An Integrated Measurement Method for Electrothermal Chemical Guns Based on Synchronous Clock and Electromagnetic Shielding

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Abstract. To analyze influence factors to ballistic performance of electrothermal chemical guns and specific reaction process between plasma and propellants in electrothermal chemical guns firing, measurement data of multiple physical parameters involved in firing process are needed to be materials for analyzing. An integrated measurement method for electrothermal chemical guns based on synchronous clock and electromagnetic shielding is proposed in this paper, synchronization of multiple test measurement systems is realized by synchronous clock to be convenient for data fusion and research, accuracy and precision of multiple measurements are increased by shielding electromagnetic interface through electromagnetic shielding boxes. The method proposed is verified by experiments and simulation, results shows that the method proposed could reach expected effect.

Introduction

The principle of electrothermal chemical guns firing is that, plasma is generated by arc discharge, which reacts with solid propellants, high-temperature high-pressure gas is generated in reaction to accelerate the projectile. Compared with traditional guns, there’re great increments in muzzle velocity and firing range [1-4]. To analyze influence factors to ballistic performance of electrothermal chemical guns and specific reaction process between plasma and propellants in electrothermal chemical guns firing, measurement data of multiple physical parameters involved in firing process are needed to be materials for analyzing [5].

Nowadays, electrothermal chemical guns measurement system commonly takes independent subsystems for different parameter measurements; each subsystems are not synchronous and have differences in sampling rates and storage depths. Measurement data from different subsystems should be modified by characteristic values of signal waveforms, which makes it hard to do data fusion and analysis and increase accuracy of measurement and analysis. Meanwhile, there is large pulse current in the circuit when electrothermal chemical guns firing [6], which induces strong electromagnetic field around. To realize electromagnetic conference in signal transmissions, photoelectric converters are usually used in the systems. But there are still interference noises coupled from exposed ports of data acquisition, which influences accuracy and precision of measurements. In some serious cases, coupled electromagnetic interference might damage devices in measurement systems.

In order to increase accuracy of electrothermal chemical guns measurements and make it easier to analyze specific reaction process in interior ballistic and influence elements of ballistic performance. An integrated measurement method for electrothermal chemical guns based on synchronous clock and electromagnetic shielding is proposed in this paper. By providing same synchronous clock and trigger signal for each measurement subsystems, unification for acquisition step and time reference of multiple measurements is realized, which increases synchronous accuracy of multiple measurement systems and makes it easier to do data fusion and analysis for measurement result. Accuracy and reliability of measurement results are increased by using electromagnetic shielding boxes to shield electromagnetic interference around measurement system.
Multiple Parameter Measurement Synchronous System

Voltage, current, chamber pressure and muzzle velocity are main parameters measured in electrothermal chemical guns experiments. Measurements of voltage and current are separately realized by high-voltage differential probe and fiber optic current transformer (FOCT) set on breechblock, which is used to reflect and estimate generation and discharging process of plasma. Measurements of chamber pressure are realized by piezoresistive pressure sensor set in several places inside barrel, which is used to reflect reaction process of propellants in barrel. Muzzle velocity is measured by Laser screen to indicate ballistic performance. Measurements of different physical parameters have different in installation and measurement principles; their data are acquired and managed by their own data acquisition and signal processor.

Structural schematic of multiple parameter measurement synchronous system is shown in Fig.1. To realize high accuracy synchronization of different physical measurement result, synchronous clock is used to provide same acquisition clock for every data acquisition. A/D converters and real-time signal processors in data acquisitions receive acquisition clock and take it as base clock for acquisition, to ensure that acquisition step and time point of each A/D converters and real-time signal processors are exactly same. When Electrothermal Chemical Gun is triggered, the trigger signal is sent to synchronous clock, synchronous clock modifies the trigger signal to a rectangular wave and sends it to every data acquisition. Data acquisitions take first data point acquired after receiving the rectangular wave as time mark point, time mark point is used to align each measurement data when analyzing multiple parameter measurement results.

Test Result of Synchronization

Acquisition clock signal output by synchronous clock is an 1MHz square wave with 50% duty cycle, modified trigger signal is a active low rectangular wave with 200us width. Each data acquisitions receive acquisition clock signal and modified trigger signal by cable. To avoid time error caused by transmission, cable lengths are exactly same from synchronous clock to each data acquisitions. An oscilloscope with 20MHz sampling frequency is used to measure 4 channels acquisition clock signals and modified trigger signals from cable output ports. Acquisition clock signal results and modified trigger signal results are shown in Fig.2.
According to acquisition clock signal results, characteristic of 4 channel clock signals are completely same, period and phase are same and stable in every channel. According to modified trigger signal results, output trigger signal of each channels are superposition in timeline.

In conclusion, every data acquisition takes acquisition clock signal from synchronous clock to acquire data, takes first data point acquired after receiving the modified trigger signal as time mark point. Time characteristics of acquisition clock signal and modified trigger signal are completely same, so after aligning acquired data by time mark point, measured data from every data acquisition are guaranteed to be perfectly synchronous.

**Analysis of Measurement System Electromagnetic Interference**

To analyze electromagnetic interference induced from electrothermal chemical guns firing, we should start it from analysis of interference source and its strength. In discharge circuit, pulse power supply is far from measurement system, whose induced electromagnetic field could barely influence measurement devices; coaxial cables are used to transmit electric energy, whose induced electromagnetic interference could be ignored. The main electromagnetic interference source around measurement system are pulse strong electromagnetic field induced by current circulated in plasma generator, breechblock and single-core cables connected to breechblock.

Finite element simulation is used to study characteristic of magnetic field induced by interference source, simulation model of interference source is shown in Fig. 3 (a). In the model, breechblock and single-core cables connected to it are considered as excitation, excitation current is similar to current wave in experiment, and induced magnetic field is simulated in this model.

