Layout and Test of Stun Grenade of a Certain Mode

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Abstract. In this study, for the issues including the large size, poor safety, and lethality of fragments during the explosion of the stun grenade of a certain model, a new model of stun grenade was designed. The design concept of miniaturization, oval structure of the grenade body, lighting by serial dual time-delay tubes, and an additional ring pull locking buckle was adopted to effectively improve the safety of carrying; a simulation analysis of the stress distribution, force on thread, and pressure changes during the shear separation of the connection seat was conducted to verify the feasibility of the separation of the connection seat; the separation test for the connection seat, fracture test for the grenade body, and safety test for the fragments were conducted to verify the reliability and safety of the designed structure.

Keywords: Small Stun Grenade, Serial Dual Time-Delay Tubes, Shear Separation

1. Introduction
Stun grenade is a non-fatal bomb that produces strong sounds and dazzling flashes which cause temporary blindness and loss of strength for resistance as the grenade explodes [1-2]. It plays an important role in armed assaults, forced dispersal, etc. for emergency handling and social stability maintaining. Because of its powerfulness and excellent performance in repelling [3], it has been widely applied in national police forces. Therefore, the methods to further enhance its portability, safety, and non-lethality under the premise of ensuring its effectiveness have always been a topic attracting attention in grenade-related researches [4-5]. For instance, the Flashbang 7290 from the US [6] adopts the steel metal casing and does not produce any fragments during the explosion, which ensures its non-lethality and makes the grenade body recyclable, but increases the weight of the grenade, thus is inconvenient for carrying and throwing; the M84 Stun Grenade [7] also adopts steel casing, but due to the reduction in the size and weight, the intensity of flash is significantly reduced; the grenade body of the Type 241 Blinding Hand Grenade of Ruggieri from France, although using plastic material, also produces lethal fragments during explosion; the Type 241 Stun Grenade of Ruggieri adopts the prefabricated fragmentation to control the lethality the fragments.

Stun grenades with plastic casing produce more fragments during the explosion, and the entire lighting seat may be blasted, resulting in lethal consequences. In addition, the safety mechanism can be easily disabled by pulling off the pin, causing accidental lighting, leading to casualties.

To solve the above problems, in this study, the miniaturization design was carried out based on the shape of the stun grenade, the lighting mechanism, the safety mechanism, the explosive component,
the connection seat, etc.; the separation process of the connection seat was closely analyzed based on the simulation platform LS-DYNA; in the end, the safety and reliability of the designed grenade were verified by tests.

2. Structural Design
For easy grip and throwing, the small stun grenade was designed to be oval in shape, and a bumpy texture design was used in the middle part of the casing of the grenade to increase the friction for grip and prevent slippage, thus increasing the range and accuracy for throwing.

2.1. Design of the Lighting Mechanism and Safety Mechanism
At present, hand-cast anti-riot grenades generally adopt the flap-type needle-striking lighting and safety mechanisms [8]. To enhance the versatility of the components and reduce production costs, in this study, the main components of the lighting mechanism and the safety mechanism are all common parts. Meanwhile, in order to improve the safety of grenade for carrying, a ring pull locking buckle was added to the safety mechanism. When not in use, the safety pull ring is locked by the ring pull locking buckle. To ignite, the ring needs to rotate off the ring pull locking buckle for the safety pin to be pulled out, which implements the dual guarantee of the safety mechanism.

In this study, in addition to ignition and time delaying, the lighting mechanism was also designed with separation and lighting functions. It is designed with a primary separation ignition tube, the output end of which is loaded with the chamber opening agent that produces large amount of gas. After the ignition tube is ignited, the ignition chemical burns to produce gas of high temperature and high pressure, which then separates the connection seat from the explosive components and ignites the secondary time-delay igniter.

2.2. Design of the Explosive Component
The explosive component is the main part of the grenade. It must have sufficient strength to ensure that the structure is intact during the separation process; it must show no obvious deformation and cannot be destroyed upon explosion.

Among various plastic materials, ABS has good strength [9] that meets the requirement of the casing and ensures sufficient initial pressure during the explosion to achieve good flash and sound effects. Therefore, the explosive component designed in this study is injection molded from ABS material. Specifically, it consists of a casing and a load. The casing is composed of a secondary time-delay igniting body and a lower cover, wherein the secondary time-delay igniter is filled with a press-fitted load of time-delay gunpowder, and the lower cover is filled with flashing agent.

