Research on EFI multi-point synchronous initiation technology based on mems process

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Abstract: In order to solve the problems of the warhead initiation system due to the low safety of conventional detonator arrays and the poor synchronization of the explosion logic network, as well as the MEMS batch integration requirements, a research on EFI multi-point synchronous initiation technology based on MEMS technology was carried out. Explosive foil was prepared by magnetron sputtering and photolithography. SU-8 photoresist flying sheet layer and acceleration chamber were prepared on the bridge foil by UV thick glue technology, and single-point, two-point parallel and three-point parallel were realized. The two batches of two and a total of four points and three strings of three and a total of nine points explosion foil initiators were batch-integrated and tested for the synchronism of the flying sheet effect. The test results show that the average time between two points, three points, and four points is less than 80ns, and the synchronization time is small; the average time at nine points is less than 200ns, and the synchronization time is large.

1. Introduction

With the development of intelligent ammunition, multi-point synchronous initiation meets the requirements of the warhead initiation system [1-3]. At present, the domestic warhead multi-point initiation method uses conventional electric detonator initiation array and explosion logic network technology. The large-scale use of conventional detonators not only reduces the safety and reliability of the initiation system; it also fails to meet the synchronous dispersion requirements of the warhead initiation system [4-5]. Explosive foil initiators (EFI) have attracted wide attention from various countries since it was proposed for its high safety and high instantaneity [6]. In the 1980s, Earl E. Wilhelm [7] of the Boeing Company in the United States for the first time used a multi-point detonation technology of impact detonators in a directional warhead to increase the probability of killing. Yang Zhenying [8] designed a three-point to six-point ring impact plate detonator array and detonated the warhead safely and reliably. In recent years, with the development of micro-electro-mechanical systems (MEMS) technology, batch integration of explosive foil initiators has been realized. H. Bruce Wallace [9] showed a nine-point impact sheet detonator synchronous initiation array device prepared by MEMS technology in 2004. The measured nine-point synchronous
initiation time was within 100ns. Shi Zhigui [10-11] used silicon MEMS technology to produce an integrated explosive foil initiator, and successfully detonated HNS-IV grains. Li Kewei [12] integrated a non-silicon-based microfabrication on a glass substrate with copper as the bridge foil, polymethyl methacrylate (PMMA) photoresist as the flying sheet layer, and SU-8 glue as the acceleration chamber. Craft of explosive foil initiator. Chen Kai [13] On the Al₂O₃ ceramic substrate, Cu explosive bridge foil was deposited by magnetron sputtering, and PC / Cu composite flying sheet layers were deposited by vapor deposition. SUEX dry film was used to prepare an accelerated chamber. An explosive foil initiator was prepared and successfully detonated HNS-IV pellets. Compared with foreign developments, domestic research on single-point McEFI is more extensive, but there is a lack of research on McEFI multi-point synchronous initiation technology. Therefore, a single-point, two-point parallel, three-point parallel, two-string two-to-four total and four-string three-to-three total nine-point explosion foil initiator are designed in this paper, and a multi-point explosion foil transduction module is integrated using MEMS technology. It is tested synchronously to provide a reference for the warhead initiation system.

2. Multi-point McEFI design and process preparation

2.1. Multipoint McEFI Design
In the design of the multi-point initiation device, in order to reduce the waste of charging energy and ensure the reliable initiation of the detonator array, the connection method of the multi-point bridge foil affects the electrical explosion performance of the bridge foil, and further affects the initiation performance of the multi-point initiator. This article designs integrated single-point, two-point parallel, three-point parallel, two-string two-parallel total four points and three-string three-parallel total nine-point explosion foil structures, of which four-point and nine-point explosion foil initiators are designed in series and parallel. The connection method on the one hand takes into account the consistency of series initiation and the advantages of using the energy of pulse power source in parallel initiation, which can improve the synchronization of multi-point initiation and the energy utilization of bridge foil explosion [14]; The design pattern of 2 or 3 impact detonators is first connected in series and then in multiple groups in parallel. In the design of system equivalent resistance and equivalent inductance parameters, keep as close as possible to the parameters of a single point to reduce the explosion of bridge foil. The effect of burst current and burst current density. (See figure 1 for a schematic diagram of the explosion foil structure, Single-point resistance and inductance measured in table 1). In the integrated multi-point explosion foil, the bridge area of each single explosion foil is the same. The specific bridge area size (length × width) is designed to be 0.4mm × 0.4mm and the thickness is 4μm. In order to reduce the interaction between the preparation process and the explosion time, the multi-point flying sheet layer and the multi-point acceleration chamber are independently designed with multiple points. The design of the flying sheet layer thickness is 20 μm, the acceleration chamber thickness is 300 μm, and the design acceleration chamber diameter is 0.45 mm.
Figure 1. Schematic diagram of multi-point explosion foil structure.

