Design of High Power EMI Filter for Anechoic Chamber

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Abstract. This paper analyzes the filter requirements of high voltage and high power anechoic chamber and proposes a design method of high power EMI filter for anechoic chamber. The EMI filter adopts the PI type filter network structure and security mechanism. On one hand, it guarantees the shielding effectiveness of the anechoic chamber. On the other hand, it effectively reduces the leakage current of the filter and ensures the safety of the filter. The validity of the EMI filter is verified by taking the 10kV filter as the experimental object.

1. Introduction

With the rapid development of high-efficiency fully mechanized mining technology and production safety technology of coal mine, the whole mine safety monitoring system based on computer network is widely used in coal mine [1]. The intensiveness and automation degree of mine is increasing day by day, which leads the development of mining, excavation and transportation equipment to the direction of high voltage and high power, and the density of electrical equipment is significantly increased. Thanks to its superior speed regulation performance, the high-power converter has been widely used in various industries, especially in underground coal mines. With IGBT applied, the converter is characterized by low harmonic and high power factor [2-3], which improves the power quality and utilization ratio obviously, but also produces serious high-frequency electromagnetic interference EMI (Electro Magnetic Interference) with its own system and the surrounding power grid [4]. The frequent occurrence of electromagnetic interference leads to the deterioration of underground electromagnetic environment, which seriously affects the reliable and stable operation of underground electronic control system and safety monitoring system [5-6]. In this case, equipment manufacturers, users and safety regulators begin to pay attention to the interference emission of underground frequency converters [7].

In this context, the voltage level and power of the equipment are rising continuously, the 3.3kV, 6kV and 10kV electrical equipment has been widely used in most mines in China. The highest voltage level of equipment covered by EMC test in China is only 660V, which can’t meet the application status of 10 kV rated voltage of electrical mining equipment. Filter is the key to the design of a high voltage and high power EMC anechoic chamber. In this paper, the filter requirements of high-voltage and high-power anechoic chamber are analyzed and designed.

2. Demand Analysis and Design Ideas

High-voltage EMI filters are similar to 380V power supply filters in filtering principle and circuit structure. They are LC low-pass filters. Their function is to filter out the high-frequency interference signals on power lines. However, compared with common filters, high-voltage EMI power filter needs
to consider the security and reliability of power filter. Only on the basis of ensuring security, can the filtering performance be meaningful.

The security of power filter is mainly determined by internal filter elements and electrical structure. The main filter elements are inductor and bypass capacitor. The electrical structure mainly includes creepage distance, electrical gap and insulation material. For bypass capacitors and core-piercing capacitors, first of all, their electrical structures should meet the requirements of electrical specifications. Secondly, capacitors should have high voltage withstand to ensure safe and reliable operation. For AC capacitors, the DC withstand voltage we set is 4 times the rated voltage.

In high power anechoic chamber, the converter is tested. From the point of view of power filter, we are concerned about the lower limit of test frequency of conductive interference and the upper limit of test frequency of radiative interference. It is known that the frequency range of conductive interference is 0.15MHz-30MHz. Because the maximum operating voltage is 10kAC, the insertion loss of power filter is caused by the insertion loss of power filter. It can’t be very high at low frequencies. In this way, not only the background noise requirement of conductive interference test can be satisfied, but also the radio frequency shielding efficiency of anechoic chamber remains intact. Moreover, the capacity of bypass capacitor in the filter can be designed to be smaller, which can reduce the leakage current of power filter. Based on safety considerations, leakage current of 10kVAC/100A power filter is less than 10A, under normal working conditions, less than 2A.

In addition, it is also necessary to ensure that the voltage drop and power loss on the inductor coil can’t be too high under high voltage and high current conditions.

In summary, as a power supply EMI design of high voltage anechoic chamber, the following parameters are mainly considered:

- Nominal voltage
- Max.THOU(THDU,Total Harmonic Voltage distortion)
- Nominal current
- Maximum current
- Leakage current calculated
- Voltage drop
- Power loss at 100Hz
- Insulation

Among them, rated voltage and current, insertion loss are the general indicators of the filter. For testing high-power filters used in anechoic chamber for converter, special consideration should be given to leakage current, insulation withstand voltage, allowable voltage distortion rate and voltage drop.

3. Design of EMI filter

3.1. Circuit design

![Filter structure schematic diagram](image)

**Figure 1.** Filter structure schematic diagram

The design of EMI filter first considers the source impedance and load impedance. The power supply end of the filter is supplied by a long cable. According to experience, the impedance is higher, and the load end is the transformer of the frequency converter. Impedance mismatch can effectively improve
the insertion loss of EMI filter in operation. Considering the volume and weight of high-voltage devices, the filter circuit adopts a simple PI filter structure as shown in Figure 1. Each phase is filtered independently, while common-mode interference and differential-mode interference are eliminated.

3.2. Safety design
In order to reduce the distribution parameters of devices in high voltage filters, differential inductance is used. There is only one winding on each magnetic core. The potential difference between turns and between input and output terminals is close to zero. Therefore, the electrical gap and insulation between inductance coils with different phases, as well as the electrical gap and insulation of the inductance coil and metal shell are the main considerations. During processing, the position of inductance coil is fixed, and the insulation material is filled after testing the performance index, so that no relative displacement will occur under any circumstances, so as to ensure safe electrical clearance. To ensure electrical safety, a larger electrical gap is designed for high-voltage inductor, and proper insulation material is used in the design for isolation.

