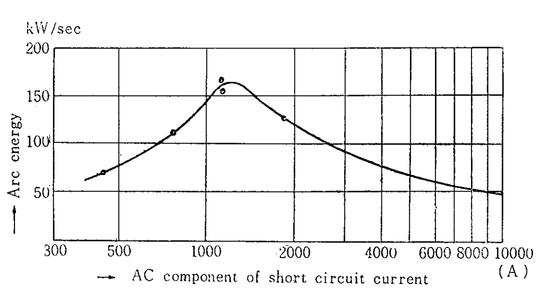


Fig. 11. Relation between arc energy and short-circuit current in the test data of HH fuse, 23 kV, 20 A rating

This tendency of the arc energy can be understood by comparing the diameter and length of "Schmelzraupe", taken out of the many fuses, which have interrupted the various magnitude of short-circuit current.

Fig. 11 is the test data of HH fuse with a rating of 23 kV, 20 A. Moreover, by the test data of the various kind of rating of HH fuses, it is clear that the prospective short-circuit current of 20 to 80 times the rated current is most severe to be broken and all kinds of rating of HH fuses can break completely these most severe current.

As mentioned above, the HH fuse can succesfully break not only over-load current but short-circuit current regardless of the amount of current. The interrupting capacity of HH fuse is non-limitted.

V. INDUCED OVER VOLTAGE BY INTERRUPTION OF SHORT-CIRCUIT CURRENT

When the fuse wire melts over most of its length instantaneously by short-circuit current, degree of current decrease would be large due to instant resistance variation, so abnormally high voltage is induced by the inductance in the circuit, as shown in Fig. 4. Consideration must be given towards co-operation with discharging voltage of arrester at circuit frequency, as this induced over voltage could impair the insulation of the apparatus, and must be suppressed below 2 times the crest value of nominal voltage ($2 \cdot \sqrt{2} \cdot E$). The new HH fuse is free from the above mentioned danger because its pure silver wire is of graduated diameters with the largest diameters at both end becoming smaller in the middle of its length. The reason for the different diameters is to prevent the melting along its total length at the same time.

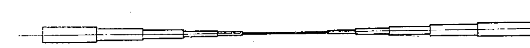


Fig. 12. Control fuse wire

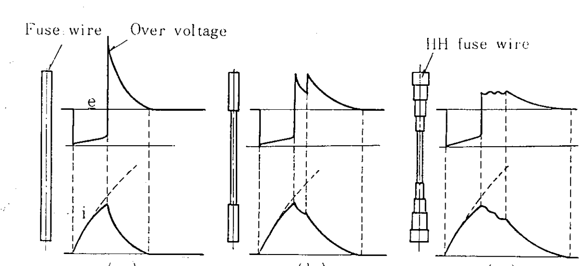


Fig. 13. Comparison of induced over voltage at melting instant, about various kinds of fuse wire

Fig. 13 shows difference between conventional fuse wires and the control fuse wire of the HH fuse regarding the induced over voltage, and also Fig. 13 (c) shows that the control fuse wire can completely suppress an over voltage (but for easy understanding in Fig. 13, the fuses are applied by DC voltage).

VI. TIME-CURRENT CHARACTERISTIC CURVE

The time-current characteristic curve between the time required for melting fuse wire and the over current is described here.

The HH fuse wire has simple construction as shown in Fig. 12, and can be served without ageing for long time, because the fuse wire is not provided with solder globules, which give the slow acting characteristic and the parts of reduced cross-sectional area, and every products have same time-current characteristic and are extremely stable.

VII. RATINGS AND CONSTRUCTION

Table 1 shows a list of new types of HH fuses, HF 337 and HF 338, with the ratings of each; HF 337 has a small current rating and the diameter of the tube is narrow, while the HF 338 has a large current rating and the diameter of the tube is large. Fig. 15 photograph shows the appearance of every kinds of HH fuse elements.

Fig. 16 shows the inner construction of type HF 337 used for the ratings 3.45 kV～34.5 kV, and Fig. 17 shows the inner construction of type HF 338 and type HF 337 used for the rating of 69 kV.

