Active Control of Vibration and Noise of Energy Equipment

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Abstract. Vibration and noise control is an important topic in the field of energy equipment research. The traditional passive control has better control effect in dealing with high frequency vibration noise, but it is not satisfactory in low frequency noise control. The active control solves this problem better. This article gives a reference for subsequent research in this field through a review method, which has certain reference value.

1. Introduction
Vibration and noise control has always been an important direction in energy equipment research. Traditional vibration treatment methods include vibration isolation, vibration absorption and vibration reduction. With the development of emerging technologies such as signal processing technology, automatic control technology and computer technology, the importance of active vibration control is becoming more and more prominent. In 1930, Den[1] used the vibration absorber to solve the low-frequency vibration problem of the rotating machinery, and opened the first year of active control of vibration and noise. However, subject to the obstacles of other technologies, it is unrealistic to carry out active control engineering applications, because the technical means of dealing with complex signals was scarce at the time. Active control was re-developed after extensive use of electronic computer technology, and it was rapidly developed after the cost was reduced to a certain extent and the demand for vibration and noise reduction was raised to a certain height. Active control has good adaptability compared to passive control. With in-depth research, the trend of cross-integration with other technologies has become an important direction in the practical application of modern control theory. Active control technology has been developing for decades, and a large number of scholars have carried out research in this area. This paper classifies the aspects of control system composition and summarizes the research status at home and abroad. It then introduces the four components of the control system: sensors, controllers, actuators, and control algorithms. Finally, the future development of active control is summarized.

2. Control System

2.1 Sensor
Sensors are mainly used for data acquisition and detection. They are the sensing modules of the control system and are a very important part of the system [2]. Speed sensors and acceleration sensors are mainly used in the field of active control. Among them, the speed sensor is generally used for vibration measurement and control of low and medium frequency, and the acceleration sensor is
mainly used for vibration measurement and control of medium and high frequency, and the latter is used more. Mainstream sensors at home and abroad include piezoresistive accelerometers, piezoelectric accelerometers, and capacitive accelerometers.

The sensitive core of the piezoresistive accelerometer is a resistance measuring bridge made of semiconductor material, and its structural dynamic model is still a spring mass system. The development of modern micromachining manufacturing technology has made the design of piezoresistive sensitive cores very flexible to suit a variety of different measurement requirements [3]. Amarasinghe [4] and so on studied an ultra-small piezoresistive accelerometer with excellent performance. Hezarjaribi Y [5] developed a capacitive piezoresistive sensor with good linearity when the pressure is 0.05-10 MPa. Kistler and Yole [6] have developed a high sensitivity, low noise capacitive piezoresistive acceleration sensor with good stability and reliability. Piezoresistive sensors have the advantages of small size, wide measurement frequency range and high sensitivity. However, piezoresistive accelerometers have poor environmental adaptability and high cost.

The piezoelectric acceleration sensor is constructed by using the principle of a spring mass system. The sensitive core mass is subjected to a vibration acceleration to generate a force proportional to the acceleration. After the piezoelectric material is applied by this force, a charge signal proportional to the force is formed along the surface, so that the data can be collected [3]. According to the piezoelectric material, it can be divided into a piezoelectric crystal acceleration sensor and a piezoelectric ceramic acceleration sensor. According to the signal output form, it can be divided into a charge output type sensor and an ICP/IEPE output type acceleration sensor. Lu Zhaofeng [7] comprehensively analyzed the application research of piezoelectric accelerometer in vibration measurement system. Ye Weigu [8] has made some structural improvements to the traditional piezoelectric accelerometer and improved its performance. Piezoelectric accelerometers have the advantages of large dynamic range, wide frequency range, low price, and low external interference. They are one of the most widely used sensors in engineering. However, it also has the disadvantage of not being able to measure the zero-frequency response. This type of sensor is currently widely used in engineering due to its advantages.

The structural form of the capacitive accelerometer also uses a spring mass system. When the mass is affected by the acceleration motion, the gap between the mass and the fixed electrode is changed to change the capacitance value [3]. Cheng Wei [9] designed a microcapacitive acceleration sensor based on MEMS technology, which proved to have better measurement performance. Wen Shuhui [9] designed an inertial vibration sensor. The experiment proves that the sensor has high sensitivity, stable output and small measurement error. The capacitive accelerometer has the advantages of high sensitivity, zero frequency response and good environmental applicability. The downside is that the range is limited, and the versatility is not strong and the cost is high.

2.2 Controller
The controller is a central module of the control system, which mainly takes the collected signals into the algorithm for calculation and outputs new signals. The mainstream controllers at home and abroad include ARM [10], DSP [11], NI [12], FPGA [13] and so on. Among them, DSP controllers and FPGA controllers are most widely used in engineering because of their low price, good performance and low development difficulty.

The ARM controller is a common RISC microprocessor. Freescale [14] and STMicroelectronics [15] have also introduced microcontrollers based on new chips. The ARM controller is powerful and fast. However, development is more difficult and more expensive.

