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Research on EMC based on High Power Robot Joint Servo Motor Controller

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***Abstract* - In the robot industry, the robot joint motor often plays the key role of instantaneous output high power and high torque. In the process of high power and large torque output, the support of large current output of the controller is needed. The electromagnetic environment is quite complex in such a working state. How to ensure the reliable operation of the controller in the harsh electromagnetic environment becomes an inevitable problem to be considered. This article first introduced the controller to enhance the electromagnetic compatibility of the relevant principle and applied to practice. And then through test motor controller components under the working conditions of the electromagnetic behavior summarized the electromagnetic properties of different function modules. According to the different electromagnetic characteristics, an optimization strategy is adopted to isolate the partition and decouple the in-place. Finally through the experiment compares the differences between similar controller of electromagnetic compatibility is verified the effectiveness of the proposed scheme improve the electromagnetic compatibility. Technical support is provided for the complex electromagnetic conditions of multiple large torque joint motors simultaneously served by multiple controllers.**

Index Terms* – *Robot joint motor controller, Industrial robot, EMC

I. INTRODUCTION

Robots play a more and more important role in the industrial field, and will accelerate the spread of other fields in addition to the industrial field. In the process of continuous optimization of the robot joint motor, the motor controller needs matching ability to maximize the torque and speed of the motor. Many scholars focus on improving the output capacity of the controller's current and power, or on the design of miniaturization of the controller, but ignore the electromagnetic compatibility of the entire electromechanical system. In the previous research of servo controller, the author also focused on the completion of relevant performance indicators, but lacked the consideration of electromagnetic compatibility, which caused some new control problems. For example, when the voltage of DC-bus is high, sometimes there will be a jump in the position signal collected by the rotating transformer, which cannot accurately reflect the motor parameters and thus affect the control effect. Another example is that in the case of high current, the communication between PC and controller will be dropped in the middle of the interruption of data exchange because of EMI. It will cause a sharp rise in the motor speed under the condition of high current, and in serious cases, it will also lead to the motor over temperature, burning winding and other irreparable loss. If these conditions occur in the whole debugging process of multi-motor and multi-controller, it is likely to cause the whole system maladjustment or even mutual damage. So it is considered that designing a controller with high electromagnetic compatibility to match the motor performance is an important part of optimizing servo control. In this paper, the controller is improved according to the design principle of improving electromagnetic compatibility, and EMC crosstalk test and radiation test are carried out on the controller's main PCB board. The experiment verifies the advantages of the improved scheme and the feasibility of the design based on partition isolation and local decoupling according to the filter frequency.

II. NOISE ANALYSIS

There are three factors that must be addressed in any study of electromagnetic compatibility. The first is the noise source, the second is the coupling mechanism, and the third is the sensitive circuit that is susceptible to interference. In this part, theoretical introduction and analysis of noise source and coupling path will be carried out, and the analysis results will be applied to the design of the controller in this paper. The accuracy and feasibility of the optimization strategies are verified by the experiment in the following text.

A. Noise Generation

Integrated circuits (IC) are the source of EMI noise. Whether the DC-DC power module, or the digital component devices realizing relevant functions such as DSP, decoding chip of rotary transformer on the controller, etc. They all turn on and off repeatedly by switching tube to realize relevant logic to achieve performance requirements. The noise produced by the switching process of the switch tube is called switching noise. At present, most digital logic circuits are composed of CMOS inverter architecture. When the input signal is switched between high and low position quasi-state, for example, the upper arm switch tube changes from high level to low level, and the lower arm switch tube changes from low level to high level. When the switch tube is switched from low level to high level, one PMOS and the other NMOS will be switched on and off. There will be a short circuit current, during this extremely short switching state, the power supply and the ground will be briefly connected. There are tens of

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millions of logic gates in the high-speed digital logic circuit, which makes the instantaneous synchronous switching noise hard to ignore. The EMI problems brought by this are mainly as follows. The first is the equipotential of the power supply and the ground position are all floating. The second is these high-frequency digital switching noises will spread along the PCB wire and affect other working elements. Generally speaking, the higher the switching IC frequency is, the higher the working efficiency of the components will be. Considering that different manufacturers are limited by the frequency control range and design technology of conducting interference, the operating frequency of IC varies. Therefore, this influence is also taken into account when selecting the components of the controller in this paper.