When several inductors and capacitors are combined in a metal shell, the relative displacement of their installation position should be ensured, and the mutual coupling between different devices should be minimized so as to stabilize the distribution parameters. In a compact shell, epoxy resin encapsulation method is used to achieve electrical insulation.

Formula for calculating leakage current:

$$I_{leak} = 2\pi \cdot f_0 \cdot U_0 \cdot C_0$$  \hspace{1cm} (1)

When the voltage is 10 kV, calculated according to formula (1), the leakage current is not more than 10A and the maximum capacitance is obtained.

In the case of 700A, the voltage drop on the inductance coil of each phase is less than 10V. If the load is nearly purely resistive, there is no voltage drop at the load end because the phase difference between the inductance voltage and the load end voltage is 90 degrees. The above leakage current and voltage drop are calculated on the basis of the assumption that the power supply frequency is 50Hz.

In order to ensure that the safe voltage of the anechoic chamber interface can be restored as soon as possible after the power is cut off, a high voltage switch is added outside the filter. After the power is turned off, the discharge resistance to the ground is turned on, which makes the voltage of the interface terminal of the filter drop rapidly and ensures that there is no dangerous voltage.

4. Examples of EMI Filter
After comprehensive evaluation of the parameters, a 10 kV filter is used to verify the effectiveness of the design. The filter indices are shown in Table 1.

| Table 1. EMI filter performance indicators. |
|--------------------------------------------|
| Nominal voltage /L-PE | 10kVAC(50-75Hz) |
| Max.THOU (THDU, Total Harmonic Voltage distortion) | 3% |
| Nominal current | 700A |
| Maximum current | 750A |
| Leakage current calculated | <5.2A/Ph 10kVAC(50Hz) |
| Voltage drop | <10VAC(700A/50Hz) |
| Power loss at 100Hz | <210W |

Test the filter insertion loss:
The interphase-to-ground L-PE insertion loss test results are shown in Fig. 3.

![Network Analyzer](image1)

**Figure 2.** Filter test connection diagram.

| Zweiseitig line | Frequenz / frequency [kHz] | Grenzw. min. / Low Limit [dB] | Grenzw. max. / High Limit [dB] | Messwert/ Reading [dB] | Ergebnis/ Evaluation |
|----------------|----------------------------|--------------------------------|--------------------------------|------------------------|----------------------|
| L-PE           | 20                         | 130                            | 64                             | ok                     |
|                | 40                         | 130                            | 98                             | ok                     |
|                | 60                         | 130                            | 100                            | ok                     |
|                | 100                        | 130                            | 109                            | ok                     |
|                | 500                        | 130                            | 113                            | ok                     |
|                | 1000                       | 130                            | 108                            | ok                     |
|                | 10000                      | 130                            | 112                            | ok                     |
|                | 100000                     | 130                            | 102                            | ok                     |
|                | 1000000                    | 130                            | 104                            | ok                     |
|                | 10000000                   | 130                            | 109                            | ok                     |
|                | 20000000                   | 130                            | 113                            | ok                     |
|                | 30000000                   | 130                            | 110                            | ok                     |

**Figure 3.** Interphase ground interpolation loss.

The interphase insertion loss is shown in Figure 4 below.

![Graphs](image2)

**Figure 4.** Interphase insertion loss.
After installing the filter on the shielding chamber, the shielding effectiveness test is carried out. The test arrangement is shown in Fig. 5, and the test results are shown in Table 2.

![Shielding effectiveness test](image)

**Figure 5.** Shielding effectiveness test.

**Table 2.** Test data of anechoic chamber shielding effectiveness.

| Location | Test Frequency | Through Value | Measured Value Horizontal | Measured Value Vertical | Efficiency Value Horizontal | Efficiency Value Vertical |
|----------|----------------|---------------|----------------------------|-------------------------|----------------------------|----------------------------|
| Filter   | 14kHz          | 108           | -2                         | -3                      | 110                        | 111                        |
| Filter   | 150kHz         | 113           | -15                        | -20                     | 128                        | 133                        |
| Filter   | 15MHz          | 94            | -17                        | -19                     | 111                        | 113                        |
| Filter   | 100MHz         | 105           | -23                        | -21                     | 128                        | 126                        |
| Filter   | 450MHz         | 113           | 0                          | -14                     | 113                        | 127                        |
| Filter   | 950MHz         | 104           | -7                         | -8                      | 111                        | 112                        |
| Filter   | 10GHz          | 111           | -9                         | -6                      | 120                        | 117                        |
| Filter   | 18GHz          | 98            | -21                        | -19                     | 119                        | 117                        |

From the above data, it can be seen that the insertion loss and shielding effectiveness of the filter meet the test requirements of the anechoic chamber.

### 5. Conclusion

By analyzing the requirements of high-voltage and high-power anechoic chamber, an EMI filter based on PI filter network structure and security mechanism is proposed. It is verified that the filter has high insertion loss and can ensure the shielding effectiveness of anechoic chamber.

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