Research on Data Acquisition System of EMU Structure Health Monitoring Based on DSP and FPGA

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Abstract. According to the characteristic that structural health monitoring have many monitoring sensors and monitoring signal types, with DSP and FPGA used as the core controller, a data collection system was designed. The designed system can realize multi-channel parallel data collection, flexible port configuration and good scalability, which meets the requirements of high-speed collection and processing and real-time online monitoring. The designed data acquisition system has the advantages of high performance, low cost and convenient application. In addition, the system has a wide sampling frequency range, which can adapt to a variety of sensor signal sampling requirements, is easy to install, easy to achieve network configuration, and can better meet the structural health monitoring of railway vehicles.

1. Introduction

Structural Health Monitoring refers to the use of on-site non-destructive sensing technology to analyze structural system characteristics including structural response to detect changes in structural damage or degradation [1]. As a complex, multidisciplinary online real-time monitoring technology, the structural health monitoring system architecture can be divided into the following subsystems: 1) sensor subsystem; 2) data acquisition, processing and transmission subsystem; 3) data management subsystem; 4) damage diagnosis and safety assessment subsystem [2].

In the structure of railway vehicles, due to factors such as vibration shock, stress and thermal fatigue, different degrees of damage are inevitable. If these damages cannot be detected accurately and monitored in time, serious accidents may occur. Many structures in a vehicle are determined based on safety life whether to replace, and the safety life can be obtained by fatigue testing. As long as the safe life is reached, it should be replaced regardless of whether there is any damage. This leads to two problems:

1) If certain structures are defective or damaged during manufacturing, the safe life cannot be protected;
2) Decommissioning time is based on safe life. To ensure a high degree of safety, the choice of safe life is conservative, leading to premature decommissioning of certain damage-free structures.

Based on the above reasons, the application of structural health monitoring technology in railway vehicles should be highly valued. At present, in the field of civil engineering and aeronautical engineering, structural health monitoring technology has been widely used and achieved good results [3-11]. Based on the full understanding of structural health monitoring technology, the author proposes a structural health monitoring data acquisition system based on DSP and FPGA, and strives to be widely promoted and applied.
2. Working principle of the data acquisition system
The structural health monitoring data acquisition system uses DSP and FPGA as the core control chip, and its basic working principle is shown in Figure 1.

The acquisition system collects a large number of signals, mainly including displacement, strain, temperature, acceleration, etc., and multi-channel sensor signals are input to the isolation driving module through the acquisition interface. For different types of signals, the amplitude and frequency are different, and the signal is converted to the allowable range of the FPGA input by isolating the driver module. At the same time, the isolated driver module isolates the control signal from the external input signal, which better protects the control components. For different kinds of signals, the FPGA uses different frequencies for sampling, and the data is amplified and filtered. The FPGA and the DSP realize data interaction through parallel communication, and the DSP performs FFT transformation (fast Fourier transform) on the data and extracts the fundamental frequency. The DSP performs operational analysis and damage assessment on the data, and stores huge data information such as data analysis results and damage assessment results in the FPGA through the FIFO. The FPGA is connected to the CH365, and the various analysis results are transmitted to the host computer through the PCI interface. At the same time, the host computer stores the health information of the monitoring object and the like in the FPGA for the DSP to call. The host computer displays the results and data and transmits it to the Ethernet to share data with other computers.

For some structures of railway vehicles, it is necessary to obtain data using an excitation-response mode, as shown in Fig. 2, that is, by using a specific excitation signal to drive a monitoring object by driving a piezoelectric piece, the excitation signal generates a stress wave in the monitoring structure. At the same time, the acquisition system receives the response signal of the stress wave through the sensing piezoelectric piece and performs data analysis and processing. The system is based on DDS (Direct Digital Frequency Synthesis) technology. The DDS module is designed inside the FPGA to generate excitation signals of different frequencies. The excitation signal is amplified and output through the isolation drive module.

