# Review of Typical Interference Suppression Measures for Industrial Control Systems

**Hanqing Liu*, Weijun Zheng**
*Huadian Electric Power Research Institute Co., Ltd, Hangzhou 310030, Zhejiang, China*
**Corresponding Author.*

**Abstract: Interference suppression is one of the core issues in the research of industrial control systems, and the research of interference suppression methods is an essential technology to ensure the reliable and stable operation of control systems. In this paper, from the conductive coupling, common impedance coupling, capacitive coupling, inductive coupling and electromagnetic field coupling, and other propagation paths to start, a comprehensive and systematic description and analysis of all types of interference suppression, including magnetic loop suppression, cable shielding, surge suppression and isolation of interference and other related methods and measures, the basic principle of suppression, the implementation of the method and the characteristics of the analysis and summary of the choice of interference suppression methods for industrial control systems. The basic suppression principles, implementation methods, and characteristics are analyzed and summarized to provide a reference for the selection of interference suppression methods for industrial control systems.**

**Keywords: Industrial Control System; Interference Suppression; Magnet Ring; Shielding Layer; Surge Protection; Interference Isolation**

## 1. Introduction

With the rapid development of microelectronics technology, highly integrated circuits, data transfer current, voltage detection signal is getting smaller and smaller, the control system to the interference signal to the more sensitive. A variety of electronic devices are widely used in various production areas, greatly increasing the electromagnetic noise in the surrounding environment, causing serious interference to industrial control systems, whether it is the decentralised control system (DCS) of thermal power plants, or the monitoring system of hydroelectric power plants, are faced with serious interference problems, so the interference suppression is still a constant problem.

Interference and noise, in many cases are generally viewed as synonymous, noise is the cause of interference, interference is the fruit of noise, the noise amplitude and intensity reaches a certain value, it becomes interference. The so-called interference is a general term for all electronic signals other than useful signals, and interference contains three elements: the source of interference, the propagation path and the receptor. Interference suppression is also started from the three elements of interference, the source of interference is objective, but not all sources of interference can be suppressed or eliminated; to improve the receptor anti-interference degree, depending on the control system itself electromagnetic compatibility (EMC) design; in the propagation path to reduce, intercept or inhibit the amount of coupled transmission interference, is the most effective interference suppression measures in industrial control systems, but also the focus of this paper to analyse and elaborate on the key technologies. This is also the key technology analysed and described in this paper. Interference propagation coupling pathway mainly includes conductive coupling, public impedance coupling, capacitive coupling, inductive coupling and electromagnetic field coupling and other five [1-4]. For the above propagation pathway, corresponding to the main interference suppression technology has a magnetic ring, cable shielding, surge limiting, signal isolation and so on.

In this paper, for the thermal power decentralised control system and hydropower monitoring system and other industrial control system interference, summarise the various interference suppression techniques in recent years, its basic suppression principle, implementation methods and characteristics of the detailed analysis and overview, for the industrial control system interference suppression method selection to provide a reference.

## 2. Magnetic Ring Suppression

### 2.1 Principle of Interference Suppression

Magnetic ring interference suppression works as a single-turn or multi-turn wire through the magnetic ring, or the magnetic ring on the wire, the design principle shown in Figure 1.

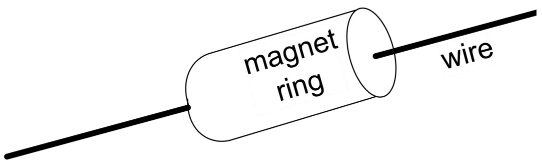


**Figure 1. Schematic Diagram of the Magnet Ring Set**

The magnetic field generated around the conductor interacts with the magnetic field of the magnetic ring, increasing the impedance of the conductor there, which is equivalent to stringing a nonlinear impedance, i.e., resistance and inductance, on the original line, changing the frequency response parameters of the original circuit, and the impedance increases the energy loss with the increase of the corresponding resistive component in the magnetic ring into the consumption of thermal energy [5,6]. especially in the case of large currents, the magnetic ring heat dissipation should be taken into account, and the equivalent circuit is shown in Figure 2 below.

