I.J. Education and Management Engineering **2012, 7, 22-28**
Published Online July 2012 in MECS (http://www.mecs-press.net)
DOI: 10.5815/ijeme.2012.07.04

Available online at http://www.mecs-press.net/ijeme

Design of Active Vibration Control System for Piezoelectric Intelligent Structures

Jian LI[a,*]

[a] *Weifang University, Weifang, 261061,China*

Abstract

Intelligent structure has gradually become a research focus in the field of active vibration control. Intelligent structure based on active vibration control has broad application prospects in the modern high-tech fields. This paper has designed the hardware circuit and control algorithm of active vibration control based on SCM. The design has an effective application in the "research on vibration charging system based on piezoelectric ceramic".

Index Terms: Intelligent Structure; Active Vibration Control; Sensor; Controller; Control Algorithm

1. Introduction

The combination of piezoelectric intelligent structure and active vibration control technology opens up a new approach to vibration control. Piezoelectric intelligent structure is a kind of intelligent structure that takes piezoelectric material as sensitive elements; an important application of intelligent structure is for active vibration control. And active vibration control technology is an important research orientation in vibration noise control field in recent years. It means that in the vibration control process, certain control strategies are used according to the structure or system vibration checked by sensors; through real-time calculation, the driver imposes certain force or moment on structure or system to inhibit vibration of structure or system. This technology is widely applied to high-technology field, possessing good control effect towards low-frequency vibration and noise, so it has important application value and application prospects [1].

In the active vibration control with piezoelectric intelligent structure, piezoelectric elements can be respectively used as sensor and actuator. Its position distribution in structure has a great influence on the vibration control performance, which seems especially important in active vibration control system design. Active vibration control of intelligent structure inputs energy from outside, actively imposing reaction force to inhibit vibration of system. In the intelligent structure, sensitive elements monitor the vibration of structure; drive elements accurately makes movements under the control of microelectronic system to change vibration

* Corresponding author.
E-mail address: wfxylj@163.com

status of structure. There are various drive elements used for active vibration control, such as piezoelectric material, shape memory alloy, magnet-rheological fluid and electro-rheological fluid. Therein, the piezoelectric smart elements are small in volume and weight, quick in response, easy for structure integration and possessing double functions of sensing and execution, so choosing piezoelectric elements as the piezoelectric intelligent structure of sensor and actuator is one of the main modes for the structure's active control. In the active vibration system, one of the keys to improving performance of active vibration control is to improve the performance of designed controller. This article chooses the single chip microcomputer MSC1211 as the system's controller, because MSC1211 chip integrates plenty of functional modules, completely satisfying the active vibration system's requirements for much input and output.

2. Working Principle of Active Vibration Control System

The key to obtaining the optimum controlling effect lies in the controller's optimum allocation strategy design in active vibration control of intelligent structure. In the active vibration control system based on single chip microcomputer, the control idea of active vibration control of intelligent structure is sticking piezoelectric material to the surface of structure material as sensor and actuator; the sensor transforms the received response into corresponding voltage signal through signal conditioning circuit; the voltage signal is input into control system and generates corresponding control signal through calculation of corresponding control algorithm, acting on the diver through power amplifier; the driver transforms electric power into mechanical power to generate deformation so as to change the stress state or damping of structure material in order for active vibration control.

System's working principle: signals output by the sensor are transformed into the voltage signals of $\pm 5V$ through signal conditioning circuit; the signals are input into the measurement and control system of single chip microcomputer and then are processed into fixed frequency and square wave with adjustable pulse width through single chip microcomputer system. Such square wave signals are amplified into square wave signals used for bus voltage like amplitude through switch power amplifier; the high-voltage control signals of ±300Vare demodulated by low pass filter to control piezoelectric driver just as shown in Fig.1.