### Table 1. Single point explosion foil resistance value and inductance value.

|          | 1     | 2     | 3     | 4     | 5     | 6     | 平均值 |
|----------|-------|-------|-------|-------|-------|-------|-------|
| resistance/ mΩ | 36.62 | 39.25 | 35.40 | 40.08 | 36.35 | 35.21 | 37.15 |
| inductance/ nH  | 50.3  | 52.4  | 55.8  | 52.1  | 48.6  | 55.2  | 52.4  |

2.2. **Process preparation**

The multi-point explosion foil initiator transducer assembly is integrated in situ using MEMS technology. The specific process is to first magnetron sputter a copper film on a glass substrate, and
obtain an integrated array explosion through homogenization, photolithography, debonding, and wet etching. The foil structure, the flying layer, and the acceleration chamber are selected by SU8 glue through homogenization, photolithography, and development, as shown in Figure 2. A laser confocal microscope is used to take pictures of the prepared detonator assembly as shown in Figure 3.

Figure 2. MEMS process flow chart.

Figure 3. Nine-point impact detonator assembly.

3. Multipoint McEFI synchronization test

3.1. Test principle and device
Under the narrow pulse and high current generated by the high-voltage pulse power source, the metal bridge foil instantaneously electrical explosion, which generates a plasma bombarding the flying disc, shearing in the acceleration chamber, and impacting the explosive column. The test methods for the synchronization of multi-point impact sheet detonators include the synchronization of multi-point explosion foil electrical explosion, the synchronization of multi-point flying sheet, and the synchronization of multi-point detonation detonation. This article uses the multi-point flying sheet synchronization to perform multi-point McEFI synchronization characterization. It mainly records the multi-point flying sheet acting time at the output of the acceleration chamber.

Is the synchronization time, where the maximum value in the synchronization time data is the maximum synchronization time. The test equipment includes: high voltage charging power source, pulse power source, spark gap switch, high voltage resistant capacitor, voltage divider, PVDF piezoelectric sensor, oscilloscope, etc. The capacitor is charged by a high-voltage charging power supply. The spark gap switch in the circuit is triggered by a pulsed power source. The capacitor
discharges an electric explosion through a multi-point explosion foil. The electrical signal, the voltage divider records the moment of electrical explosion of the explosion foil, the schematic diagram of the synchronization test circuit of the multi-point explosion foil initiator is shown in figure 4.

![Figure 4. Schematic diagram of the synchronization test circuit.](image)

### 3.2. Explosion synchronization test

#### 3.2.1. Two-point parallel synchronization test

The integrated two-point parallel explosion foil initiator using the MEMS process is connected to the test circuit through two ends of the welding wire to conduct the synchronization test. Six groups of tests are performed. The synchronization test results are shown in table 2.

| Group times | resistance/mΩ | inductance/nH | Charging voltage/KV | Synchronization time/µs |
|-------------|---------------|---------------|---------------------|-------------------------|
| 1           | 18.31         | 23.7          | 2.0                 | 20.0                    |
| 2           | 19.63         | 26.9          | 2.0                 | 17.2                    |
| 3           | 22.70         | 28.3          | 2.0                 | 18.3                    |
| 4           | 20.04         | 28.1          | 2.0                 | 15.8                    |
| 5           | 25.17         | 25.8          | 2.0                 | 15.4                    |
| 6           | 23.61         | 29.2          | 2.0                 | 13.3                    |
| average     | 21.58         | 27.0          | 2.0                 | 16.7                    |

#### 3.2.2. Three-point parallel synchronization test

An integrated three-point parallel explosion foil initiator using the MEMS process is connected to the circuit through two ends of the welding wire for synchronization test. Six groups of tests were performed. The synchronization test results are shown in table 3.
3.2.4. Nine-point synchronization test

The integrated three-point series and three-three-parallel total
nine-point explosive foil initiators prepared by MEMS process are connected to the circuit through
the welding wires at both ends to conduct synchronization tests. Six groups of tests are performed. The results of the synchronization tests are shown in table 5.