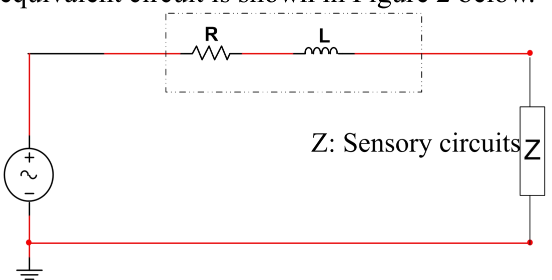


**Figure 2. Magnetic Ring Equivalent Circuit**

One of the inductor (L) is a circuit energy storage element, with “through DC, AC resistance”, “low-pass high-resistance” and “to refuse to stay” and other characteristics. When the current through the inductor increases, part of the current is converted into magnetic energy, thus suppressing the current surge; when the current through the inductor decreases, the magnetic energy of the inductor is converted into electrical energy to slow down the reduction of the current, while the current through the stable current will not affect the current, equivalent to a section of the wire.

The resistance mainly loses the energy of the magnetic ring and affects the saturation characteristics of the ring. When the low frequency, the magnetic ring becomes low impedance, the current through the ring is not attenuated, and at high frequency, the impedance increases, the inductive impedance is still small, the resistance increases, and it mainly becomes resistive[7].

### 2.2 Magnetic Ring Types and Applications

From the equivalent circuit of Figure 2, the magnet ring impedance Z is:

$$Z = R + j * \omega * L \qquad (1)$$

where R and L are equivalent to the resistance and inductance of the magnetic loop, respectively, both as a function of frequency.

Magnetic rings are mainly divided into three major categories such as nickel-zinc, manganese-zinc and amorphous, but in different frequency ranges, their suppression effect is not nearly the same. Mn-Zn magnetic rings are used to suppress interference from 1 kHz to 10 MHz, and NiZn magnetic rings are used to suppress interference from 1 MHz to 300 MHz[8].

Usually, the impedance provided by a single magnetic ring is generally around 100 ohms, so the effect of suppressing high-frequency noise is more obvious in communication and I/O signal loops. If a magnetic ring does not provide enough magnetic energy attenuation, you can also connect multiple magnetic rings in series, the design route shown in Figure 3 and Figure 4:

Magnetic rings are used not only for DC output noise suppression, but also to filter out high frequency noise from AC high power supplies.

Therefore, magnetic rings can be used not only for filtering out I/O signal noise, but also for shielding out high-frequency spike noise signals in the power supply, which is easy to install and economical, and is a relatively cost-effective interference suppression measure. When using magnetic rings, generally select the appropriate type of ring according to the frequency and install it as close to the interference source as possible.

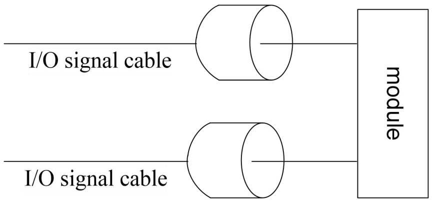


**Figure 3. I/O Signal Magnetic Ring Mounting**

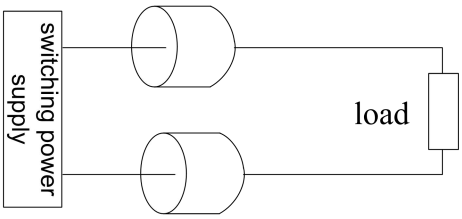


**Figure 4. DC Power Circuit Installation**

## 3. Cable Shielding Interference Suppression

Cables are not only the longest in industrial control systems, but also the most likely to interfere with the control system through near-field coupling, similar to an efficient antenna that picks up and radiates interfering signals [9,10], which is unavoidable, especially in longer cables and I/O signal lines, where capacitive coupling, inductive coupling, and electromagnetic field coupling are predominantly present along the cable.

