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RESEARCH ON HORSE SHOE CORE TYPE AXIAL MAGNETIC FIELD VACUUM FUSE

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INTRODUCTION

In recent years the interrupters of the vacuum circuit breakers are applied various configurations of the axial magnetic field which are to really effective to improve the interrupting performance. Here we apply this method into our newly developed vacuum fuse which was not only successfully preventing local overheating of an electrode when it interrupted large current, but also simplified the coil type of the original axial magnetic field configuration which is adopted horse shoe core type axial magnetic field.

This vacuum fuse shows an excellent interrupting capacity in a wide current range from a overload fault current to a larger short-circuit fault current. Thus, it can be reliably used as a general purpose fuse especially as a motor protection fuse.

CONFIGURATION, OPERATING PRINCIPLE AND ADVANTAGES

The configuration of vacuum fuse is similar to ordinary fuses. It consists of element, dielectric for extinguishing arc, envelop and conducting rod. The main difference is dielectric which is vacuum. It is usually provided with an axial magnetic field device for improving the interrupting capacity.

Figure 1 shows a general type vacuum fuse of early products with rated voltage 15kV, rated current 300A and interrupting capacity 12kA [1].

Figure 2 shows an axial magnetic field coil type vacuum fuse, an experimental product made in 1985 by Japan; the rated voltage, rated current and interrupting capacity being 12kV, 630A and 21kA respectively [2].

Figure 3(b) shows a horse shoe core type of axial magnetic field vacuum fuse, a research sample made by our university's factory in 1988; the rated voltage, rated current and interrupting capacity being 10kV, 250A and 31.5kA respectively [3].

In this type of the vacuum fuse, the axial magnetic field is produced by two plates of horse shoe iron core located on the back of electrodes. The principal configuration is showing in Figure 4. When the short-circuit current passes through to the vacuum fuse,

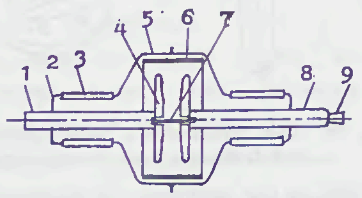

Fig. 1 A General Type of Vacuum Fuse

1-conducting rod, 2-end cap, 3-porcelain tube, 4-arc electrode, 5-metal envelop, 6-shield, 7-fuse element, 8-conducting rod, 9-seal

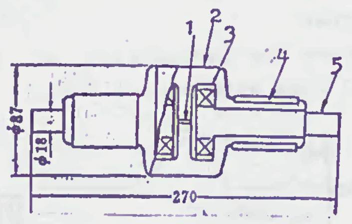

Fig. 2 An Axial Magnetic Field Coil Type Vacuum Fuse

1-fuse element, 2-shield, 3-arc electrode, 4-porcelain tube, 5-conducting rod

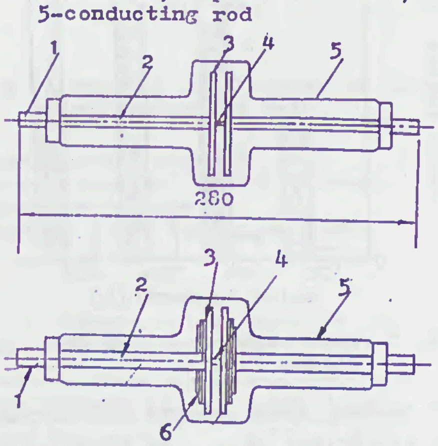

Fig. 3 A Horse Shoe Core Type of Axial Magnetic Field Vacuum Fuse

1-conducting rod, 2-glass tube, 2-electrode, 4-fuse element, 5-glass tube, 6-horse shoe iron core the fuse element operates and produces arc between the two electrodes. Meanwhile, the surfaces of electrodes will build an axial magnetic field which is produced by two plates of horse shoe iron core. Due to two opposite axial magnetic field on the surfaces of the electrodes, most of eddy current will be cancelled out each other. Hence, the surfaces of the electrodes leave out cutting slot.