2.3. Design of Connection Seat
The connection seat is the joint of the lighting seat and the explosive component that connects the components as a whole. On the basis of ensuring the performance requirements of the grenade, it is necessary to minimize the joint strength and shear destructive force of the connection seat and the explosive component to ensure reliable separation of the two under the effect of high-pressure gunpowder gas. In addition, it is necessary to avoid separation or gas leakage from the joint of the connection seat and the lighting seat.

The ABS plastic adopted for the design [9] is for the material of the connection seat by injection molding. The connection seat is fitted with the explosive component and the lighting seat by threads. In order to achieve the joint strength requirements above, the upper and lower threads are of the same pitch, but the joint length of the upper thread and the lighting seat is much larger than the joint length of the lower thread and the explosive component. Meanwhile, epoxy glue is applied to the upper thread to further enhance the joint strength.

In summary, the working principle of the grenade is as follows. When throwing, the rotating pull ring is released from the ring pull locking buckle. After the safety pin is pulled out, under the effect of the torsion spring, the safety handle is detached, the plate with a needle is flapped, and the needle
strikes time-delay ignition tube for lighting. After time-delay, the primary separation ignition tube lights, producing gas of high temperature and high pressure. The connection seat and explosive component are separated by the gas. The gunpowder gas simultaneously ignites the ignition drug in the secondary time-delay igniter. After the second time-delay, the secondary time-delay igniting body lights up, stimulating flash agent to explode. The explosive component casing is then broken, producing a loud sound and a strong flash.

3. Analysis of Shear Separation Process of Connection Seat Based on LS-DYNA
The separation of the connection seat and the explosive component is driven by the impact of the explosion, which is essentially the elastoplastic dynamics of multi-material fluids. Among various platforms for finite element analysis, LS-DYNA has unique advantages in analyzing various nonlinear dynamic problems such as the explosion, structural shock, and impact [10-11]. In this study, the software was used as the simulation platform.

3.1. Establishment of Physical Model
In this study, since there was no need to consider the explosion of the secondary time-delay igniter, in order to simplify the calculation, only the models of the primary separation ignition tube chamber and the chamber opening agent were established.

i) Establishing a 2D model. As shown in Fig. 1, the purple part is the chamber opening agent and the pink part is the air. The threads were modeled according to the national standard thread specification, and the pitch was set to 1.5 mm.

![Figure 1. 2D model](image1)

ii) Generating a 1/4 3D model. As shown in Fig. 2.

![Figure 2. 3D model](image2)

3.2. Meshing
Since the grenade structure was symmetrical, the quadrilateral mesh helped to quickly build a mesh model, thus improving accuracy. In addition, map meshing was used. For the explosive component, in order to ensure the accuracy of the calculation, the mesh was made with a higher degree of fineness. The meshing is shown in Fig. 3.

![Figure 3. Meshing](image3)

3.3. Boundary Conditions and Contact Types
The threads were of surface-to-surface contact. In order to make the deformation of the threads more precise, the means of two-way contact search was adopted to search the penetration of the slave node and the master node.
Setting symmetric boundary conditions. That is, in the established coordinate system, the YZ plane was selected to apply the UX constraint, and the XY plane was selected to apply the UZ constraint (equivalent to the application of the symmetric boundary conditions of YZ and XY).

The shear separation of the connection seat involved three materials, i.e., chamber opening agent, air, and connection seat.

3.3.1 Chamber Opening Agent
The material model of 'MAT_HIGH_EXPLOSIVE_BURN was adopted, and the state equation 'EOS_JWL was adopted. The JWL equation of the state accurately describes the energy characteristics, pressure, and volume of the explosion-driven gas product. The parameters of state equation are shown in Tab 1.

| Parameters | A(GPa) | B(GPa) | R1  | R2  | ω  |
|------------|--------|--------|-----|-----|----|
| Values     | 2.95   | 0.019  | 4.85| 1.34| 0.51|

3.3.2. Air
'MAT_NULL was adopted for the material of the air, and the state equation 'EOS_LINEAR_POLYNOMIAL was adopted. The parameters are shown in Tab 2.

| Parameters | Density (kg/m³) | ρ  | c₄  | c₅  | e₀  |
|------------|-----------------|----|-----|-----|-----|
| Values     | 1.29            | 0.4| 0.4 | 2.5E6|

3.3.3. Connection Seat
'MAT_NULL was adopted for the connection seat. For the model of plastic material that solidifies with dynamics, the parameters are shown in Tab 3.

| Parameters | Density (kg/m³) | Elastic modulus (GPa) | Poisson’s ratio | Yield strength (MPa) |
|------------|-----------------|-----------------------|-----------------|---------------------|
| Values     | 1400            | 3.2                   | 0.319           | 63                  |

The ultimate plastic strain was set to 0.06.