### 3.1 Capacitive Coupling Interference and Suppression

There is a certain distributed capacitance between the wires and between the wires and the ground in the industrial control system, and its capacitive coupling and equivalent circuit is shown in Figure 5 and Figure 6:

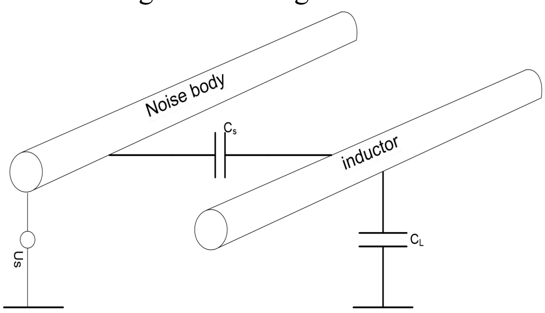


**Figure 5. Distributed Capacitance between Conductors**

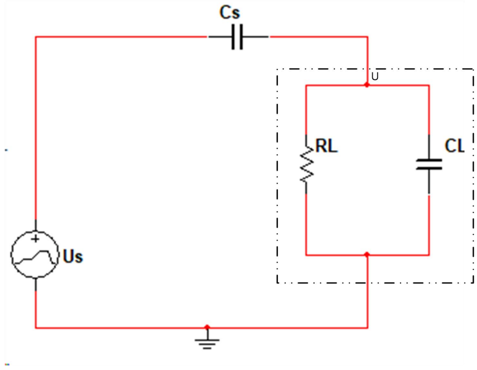


**Figure 6. Equivalent Circuit of Capacitive Coupling of Conductors**

Where Us is the noise voltage, Cs is the distributed capacitance between the wires, RL is the receptor resistance, and CL is the conductor-to-ground capacitance. The induced voltage U can be obtained from the equivalent circuit.

$$\mathrm{U} = \frac{j\times\omega\times C_s\times Z}{j\times\omega\times C_s\times Z+1}\times U_s \tag{2}$$

where Z is the receptor impedance, i.e., the parallel impedance of RL and CL.

If the noise voltage frequency is low, RL is less than CL, then Z is approximately equal to RL, so the induced voltage U is approximated as the terminal voltage of RL and U can be calculated:

$$U = 2\times\pi\times f\times R_L\times C_s\times Us \tag{3}$$

If the position of the wire is determined, RL, Cs and Us can be approximated as constants, so the induced voltage U is proportional to the noise f as a function of frequency. According to the frequency characteristics of the induced voltage: the induced voltage increases with the noise frequency, and when the frequency f increases to a certain value, the induced voltage U saturates and tends to a constant value. When the noise frequency is low, RL, f and Us are not controllable, so the way to suppress capacitive coupling is to reduce the distributed capacitance, and an effective way to reduce the distributed capacitance is to use the method of electrostatic shielding [9,10].

As shown in Figure 5, when the inductor conductor outer layer is wrapped with a shield, the shield is not grounded, and the voltage on the inductor is the noise induced voltage U. If the shield is grounded, the induced noise voltage on the inductor is 0. Therefore, the best way to eliminate capacitive coupling is to ground the shield.

### 3.2 Inductive Coupling Interference and Suppression

When the coil cuts the magnetic lines of force, or when the magnetic lines of force around the coil change, an induced electromotive force is generated. So when the current in a charged body changes, a changing magnetic field is generated around the conductor, and at this point, if there is a circuit loop around it, an induced electromotive force is generated in the loop, as shown schematically in Figure 7:

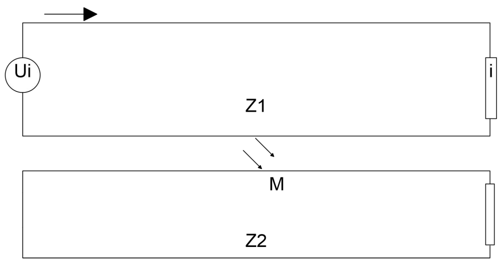


**Figure 7. Schematic Diagram of Inductive Coupling Mechanism**

Where Ui is the noise source voltage, the current generated by Ui in the Z1 loop is i, and M is the mutual inductance, then the induced electromotive force U generated by Z1 on the Z2 loop can be calculated.

$$U = M \times \frac{di}{dt} \; or \; U = n \times \frac{\Delta\Phi}{\Delta t} \qquad (4)$$

In the expression φ is the magnetic flux and n is the number of circuits.

Generally speaking, i in the circuit loop is uncontrollable, and measures such as increasing the mutual inductance loop distance and reducing the inductive loop area are not well implemented due to many factors in the field, therefore, the use of electromagnetic shielding to reduce the mutual inductance M, and thus reduce the inductive coupling, is one of the effective methods at present.

Assuming that the conductors all have additional shields and that the shields are grounded at one end, as shown in Figure 8 below.

In the above Fig. 8, after the current flows through the load Z, all of it returns to the interference source through the conductor shielding layer, and the magnetic flux generated in the shielding layer is equal in size and opposite in direction, so the conductor is shielded to reduce the magnetic flux leakage and weaken the inductive coupling, so that the inductive coupling can be effectively suppressed.

**Figure 8. Schematic Diagram of Single-Ended Grounding of Shielding Layer**

If both the interference source and the conductor shield are grounded, the schematic is shown in Figure 9 below. The current I2 flowing through the shield is less than the current I flowing through the conductor, therefore, the amount of magnetic flux that can be cancelled out by I2 is smaller than it would otherwise be (Zhuang,2019;Xu,2010).

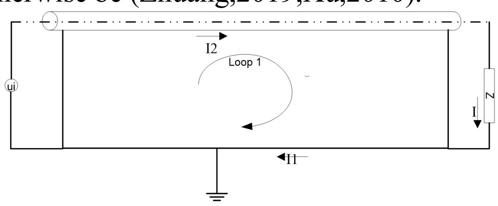


**Figure 9. Schematic Diagram of Shield Double-Ended Grounding**

The cut-off frequency $\omega_c$ is an important characteristic parameter of the shield:

$$\omega_c = \frac{R_s}{L_s} \qquad (5)$$

where Rs is the resistance of the shield and Ls is the inductance of the shield. This is obtained from loop 1 in Figure 8:

$$0 = I_2 \times (j\omega \times L_s + R_s) - I \times j\omega \times M \qquad (6)$$

Where M is the mutual inductance between the shield and the conductor and its value is equal to Ls, which is simplified by bringing into the equation:

$$I_2 = I \times \frac{j\omega}{j\omega + \omega_c} \qquad (7)$$

Therefore, when the conductor current frequency is much greater than ω_c, the vast majority of the current flows through the shield, the shielding effect is better; when the frequency of the current in the conductor is lower than 5ω_c, most of the current is returned from the ground, the shielding effect is poor, so the shielding layer is not suitable to be grounded at both ends at low frequencies [9,10].

### 3.3 Electromagnetic Field Coupling Interference and Suppression

Electromagnetic field coupling is a combination of electric and magnetic fields, the properties of which depend on the source and the medium surrounding the source, as well as on the distance between the source and the observation point, based on which the electromagnetic source space is classified as near-field and far-field.

When the distance is greater than λ/2π (λ is the wavelength of electromagnetic wave), it is called far field. In the far field, the interference to the control system is mainly radiative coupling, which can be cut off from the coupling path by using shielding body or metal cover. One is active shielding, that is, the use of metal shielding body will be closed to the source of interference, or shielding plate blocking, to prevent the leakage of electromagnetic radiation from the source of interference. The second is passive shielding, the inductor will be shielded metal body encapsulation, or metal plate isolation, so that the inductor from electromagnetic radiation interference.