Table 3. Two-point parallel synchronization test.

| Group times | resistance/mΩ | inductance/nH | Charging voltage/KV | Synchronization time/ns |
|-------------|---------------|---------------|---------------------|------------------------|
| 1           | 17.31         | 20.9          | 2.5                 | 20.5                   |
| 2           | 15.84         | 18.3          | 2.5                 | 23.7                   |
| 3           | 15.66         | 23.1          | 2.5                 | 28.6                   |
| 4           | 15.53         | 22.4          | 2.5                 | 28.1                   |
| 5           | 16.18         | 23.5          | 2.5                 | 33.2                   |
| 6           | 13.32         | 22.1          | 2.5                 | 27.9                   |
| average     | 15.64         | 21.7          | 2.5                 | 27.0                   |

3.2.3. Four-point synchronization test

The integrated two-point serial connection made by MEMS technology is followed by a two-parallel
parallel connection and a total of four points. The foil foil initiator is connected to the circuit through
the two ends of the welding wire to conduct the synchronization test. Six groups of tests are performed. The results of the synchronization test are shown in table 4.

Table 4. Four points synchronization test after two points are connected in series.

| Group times | resistance/mΩ | inductance/nH | Charging voltage/KV | Synchronization time/ns |
|-------------|---------------|---------------|---------------------|------------------------|
| 1           | 38.22         | 50.2          | 2.8                 | 72.5                   |
| 2           | 39.07         | 49.5          | 2.8                 | 65.7                   |
| 3           | 39.71         | 53.1          | 2.8                 | 58.1                   |
| 4           | 42.18         | 50.9          | 2.8                 | 59.1                   |
| 5           | 35.89         | 55.3          | 2.8                 | 66.2                   |
| 6           | 40.36         | 52.7          | 2.8                 | 53.2                   |
| average     | 39.24         | 52.0          | 2.8                 | 62.5                   |

3.2.4. Nine-point synchronization test

The integrated three-point series and three-three-parallel total
nine-point explosive foil initiators prepared by MEMS process are connected to the circuit through
the welding wires at both ends to conduct synchronization tests. Six groups of tests are performed. The results of the synchronization tests are shown in table 5.

Table 5. Nine-point synchronization test after three-point series connection.

| Group times | resistance/mΩ | inductance/nH | Charging voltage/KV | Synchronization time/ns |
|-------------|---------------|---------------|---------------------|------------------------|
| 1           | 43.08         | 70.3          | 3.0                 | 180.1                  |
| 2           | 45.91         | 69.5          | 3.0                 | 187.4                  |
| 3           | 41.89         | 71.9          | 3.0                 | 200.4                  |
| 4           | 45.21         | 68.4          | 3.0                 | 160.8                  |
| 5           | 44.52         | 72.1          | 3.0                 | 165.1                  |
Comparing the two-point parallel, three-point parallel, two-string two-parallel total four points and three-string three-parallel total nine-point explosion foil initiator synchronism test results, it can be seen that the integrated multi-point explosion foil initiator resistance prepared by MEMS process The value and inductance value are small, the consistency is good, and it basically conforms to the principle of series-parallel circuit. The minimum synchronization time of an integrated two-point parallel explosion foil initiator is 13.3ns, and the average synchronization time is 16.7ns. The minimum synchronism time of a parallel explosion foil initiator is 20.5ns and the average synchronization time is 27.0ns; the minimum synchronization time of an integrated four-point explosion foil is 53.2ns and the average synchronization time is 62.5ns; the minimum of an integrated nine-point explosion foil is The synchronization time is 160.8ns, and the average synchronization time is 180.4ns. The factors that affect the synchronization time of multi-point initiation are input energy (including charging voltage and capacitance), the difference in the size of the bridge area at each point, and the flying layer at each point. And the difference of the acceleration chamber, the influence of the wire resistance and inductance in the circuit. As the number of series and parallel initiation points increases, the synchronic walk increases.

4. Conclusion

In this paper, a multi-point explosive foil initiator prepared by MEMS process and conducting a multi-point synchronization test can draw the following conclusions:
(1) Adopting magnetron sputtering copper foil, uniform photolithography su8 glue to achieve integrated single point, two point parallel, three point parallel, two string two parallel and four string three and three string three And a total of nine points of impact detonator in-situ preparation of the transducer, good process consistency;
(2) The multi-point synchronous initiation device adopts a serial-parallel connection method, and the resistance value and inductance value basically comply with the circuit series-parallel principle;
(3) Through the multi-point flying sheet synchronization test, as the number of series and parallel initiation points increases, the synchronization walk increases. Among them, two points in parallel, three points in parallel, and two strings in parallel and a total of four points explode foil initiators. The average synchronization time is less than 80ns, and the synchronization time is small. Synchronic time for a walk.

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