文章编号：0258-8013 (2008) 24-0124-06　　**中图分类号**：TM 561　　**文献标识码**：A　　**学科分类号**：470·40

一种新型高压真空灭弧室触头及其特性

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A New Electrode Applied to High Voltage Vacuum Interrupter and its Performance

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ABSTRACT: Vacuum interrupter is the core of high voltage vacuum switch. Because of the long contact gap, the axial magnetic field (AMF) contact is widely used to generate stronger and evener AMF in the contacts' gap. It can reduce arc current density and arc energy, so its interrupting performance is improved. A new AMF electrode applied to high voltage vacuum interrupter was introduced, it has some advantages such as simple structure, easy-machining, strong mechanism intensity and so on. Its axial magnetic field characteristic was calculated and analyzed with the solution of finite element. The calculation results indicated that the axial magnetic field characteristic for the new one is superior to a few traditional electrodes. The vacuum interrupter used the new electrode was tested in the synthetic test circuit, the short-circuit current interrupting ability was still excellent when the contact gap was 40 mm and 60 mm.

KEY WORDS: axial magnetic field; vacuum arc; high voltage vacuum interrupter; electrode structure

摘要：高压真空开关的核心部件之一是真空灭弧室，由于其触头开距较大，因此多采用纵向磁场触头，希望触头间隙有较强且较均匀的纵向磁场，这样可降低电弧电流密度，降低电弧能量，从而提高开断性能。该文提出了一种适合应用于高电压等级真空灭弧室的新型纵向磁场触头结构，该触头结构结构简单，便于加工，而且结构强度更好。利用有限元方法对这种新型的真空灭弧室磁向磁场触头间隙的磁场分布特性进行了计算与分析，　结果表明其磁场特性优于现有传统纵磁触头结构。利用这种新型触头结构制做了真空灭弧室样机，在单频LC振荡回路上进行了性能测试，结果表明在触头开距为 40 和 60 mm时其同样具有良好的开断短路电流的性能。

关键词：纵向磁场；真空电弧；高压真空灭弧室；触头结构

基金项目：国家自然科学基金项目(50477024)。

Project Supported by National Natural Science Foundation of China (50477024).

0　INTRODUCTION

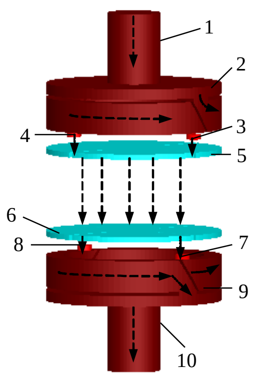
As the theory of vacuum arc and its related technology progressed, the vacuum switch was not localized in the medium voltage area any more, it was developing for high voltage and high capability [1-7]. It's necessary to increase the gap distance between the up and down electrodes for the high voltage vacuum switch, and a key problem for longer gap distance was the control of the vacuum arc. In the 1970 s-80 s, the Japanese researchers firstly came up with the axial magnetic field electrode which generate axial magnetic field by the arc current. And the axial magnetic field can stop the loss of the plasma and make the arc current distribute evenly, it can also decrease the arc temperature and the arc voltage to avoid the formation of an anode spot. Therefore the axial magnetic field electrode has been applied to the vacuum interrupters widely [8-11].

Now there are several axial magnetic field electrodes used for vacuum interrupters such as cup type electrode, multipole electrode, monopole coil type electrode. The magnetic characteristic of the cup type electrode was investigated by some researchers [12-15], the results indicated the axial magnetic field became weaker at the long gap distance, that would be bad for high current interrupting, and the experiment results revealed that the vacuum arc between the up and down cup type electrodes was very unstable at the long gap distance due to its weak axial magnetic field. As for the multipole electrode, the axial magnetic field generated by it was so uneven that the self-magnetic pressure was asymmetric, the arc may spurt out of the gap as a result. The axial magnetic field generated by monopole coil type electrode was strong, but there were other problems such as complex structure, high machining cost, poor mechanical strength and so on. For these above reasons, a new AMF electrode applied to high voltage vacuum interrupter was developed in this paper, the axial magnetic field generated by it was stronger, and its machining cost was lower. The test results proved that the interrupting ability of the vacuum interrupter used the new electrode was excellent.

1　STRUCTURE AND PRINCIPLE OF THE ELECTRODE

The structure of the new electrode was shown as Fig.1, the current path was as follows: firstly the current I flew into the up conduct rod 1, then divided to two branch through up coil 2, the two branch current respectively flew into up contact plate 5 by way of the conduct column 3 and 4 next, then to the vacuum arc column, then to the down contact plate 6,to down coil 9 via the conduct column 7 and 8 next, the current flew out from the down conduct rod 10 finally.

