The design of low-velocity penetrating equipment for high-energy explosives

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Abstract. Accident scenarios involving explosive workers handling cased charges can result in low-velocity impact incidents. A series of low-velocity penetrating safety researches and experiments should be performed to high-energy explosives, and to determine whether such a penetrating impact can cause ignition and violent reaction, and to demonstrate heat generation mechanisms of low-velocity penetrations. This design of low-velocity penetrating equipment seeks to imitate the accident scenarios, perform safety researches and experiments, and demonstrate heat generation mechanisms of low-velocity penetrating for high-energy explosive. The structure design, controller design, control software design and test effects were elaborated in this paper.

1. Introduction
Explosives are the means by which a warhead achieves its destructive effects. Explosive charges might cause combustion explosion during transportation, storage and using process, or under unusual accidents such as mechanical stimulation, fragment impact and shock wave [1–2]. Hazard is one of the most important technical indexes for explosive and propellant performance. It is strongly connected to safety of explosive production, processing and handling, using safety and survival ability of rocket, missile, ship and aircraft.

Explosives workers must occasionally handle explosives and propellants. A plausible accident scenario involves dropping a charge onto an exposed point or protrusion during handling, or conversely dropping or falling with a tool in hand to impact a stationary cased charge. Unlike conventional projectile impact studies, drop or “stabbing” scenarios have quite low velocities, in the (0~10)m/s regime. However, the projectile mass can be large, up to 20kg (practically only limited by the mass that a worker can safely lift). This design of low-velocity penetrating equipment seeks to imitate the accident scenarios, perform safety researches and experiments, and demonstrate heat generation mechanisms of low-velocity penetrating for high-energy explosive.

2. Technical indexes
a) projectile mass: 50g~20kg;
b) catapult velocity: (0~20) m/s;
c) pneumatic maximum pressure: 10MPa;
d) maximum loading velocity: 20m/s;
e) maximum temperature measuring: 1400℃, acquisition frequency>100kHz;
f) penetrating force measuring: (0~10)kN, acquisition frequency>60kHz
3. Structural design

3.1. Overall structure
Overall structure was shown in figure 1. The fore-end was the sample part, sensors and testers were installed on it. The rear-end was the driving part, projectile was accelerated and penetrated through it. The equipment was fixedly installed on the flexible table in order to transport conveniently.

![Figure 1. Overall structure of low-velocity penetrating equipment.](image)

3.2. Sample part
Sample part structure was shown in figure 2. It was composed of shell, pressed circular ring, circular plate etc. The shell can be adjusted by different size and shape of sample.

![Figure 2. Sample part structure.](image)

The M10 thread was designed to connect the force sensor. Stainless steel, aluminium, or copper can be chose to be the circular plate material according to the actual cases. Cushion material, explosive
cylinder and circular plate were loaded in the sample tester sequentially, and then were locked by the pressed circular ring and bolts.

4. Controller design
Penetrating process is a short time history from μs to ms. It is a impact dynamic theory. The moment of penetrating is very short and its frequency is very fast. High speed data acquisition system was shown in figure 3. quick-response force sensor, high-speed temperature sensor and quick-response speed sensor were sent to channel 1, 2 and 3 of high-speed data acquisition card.

![Diagram of high speed data acquisition system](image)

**Figure 3.** High speed data acquisition system.

4.1. Controller appearance
Consider the convenience of penetrating experiments, the controller was designed portable. Portable controller was shown in figure 4.
4.2. Principle of force-measurement system

4.2.1. Force-measurement system.
The principle of force-measurement system was shown in figure 5. When the projectile was penetrated to the impact board, the force sensor transferred force value to corresponding electric signal (mV). And then the high-accuracy electric charge amplifier received and amplified this signal to standard analog signal (0–5)V which was easy to collect. High-speed data acquisition card received this signal and transferred it to digital signal. The acquisition frequency was high as 100kHz. The time-force curve figure was automatically get by the collected data.