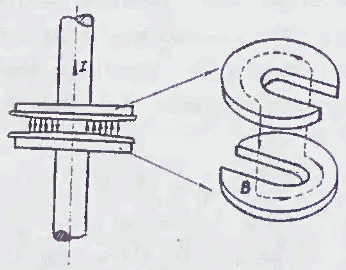

Fig. 4 The Principal Configuration of horse shoe iron core

The advantages of the vacuum fuse are:

(1) The fuse element is very short, only few milimeters and its power loss is lower than that of any other types of fuse. The power loss is nearly only 10% of same rated current of other types.

Figure 5 shows the comparision of the power loss of HRC fuse with vacuum fuse.

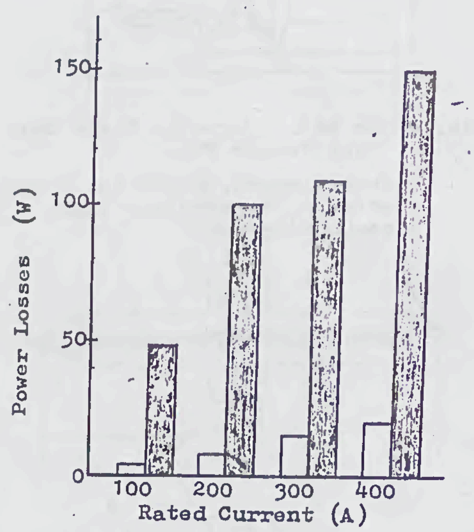

Fig. 5 Power Losses of HRC Fuse and Vacuum Fuse

(2) The vacuum fuse always interrupts fault current at current zero, so there is no over voltage occurred.

(3) The heat-capacity of connecting terminal of vacuum fuse is large and its conducting heat is better. So that, under rated current condition, its temperature rise is small in comparision with the same rated current of other types. It is only 30-50%.

(4) Many times of over current tests of vacuum fuse, there is no deterioration phenomena and no resistance deviation of fuse element. Hence, it is fit for applications of the frequent operation such as for motor protection. Figure 6 shows the number of tests against over current ratio S of the vacuum fuse and HRC fuse.

(Over current ratio S = $= \frac{\text{over current during 10 sec.}}{\text{10 sec. fusing current}}$)

(5) During operation, no explosion, no gas spraying out and no noise will occur.

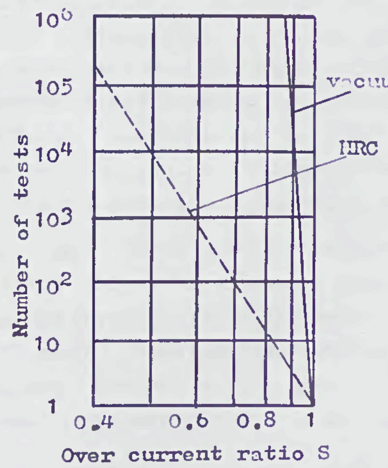

Fig. 6 The Number of Tests Against Over Current Ratio S of The Vacuum Fuse and HRC Fuse

THE CHARACTERISTICS OF VACUUM FUSE

The operation process of the vacuum fuse during over load current or short circuit current is similar to that of the general fuse involving melting, vaporizing, restriking and arcing, Finally, the vacuum fuse quenches this arc at current zero. The conducting rod of vacuum fuse is made by a good conductive material (Cu) having large heat-capacity. Therefore it has lower temperature rise at normal working condition and higher overload ability. When the vacuum fuse suddenly happens short-circuit current fault, the fuse element temperature rise will be attained very rapidly to the melting point until the arc produced. This is nearly an adiabatic process. But at low overload current, the melting time will be increased more and more.

Therefore the prearcing characteristic of the vacuum fuse becomes a steep curve. Figure 7 shows a steep time-current characteristic of the vacuum fuse.

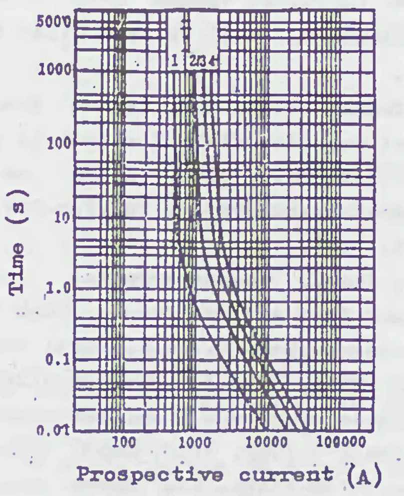

Fig. 7 Time-current characteristics of vacuum fuse

T. Tanaka et al [2] gave the optimizing data of flux density against interrupting current for axial magnetic field type vacuum fuse as shown in Figure 8. In Figure 8 it shows that when the electrode diameter of the vacuum fuse equals 50mm, the optimization of the flux density is $(8-13.6)\times10^{-3}$ Wb. m^{-2} kA^{-1}; when the electrode diameter of the vacuum fuse equals 60mm, the optimization of the flux density is $(8.2-14)\times10^{-3}$ Wb. m^{-2} kA^{-1}.