The indicator of fusing consists of a projecting rod, springs and a high resistance fuse wire for indicating. When the high resistance fuse wire should melt caused by a overload current, the projecting

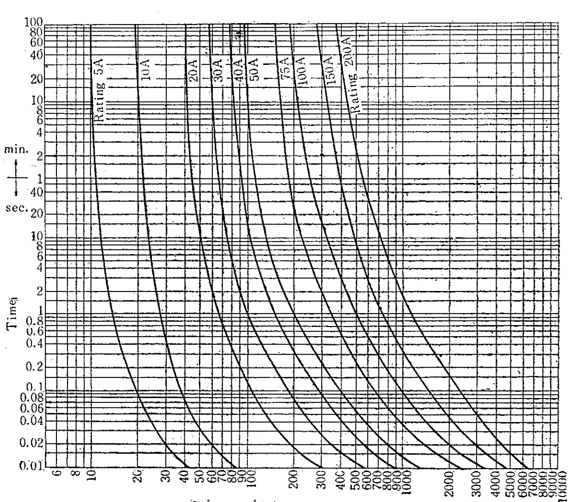


Fig. 14. Time-current characteristic curves of HH fuse, type HF 337, HF 338.

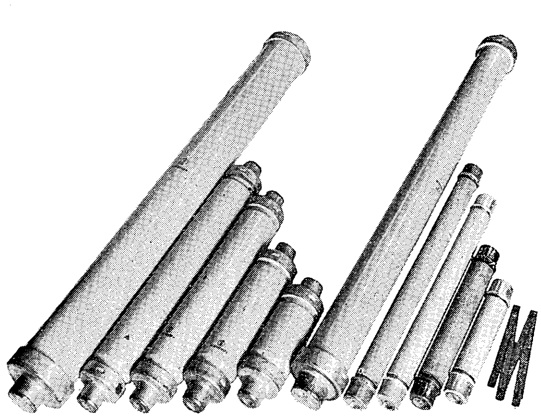


Fig. 15. HH fuse elements, 3.45～80.5 kV rating, type HF 337 (right) and HF 338 (left)

Table 1. List of types and ratings of new type HH fuses

Rated voltage (kV)	Rated current (A)	Type of fuse element	
3.45	5	HF 337/ 3 / 5	
	10	HF 337/ 3 /10	
	20	HF 337/ 3 /20	
	30	HF 337/ 3 /30	
	40	HF 337/ 3 /40	
	50		HF 338/ 3 /50
	75		HF 338/ 3 /75
	100		HF 338/ 3 /100
	150		HF 338/ 3 /150
	200		HF 338/ 3 /200
6.9	5	HF 337/ 6 / 5	
	10	HF 337/ 6 /10	
	20	HF 337/ 6 /20	
	30	HF 337/ 6 /30	
	40		HF 338/ 6 /40
	50		HF 338/ 6 /50
	75		HF 338/ 6 /75
	100		HF 338/ 6 /100
	150		HF 338/ 6 /150
11.5	5	HF 337/10/ 5	
	10	HF 337/10/10	
	20		HF 338/10/20
	30		HF 338/10/30
	40		HF 338/10/40
	50		HF 338/10/50
	75		HF 338/10/75
	100		HF 338/10/100
23	5	HF 337/20/ 5	
	10	HF 337/20/10	
	20		HF 338/20/20
	30		HF 338/20/30
	40		HF 338/20/40
34.5	5	HF 337/30/ 5	
	10	HF 337/30/10	
	20		HF 338/30/20
	30		HF 338/30/30
	40		HF 338/30/40
69	5	HF 337/60/ 5	
	10		HF 338/60/10
80.5	5		HF 338/70/ 5
	10		HF 338/70/10

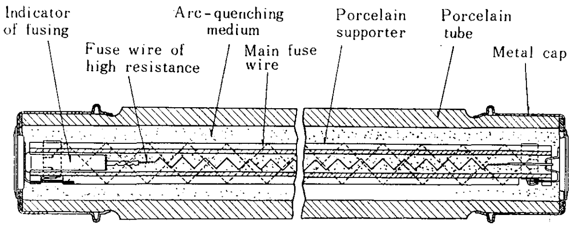


Fig. 16. Construction diagram of HH fuse, type HF 337

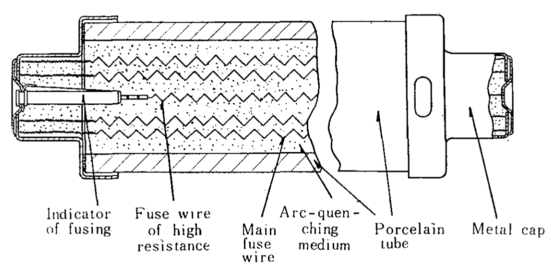


Fig. 17. Construction diagram of HH fuse, type HF 338

rod is thrusted out by the spring, and the interruption of fuse is indicated.