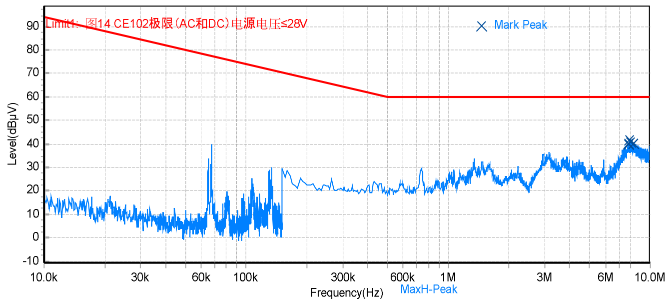

Fig. 1 Frequency labeling diagram of positive electrode EMI of power supply when the main control board is not working

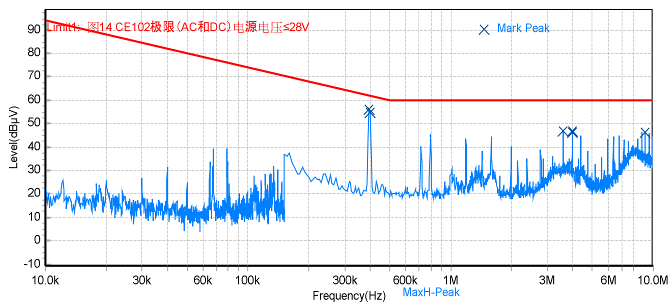

Fig. 2 Frequency labeling diagram of positive electrode EMI of power supply under the working state of main control board

Fig.1 and Fig.2 show the difference between the operation of some IC chips and the operation of all IC chips on the main control board of this controller. It can be seen that under the operation state of all IC, the main control board has a large number of harmonic peaks in the high-frequency part, which has caused serious damage to the electromagnetic compatibility environment. These noise frequencies are different, which also shows that the noise frequency produced by different IC work is not the same, and the ability to produce noise is not the same. In this paper, according to the characteristics of these frequencies, these noises are filtered to achieve the effect of improving EMC environment.

B. Crosstalk and Radiation

The second element of EMC is the coupling mechanism. Coupling is the relationship between electromagnetic fields between the conductor and the conductor. And a signal is called crosstalk if the coupling is useless. Crosstalk is not only contained between wires, but also between chips and even pins. Analog devices are often more susceptible to crosstalk wound than digital devices, which can lead to signal distortion. However, no device can ignore the adverse effects caused by crosstalk.

The radiation coupling effect will be more obvious when the noise frequency increases. It includes differential mode noise generated by signal loop and common mode noise generated by external transmission line. The former is inevitable in the operation of the circuit, and its influence should be minimized. The latter is useless noise and should be eliminated in PCB design.

III. EMC DESIGN STRATEGY OF CONTROLLER

A. Component Layout

Before component layout, it is also important to select components. As mentioned above, switching noise of IC devices is the source of EMI. Therefore, IC devices with high signal integrity and EMC characteristics should be selected. After that, it is necessary to understand their noise characteristics and make targeted processing in the filtering process so as to effectively control the noise at the source. For the component layout, the controller layout has the following principles:

1) In order to reduce the whole PCB wire length, this controller places the component with many pins and dense in the center of the PCB board, which can also reduce the unnecessary coupling effect.

2) In order to prevent the components from POWER and GND fluctuation and external noise affecting the components power supply in the process of operation, this controller adds filter and voltage stabilizing capacitance between the power supply port next to IC and the ground. It is necessary to add many such capacitors, such as the external interface of DC-DC conversion module and DSP.

3) In order to reduce the radiation of common mode noise, the controller will lay the connector on the edge of the PCB board.

