Analysis and Research of a DC24V Surge Suppression Circuit

JianFu Zhong, ChangHong Yu*, MengLi Liu and SongQing Cen
School of Information and Electronic Engineering, Zhejiang Gongshang University, Hangzhou, Zhejiang Province, 310018, China
*Corresponding author’s e-mail: yuch_2007@163.com

Abstract. In the industrial environment, the stability and safety of the electronic equipment are determined by the anti-interference degree of electromagnetic compatibility. In this paper, a DC24V surge suppression circuit which can be used in embedded data collector is studied theoretically and experimentally. The feasibility of the circuit is verified by the circuit simulation, and then the surge experiment is carried out according to the circuit design board. At the end of the paper, we make a summary based on the experimental data to verify the practicability and feasibility of the circuit.

1. Introduction
Electronic equipment has become an indispensable part of modern industry and life. Most electronic equipment is not purely resistive load, but capacitive and inductive load. Especially in order to effectively suppress interference, most electronic equipment is designed with power module with filter circuit, so as to improve the reliability of the equipment in the interference environment. [1] A good electronic product in the design phase will solve the problem of electromagnetic compatibility. Thus, the improvement cost after product design is finalized and even mass production is greatly reduced [2]. As DC24V is a common dc voltage in industrial environment, this paper conducts theoretical research and experimental analysis on a DC24V surge suppression circuit which can be applied in embedded data collector. First, the feasibility of the circuit is verified by circuit simulation, and then by the surge experiment of the circuit board designed according to the circuit. At the end of the paper, we make a summary according to the experimental data scheme.

The term "Electromagnetic Compatibility", or EMC for short, is a science that studies how electronic devices can work together without affecting their performance under the same Electromagnetic environment [2]. Another explanation is that EMC is a technology whose purpose is to make electrical equipment in a common electromagnetic environment, which is neither affected by the electromagnetic environment nor has such an impact on the environment.

The term "surge" refers to a transient overvoltage that exceeds the normal operating voltage and lasts for a few microseconds. This transient overvoltage, which exceeds the insulation level of the electrical equipment, causes insulation degradation, reduces the MTBF (mean time between failures) of the equipment, and causes immediate damage to the equipment. As a result, equipment has to be repaired and even replaced more frequently, thus increasing operating costs [3].

The term "DC24V" is a common DC24V voltage for industrial products and equipment. Many devices and modules use this voltage, such as relays, proximity switches, valves, etc.

The term "Ceramic Gas Discharge Tubes" is short for GDT. Ceramic gas discharge tube is a ceramic (or glass) encapsulated short-circuit protection device with low pressure inert gas [2]. When the voltage of the GDT poles reaches the breakdown voltage, it can transform the insulation between
the poles into a conductive state at the speed of microseconds, thus absorbing up to several kilowatts of surge power and protecting the electronic equipment from the impact of surge pulse.

The term "Transient Voltage Suppressor" is short for TVS. With GDT similar, when the poles TVS diode reverse transient high-energy impact, it can, at the rate of picosecond level between the two poles of high impedance is a low impedance, which absorbs the surge of power, the voltage between the poles clamp which is located in a predetermined value, effectively protect the electronic line of precision components, from the damage of surge pulse.

The term Inductor. A component that can be stored by converting electrical energy into magnetic energy. The inductance has the function of decouple and delay in the circuit.

2. The simulation

Surge is also called lightning surge. Direct lightning strikes the external circuit (outdoor), the injected large current flows through the grounding resistance or external circuit impedance to generate surge voltage; in addition, the switching of the main power supply system in the loop will also generate pulse disturbance. [4] This is very common in industrial environments.

2.1. Schematic introduction

![Circuit schematic.](image)

Figure 1. Circuit schematic.

Figure 1 is the schematic diagram of DC24V surge suppression circuit. The protection circuit is designed in two stages. GDT is used in the first stage to release large surge pulse, and TVS is used in the second stage to further release residual voltage. We choose BC301N - D for GDT, which impulse breakdown voltage is 700 V, fast response time of 0.5 us, protective 6KV @ 10/700us surge current, insulation resistance is higher than 1 G Ω. For the second level, TVS, we used SMBJ30CA with rated power of 600W and impact breakdown voltage of 33V. Inductance decoupling is adopted between the first and second stage to play the role of delay, so that GDT can act first before TVS, releasing most of the surge pulse energy, and then releasing the remaining low-voltage surge pulse by TVS. This hierarchical release can ensure that TVS will not be directly damaged due to the excessive energy released, and guarantee the life of the protection circuit, so the selection of inductance is particularly important.