The waveforms used to synthesize signals using DDS technology, which can not only easy to control, simple and reliable, but also be repeatedly programmed and fully digitized. Designing DDS circuits with FPGAs provides greater flexibility than dedicated DDS chips. Since only the waveform data in the FPGA internal signal data memory needs to be changed, the output of any signal can be realized, so the FPGA is very flexible to implement the DDS circuit. The price of a dedicated DDS chip is generally higher than that of an FPGA. Therefore, the use of FPGA to design DDS system has a high cost performance.
3. Communication between system modules

3.1. Communication between DSP and FPGA
The DSP's external interface XINTF uses an asynchronous non-multiplexed bus (Nonmultiplexed Asynchronous Bus) to extend external storage devices, and devices connected to XINTF can be accessed directly through the CPU. A memory module was designed inside the FPGA, which directly connected to the XINTF interface of the DSP to achieve high-speed parallel port communication.

The DSP's external interface maps to three fixed memory areas. XINTF has a 20-bit wide address bus XA, and all areas are shared. The data bus of one of the XINTF areas is configured in 16-bit bus mode, and the function of the pin XA0/XWE1 is the last bit XA0 of the address, as shown in Fig. 3.

3.2. Communication between FPGA and host computer
The internal design of FPGA is shown in Fig. 4. A FIFO module and other logic control modules are designed inside the FPGA. The FIFO module is used to receive data and buffer the data. When it receives the read command from the computer, it further processes. The FPGA_CTRL module is used to receive the read and write instructions of CH365, decode the instructions, and set related parameters for some fixed parameters. The frequency division module divides the PCI bus clock to provide the necessary clock signal for the FIFO module.

The computer sends the instruction to start the acquisition to the FPGA through the PCI bus. The FPGA modules start working, buffer the collected data, and transmit some data to be processed to the DSP. After processed by DSP, the data is stored in the FPGA. Then the FPGA will upload the data needed and buffered it in the FIFO. When the data is full, an interrupt request is sent to CH365, and
then the computer reads the data through the PCI bus while continuing to store data into the FIFO. Write in and write out simultaneously, ensuring efficient data transfer.

As a bridge chip, CH365 has powerful functions but simple interface. High-speed data transmission between PCI interface and FPGA can be realized by designing corresponding peripheral circuits, which ensures high-speed data interaction between computer and structural health monitoring data acquisition system.

4. Advantages of each module of the data acquisition system

The programmable logic controller FPGA can flexibly design the hardware circuit through programming. The number of acquisition channels can be configured as needed, and has good scalability. It is especially suitable for many features of railway vehicle monitoring system sensors. FPGA can realize multi-channel high-speed parallel acquisition, which is unmatched by other control chips such as single-chip microcomputer.

DSP has powerful data processing capabilities, can perform some complex operations, and has high speed, low power consumption, high precision and so on. Some data collected by the structural health monitoring data acquisition system needs to be processed and then transmitted to the computer, so as to reduce the computing burden of the computer, which function can easily be achieved by DSP.

The acquisition system and the host computer exchange data through the PCI bus. The PCI bus is independent of the CPU and can be used to communicate with multiple processors by simply adding the appropriate bridge components. This design uses CH365 as a bridge component to communicate with the FPGA. In addition, the PCI bus has parallel operation capability for high-speed data transfer.

5. Conclusion

For the purpose of structure health monitoring of EMU, a high-speed data acquisition system based on FPGA and DSP is designed, which makes full use of the advantages of two processors, efficient data processing capability and programmable logic circuit design. The data acquisition system designed in this paper has the advantages of high performance, low cost and convenient application. The data acquisition system has the characteristics of high-speed acquisition, transmission and storage, and can better meet the structural health monitoring of railway vehicles. In addition, the system has a wide sampling frequency range, can adapt to a variety of sensor signal sampling requirements, which is easy to install, easy to implement network configuration, and can realize signal monitoring for large-scale engineering.

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