4) In order to avoid mutual interference between digital and analog signals, between high-speed and low-speed signals, and between strong and weak current, the controller puts its sub-board and sub-section. It is mainly divided into power supply area, communication area, DSP system area and acquisition area.

Partition isolation can solve the problem of zero potential high frequency noise. It is common knowledge that higher frequencies of noise will propagate along circuits with lower impedance. If a magnetic bead or a 0 ohm resistor can be added to the edge of the partition as a barrier, the noise cannot escape from its own region and thus cannot affect other functional circuits.

Decoupling can solve the noise problem of power supply. The power supply of integrated circuit should be directly supplied by the power module, and should not pass through other integrated chips, so as to avoid the working of the chip halfway and the potential drop affecting the subsequent chip.

The power supply end of the integrated chip needs the decoupling capacitor and voltage stabilizing capacitor to work together, and the two capacitors should be different by more than two orders of magnitude. Voltage stabilizing capacitance can be used to supplement the necessary working charge of IC which is difficult to supplement in the high frequency state. Decoupling capacitor can filter the high frequency signal generated by IC and avoid high frequency noise along the power line.

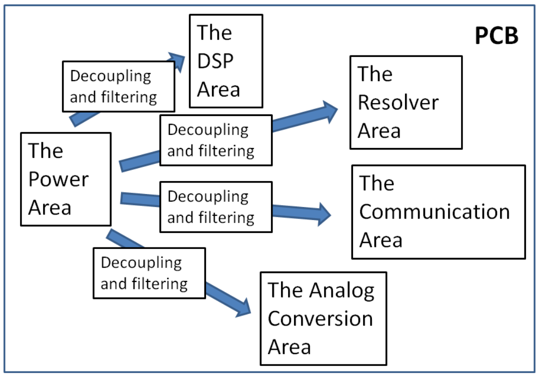

Fig. 3 PCB partition layout and in-place decoupling between regions

B. Wiring Design

After the layout design is completed, wiring is required. In order to take power integrity and signal integrity into consideration, this main control board is composed of four layers: TOP layer and BOTTOM layer of signal, POWER layer and GND layer of zero potential.

Fig. 4 Layout and wiring of the main control board of this controller

The wiring design of the controller meets the following principles:

1) The wiring sequence is power line, high frequency signal line and low frequency signal line. The grounding wire is drilled to the GND layer at the shortest distance to keep the working circuit as small as possible. In order to reduce crosstalk and radiation, the power layer and stratum are widely used, and the GND layer is large enough compared with the POWER layer.

2) Zero potential ground is divided into digital ground, analog ground. The weakly electric fields are isolated by inductance. Digital and analog power sources of 5V and 3.3V are separated in the same way.

3) Because right-angle routing is equivalent to capacitive load and electromagnetic interference emission is easily generated, this controller satisfies obtuse angle routing.

4) In order to avoid the loop coupling input and output signals, this controller requires that adjacent signal lines should not be parallel as far as possible.

IV. EXPERIMENTAL ANALYSIS

This chapter applies the desktop EMI receiver and its supporting equipment to test the motor controller designed according to the previous principle. The experimental platform is shown in Fig.5. The experiment includes external test and internal test. The noise of different frequency in the controller can be found by external test. The content of the internal test is divided into crosstalk test and radiation test. The purpose is to analyze the source of noise and the coupling path of noise propagation. By replacing and changing the filter circuit of modules, repeated tests are carried out to finally verify the necessity of EMC design and the effectiveness of optimization.

A. External Test

The content of the experiment is to test the interference of the main control board of the controller on the power supply line. Without power filter, the noise frequency generated by all components of the controller can be recorded. As shown in Fig.2 above, the red line represents the limit value of the reference standard, and the blue line represents the measurement result of circuit board noise. The results show that the high frequency noise is obvious without filtering, and it was difficult to meet the requirements if the main control board and the power board work at the same time. Therefore, EMI filter circuit should be added as the optimal design of the controller. The filter circuit is shown in Fig.6. Although the external electromagnetic interference of the controller is somewhat relieved after filtering, the internal electromagnetic environment of the controller cannot be guaranteed to be ideal. As is now widely accepted in engineering, adding similar filtering circuits to the power supply greatly increases the product's chances of passing the test. Therefore, the fact that the electromagnetic environment inside the product is still bad is ignored. This to the stable operation of the product increased a lot of hidden trouble.