2.2. The simulation introduction

![The simulation circuit.](image)

![pulse waveform.](image)

![Pulse after inductance.](image)

Figure 2. The simulation circuit.  Figure 2. pulse waveform.  Figure 4. Pulse after inductance.

Here we use Proteus simulation software for simulation, to select the appropriate value of inductance. The simulation circuit is shown in Figure 2. The pulse generator will generate 1.2/50us pulse of Figure 3, front time T1=1.2=us±20%, time to half value: T2=50us±20%. Through inductance L1, resistance R to the ground. We grab the waveform at TP1 and compare it with the waveform generated by the plus
generator. So as to get the appropriate value of the inductance range. Figure 4 shows that after the inductance, the voltage rise at TP1 is much slower than before the inductance.

2.3. The simulation results

![Figure 5. Statistical graph of simulation results of 1000V 2000V 4000V.](image)

According to the test requirements of surge (impact) immunity specified in IEC 61000-4-5:2008, we studied the delay effect of inductance pairs by generating three different 1.2/50μs pulse voltages, namely 1000V, 2000V and 4000V [5]. In Figure 5, the horizontal axis is the inductance value, and the vertical axis is the time. PLUSE refers to the time required for the voltage before the inductance to reach 700V, that is, the time to reach the response voltage of GDT. TP1 refers to the time required for the voltage to reach 33V after the inductance, that is, the time to reach the response voltage of TVS. It can be seen that under the same pulse waveform, the higher the pulse voltage, the shorter the time to reach the response voltage of GDT and TVS. Therefore, choosing a suitable inductor can realize GDT response earlier than TVS, so that most of the pulse energy can be released first.

3. Surge test

According to the scheme provided in the schematic diagram in Figure 1, a test PCB is designed for the actual surge test.

3.1. Surge test introduction

The function of the circuit board is to convert the input 24VDC into 5VDC and light a red led light through 5V. Teseq NSG3040, a generator used to simulate the electromagnetic interference effect in the immunity test, was used in the test.

![Figure 6. Experimental scene and physical drawing.](image)

In the experiment, we used 220uH, 330uH, 470uH, 680uH and 1MH. Five kinds of inductance are tested for surge. The 1.2/50 μs pulse of various voltages is generated by NSG3040. The test rate is once per minute, so that the performance of the protection device can be restored. In fact, the phenomenon of lightning strikes in nature and the switching of large switches in switching stations cannot have very high repetition rate. The test voltage increases gradually from low to high, avoiding the false appearance of the test results due to the nonlinear characteristics of V-A. During the experiment, relevant components were prepared for replacement in case of device damage.
3.2. Surge test introduction
GDT works in accordance with the gas physics principle of high efficiency arc light discharge. The short-circuit protection device with low pressure inert gas inside will produce visible arc light when it conducts. In the experiment, we determine whether GDT ACTS by observing whether GDT emits arc light. And record the results as the Table 1.

Table 1. Surge test pulse discharge path record sheet.

| Inductance | 220V | 300V | 400V | 500V | 600V | 700V | 800V | 900V | 1000V | 2000V | 4000V |
|------------|------|------|------|------|------|------|------|------|-------|-------|-------|
| 220uH      | 0 ^a | 0    | 0    | 0    | 0    | 1 ^b | 1    | 1    | 1     | 1     | 1     |
| 330uH      | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1    | 1     | 1     | 1     |
| 470uH      | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1    | 1     | 1     | 1     |
| 680uH      | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1     | 1     | 1     |
| 1MH        | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1     | 1     | 1     |

^a^ indicates that GDT has no action under inductance and voltage.
^b^ indicates that the GDT moves to release most of the pulse energy.

In the process of the experiment, when 220uh inductor is selected for 600V, 700V and 800V surge test, TVS is damaged, resulting in TVS short circuit, and then fuse is burnt. The rest of the inductors performed well during the test without any damage. Analysis reason: due to the switch action characteristics of GDT, the problem of passing the standard high voltage test and failing the non-standard low voltage test may occur during the test of the actual single board [6]. According to the analysis of the simulation results, compared with the high-voltage pulse, the low-voltage pulse due to the slow speed of voltage rise, TVS is likely to be prior to the threshold voltage of GDT discharge pulse, and the excessive energy impact exceeds the upper power limit of TVS, resulting in the damage of TVS. After replacing the device, the follow-up circuit is normal, and only the protective device is damaged.

4. Conclusion
When the inductance value is above 220uh, it can protect the high voltage pulse very well. Because the TVS of 220uh was damaged during the test. Due to the delay effect of the inductor, if there is a short-time power increase in the normal operation of the circuit, the current is increased. Selecting too large inductor may cause unknown problems due to the delay of inductor and the short supply of current for a time. It is recommended to select 470uh power inductor.

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