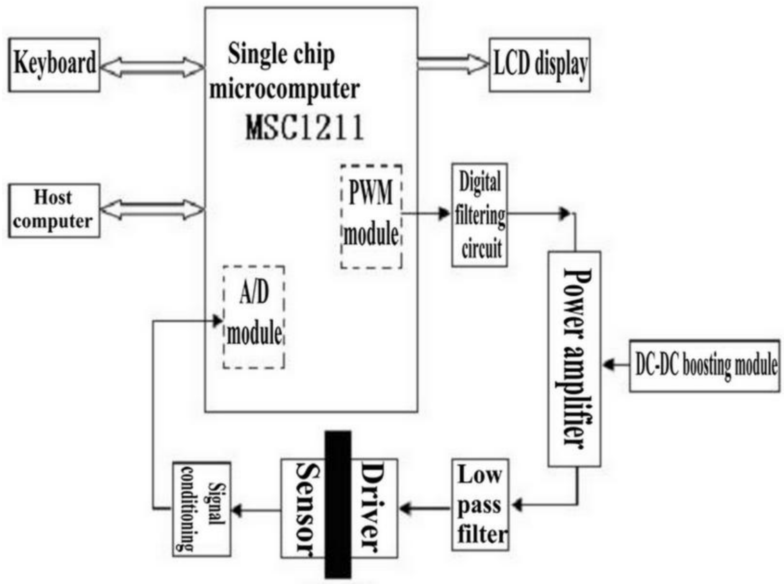

Fig. 1. Schematic diagram of active vibration control system

3. Circuit Design of the System

The active vibration control system of intelligent structure usually consists of structure material (controlled structure), sensor, driver, signal conditioning circuit, power amplifier, control system and corresponding control algorithm, which make up an inseparable whole.

3.1. Selection of Controller

The controller in hardware circuit is chosen as the high-performance chip MSC1211 of integrating digital and simulating mixed signal pushed by Texas Instrument Company, America. The inside of the chip integrates an $\sum-\Delta$ analog-to-digital converter (ADC) with resolution of 24 bits, multiplexer with 8 channels, analog input channel test current source, input buffer, programmable-gain amplifier, temperature sensor and inner reference voltage source; digital-to-analog converter (DAC) of 16 bits with 4 channels; microcontroller of 8 bits; lots of analog and data peripheral modules like program/ data Flash memory and data SRAM, which possess great ability of processing data and can be widely applied to intelligent sensor, intelligent transmitter, control system for industrial process, high-accuracy measurement devices and portable instrument.

3.2. Circuit Design for Signal conditioning

The piezoelectric material as sensitive element can transform the received response into electric charge output, but the electric charge must be transformed into voltage signals so that the control system can use it, just shown as Fig.2.

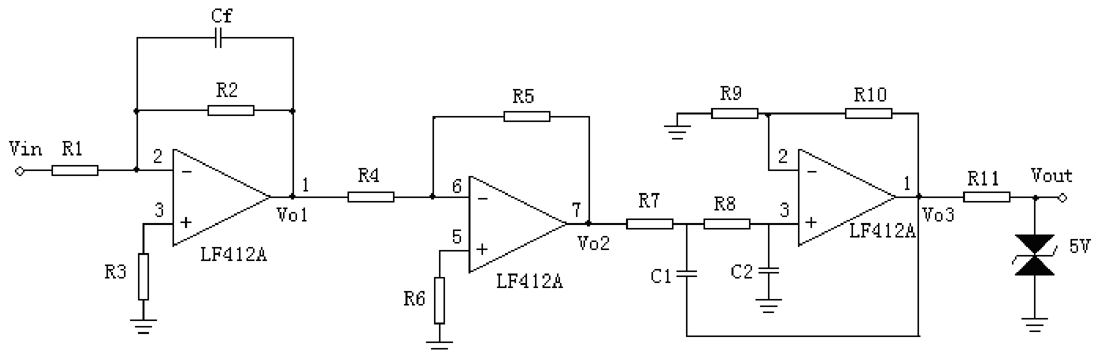

Fig. 2. Signal Conditioning Circuit

The electric charge signals output by piezoelectric sensor are transferred into voltage signals V_{O1} , $V_{O1} = -Q/C_f$ through charge amplifier; generally, the feedback capacitance C_f can not be too small and should be amplified as much as possible by last-stage unit, but the last-stage amplification can not be too large, otherwise, it's easy to saturate output to cause distortion and error increases; generally, it's suitable to choose several times and even more; from diagram 2 we can obtain

$$V_{O2} = -\frac{R5}{R4} V_{O1} = \frac{R5}{R4} Q / C_f \,. \tag{1}$$

The voltage filters high-frequency noise and outputs voltage V_{O3} through second-order low pass filter and propositional amplifier;

$$V_{O3} = -V_{O2} = -\frac{R5}{R4} Q / C_f \tag{2}$$

V_{O3} outputs voltage amount of $-5V \sim +5V$ through limiter circuit.

The signals output by piezoelectric sensor are very weak, generally detected by amplifying electric signals. Chip LF412 possesses such advantages as input resistance up to $10^{12}\,\Omega$ and low bias voltage, so it satisfies the charge sensor's requirements for being composed of operational amplifier with high input resistance [2].

3.3. Circuit Design for Digital Filter

The filter chip that digital filter circuit adopts is MAX7400, which is an eight-order low pass elliptic switch capacitance filter. Sine wave is generated under the control of single chip microcomputer and peripheral capacitance, the circuit structure of which is shown as Fig.3.

