Research on MEMS Technology Application in Fuse

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Abstract. Along with the development of MEMS and the requirements by information war of the abilities of ammunition precision attacking and efficient destroying, MEMS has become the one key technology of realizing fuse miniaturization and extending fuse functions. Firstly, the necessity of using MEMS in fuse is analysed. Secondly, the ignition system and safety system referring MEMS are summarized. Then MEMS device, sensor particularly, used in fuse is introduced. Finally, the development trends of MEMS technology in fuse are discussed.

1. Introduction
Microelectromechanical system refers to the micro-device or system that can be mass-produced, set micro-mechanism, micro-sensor, micro-actuator and signal processing and control circuit, until the interface, communication and power supply equal [1]. It is a cross-cutting and strategic cutting edge technology for the development of intelligent products, can improve the computing power of microelectronics products and perception and controlling capabilities of micro sensors and micro-actuators, and is one of the leading industries in the future [2]. Microelectromechanical system has special characteristics with miniaturization, integration, mass production, low cost and fuse technology, one of the fastest and most sensitive core technologies. It is the weapon system which can response to high-tech. MEMS technology provides a support to promote the development of fuse [3].

With the development of information warfare, ammunition must have the ability of attacking precision, efficient damage. As ammunition "brain", the machinery-based trigger fuse cannot meet the requirements of the future battlefield [4-5]. In order to improve the operational effectiveness, requiring the design of a regular/ fixed-range detonation, and self-destruction and other functions of the fuse, its miniaturization, intelligence, and dexterity become an inevitable trend. As the available space of the fuse is limited, the use of MEMS technology can effectively expand the application of fuse function and reduce the difficulty of design work. The MEMS fuse system used in weapon design, can greatly improve the stability and reliability of weapons and equipment, its ability of killing damage.

The development of modern high-tech weapons and equipment has brought about the innovative changes of combat mode. The weapon system requires the fuse to have the ability of target and disturbance identification, target positioning and initiation control ability, safety control capability and information crosslinking ability [6]. This paper expounds the necessity of MEMS applied to fuse, and summarizes the present situation of using MEMS technology to design the fuse mechanism. This paper analyzes the characteristics of MEMS devices used in fuse. MEMS sensor in particular [7], summarizes the application status of MEMS sensors in fuse, introduces the trend of MEMS technology applied to fuse.
2. The Necessity of Studying MEMS Fuse

With the continuous development of the battlefield environment and the emergence of high-tech, new intelligent ammunition continue to emerge, such as high-energy damage ammunition, guided ammunition, extended range ammunition, non-spin and micro-spin ammunition. To achieve effective control of new intelligent ammunition, new fuse systems that are suitable for complex battlefield environments must be studied.

Traditional fuse only requires the main function of protecting the fuse in service, launch, and safety separation. In addition to the original requirements, the future fuse needs to detect the entire flight trajectory detection, adjust the projectile posture before hitting the target. The new war features also require modern fuse having the use of battlefield information, including environmental information, target information, command and control information, to achieve automatic perception, independent analysis and decision-making ability [8-9]; fuse not only requires the realization of the fuse system Information transmission and processing, but also must have the ability to communicate with the fire control system [10]; for hard target penetration fuse, the fuse system must have the signal perception, signal transmission, signal processing capacity; in the precise guidance fuse, involving the new detection technology, information processing technology, transmission technology, controlling technology and aero dynamic technology and other applications, effectively improve the bursting accuracy of ammunition.

The function of the fuse is constantly expanding, but the appearance of the fuse is difficult to change greatly, and the interface size of the fuse in the ammunition is also limited. The available volume of the fuse is very limited. In order to accommodate more functional modules in the fuse, smaller modules must be used in the fuse. The traditional technology has been unable to meet this requirement. New technology must be used in fuse.

MEMS technology with ultra-miniaturization features, using the same or similar with the integrated circuit manufacturing process, low cost, low energy consumption, high reliability, impact resistance, especially suitable for the completion of fuse multi-functional expansion and maintain the same volume, to maximize Weapons and ammunition precision strike and efficient damage requirements. (1) reduce the size of ammunition and reduce the weight of ammunition, and improve the performance of ammunition system or increase the new function; (2) can effectively improve the fuse function and reduce the design difficulty; (2) can be used to improve the performance of fuse, (4) MEMS technology is widely used in ammunition to greatly reduce the cost of ammunition, (5) the use of micro-electromechanical technology is easy to achieve in the volume and weight requirements of the fuse multi-functional, better adapt to the future battlefield complex situation; (6) to improve the degree of ammunition intelligence, improve the lethality, an increase of ammunition storage life; (7) so that no control ammunition to dexterity, guidance of the development.

3. The Applications of the MEMS Technology in Fuse

3.1. Design of MEMS Fuse System

3.1.1. The Ignition Control System. The ignition control system is an important functional system that influences the fuse tactical performance index. The ignition control system generally includes a sensitive device, a signal processor, and an execution device. During the flight of the projectile, the ignition control system transmits the self and the target information signal sensed by the sensitive device to the signal processor, judges the flight status of the projectile, controls the fuse safety system through the execution device, releases the insurance against the positive explosion sequence, and detonate the projectile.