When the distance is less than λ/2π (λ is the wavelength of the electromagnetic wave), it is called the near field, in the near field, the interference is generally input into the control system through the capacitive and inductive coupling, all can be taken to reduce the interference coupling by shielding and grounding, the relevant principles can be referred to the chapters 2.1 and 2.2.

Overall, regardless of the cable, or I / O signal line interference between the coupling, mainly capacitive coupling and inductive coupling, can be taken to the cable or I / O signal line shield grounding way to cut off or reduce the amount of coupling, so as to achieve the purpose of reducing interference. Shield grounding, the interference source of low frequency, the control cabinet side of the single-ended grounding, if the source of interference for the high frequency, the use of shielding layer double-ended grounding. If the control system in the electromagnetic pulse interference source energy powerful region or minefield, you can use double shielded cable, cable memory shielding single-ended grounding, inhibit capacitive coupling, the outer layer of two-ended grounding, inhibit inductive coupling, the interference current flows only outside the shielding layer, so as to achieve the effect of suppressing interference.

## 4. Surge Protection Suppression Technology

Lightning's high voltage, strong current or strong pulse invasion place, will be accompanied by high voltage invasion of industrial control systems, with the highly integrated control system, the overvoltage or overcurrent is more sensitive to the hazards are also becoming more and more serious, will not only cause the control system error, or even damage to the control system, therefore, surge protection is also a control system to inhibit the interference of the necessary measures.

### 4.1 Principle of Surge Protection

Surge Protective Device (SPD) is a device that limits transient overvoltage and diverts surge current [9,10]. Parallel connection in the front of the protected equipment, in the absence of surge appears as a high impedance (i.e, open-circuit state), when a surge occurs in the shortest possible time to quickly drain the current to earth, the voltage is controlled in a safe range, so as to play a role in protecting the equipment, as shown in Figure 10.

Surge protectors can be divided into the following categories [11]:

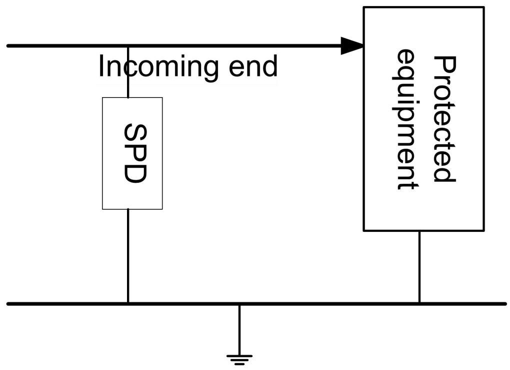


**Figure 10. Basic Principle of Surge Protector**

(1) Voltage switching type: It consists of a discharge gap, a gas-filled discharge tube, a gate current tube and a triac element. This type is high impedance when there is no surge, and low impedance when there is a surge.

(2) Voltage limiting type: It consists of varistor, Zener diode, avalanche diode and so on. This type of SPD in the absence of surge presents a high impedance, with the surge voltage and current rise, its impedance continues to fall to a low impedance conduction state.

(3) Combined SPD: Composed of the voltage switching SPD and voltage limiting SPD mentioned above.

From the application point of view, surge protectors are generally classified into signal network SPD and power SPD types [12]:

(1) Signal SPD: It is mainly used for the protection of PLC, DCS, SCADA, transmitter and other signal devices, applicable to signals such as AI, AO, DI and other I/O data acquisition and RS485, RS232 communication, etc. It is generally used in a serial connection in accordance with the method, and adopts two levels of protection, GDT and TVS.