VIII. APPLICATION

The HH fuses are used for preventing the damages, caused by the short circuit of inside or outside of transformers, or condensers, or motors, by connecting to the power source side of these equipments. The HH fuses are used also for compensate the ability of circuit breaker of the small breaking capacity which is installed for the purpose of economizing. The rated current of HH fuse is to be selected as following.

1) On application of HH fuse, it is necessary to select the HH fuse of such a current rating from the time-current characteristic, as that do not melt by the rush current of the equipment, i.e. transformer, or condenser, or motor, to be protected by the HH fuse. Generally, the magnitude of the rated current of applied HH fuse is larger than the rated current of the equipment to be protected by fuse. Table 2 shows the application of HH fuse for transformers or condensers.

2) When the HH fuse is used in the circuit of the transformer primary side, it is necessary to select the HH fuse of such a current rating from the time-current characteristic, as that do not operate earlier than the fuses or circuit breakers of transformer secondary side, by the short circuit fault of transformer secondary side. When the HH fuse as shown in Table 2 can not cooperate, it is necessary to use a HH fuse with the rated current one step above that, which is shown in Table 2.

Table 2. Table for application of HH fuse for transformer or condenser

Rated current of HH fuse (A)	Rated current of trans. or condenser, approximately (A)	3.3 kV	6.6 kV	11 kV	22 kV	33 kV	66 kV	77 kV
		3 phase capacity of transformer or condenser (kVA)						
5	2	10	20	30	75	100	200	250
10	4	25	50	75	150	250	500	600
20	8	50	100	150	300	500		
30	13	75	150	250	500	750		
40	18	100	200	300	600	1,000		
50	36	150	300	500				
75	44	250	500	750				
100	53	300	600	1,000				
150	88	500	1,000					
200	105	600						

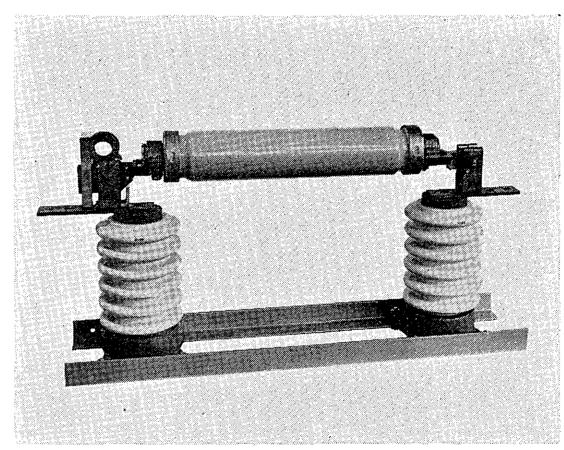


Fig. 18. HH fuse with indoor use disconnecting switch type holder, 23 kV rating

IX. TEST OF FUSE WIRE

Because the fuse wire is made of a thin silver wire, even with just a slight hurt to it, during use, that part heats quickly, and it may melt caused by a short time overload current, such as a rush current of transformers or a starting current of motors. These small hurt can not detect by resistance measurement, so the checking test for all HH fuses are carried out by the following method.

1. Over Current Test

90% of the current, which is enough to melt the tested HH fuse in one second, is carried through its fuse element. If there is a hurt wire, in parallel connected wires it would melt by this test. Other no hurtparallel fuse wires may remain without melting, but these impracticable wires can be checked by the following test.

2. Measurement of resistance

After the over current test, the resistance of this HH fuse is measured, and if the resistance is unpermissible value, this fuse will be removed as a rejected articles. As mentioned above, the perfect inspection of products is achieved by two kinds of test for each our products.

X. CONCLUSION

With the results of our many tests and researches about our recently developed new type HH fuse, type HF 337 and HF 338, as described in the above, we sincerely believe that, because of this fuse's reliability, we feel sure that our customers will also agree with us.

Reference:

(1) R. Rudenberg: Elektr. Schaltvorgänge, 1950.
(2) H. Bitter: "Einfuß der Bemessung des Steuer-Schmelzleiters auf die Große der Löscharbeit bei HH Sicherung". Siemens Z., H. 1, 1958.