The ignition device is a device that accepts external signals or stimulates to deflate or explode and work, and is a typical sensitive device in an ignition control system. With depth application of the modern information technology and micro-nano technology in the field of space, micro-satellite, smart ammunition and micro-spacecraft and other sophisticated MEMS have become an important regional...
forward competition areas. Micro, integrated, intelligent become the mainstream of the incident to meet the development needs of intelligent micro-systems [11-13]. MEMS, because of its high integration capabilities, ultra-processing capacity and strong scalability, has become the main means in equipment manufacturing field to achieve micro-integration. MEMS firing devices are both small, low cost, large-scale manufacturing, high-density integration advantages, and can achieve more sophisticated, more accurate fire operation needs, to solve many problems difficult for traditional methods [14]. Figure 1 shows the silicon bridge detonator, the size of each direction is only about 10um. The plasma generated by this initiator can pass through the air gap of 2 ~ 5um to initiate the explosive. 2012 Indian Navy Surface Operations Center Indiana headquarters produced the ignition device using micro-nano copper and chemical reaction of the reaction of the gas. The size of the charge diameter is only 2mm, and the production of MEMS fuse area is about 1cm³. A patent by Robinsin in 2012 [15] introduced a MEMS fuse which integrated the ignition control circuit, the MEMS security system and the micro-fireworks.

![Testing equipment of micro-silicon detonate switch](image)

**Figure 1.** Testing equipment of micro-silicon detonate switch

3.1.2. Security System. The essence of the fuse security system is to achieve the control of the interference energy through the fuse safety system to ensure that energy cannot be effectively transmitted before it enters the intended de-insurance procedure, so that it can be in a safe state of safety. After entering the scheduled cancellation insurance procedure and reaching the de-insurance Conditions, the energy can be efficiently transmitted, so that the fuse can complete the lifting of the insurance action in progress. The use of MEMS technology for fuse security system can be designed to achieve the integration of the device and the ignition system can save space, reduce the size of the organization, and reduce the difficulty of manufacturing.

- **a) Typical plane security system**
  Clock and watch mechanism using single-chip design idea is a typical plane security. It has anti-interference ability, high reliability, efficient particularly in the complex environment. As is shown in Figure 3, during the rotation of the projectile, the watch mechanism rotates around the elastic axis. Under the centrifugal force, the three pairs of teeth have a clock wise rotation, and the right most gear 1 rotates against the resistance of the spring. The middle tooth pendulum 2 cannot turn because of limitation of 3 teeth. When the tooth 1 rotates a certain angle, the release of the tooth 2. The tooth 3 is released after tooth 2 in place. The tooth 3 and the rear of the body are connected. When the tooth 3 rotation is in place, the insurance is lifted. When there is an unexpected impact, due to the short impact time, tooth 2 or tooth 1 has not been rotated to the original position by the spring resistance back.
b) Typical hierarchical security system

As is shown in Figure 4, Koehler et al designed and manufactured a MEMS security system with a hierarchical structure. The system consists of slider, rear card lock, substrate, spring, card pin and other components. In the usual state the back card lock will be stuck in the insurance position; when launching, in the recoil under the role of the back card lock movement from the slider, the slider of the first insurance is lift; the role of centrifugal force overcomes the slider by the resistance of the spring to the right to move to reach a certain distance after the movement of the muzzle in place. The card stuck into the slider stop card slot, and the second insurance is lift. When the sequence is correct, the fuse is in the pending state. In the United States Atlanta Georgia Institute of Technology and the Naval Water Operations Center in 2007 presented a MEMSfuse, as shown in Figure 5, the MEMS fuse mainly involved the bottom of the micro-detonator, the top MEMS security system and MEMS security system, including the rear Insurance, instruction lock, explosion-proof slider and detonator and other components.
3.2. Application of MEMS Sensor in Fuse

MEMS sensor is an important branch of MEMS device, generally made of silicon-based materials and using semiconductor integrated circuit manufacturing process. It is a set of micro-mechanical, microelectronics function of a highly integrated sensor system, with small, lightweight, high reliability, easy integration, anti-vibration impact ability and other characteristics. The feature size of the order of micrometers makes it possible to achieve the functionality that some conventional sensors cannot perform [7]. Various types of sensors detect the environment during the launch and flight information, and the information can be a variety of logic processing, digital processing, time window controlling, and through a variety of actuators to imply the action, easy to achieve fuse intelligence, Ammunition has the ability to strike targets precisely.

MEMS gyro and MEMS acceleration sensors have the advantages of impact resistance, low cost, small size, high reliability and low power consumption. The MEMS inertial measurement combination is mainly used for navigation and guidance of platform and ammunition. American EX171 Extended Range Projectile applied MEMS Inertial Measurement Combination Technology. The United States is currently using this technology in the development of long-range ammunition of the MLRS multi-barrel rocket weapon system, which represents a 60 km 227 mm long-range guided rocket and the Army Tactical Missile System.

The miniature temperature sensor measures the change in the local temperature of the fuse head due to friction with the air during flight and uses it as information to lift the insurance. The miniature pressure sensor can be used to measure the head air pressure on the head of the fuse in flight. The micro-acoustic sensor measures the noise generated by the friction during the flight due to the friction with the air, and uses it as information to lift the insurance.

4. Development Trend of MEMS Fuse

The development of modern high-tech weapons and equipment has brought about the innovation of the combat mode. The weapon system requires the fuse to have the military capability such as target positioning and initiation control ability, target and disturbance recognition ability, information cross-linking ability and safety control ability. These require a more thorough study of modern fuse technology. MEMS technology makes fuse reduce the size and weight, the fuse function can be fully expanded; so that conventional uncontrolled ammunition gradually develops to the guidance, dexterity direction of development possible. It makes the conventional uncontrolled ammunition and missile boundaries more and more blurred; to achieve the fuse generalization, serialization and combination. The technology is conducive to large-scale production, the formation of economies of scale, thereby reducing the cost of fuse; with the new semiconductor materials and MEMS processing technology, sensor design and sensor structure design breakthrough, the new MEMS sensor is emerging, which will further improve the precision guidance capability of the MEMS fuse. In the future development of fuse, MEMS technology in the fuse will be more and more widely used.
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