Its working principle: the first level of protection structure consists of a GDT, the main role is to let the interline induced current to ground quickly release, the second level of structure is composed of TVS interline clamping circuit, mainly to quickly inhibit the interline residual voltage generated by the GDT, the two levels of the protection circuit of the resistor for the decoupling element R [12], the AB end of the unprotected side, ab is the side of the protected side, the circuit structure is shown in Figure 11:

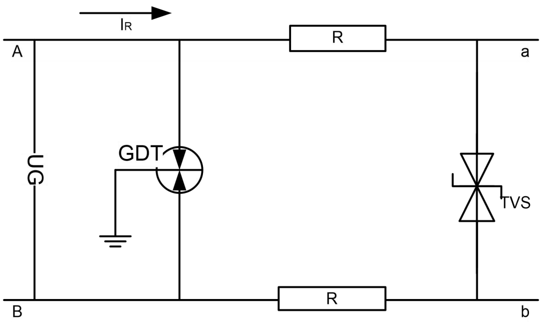


**Figure 11. Signal SPD Circuit Structural Principle**

(2) Power SPD: Used in power supply and distribution system, generally connected to the power inlet end, to protect the power-using equipment, mainly using MOV single-stage protection.

Selection of the main parameters of the surge protector SPD [9,10]:

Voltage protection level Up: characterise the performance parameters of SPD to limit the voltage between the terminals, its value should be greater than the maximum value of the limiting voltage.

Maximum Continuous Operating Voltage Uc: The maximum AC voltage RMS or DC voltage that can be continuously applied to the SPD protection mode.

Continuous operating current Ic:The value of the current flowing through each protection mode of the SPD at the maximum continuous operating voltage.

Residual voltage Ures: The peak voltage generated at the terminals of the SPD when the discharge current flows through it.

### 4.2 Surge Protector Selection and Application

Power surge protector (SPD) can be based on GB/T 18802.12-2014 "low-voltage surge protector (SPD) Part 12: Low-voltage power distribution system surge protector selection and use of guidelines" and GB/T 21431-2015 "building lightning protection device detection technical specifications" in the relevant provisions of the requirements, combined with the actual situation of the control system, SPD selection, which Voltage-limited SPD performance is more superior, you can give priority to.

SPD lead end length, also directly affects the SPD protection effect. As shown in Figure 8, in the SPD installation wiring, the SPD ends were accessed through the introduction of wires, there are wires there is a line of resistance, there is a line of resistance will produce a voltage drop, therefore, the SPD ends of the length of the lead, cross-sectional area will affect the protection function of the SPD, the two ends of the lead will make the superimposed residual voltage exceeds the insulated impact resistance voltage of the insured equipment, resulting in the failure of the equipment SPD protection, according to the standard According to the standard, the SPD lead should not exceed 0.5 m. In order to reduce the voltage drop and avoid SPD protection failure, V-type wiring or Kevin-type wiring [13], as shown in Figure 12:

Signal surge protector (SPD) can refer to the requirements of the relevant provisions of GB/T 21431-2015 "Technical Specification for Detection of Lightning Protection Devices for Buildings" to determine the appropriate residual voltage, decoupling resistance and other parameters according to the type of signal to be protected.

Signal SPD wiring is different from the power SPD, and is installed in series with the protected equipment, as shown in Figure 13, where the dotted line box is the signal SPD.

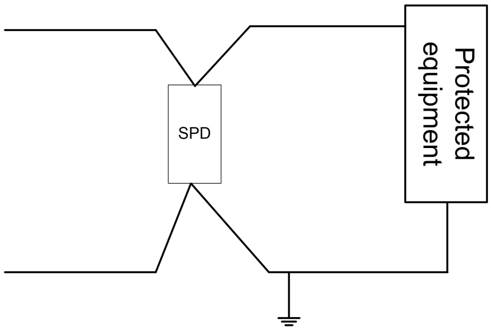


**Figure 12. SPD Kevin Wiring**

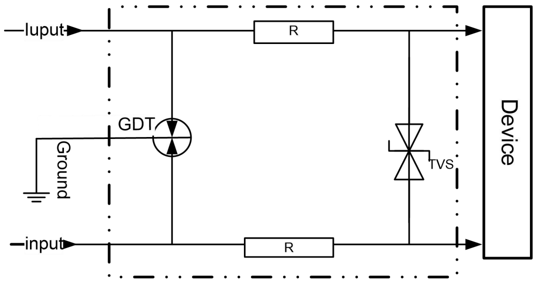


**Figure 13. Signal SPD String Installation**

## 5. Isolation Suppression Technology

The control system suffers from the conductive interference of the line, one is from the noise of the power supply system, and the other is from the intrusion of external interference signals from the I/O signal line. Therefore, the interference isolation in this paper is only for power supply and I/O signal interference isolation suppression is introduced.