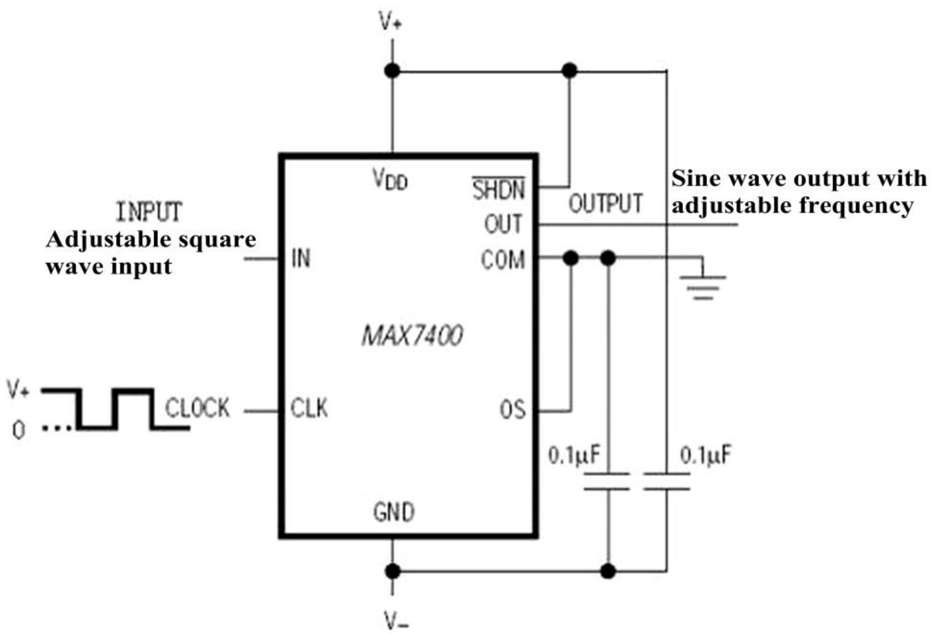

Fig. 3. Digital Filter Circuit

Working principle: square wave with adjustable frequency can be generated by single chip microcomputer and input into input terminal (two cruses) of MAX7400; the filter switch frequency is input into the CLOCK terminal (8 cruses) of MAX7400 and the software control guarantees output frequency:

$$f_O = f_{CLK} / 100 \tag{3}$$

3.4. Design of Power Amplifier

In order to guarantee enough power for driving piezoelectric actuator, power amplifier must be set up. Piezoelectric ceramic can generally be equivalent to capacitive load, so VMOS tube is selected which is of low output resistance (on- resistance is just several ohms), high current load ability and high- speed switch; the voltage control makes up push-full power amplifier.

As a kind of filed effect tube, VMOS tube is a device of voltage control type with high input resistance, so it has no influence on voltage amplification; but there is a parasitic output capacitance between gate cognate and drain, because the gate source capacitance and gate drain capacitance are usually hundreds of micro microfarad. In order to inhibit the influence of parasitic vibration caused by it on voltage amplification, each gate should cascade a small resistance shown as Fig.4. The driving current of piezoelectric ceramic is weak (weaker than 20mA), but it needs relatively high driving voltage (80～500V). In order to reduce the device cost, improve reliability and enhance amplification efficiency, low-voltage power amplification is selected (DC24V), then the driving requirements for high voltage and weak current are satisfied by pressure boost of transformer, the main advantage of which is adopting the design of transformer, that is, make the output short circuit for long, because the transformer's magnetic saturation and function can not cause the damage of power amplifier. Power amplifier circuit adopted by this system is D-class power amplifier taking MP7720 chip as the core [3].