The DSP controller is a fast and powerful microprocessor that is unique in that it processes data in real time. The interior of the DSP chip uses a Harvard structure with separate programs and data, and has a dedicated hardware multiplier that can be used to quickly implement various digital signal processing algorithms [16]. Shen Gang [17] applied DSP to the design of railway simulation vibration table control system and achieved good control results. DSP has powerful data processing capabilities and high operating speed, and is widely used in various complex control systems. However, DSP also
has shortcomings such as limited sampling frequency, limited processing frequency, and the need for digital-to-analog conversion, but overall it is more practical.

The NI controller is a controller developed by National Instruments and has a wide range of applications in the field of control. Zhu Xiaotong [18] used the NIPXI control system to build a vibration console frame and achieved better control results. NI has the advantages of high reliability, easy programming, and fast operation, but its cost is high.

The FPGA device is a semi-custom circuit in the ASIC. It is a programmable logic array, which can effectively solve the problem of fewer gates of the original device. Liu Bin [19] designed a controller based on CH372-USB bus chip, which uses FPGA and bus chip with USB underlying protocol to realize USB interface communication. FPGA has the advantages of fast processing speed, high execution efficiency, simple and convenient programming and reprogramming. The disadvantage is that it can not handle multiple events, and the timing is difficult to plan.

2.3 Actuator
Actuators, as active control actuators, are an important part of active control research. Actuators come in a variety of forms. In the early days, there were pneumatic, hydraulic, electric, electromagnetic and other actuators. Currently, with the development of materials technology, there are magnetostriction [20], electrorheological fluid [20], magnetorheological fluid. [20], piezoelectric actuators [20]. Because the gas actuator leaks, hydraulic oil leakage, and the operating frequency is generally within 10Hz, in addition to early research and application, it is no longer a hot issue. In the research of electrorheological fluid and magnetorheological fluid actuators, Abdel [21] proposed a tuning fluid damper to control the ship's rocking vibration through liquid vibration in the pipeline, and achieved satisfactory results. Hochrainer [22] improved the tuning fluid damper to replace the liquid in the pipe with a controlled air spring support, and proposed a new tuning fluid damper. Studies have shown that the improved new active damper has a large improvement in performance, and is often used in semi-active applications where the damping of the structure is enhanced.

Magnetostrictive actuators have the advantages of large displacement, fast response, high reliability, low driving voltage, etc. Kumar [23] studied a magnetostrictive material actuator using a speed negative feedback control algorithm. A control signal is input to a solenoid wound around the device to generate a magnetic field to cause the actuator to generate power. The change of damping characteristics and the influence of different positions of the solenoid on it are analyzed. However, there is a significant hysteresis nonlinearity between the applied magnetic field and the output displacement and force of the giant magnetostrictive actuator, which brings great difficulties to its application.

Electromagnetic actuators and electric actuators have a wide range of applications in engineering due to their simple structure and ease of implementation; Johnson [24] studied an active damping actuator in parallel with a common spring and an electromagnetic actuator and performed experiments, and experiments show that the actuator has good performance. Giron [25] proposed a mobile damped movable actuator and experimented. The results show that the actuator can reduce the vertical vibration of the ship.

Piezoelectric materials are fast in response, high in output, high in reliability, and have both sensing and actuation functions. Moon [26] used piezoelectric ceramic actuators in the study of active vibration isolation of ships and achieved good results. Loussert [27] designed a moving magnet actuator for active vibration control that has good performance in terms of mass, output force and required magnetic field. Paulitsch [28] studied an active damping piezoelectric actuator that positions the force actuator and the velocity sensor in the same position. The actuator has a small mass and good performance indicators such as output force and operating frequency range.

2.4 Control Strategy
The control algorithm describes the transfer relationship between the input and output of the controller and is the core of active control technology research. If the hardware meets the control requirements,
the control algorithm plays a decisive role in the control accuracy after convergence. The design methods of control algorithms commonly used at home and abroad include: modal control [29], neural network control [29], feedback filtering control [29], optimal solution control [29], adaptive control [29], robustness control [29] and so on. The mathematical model of the system is involved in these control methods. The mathematical model is built to solve the system response of the system under external excitation. It requires to reflect the response of the system under different excitations in as much detail as possible. Early research on control algorithms includes unconditionally stable feed forward control, without the need to know the feedback control of the controlled object model and the LMS and RLS algorithms with adaptive adjustment capabilities [30]. Later research included improvements to these algorithms and the application of algorithms to new control objects [31].

Some scholars at home and abroad have made a lot of research on the algorithms of active control. Rohlfin [32] studied a new compensation filter algorithm that improves the stability and performance of the feedback loop and significantly improves control performance. Martino [33] proposed an adaptive filtering algorithm combined with fast Fourier transform and carried out the output force test experiment of the control exciter. The experimental results show that the algorithm has a good effect in reducing the computational complexity.

3. Conclusion
Active control technology is a simple and efficient control technology with a wide range of applications in the field of energy equipment research. This paper describes some basic devices and techniques commonly used to various components of the active control system according to different controlled objects. It provides a theoretical reference for the further development of subsequent research.

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