Study on Electrical Characteristics of Titanium Diboride Powder Applied in Power Field

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Abstract. Based on the properties of Titanium Diboride (TiB_2) combined with the knowledge of electrical engineering, a novel application of TiB_2 in the field of electric power has been proposed. The contact resistance of the particulate matter changes greatly when the external stress changes. Therefore, particulate matter can be used as a variable resistor in the field of fault current limiting. First, the pressure-resistance characteristics of TiB_2 were studied experimentally, and the law of resistance change with pressure was summarized. The explanation was given from the perspective of particle mechanics. Then, combined with the operating mechanism, a device with variable resistance was fabricated. And the curve of material resistance with time was tested. Finally, the material was passed through current, which proved that the material properties have not changed under large current. Thus the feasibility of the application of the material in the power field was verified.

1. Introduction

In the field of power, fault current limiters have always been a research hotspot. The essence of FCL is to suddenly insert a large resistor in the line to reduce the short-circuit current [1]. Therefore, the key to fault current limiting technology is to achieve an ideal variable resistor. For example, the superconducting current limiting technology utilizes the superconducting property of the material [2-3]. Under normal conditions, the material is in a superconducting state, and the resistance is substantially zero, and the load current can flow normally. When a short circuit occurs, the material enters a quench state and the resistance increases, thereby achieving the function of current limiting. However, the cost of superconducting materials is relatively high. And it requires complicated equipment to maintain its superconducting state during normal operation, and thus is bulky. There is still a long way to go to achieve widespread use of superconducting materials. Therefore, it is the main research purpose of this paper to find a easily achievable variable resistance material.

It is well known that the contact resistance is significantly affected by the contact pressure. The empirical formula concludes that the contact resistance has the following relationship with the contact pressure [4]:

$$R_j = K_c(0.102F)^{-m} \tag{1}$$

Where m is related to the contact form, which is a number greater than 0 and less than 1. K_c is the coefficient associated with the contact material. It can be seen that the contact resistance is inversely related to the pressure. Thus, a controllable change in resistance can be achieved by varying the magnitude of the contact pressure. Under normal conditions, the contact pressure is at a large value, the contact resistance is in a low resistance state, and the current is normally flowed. When current limiting is required, the contact pressure is reduced, and the contact resistance is changed to a high resistance state, thereby limiting the short circuit current.

In order to achieve the above functions, the material is required to have the following characteristics:

- The resistivity of the material should be as small as possible.
- The material itself must have sufficient hardness so that plastic deformation does not occur under large pressure. Therefore, after the pressure is reduced, the material can restore the original high resistance state.
- The material needs to flow current for a long time, so it should have a high melting point and strong antioxidant. To prevent the production of oxide film on the surface of the material to increase the contact resistance.
- In order to make the material resistance change sufficiently, the number of contact points should be sufficient. So the shape of the material should be granular.

In combination with the above requirements, TiB_2 is an ideal material. TiB_2 is a stable metal compound which is generally used as a conductive ceramic material and an electrode coating material for an electrolytic cell because of its good electrical conductivity. Its main properties are shown in Table 1 [5-6]:

Table 1. Properties of TiB_2 particle

Crystal structure	Hexagonal
Density [g/cm^3]	4.4
Melting point [°C]	2930
Hardness [GPa]	30
Young's modulus [GPa]	574
Poisson's ratio	0.11
Resistivity [μΩ·cm]	14.4
Antioxidant temperature [°C]	1100

It can be seen that TiB2 can perfectly meet all the above requirements. Its resistance will change significantly under the action of external pressure. In order to further verify the feasibility of the application of TiB_2 in the field of fault current limiting, the characteristics of TiB_2 were studied. First, the variation law of material resistance and pressure was tested by universal testing machine and analyzed theoretically. Then, a device of a variable resistance material was fabricated in combination with the operating mechanism. And the dynamic resistance curve of the material was tested. Finally, the material was subjected to a current-flow test to observe the characteristics of the material under high current impact. Through the preliminary study of material properties, the feasibility of using TiB_2 in the field of fault current limiting is verified.

2. Characteristic Test Method

2.1. Pressure-Resistance Characteristic Test

In order to verify the feasibility of TiB_2 in the power field, the pressure-resistance characteristics of TiB_2 were first studied. TiB_2 with a particle size of 30 μm, which is commonly found on the market, was selected. The test apparatus is shown in Figure 1. The material was placed in a cylindrical insulated container. Metal electrodes were placed at the upper and lower ends of the container. The lower metal electrode is fixed to the container. The upper metal electrode can be moved automatically and the material is pressed by the universal testing machine. Material resistance is measured by digital bridge. The inner diameter of the insulating container is 50 mm, and the height of the material is 40 mm. The pressure applied from 0 N to 4000 N. The data was recorded every 100 N. And a total of 10 sets of data were tested and averaged.

It should be noted that since the upper metal electrode itself has a weight of 2 kg, the material has withstood a pressure of 20 N even if no pressure is applied. Therefore, the material actually withstands a pressure range of 20 N-4020 N.