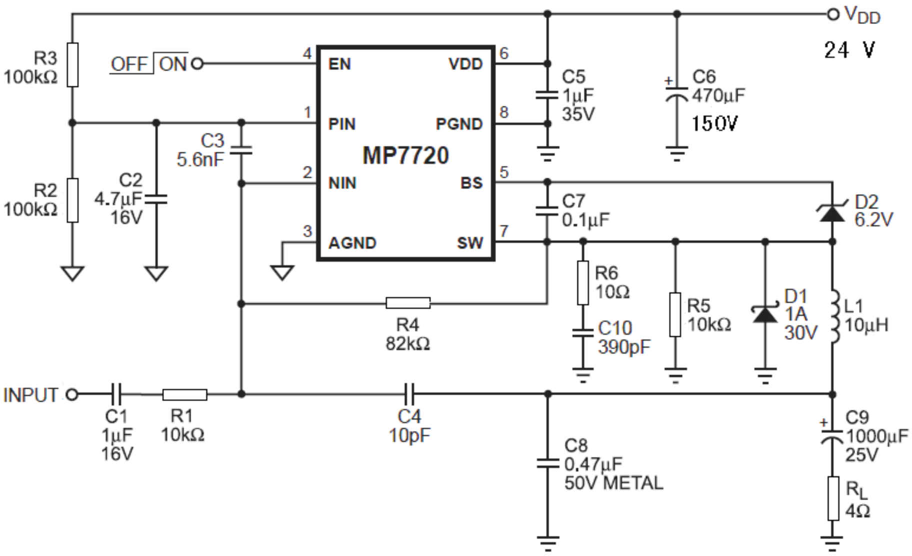

Fig. 4. Power Amplifier

4. Control Algorithm

The single chip microcomputer conducts corresponding algorithm processing on transformed digital signals. In the active vibration control, the selection of control strategy and control law design is its key problem, so the research on control law design method becomes a very important aspect in the field of active vibration control. While adaptive control method is one of the main methods for control law design at present. This method mainly uses the reference signals and error signals related to controlled signals to adaptively adjust filter coefficient, timely giving control signals to accomplish active vibration control. This method is of high control accuracy, stable control system and suitable to active vibration control system [4]. Its most prominent characteristic is that it does not need accurate mathematical modeling of controlled system; the control system is able to adapt to the change of external environment for automatic adjustment to accomplish control task.

Adaptive filter is the core of adaptive algorithm and the adaptive filter is the optimum filter taking minimum mean square error as principle. The adaptive filter is actually a wiener filter which can automatically adjust the property of its own unit series response for optimization $h(n)$. Its outstanding advantage is that designing adaptive filter does not require knowing autocorrelation function between signals and noise in advance; furthermore, in the filter process, even though autocorrelation function between signals and noise changed slowly along with time, it can conduct automatic adaptation and adjustment to meet the minimum mean square error's need. The schematic diagram of adaptive filter algorithm is shown in Fig.5.

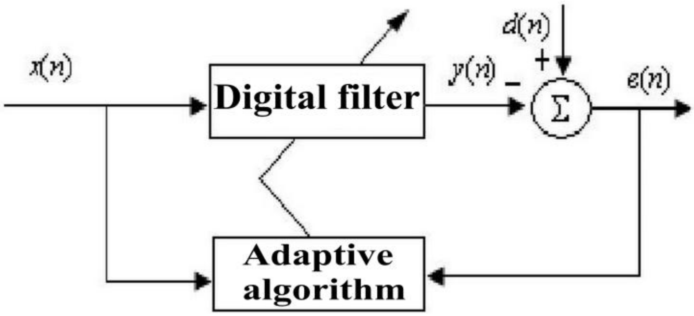

Fig. 5. Schematic diagram of adaptive filter algorithm

Make filter structure as finite impulse response filter and its mathematical representation is $w(n)$, then output signal of the filter is $y(n)$,

$$y(n) = x(n)^T w(n) \tag{4}$$

then error signal

$$e(n) = d(n) - y(n) = d(n) - x(n)^T w(n) \tag{5}$$

in which, $d(n)$ is expected signal.

5. Conclusions

This article introduces the piezoelectric transformer to deduce the volume of control system. Aiming at the active vibration control of piezoelectric intelligent structure, the optimization design principle is applied and simplified to get a kind of optimization method by which the positions of piezoelectric elements can be determined directly through structure modal vibration shape [5]. PWM technology and adaptive control algorithm can satisfy the active vibration control's technological requirements. Simulation result shows that as for the same control algorithm, the vibration control effect of piezoelectric elements in the optimization positions is much better than those in non-optimization positions so that some characteristics of vibration control like miniaturization, integration, high efficiency and low consumption are realized. This project runs well in practical application and possesses bright application prospects.

Fund project: C-class Project Funded by Torch Plan of. Project number: 2007K03. Project title: “study on feeding system with on-line control function through full-automatic piezoelectric ceramic vibration”.

References

[1] Haixia ZHU, Miniaturization Research on the System of Active Vibration Control Based on Piezoelectric Transformer [D]. Nanjing University of Aeronautics and Astronautics, 2007. (in Chinese)

[2] Liping CHEN, Research Status and Developing Trend of Active Vibration Control [J]. Modern Machinery, 2005, (5): 52-55. (in Chinese)

[3] Rilan WANG, The Design about Active Vibration Control System Based on SCM [J]. Modern Machinery, 2009, (6): 11-13. (in Chinese)

[4] Zhicheng QIU, Intelligent Structure and Its Applications in Active Vibration Control for Spacecrafts [J]. Aerospace Control, 2002,(2): 8-15.(in Chinese)

[5] Tzou HS.Distributed Piezoelectric Sensor/Actuator Active Vibration Control [C]. Beijing, China, Materials Design for Dynamic Measurement/Control of Distributed Proseminar, 1996: 133—135. (in Chinese)