![Figure 5. Principle of force-measurement system.](image)

4.2.2. Force value collecting
According to our experiment target, the projectile mass was 10kg, lading speed was 20m/s. Assume the projectile penetrated completely, so the end speed was 0m/S. Assume the whole penetrating time was 2ms.

\[
m(vt-v0)=Ft
\]

\[
F=m(vt-v0)/t=10 \times (20-0)/2 \times 1000=5kN
\]

Based on above data, the measurement range of the force sensor was defined to 10kN. Because the sample might explode during the experiment, so the sensor might use only once. Generally considering the cost and buying period, domestic brand force sensor was selected. MYDL—11 force sensor has high rigidity and resonance frequency, so it is very appropriate for rapid varied process. The main technical indexes were given in table 1.
Table 1. Main technical indexes of MYDL-11 force sensor.

| parameter               | value       |
|-------------------------|-------------|
| measurement range       | 10kN        |
| anti-overload ability   | 120%        |
| linear                  | ≤0.5%F.S.   |
| repeatability           | ≤0.5%F.S.   |
| resonance frequency     | ≥70kHz      |

4.2.3. Main technical indexes of MYDL-11 force sensor

The electric charge amplifier collected the signal from the force sensor and transferred it to match to data acquisition card. The main technical indexes were given in table 2.

Table 2. Main technical indexes.

| input          | voltage: ±10VP (maximum) | electric charge: ±106pC (maximum) |
|----------------|--------------------------|-----------------------------------|
| output         | voltage: ±10VP (maximum) | current: ±10mA (maximum)          |
| load impedance | ≥100Ω                    |                                   |
| noise          | ≤5μV                     |                                   |
| accuracy       | ±1%                      |                                   |

4.3. Temperature collecting

Because of the short penetrating time (2ms), high frequency (100kHz) and high temperature (1400°C), common temperature sensors and data acquisition system can not satisfy our requirements. The response time of typical platinum resistance temperature sensor is over ten seconds [4]. The response time of purple-copper-pipe-packaged, yellow-copper-pipe-packaged or stainless-packaged FBG fiber temperature sensor can only be 3.8s, 4.0s and 4.5s [5]. Infrared temperature sensor is a non-contact measurement sensor. Radiation measurement technology can measure the temperature through the corresponding relation between radiation energy and temperature [6] [7]. This sensor can quickly measure the high gradient temperature variety of penetrating moment. Its response time is only 6 μs, so it is very suitable for rapid detection field, such as explosive process detection, laser and welding, internal-combustion engine, plasma testing etc. The main technical indexes were given in table 3.

Table 3. Main technical indexes of temperature sensor.
| Measurement Range | Value          |
|-------------------|---------------|
| (160~1400) °C    |               |
| Output            | (4~20) mA or (0~10) V |
| Response time     | T95           |
| Current           | 9 μs          |
| Voltage           | 6 μs          |
| Uncertainty       | 0.75%         |
| Repeatability     | <0.3%         |
| Power Supply      | 24V DC        |

4.4. Software design

4.4.1. Developing platform

The software developing platform is LabVIEW 2017 profession. LabVIEW is a virtual instrument developing tool software hold by NI company [8]. It is a graphic programme language. It is accepted and used widely by industry field, academic field and universities. It is universally acknowledged as a standard data acquisition and instrument control software [9]. LabVIEW replaced traditional text programme code as flowchart program.

4.4.2. Working flow

Penetrating work flow was shown in figure 6. First started the high pressure pneumatic supply (100MPa pressed gas) which was the power of the projectile. At the same time started the controller. And then opened the high pressure valve, so the projectile started to move and accelerated until it arrived at the impact board. So the low-velocity penetrating started, the force, temperature and speed were collected, recorded, stored and analysed automatically. When force value<1kN, so closed the high pressure valve, high pressure pneumatic supply and controller. This was the end of penetrating process.
4.4.3. Penetrating simulation test

The whole penetrating process was simulated. Force, temperature and speed value curve was shown in figure 7. When penetrating started, speed value was down from 20m/s, force value was up from 0kN, temperature value was up from environment temperature, if there was an explosion, temperature would be about 1200℃, the whole penetrating process continued about 2ms.
5. Conclusion
The low-velocity penetrating equipment for high-energy explosive has been designed and manufactured. This equipment had the advantages: portable design was easy to measure and experiment on scene; force, temperature and speed signals were all collected and analysed; maximum acquisition frequency was 100Hz; all data were displayed, stored and analysed at real time. Based on the successful design and manufacture of low-velocity penetrating equipment, the technical base for imitating the projectile accident scenarios could be supplied, explosive safety researches and experiments could be performed, heat generation mechanisms of low-velocity penetrating for high-energy explosive could be demonstrated, a new way and method to determine whether such a penetrating impact can cause ignition and violent reaction could be approached.

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