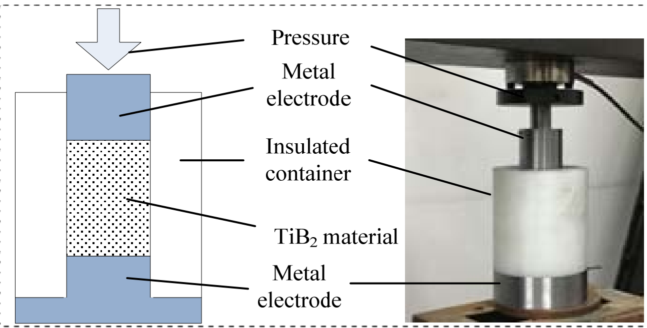

Figure 1. Test apparatus schematic

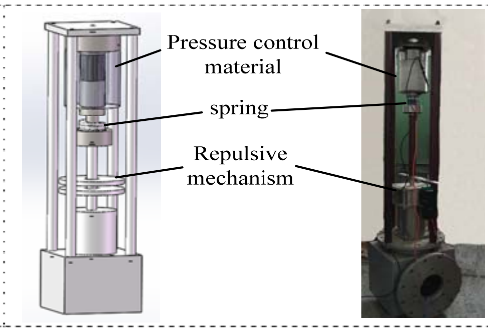

Figure 2. Variable resistance device

2.2. Dynamic Resistance Characteristic Test

Since the resistance change of TiB_2 is dependent on the change of pressure. Additional device is required to provide variable pressure. The operating mechanism of the vacuum circuit breaker can perform fast motions and can therefore be used to provide variable pressure. The overall structure is shown in Figure 2. The repulsive mechanism is connected to the metal electrode through a spring and an insulating rod. Under normal state, the mechanism is at the upper end, and the material is pressed by the spring. When the current limiting is required, the mechanism moves downward. And the pressure of the material is rapidly reduced. Material resistance will increase rapidly.

In order to measure the material resistance curve, connect it to the fixed value resistor apply a constant voltage. The voltage curve of material is the resistance curve. The changes of the material resistance under the opening and closing actions are respectively measured.

2.3. Current Test

Because the material is to be applied to the power field, the material itself has to flow a large current for a long time. Therefore, it is necessary to study the current characteristics of the material under large current. The test uses a large current generator to provide the required current, with a current range of 0-2000 A.

The test process is as follows: 1) Control the output current of the large current generator gradually increase from 0 to 2000 A, record the current and voltage values of the material every 200 A, and observe whether the material resistance changes with the increase of the current. 2) The material is subjected to a 5 minute current test. The currents are 200 A, 500 A, and 1000 A respectively. And the voltage and current data on the material are recorded every 1 min. After the current test, the pressure-resistance characteristics of the material were tested immediately. Compare with pre-flow data to observe whether the characteristics of TiB_2 have changed.

3. Results and Analysis

3.1. Pressure-Resistance Characteristic Analysis

The relationship between the pressure and the resistance is shown in Figure 3. It can be seen that the relationship between resistance and pressure is a power function, which is consistent with the description in Equation (1). And it can be clearly seen that when the pressure is greater than 500 N, the change trend of the particle resistance begins to slow down. When the pressure is less than 500 N, the particle resistance changes more severely. It can be explained by the granary effect of the particulate matter. In a cylindrical container, as the pressure increases, the pressure of the particle system on the bottom will tend to saturate, which is called the granary effect. This is because the friction between the side wall of the container and the particles counteracts the principal stress applied in the vertical direction. So after the applied pressure increases to a certain value, the pressure at the bottom of the material reaches a saturation value. And thereafter even if the pressure is continuously increased, the principal stress of the vertical direction of the particles itself is no longer increased. Therefore, after the pressure is greater than 500 N, the resistance tends to be gentle.

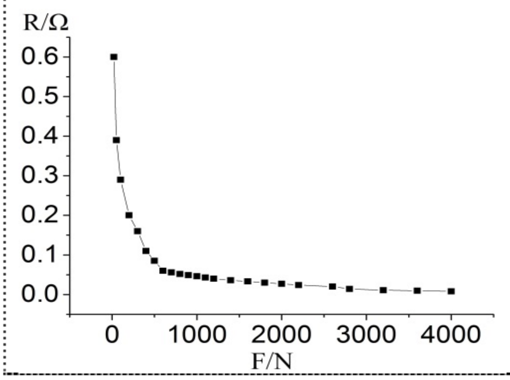

Figure 3. Relationship between the pressure and the resistance. When the pressure reaches 4020 N, the particle resistance is 0.004 Ω. When the pressure of the particles is 20 N (metal electrode gravity), the particle resistance is 0.6 Ω. From the trend of the curve, it can be reasonably estimated that when the pressure of the material is actually reduced to zero, the material resistance will become larger, which can meet the requirements of fault current limiting.

3.2. Dynamic Resistance Characteristic Analysis

The material resistance change curves measured by experiments are shown in Figure 4 and Figure 5, respectively.