![Simulation model](image)

Figure 3. Simulation model and result of interference source.

As shown in Fig.3, a reference plate is on the plate where parallel cables are, a reference line is set from center point of two cables to outside of one cable on the reference plate. Magnetic fields of reference plate and reference line are shown in Fig. 4 (b) and (c). Reason for the dent in reference line is that there’s cooper as conductor, whose relative permeability is less than 1.

According to simulation result, interference magnetic field is mainly distributed around cables. In accordance with relationship between magnetic flux density and distance, magnetic flux density is 0.5T at 15cm from cable. With distance from cable increases, magnetic flux density decreases rapidly. Considering that data acquisitions are usually placed more than 15cm from cable and breechblock, 0.5T is set to be electromagnetic interference target this measurement system should work with; system electromagnetic shielding is designed for this purpose.

**Design of Electromagnetic Shielding Box for Measurement System**

To reduce adverse effect to measurement devices from electromagnetic interference and increase accuracy of measurement, electromagnetic shielding box is designed in this system to protect measurement devices from electromagnetic interference.
If conduct material has larger relative permeability, it would have less magnetic resistance. When electromagnetic is spreading, magnetic flow prefers paths with less magnetic resistance. Because ferromagnetic material has large permeability and little magnetic resistance, when it’s put in magnetic field, magnetic flow is mainly on ferromagnetic material, magnetic flow around it reduces obviously, magnetic field shielding is realized. Shielding box made of high permeability material gives a low magnetic resistance path which makes magnetic flow easy to get through, protects sensitive elements inside from strong magnetic field outside, which is magnetic bypass principle [8]. Schematic and equivalent circuit of magnetic bypass principle is shown in Fig.4.

![Figure 4. Schematic and equivalent circuit of magnetic bypass principle.](image)

Magnetic field is equivalent to electric field to calculate magnetic flow distribution in magnetic paths, relationship between shielding effectiveness and magnetic resistance could be confirmed from calculation. Magnetic resistance is equivalent to resistance; magnetic flow is equivalent to current, relationship between magnetic fields inside and outside could be calculated as:

\[
H_1 = H_0 R_s / (R_s + R_0)
\]

\(H_1\) is magnetic field intensity inside, \(H_0\) is magnetic field intensity outside, \(R_s\) is magnetic resistance of shielding box, \(R_0\) is air magnetic resistance inside shielding box. Then, shielding effectiveness of shielding box could be calculated as:

\[
SE = 20 \log \left( \frac{H_0}{H_1} \right) = 20 \log \left( 1 + \frac{R_0}{R_s} \right)
\]

According to the function, air magnetic resistance is stable; shielding effectiveness of shielding box is determined by magnetic resistance of the box. Less magnetic resistance box has, more shielding effectiveness box could realize. Magnetic resistance is calculated as:

\[
R = \frac{S}{(\mu A)}
\]

\(S\) is length of magnetic path; \(A\) is cross section area that magnetic flow gets through box, \(\mu = \mu_0 \mu_r\) is permeability of box material.

To reduce length of magnetic path, volume of box should be as small as possible. To increase cross section area that magnetic flow gets through, thickness of the box should be increased. To reduce magnetic resistance, material with higher permeability should be used. By taking designs above, shielding box could have less magnetic resistance and better shielding effectiveness.

Pulse power of electrothermal chemical gun discharges in several milliseconds, magnetic field induced belongs to low frequency magnetic field. For this kind magnetic field, ferronickel is commonly used as shielding material. Considering magnetic flux density of interference source is 0.5T, ferronickel is easy to be saturated in this magnetic field [9]. Using materials that would not be easily saturated like low carbon steel could not reach shielding effect required. So shielding box takes double enclosure structure, low carbon steel, which has less permeability and is hard to be saturated, is used as outer box material to attenuate magnetic field to lower level, ferronickel is used as inner box material to provide sufficient shielding effectiveness. Box designed is hexahedron with cover and base, as is shown in Fig.5. Bolt is used to fix cover and base, rubber is used to realize insulation between two boxes.
Shielding Effectiveness Simulation of Shielding Box

Coil is usually used to generate excitation magnetic field, model established and result on reference plate is shown in Fig. 6. Excitation current is set as half period 500Hz sine, which is similar to pulse current in experiment. Magnetic flux density result on reference line is shown in Fig. 6 (c), average magnetic flux density in coil is 0.5T.

Set shielding box model inside excitation coil, as is shown in Fig. 7 (a), calculated magnetic flux density on reference plate and line is shown in Fig. 7 (b) and (c).
According to simulation result, average magnetic flux is 0.5T without shielding box and 0.0092T (92Gs) with shielding box. Designed shielding box realizes 34.5dB shielding effectiveness, could provide sufficient shielding effect for measurement system.

Conclusion

To increase accuracy of electrothermal chemical gun measurement and make it easy to analyze specific interior ballistic reaction process and influence factors to ballistic performance, an integrated measurement method is proposed in this paper. On the one hand, synchronous clock is used to provide synchronous acquisition clock and trigger signal for every subsystem to improve synchronous precision of measurement data. According to experiment result, measurement system could realize high precision synchronization. On the other hand, electromagnetic interference source in measurement is analyzed. Double enclosure structure shielding box is designed based on characteristic of interference. According to simulation result, designed shielding box realizes 34.5dB shielding effectiveness in measurement operating condition, could provide sufficient shielding effect for measurement system. In conclusion, integrated measurement method for electrothermal chemical guns proposed in this paper could realize high precision synchronization for multiple parameter measurements and increase accuracy and reliability of measurement.

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