### 5.1 Power Isolation Suppression

5.1.1 Power supply interference

Power supply is the control system controller, I / O modules, communication modules and other energy supply station, are converted from AC 220V power supply to DC 24V power supply, so the AC power line interference, easy to couple along the line to the control system, interference with the control system to operate normally and stably. For example, lightning strikes or lightning induction, a variety of electrical equipment in the split/close will produce surge voltage, large load equipment or power supply instantaneous switching caused by voltage dips or temporary disconnection and inductive load switching transient pulses, harmonics and so on, will directly and seriously affect the stable operation of the control system. Once the voltage fluctuation amplitude reaches ± 15% of the rated voltage, will not only lead to control system error, and even control system paralysis and permanent damage to equipment, therefore, the power supply to take the interference isolation, voltage regulation and the use of uninterruptible power supply is to protect the control system to ensure the reliable and stable operation of the effective measures, this section focuses on the isolation of power supply interference measures.

5.1.2 Power Interference Isolation

A general power transformer has a large distributed capacitance due to the close proximity of the primary and secondary side coils and a low impedance to high frequency noise, as shown in Figure 14:

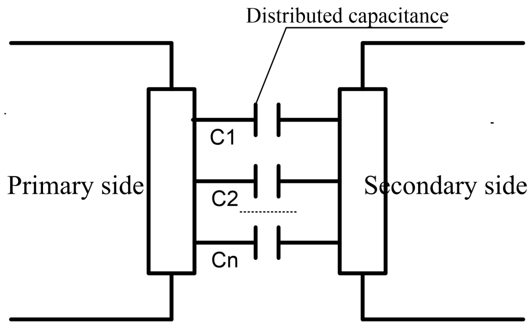


**Figure 14. Distributed Capacitive Coupling with Ordinary Transformer**

In order to reduce the distributed capacitance between the primary and secondary sides, a transformer is used to suppress the high-frequency spike pulse interference, so the isolatable transformer is generated, and its structural schematic diagram is shown in Figure 15.

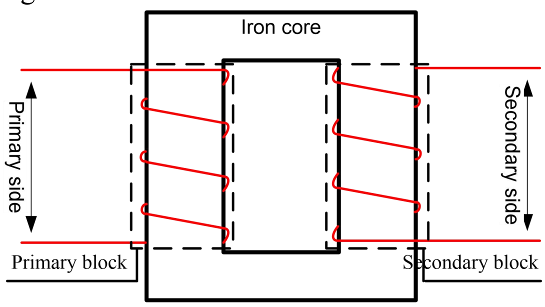


**Figure 15. Isolation Transformer**

Isolation transformer primary and secondary side turns ratio of 1/1, one and two side windings are wound separately to reduce the interstage distribution capacitance, and are added shielding layer, primary side, secondary side and iron core to take ground shielding measures, thus inhibiting the spread of high-frequency noise in the power supply circuit, and effectively improve the AC power supply interference.

### 5.2 I/O Signal Isolation

Signal isolation is to establish a barrier between the signal sender and receiver, no electrical signal traverses the two ends of the barrier, thus isolating a lot of noise and cutting off the signal line conduction interference coupling. Such as analogue signal isolation, due to the input and output of no common ground, it avoids the common impedance coupling interference between the channels. Signal isolation has a variety of uses, generally including signal transmission isolation, signal conversion isolation, signal distribution isolation and signal ground safety isolation, but in this paper only about the inhibition of high-frequency interference with signal transmission isolation, its structure schematic shown in Figure 16.