This new electrode combined the features of both the traditional monopole coil type electrode and the cup type electrode. It looked like the 1/2 coil type electrode on the current path, the axial magnetic field generated by it was unipolar and strong to control the



1—up conduct rod；2—up coil；5—up contact plate；
6—down contact plate；3，4，7，8—conduct column；
9—down contact plate；10—down contact rod

图 1　触头结构原理图

Fig. 1　Structure of the new electrode

vacuum arc at the long gap distance effectively. It also has the features of simple machining like the cup type electrode ,because the machining process was realized only by cutting two slots in the electrode body.

2　CALCULATION　AND OPTIMIZATION

2.1　Calculation Model and Optimization Method

The magnetic characteristic of the new electrode was calculated with finite element method. The calculation model looked just as Fig.1, and the vacuum arc was replaced with the cylinder, the diameter of the cylinder was the same as the electrode. The table 1 showed the material properties of every part. The eddy current solver was adopted in the whole process, and the excitation source was 40 kA –50 Hz AC current.

表 1　材料特性

Tab. 1　Material properties

Part name	Material	Conductivity(S/m)
Coil	Cu	5.8e+007
Conduct rod	Cu	5.8e+007
Arc column	Arc	2000
Contact plate	CuCr50	1.8e+007
Background	Vacuum	0

In the optimization process, the electrode diameter and the gap distance was set to 100 mm, 60 mm respectively, and both the two parameters remained the same. However, the optimization was implemented by changing the position of the contact plate , the slot style on the contact plate and the parameter *L* which was the distance between the slot on the electrode and electrode cup top, the variation of *L* is 6 to 14 mm, the step length is 2mm, the optimization process was conducted as Fig.2 shown.

2.2　Results of Calculation and Optimization

When *L* is 12 mm, at the peak value of the current, the contrast on the AMF axial distribution between 1/2 coil type electrode and the new electrode was shown as Fig. 3. To several traditional AMF electrodes, the AMF of the 1/2 coil was the strongest at long gap distance, its AMF axial distribution was just like the new electrode, both were a little weaker at the middle of the axial line. But the AMF of the new one was obviously stronger than the 1/2 coil electrode. Just by the effect the AMF has, the control ability

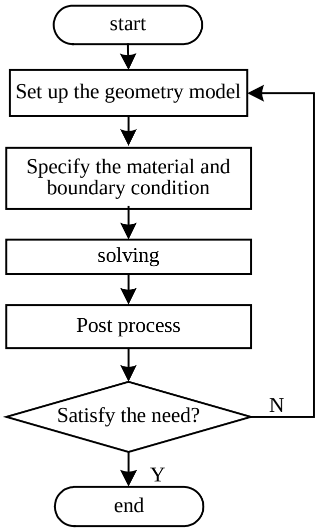


图 2 计算流程图

Fig. 2 Flow chart of the optimization process

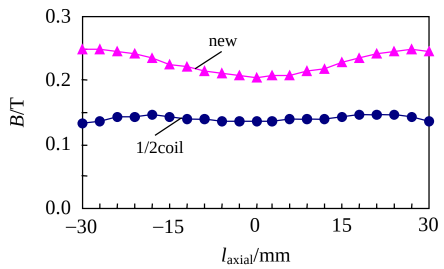


图 3 纵向磁场沿触头间隙中心轴线分布

Fig. 3 AMF axial distribution along the axial line

to the vacuum arc was more excellent for the new electrode.

Since the AMF axial distribution was a little weaker at the middle, the AMF distribution on the middle plane of the gap between up and down electrodes was investigated next. Fig. 4 showed the AMF radial distribution of the new electrode and the 1/2 coil electrode on the middle plane. From Fig. 4, the AMF of the former was stronger and evener than the latter at the peak value of the current, it would do better to restrict the constriction of the vacuum arc.

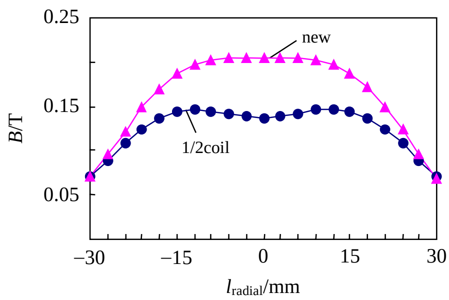


图 4 纵向磁场沿触头间隙中心平面分布

Fig. 4 AMF radial distribution on the middle plane

Besides the strength of the AMF at the peak value of the current, the residual AMF due to eddy current when the source current went zero and the phase shift time between the current and the AMF should be considered. Fig. 5 showed the phase shift time distribution of the new electrode and the 1/2 coil type electrode. Though the phase shift time of the former on the middle plane was longer than the latter, its value of the phase shift time was still small for the former, the maximum value was about 0.8 ms. The influence of the phase shift time behaved as the residual AMF at the zero value of the current and being not the maximum when the current was the peak value. Fig. 6 showed the residual AMF radial distribution at the zero value of the current, the maximum value was about 50 mT, it was weaker than the maximum value of cup type electrode, but it may still hinder the recovery of the insulation performance.