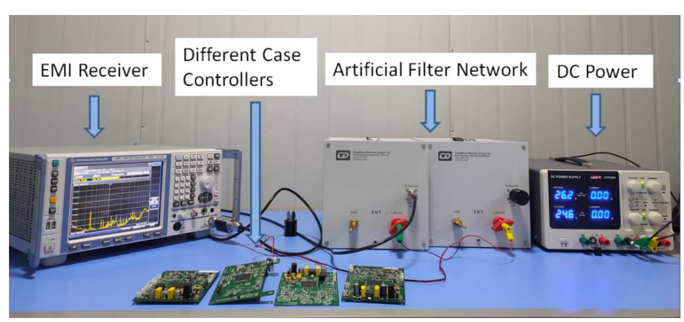

Fig. 5 EMI experimental platform

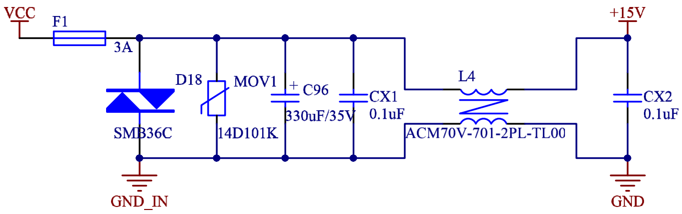

Fig. 6 EMI filter circuit of power supply

The following section addresses the interference problem from the noise source through internal testing.

B. Internal Test

Due to the large number of IC devices on the main control board, the experimental analysis process cannot be listed one by one. This paper only introduces the 15V-5V power module for analysis. For the 5V output port of DC-DC module, if no filter capacitor is set, the 5V power supply with a large amount of noise around 400KHz will affect other electrical components along the wire such as the operational amplifiers, which play a very important role in the process of voltage and current signal acquisition. However, due to the unclean power supply, the processed current and voltage signals are affected, and the unclean signal finally enters the I/O port of DSP. As a result, the probability of inaccurate data collected by DSP is greatly increased, which seriously affects the control effect. However, the situation will be greatly improved after each 5V demand end port is equipped with a filter circuit that filters the corresponding frequency, as shown in the Fig.9 and Fig.10, the display frequency range is from 200KHz to 650KHz.

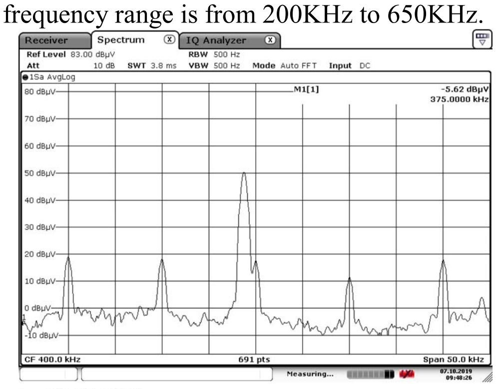

Fig.7 Noise of the operational amplifier power supply port without filter circuit (The center frequency is 400KHz).

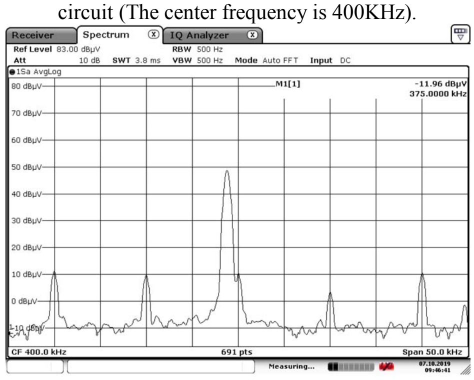

Fig.8 Noise of the current acquisition signal received by I/O port of DSP without filter circuit (The center frequency is 400KHz).