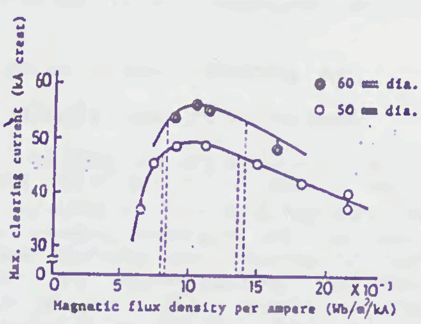

Fig. 8 The Clearable current limit as a function of magnetic flux density per ampere

If the flux density is lower than the optimization value, the max. interrupting current will be decreased rapidly with the decrease of the flux density. If the flux density is higher than the optimization value, the max. interrupting current will be decreased slowly with the increase of the flux density. The reason is that when the axial magnetic field is too weak, the arc between the two electrodes will become a constriction state easily. On the contrary, when the axial magnetic field is too strong, the arc between the two electrodes will maintain a diffusion state, but the charge particles move along the axial magnetic field longer path than the optimization flux density. So that the voltage drop between the electrodes will be increased slightly, but the interrupting current will be decreased.

TESTS AND RESULTS

Two typical samples are shown in Figure 3. One is designed for a lower interrupting capacity without horse shoe iron core structure, that is no axial magnetic field producing in the surfaces of the electrodes. The other is designed for a higher interrupting capacity with horse shoe iron core structure which can produce axial magnetic field under the test. Figure 9 shows the short circuit test result of the latter one with prospective current being 32kA. The temperature rise measured at the ends of the connecting terminals on these two typical samples were 5.8°C and 14.3°C respectively. Table 1 shows an experimental temperature rise test [5].

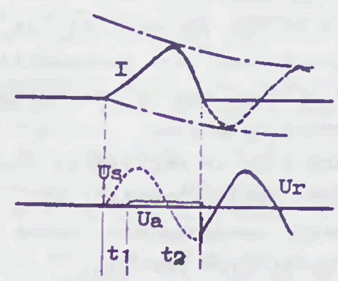

Fig. 9 A Typical Oscillogram of Short Circuit Current Test

I-Short circuit current,
Us-Source voltage, Ua-Arc voltage,
Ur-Recovery voltage,
t_1-Melting time, t_2-Arcing time,

Table 1 Experimental Results of Temperature Rise Test

Rated Current(A)	100	250
Tested Current(A)	101	253
Temperature rise(°C) (Connecting Terminal)	5.8	14.3
Area of connected wire(mm^2)	100	225

APPLICATIONS

Horse shoe iron core type vacuum fuse has many advantages in comparision with a current limiting fuse. The applications of this newly developed vacuum fuse are as follows:

(1) Overload and short circuit protection of a high voltage motor of large capacity.

(2) Protection of main transformer, distribution transformer and protection on overhead or underground distribution lines.

(3) Protection of capacitor banks.

(4) Other special devices for required low over voltage.

Furthermore, this type vacuum fuse with a higher rated voltage is easily developed without any serious increase in dimensions such as for 35kV system.

CONCLUSION

The axial magnetic field makes the arc column stable and keeps it in diffusion state, so that it has an excellent interrupting capacity.

The small over current can be interrupted without any trouble.

No over voltage is occured during operation, because the current is interrupted always at its current zero.

Power loss of the vacuum fuse is about 1/10 in comparision to a current limiting fuse with same rating, due to the fusible element being short length.

Temperature rise is negligibly small.

Fuse element deterioration and deformation are scarcely recognizable after repetitive application of over current.

It is affirmed that the vacuum fuse having such advanced characteristics can be adopted in various fields, so that it will be developed widely in the future.

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