3.4. Generating K file for solution
Since the connection seat was injection molded with the ABS material of high modulus of elasticity, excellent mechanical properties, and poor fluidity, when the gas produced by explosion of the primary time-delay gunpowder expanded rapidly in the connection seat, a large impact would be generated on the thread joint and the component strength perpendicular to the thread contact surface would reach the yield limit, which allowed the connection seat to be pulled off without major plastic deformation.

The yield criterion formula:

\[ f(\tilde{\varepsilon}) = c \]  \hspace{1cm} (1)

In the formula, \( c \) is only related to the nature of the material.

As

\[ \frac{F \cdot \sin \alpha}{S_0} > f(\tilde{\varepsilon}) \]  \hspace{1cm} (2)
The gunpowder gas of high temperature and high pressure blew off the connection seat to complete the separation. In the formula, \( F \) is the momentum of the gunpowder, \( \alpha \) is the slope of the thread, and \( S_0 \) is the area of force of the thread.

Considering that the duration of explosion is very short, the solution as was set to 0.4 ms, the number of solution steps was set to 400 steps, and the initial point of the explosive agent was set on the upper side of the axis of the explosive agent.

3.5. Analysis of Results

3.5.1. Analysis of the Separation Process of the Connection Seat

Fig 4 is a Mises stress cloud diagram of the separation process of the connection seat. It can be seen that during the separation, the connection seat and the grenade body were obviously deformed, but not destroyed. In addition, the joint threads of the connection seat and the explosive component were completely pulled off.

![Mises stress cloud diagram of the separation process of the connection seat](image)

**Figure 4.** Mises stress cloud diagram of the separation of connection seat

Since the gunpowder gas in the chamber had a back and forth impact on the connection seat and the explosive component, the top of the connection seat and the bottom of the explosive component showed obvious vibration. The speed change curve is shown in Fig. 5 and Fig. 6.

![Velocity-time curve at the top of the connection seat](image)

**Figure 5.** Velocity-time curve at the top of the connection seat

![Velocity-time curve at the bottom of the explosive component](image)

**Figure 6.** Velocity-time curve at the bottom of the explosive component

Due to the continuous impact of the wave from the chamber’s internal shock on the lighting seat and the grenade body, the explosive component had lower vibration frequency but a larger amplitude; its speed difference between positive and negative directions was as high as 40 m/s. The lighting seat had a higher vibration frequency and a smaller amplitude; its speed difference between the positive and negative directions was approximately 17.5 m/s.

3.5.2. Analysis of thread change
Figs 7 and 8 are the radial displacement-time curves of the internal and external threads, respectively.

![Figure 7](image-url) ![Figure 8](image-url)

**Figure 7.** Radial displacement-time curve of internal thread  
**Figure 8.** Radial displacement-time curve of external thread  

As can be seen from the above figure, when the gas in the chamber expanded, the thread joint of the connection seat also expanded to a certain extent, causing the connection seat to be pulled out. Corresponding to this process, the internal and external threads were also radially displaced with gas expansion. It can be seen that the pull-out process of the connection seat did not completely overcome the thread shear force and destroy the thread. Instead, with radial displacement, the actual shear force that must be overcome during the pull-out process should be less than the yield limit of the threads.

The Figs 9 below shows the deformation of the internal and external threads at t=0.24ms.

It can be seen that both the internal and external thread surfaces were plastically deformed to some extent due to the radial displacement, and the deformation of the external thread was more obvious, but there was no severe deformity damage, and it could still be used for the second time.

Internal and external thread pieces were selected to plot the Mises stress curve (Figs 10, 11).

![Figure 9](image-url)

**Figure 9.** Comparison of deformation of internal and external threads (t=0.24ms)

![Figure 10](image-url) ![Figure 11](image-url)

**Figure 10.** Mises stress curve of screw thread with time  
**Figure 11.** Mises stress curve of screw thread with time

The Mises stresses of the internal and external threads showed similar trends over time, but the maximum Mises stress of the external thread was 21.8 MPa, larger than the internal thread, indicating that the external thread was more stressed during pulling off, which further confirms the fact that the external thread surface was more plastically deformed than the internal thread surface.