However the magnetic characteristic of the new electrode was so good, the optimization work should be done to more excellent interrupting ability. Fig.7 showed the optimization results through changing the parameter *L*. when *L* became smaller, the AMF on the middle plane of the gap became stronger, especially

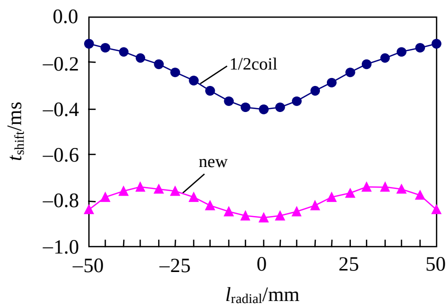


图 5 触头间隙中心平面磁场滞后时间径向分布

Fig. 5 Radial distribution of the phase shift time on the middle plane

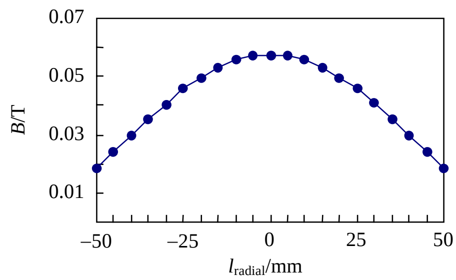


图 6 电流过零时剩余磁场的径向分布

Fig. 6 Radial distribution of the residual AMF at the zero current for the new electrode

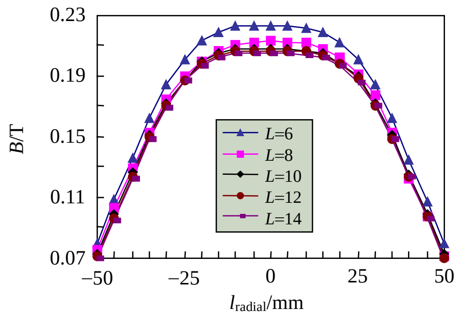


图 7　纵向磁场分布随 *L* 的变化

Fig 7　Variation of the AMF distribution with *L*

the increasing extent was large as *L* became 8 mm from 6 mm, but the AMF only increased a little when *L* varied from 10 mm to 14 mm.

Taking mechanical strength and machining into account, *L* should not be too small, but a proper value. The magnetic characteristic of the new electrode was also optimized by changing the style of the slot on the contact plate, the two different style were shown as Fig.8, and Fig. 9 showed the AMF distribution contrast corresponding to the two different style. Obviously, the AMF strength was stronger for the style 2.

The optimization work was conducted to improve the problem of residual AMF. The problem was improved mainly by increase the slots on the contact plate in tradition, but the mechanical strength became bad accordingly. In this paper, it was

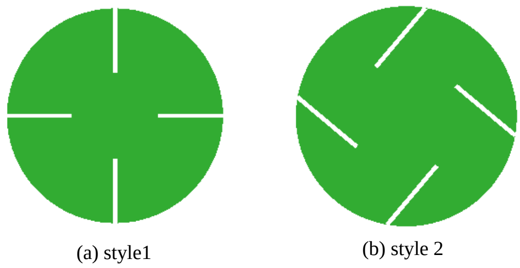


图 8　触头片开槽方式

Fig. 8　Two styles of the slots on the contact plate

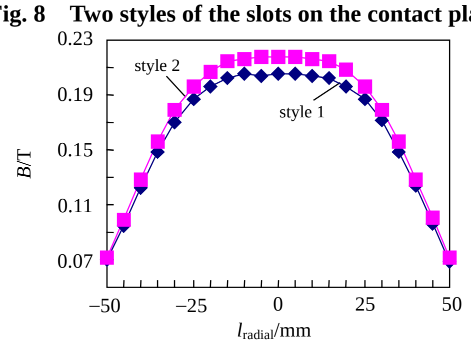


图 9　纵向磁场的径向分布

Fig. 9　AMF radial distribution for two styles

implemented through changing the position of the contact plate. Fig. 10 showed the two positions , and the position 2 was just by rotating 45° from the position 1. the residual AMF for the two position on the middle plane of the gap was shown as Fig.11, the residual AMF strength was weaker for the position 2, especially in the center of the middle plane, the value became about 40 mT from 50 mT.