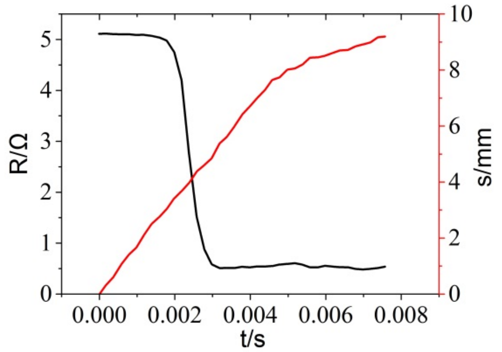

Figure 4. Resistance and displacement curve when mechanism moving up

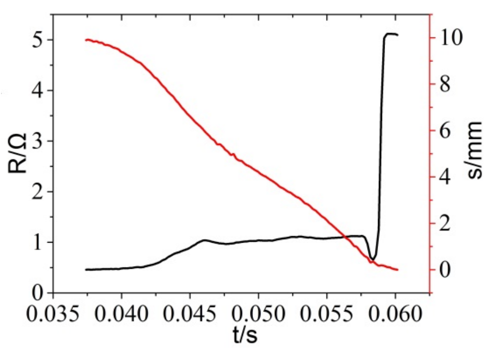

Figure 5. Resistance and displacement curve when mechanism moving down

The red line is the displacement curve of the mechanism, and the black line is the resistance curve of the material. As can be seen from Figure 4, when the mechanism moves up about 4 mm, the material resistance can be rapidly reduced and then stabilized. It can be seen from Figure 5 that when the mechanism starts to move down, the material resistance begins to have a slow rising process. But then the resistance remains stable. When the mechanism about to complete the moving, the material resistance will first become smaller and then rapidly become larger. It is because the mechanism has a bounce, which causes the pressure on the material to suddenly increase and then decrease rapidly. So the resistance curve will fluctuate at 0.058 s. However, the resistance eventually increases rapidly as the mechanism moving down.

3.3. Current Test Analysis

The results of the current-flow test of the materials are shown in Tables 2 and Tables 3. Table 2 shows the data obtained by gradually increasing the current from 0-2000 A. It can be seen that in the range of 0-1000 A, the resistance decreases as the current increases. When the current is greater than 1000 A, the resistance increases as the current increases. This is because when the current starts to increase, the internal pressure of the container increases due to the heat of the material. And when the current continues to increase, the material resistance is mainly affected by temperature. Due to the positive temperature coefficient, the material resistance is increased. However, the magnitude of the change in resistance is only 7%. And it can be considered that the resistance has not changed substantially.

Table 2. Material resistance as a function of current

Current/A	Voltage/mV	Resistance/mΩ
200	690	3.45
400	1370	3.43
600	2060	3.43
800	2660	3.33
1000	3220	3.22
1200	3970	3.31
1600	5250	3.28
2000	6700	3.35

Table 3 is the data of the materials for 5 minute current test. It can be seen that when the current is small (less than 500 A), the material resistance is mainly affected by the increase of internal pressure. As the flow time increases, the resistance is slightly reduced. When the current value is large, the material resistance is mainly affected by the temperature, and the resistance is slightly increased, but the overall variation of the resistance is still small.

Table 3. Material resistance for long-term current

Time/min	Resistance/mΩ(I=200 A)	Resistance/mΩ(I=500 A)	Resistance/mΩ(I=1000 A)
0	3.77	3.62	3.55
1	3.77	3.59	3.61
2	3.51	3.59	3.62
3	3.51	3.59	3.62
4	3.51	3.59	3.63
5	3.51	3.59	3.65

Through the above test data, it can be seen that when the material flows through a large current, its resistance value is relatively stable, indicating that the material can withstand the impact of large current. After the completion of the current-flow test, the pressure-resistance characteristics of the material were tested immediately. It was found that the overall data was not different from that before the current flows. It can be seen that the pressure-resistance characteristics of the material did not change after the current flow. So the feasibility of materials used in the power field is verified.

4. Conclusions

In this paper, a novel idea of using TiB_2 as a variable resistor in the field of electric power is proposed. The electrical properties of the TiB_2 are studied. The feasibility of using TiB_2 in fault current limiting is analyzed. The conclusion is as follows:

- Under the change of pressure, the resistance of TiB_2 will change significantly. When the pressure changes from 4020 N to 20 N, the resistance can change from 0.004 Ω to 0.6 Ω.
- The law of particle resistance and pressure is in accordance with the power function. And the change of particle resistance tends to be gentle after the pressure is greater than 500 N. This is because there is pressure saturation at the bottom of the particulate matter. So the height of the particulate material should not be too high.
- Through testing of material dynamic resistance, it is proved that the resistance can be changed quickly with the change of pressure. But in order to achieve rapid and stable change of the resistance, it is necessary to improve the operating mechanism to reduce the mechanical bouncing and action time.

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- Under the impact of large current, the properties of the TiB_2 are basically unchanged, which proves the feasibility of the material applied in the electric field.

5. Acknowledgments
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