### 3.5.3. Law of Pressure Change

The middle part of the chamber was selected to plot the pressure change curve (see Fig 12). It can be seen that due to the explosion of the agent, the internal pressure of the chamber rapidly increased to 1.35 MPa; then, due to the loss of energy during the impact, the chamber pressure was rapidly reduced to zero. At this point, the connection seat and the grenade body were completely pulled off.
4. Tests

4.1. Separation Test of the Connection Seat

In this study, to further verify the reliability of the separation of the connection seat, a weighted sand grenade was used as the explosive component for the grenade of the test. The connection seat separation test was carried out on the concrete surface and the mud surface with two fixing rods. The condition and distance of separation were tested. The results are shown in Tab 4.

| Test Ground        | Number of Grenade Pieces | Extent Of Separation   | Connection Seat Separation Distance (M) |
|--------------------|--------------------------|------------------------|----------------------------------------|
| Concrete surface   | 10                       | Complete separation    | Max 1.36 
|                    |                          |                        | Min 0.42 
|                    |                          |                        | Average 0.66 |
| Mud surface        | 10                       | Complete separation    | Max 1.12 
|                    |                          |                        | Min 0.39 
|                    |                          |                        | Average 0.52 |

The results show that the rate of separation was 100%, and the average distance of separation was less than 1 m on both the concrete surface and the mud surface.

4.2. Fracture Test on the Grenade Body

Grenade body fragmentation is another important factor affecting grenade’s lethality. Therefore, in this study, static bombing was adopted. The grenade was fixed on the station in the center of a closed space for bursting and detonating. The mass distribution of grenade fragments was recorded and analyzed, and compared with that of a hand-cast stun grenade. The statistical fragmentation results are shown in Tab 5.

| Fragment piece mass interval (g) | Hand-cast stun grenade Quantity | Average mass | Percentage (%) | Small stun grenade Quantity | Average mass | Percentage (%) |
|----------------------------------|--------------------------------|--------------|----------------|----------------------------|--------------|----------------|
| <0.3                             | 48                             | 0.16         | 44.4           | 39                         | 0.18         | 43.3           |
| 0.3-0.7                          | 15                             | 0.51         | 0.14           | 33                         | 0.49         | 36.7           |
| 0.7-1                            | 27                             | 0.81         | 0.25           | 18                         | 0.83         | 20             |
| 1-2                              | 15                             | 1.56         | 0.139          | 0                          | 0            | 0              |
| >2                               | 3                              | 6.52         | 0.03           | 0                          | 0            | 0              |

Percentage (%): the ratio of the number of fragments in a certain mass interval to the total number of fragments.

The results show that the lighting seat of the hand-cast stun grenade was not broken and remained intact. The mass of the remaining fragments was less than 2 grams; the average mass of the fragments of the small hand-cast stun grenade was less than 1 gram.
4.3. Safety Test of Fragmentation

To further assess the lethality of the fragment, in this study, by referring to GJB3287-98 [11], the lethality was judged by whether the fragments could penetrate the red pine board with a thickness of 25 mm, and the static explosion safety test was performed on 10 explosive components. The red pine boards were arranged in a fan shape and were 1 m away from the center. The test results show that the fragments produced by the explosive component failed to penetrate the 25 mm red pine board at 1 m from the center of the explosion, so it will not cause death to people beyond a distance of 1 m, and meets the requirements of a safety radius of 1m in the technical specifications.

5. Conclusion

1) Compared with the stun grenade of a certain model, of the small stun grenade, the weight is reduced from 125g to 76g, reducing by 39.2%, the length of the bullet is shortened from 122mm to 90mm, and the length is reduced by 26.2%, which solves the problem that grenade is large, inconvenient to carry, and not conducive to concealed use.

2) The small stun grenade adopts a serial dual time-delay tube structure. Compared with the single needle-striking time-delay tube structure, it greatly reduces the probability of grenade’s instant explosion (no time-delay), ensuring safe throwing, which is a prominent advantage in the design of the structure.

3) The explosion of the small stun grenade produces a maximum casing fragment weight of no more than 1 gram. The static explosion test showed that the fragment from explosion did not penetrate the pinewood board with a thickness of 25 mm at 1 m from the center of explosion, thus meeting the requirements of a safety radius of 1 m in the technical specifications for combat.

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