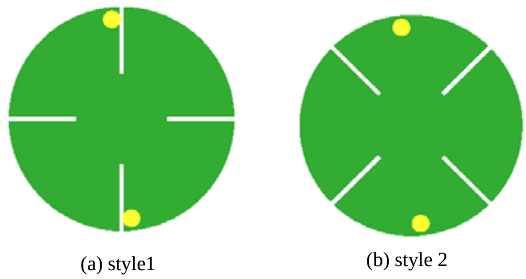


图 10　触头片的电流连通位置

Fig. 10　Two positions for the contact plate

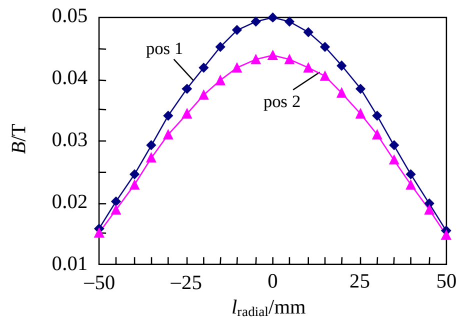


图 11　纵向磁场的径向分布

Fig. 11　Residual AMF distribution for two positions

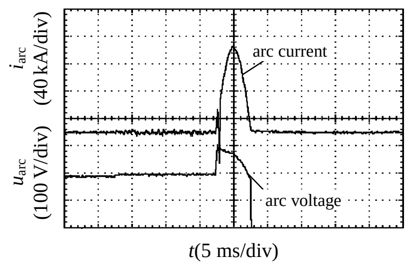
3　TEST RESULTS

The vacuum interrupter used the new electrode was tested in the synthetic test circuit at Xi’an Jiaotong University. The arc current and arc voltage waveform was recorded by the oscilloscope. In the test, the interrupting current became larger to the interrupting limit step by step. the step length was set to 10 kA when the current was less than 30 kA, and became 5 kA when it exceeded 30 kA.

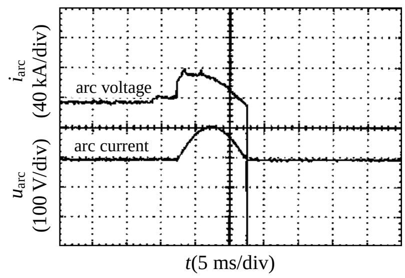
Firstly, the two vacuum interrupters were compared which the gap distances were 40 mm and 60mm respectively. The limit interrupting for 60 mm case was 50 kA, and it was more than 50 kA for 40 mm case.

In all the tests, the arc voltage remained low relatively. Fig.12 showed the arc voltage and current waveform for the two vacuum interrupters which the gap distances were 40 mm and 60 mm respectively, and both the current effective values were 50 kA.

As Fig.12 shown, the arc voltage waveform for the 60mm case rises sharply and with much noise signal, because the AMF was too weak to control the vacuum arc effectively due to the phase shift time. As the current increased, the arc voltage waveform tended to being smooth; in the contrast, the arc voltage for the 40 mm case was lower and the noise was weaker, these phenomenon indicated the control ability to the vacuum arc was stronger for the 40 mm case, because the AMF of the 40mm case was stronger than the 60 mm case just as Fig.13 shown.



(a) Gap distance=60 mm



(b) Gap distance=40 mm

图 12 电弧电压与电弧电流波形

Fig. 12 Voltage and current waveform for two cases

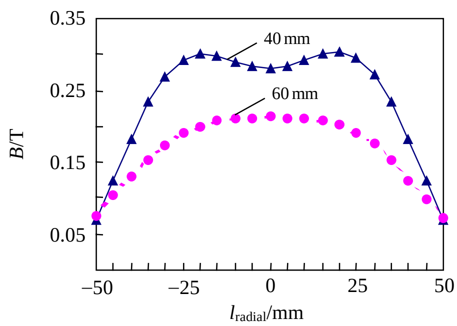


图 13 纵向磁场在触头中心平面上的径向分布

Fig. 13 Radial distribution of the AMF on the middle plane for the two cases

4 CONCLUSIONS

（1）Through the numerical analysis to the new electrode, it was concluded that not only was the machining of the new electrode simple, the new electrode can also generate stronger AMF to interrupt bigger current.

（2）The AMF of the new electrode was enhanced by changing structure parameters, the problem of the residual AMF at the zero current was improved during the optimization process.

（3）The interrupting test was conducted to confirm the excellent performance of the vacuum interrupter used the new electrode.

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收稿日期：2007-12-11。

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(编辑　郭联哲)