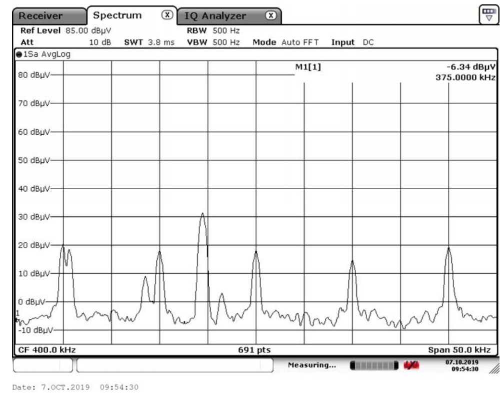

Fig.9 Noise of the operational amplifier power supply port when filter circuit is added (The center frequency is 400KHz).

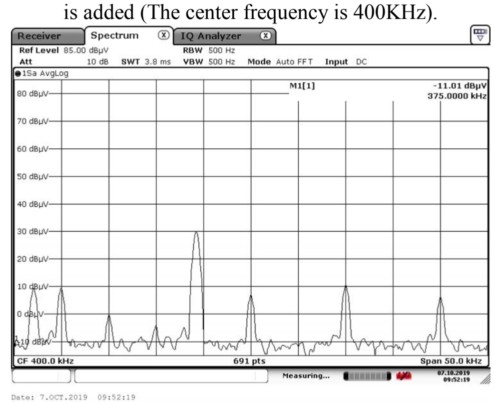

Fig.10 Noise of the current acquisition signal received by I/O port of DSP when filter circuit is added (The center frequency is 400KHz).

After many internal tests, this paper finds that the best solution to the unavoidable noise is to deal with the noise locally from the input and output end of IC chip. Attention should be paid to the coordination of voltage stabilizing capacitor and decoupling capacitor, according to different frequency of noise design. The noise generated in this area is filtered from the POWER to the GND, and due to the isolation between the GND and the GND, the noise will be firmly restricted in this area. And in order to avoid noise flowing or coupling with other wires, it is very necessary to partition components according to function.

In addition to the crosstalk and radiation test of the whole power supply, the crosstalk and radiation test of the near field probe is also carried out. Due to the use of local noise treatment and typical zoning, the noise of a single point can hardly affect other areas. This is also a kind of manifestation of the ability to prevent immune electromagnetic interference.

After rectification and optimization, the positive electrode EMI test was conducted again, and the results were shown in Fig.11. It can be seen that the noise around 400KHz caused by the 5V power supply has been significantly weakened. A large number of other high-order harmonics are also absorbed, the peak is cut, and electromagnetic compatibility is much better than before.

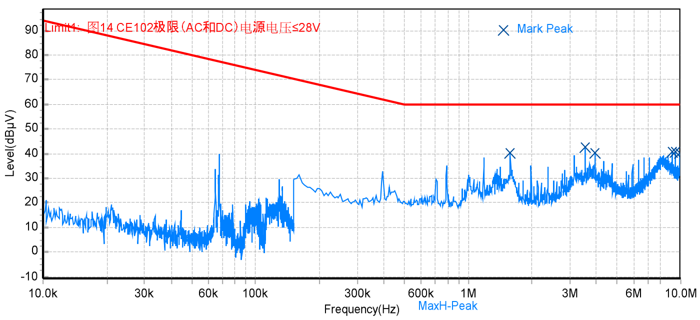

Fig.11 Frequency labeling diagram of positive electrode EMI after adding filter circuit

V. Conclusion

In order to improve the EMC of joint motor controller of large current industrial robot, this paper analyses the source of electromagnetic interference and the coupling mechanism of multiple physical fields, and summarizes the design principle of the controller. In order to avoid the problem of crosstalk between the controller and the external power supply, EMI filtering strategy is adopted in this paper. In order to avoid crosstalk and radiation in the controller interior, partition isolation and local decoupling according to filter frequency are adopted in this paper. The experiment results show that the controller can improve electromagnetic compatibility effectively. It provides the technical support for solving the problem of electromagnetic disturbance when the multi-controller of industrial robot works at the same time with large current.

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