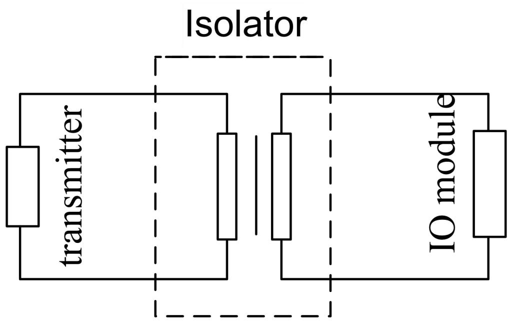


**Figure 16. Schematic Diagram of Signal Transmission Isolation Structure**

In the signal transmission process, by electromagnetic interference or ground loop current, etc. will cause signal loss or distortion, so the signal transmission on the way to isolate, so as to eliminate the ground potential difference in the formation of the loop current, but also isolate the inductive coupling, inhibit the high-frequency spike interference.

## 6. Conclusion

In this paper, from the interference in the three elements of the "propagation path" to start, for the industrial control system wire conduction coupling, public impedance coupling, capacitive coupling, inductive coupling and electromagnetic field coupling and other five kinds of interference propagation path, standing in the operable and affordable position, inductively summed up the corresponding interference suppression measures for the industrial control system interference suppression to provide a reference.

## Reference

[1] Shen, H.B & Zhu, Y.H. (2004). Anti-jamming technology for industrial control systems. Journal of Metallurgical Automation. Proceedings of the Annual Meeting of National Metallurgical Automation Information Network. (pp.567-570). (in chinese)

[2] Zhou, K.J. (2019). DCS, PLC control system interference suppression discussion. World Non-Ferrous Metals. (22), 14-15. (in chinese)

[3] Xie, K & Zhou, B. (2022). Study on Electromagnetic Interference of Automatic Control Equipment in Electrical Engineering (21), 44-46. (in chinese)

[4] Wan, Q. (2019). Analysis and research on anti-interference measures of industrial automation control system. Enterprise Technology and Development (04), 101-102. (in chinese)

[5] Xiong, B, Yi, H.B & Zhao,W.Q.(2019). Tips for using magnetic rings. Safety and Electromagnetic Compatibil (02), 45-48. (in chinese)

[6] Liu, W, Wang, W.J & Zhou, L. (2022). Conducted Continuous Nuisance Suppression Characteristics of Magnetic Rings. Safety and Electromagnetic Compatibili (02), 35-38. (in chinese)

[7] Chen, Z. N, Liu, S.C, Miao, R.D, Sun, M.H &Zhao, X.D. (2021). Characterisation of high-performance magnetic loops and their application to electrically fast transient pulse swarms. Engineering Technical Studies (03), 7-9. doi:10.19537/j.cnki.2096-2789.2021.03.003. (in chinese)

[8] Chen, G.B. (2020). Interference Suppression Ferrite Magnetic Ring Analysis and Application. Electronic Components and Information Technology (08), 17-19. doi:10.19772/j.cnki.2096-4455.2020.8.008. (in chinese)

[9] Zhuang, S. (2019).Research on anti-interference technology for industrial

 

automation control systems. China Equipment Engineering (05), 213-214. (in chinese)
[10] Xu, Y.T Anti-jamming technology in industrial control engineering (M). Version (1st).Shanghai Science and Technology Press. .2010:1-222. (in chinese)
[11] Chen, K.Q & Li, Zh. (2022). Research on the protection effect of surge protectors. Instrumentation users (09), 9-13. (in chinese)
[12] Sun, SH.Y. (2022). Study on the suppression of lightning induced overvoltage in thermocouple signal lines. Petrochemical Technology and Economics (02), 28-32. (in chinese)
[13] Li, CH.Q. (2020). Exploration of the problem of surge protector lead at both ends of the line. The Electric Age (09, 56-57. (in chinese)