Research on technology of safety automatic particle forming equipment for pyrotechnic

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Abstract. Pyrotechnic agent was a sensitive energetic material that produces explosion and combustion effects of pyrotechnics. It plays a decisive role in the safety, reliability and effectiveness of the weapon system. Because the current pyrotechnic agent is sensitive to high temperature, mechanical impact, and friction, there are many unsafe factors in its manufacture and use. The demand of continuous, automatic and environmental protection production technology for pyrotechnics in China is increasing. The traditional sensitive explosive can not meet these requirements, so it is necessary to accelerate the development of sensitive explosive to safe and insensitive explosive. Therefore, in order to solve the key issues such as the safety and high-efficiency preparation of multi-component pyrotechnical agents, realize the environmental protection, safety and low-cost production of pyrotechnical agents. Based on the project design of a mixed propellant production system in an initiating explosive device factory, this research carried out the research on the safety automatic particle forming equipment for initiating explosive. It provides technical support for the innovation of weapons and equipment, and the upgrading of weapons and equipment manufacturing and production technology.

1. Introduction
The pyrotechnic agent is mainly used for igniting, burning or exploding pyrotechnic products, and is the energy source for igniting the pyrotechnics and detonating the firework. With the wide application of explosive effects in modern industry and civil industry, the requirements for pyrotechnics has gradually increased. As the core of the development of pyrotechnics, the particle formation of pyrotechnics is worth studying[1]. Nowadays, the production and preparation of multi-components pyrotechnical mixed composition mainly depends on manual methods, which has the problems of large number of operators, high labor intensity of workers, and low production efficiency. Most of the commonly used multi-components pyrotechnical mixed composition in production are powdered
products, which are easy to cause dust flying, environmental pollution, and waste of raw materials during the process of production and use. Most of the multi-components pyrotechnical mixed composition is composed of highly sensitive oxidant and metallic combustible agent, and it is easy to cause combustion or even explosion during the process of mechanical mixing and granulation, resulting in various degrees of personal injury and economic loss. In addition, the particle size of the multi-components pyrotechnical mixed composition affects the explosive velocity and sensitivity of the explosive. Changing the particle size can change the performance of the pyrotechnic device and provide more options for production, transportation, and storage. Therefore, granular pyrotechnic agent has an incomparable advantage over powdered pyrotechnic agent[3].

To sum up, it is necessary to develop a multi-component pyrotechnic agent mixed molding process and equipment automation. In response to the requirements of mixed molding preparation of multi-component pyrotechnic agents, the research and optimization of multi-component pyrotechnic agent mixed molding technology are carried out, and the development of multi-component explosive mixture particle molding process equipment is realized. On the basis of the existing technical conditions, the numerical control system and control program are developed, the special forming mold is designed, the reagent bearing apparatus is designed, and the reliable grounding and anti-static measures are designed for the whole machine to ensure the efficient, safe and reliable automatic particle forming of different components of initiating explosive.

2. Automatic manufacturing process of pyrotechnics

2.1. Summary
The product quality is affected by the mixing uniformity, solvent content, viscosity, particle size and other parameters during the preparation of multi-component pyrotechnic agents. In order to solve the problem of quality control of multi-component pyrotechnics and low yield caused by mismatching process parameters, it is necessary to carry out the research on Intelligent particle forming technology of pyrotechnics. In this study, the new technology is used to design a set of intelligent particle forming engineering prototype of initiating explosive, which can realize the uniform particle size shape of multi-component initiating explosive, so as to meet the requirements of environmental protection, high efficiency and safety in the production of pyrotechnic.

2.2. Technological process
Firstly, the measured adhesive (shellac paint or polyvinyl butyral alcohol solution) is automatically mixed; secondly, the mixed agent is subject to alcohol volatilization by stirring and blowing; finally, the particles of the mixed agent are automatically shaped to obtain the finished particles with a diameter of 0.5mm-0.9mm.

According to the processing technology of the mixed agent in the mixing process, the mechanical structure of the key equipment model is designed by 3D software, which can reduce the design and development cycle, save the design and development cost, and obtain the solid model with high reliability. The theory can be verified by the experimental equipment.

The system can be used to set the process parameters of raw materials and mixture of pyrotechnics in course of manufacture, and realize the integrated mixed processing process of man-machine isolation, ensure the safety of production, improve the efficiency and meet the requirements of quality control. This pyrotechnic production system is suitable for silicon series, tungsten series, magnesium series delay composition and ignition composition.
3. Development of intelligent particle forming system for pyrotechnic

3.1. Technology Program

The particle forming mechanism of mixed pyrotechnic agent is complicated, and the most basic process is the formation of agglomerated particles. The granule is formed by coating, sieving and drying. The principle of granulation is extrusion molding, which is mainly composed of "liquid bridges" formed by multiple particles through a binder [3].

The granulation mechanism of multi-component pyrotechnics mixture was studied, and the physical change process of multi-component pyrotechnics mixture granulation and the influencing factors of particle size were analyzed. The special numerical control system and control program are developed on the basis of the existing technical conditions, and the key technology research of forming granulation is carried out. Combined with the control analysis of specific forming granulation trajectory, the automatic production of pyrotechnics with stable particle size and properties is achieved, and the forming granulation process and prototype with high reliability and strong universality are realized.

Based on the test conditions of mixed propellant substitutes, further research on molding and granulation technology is carried out to achieve the best working parameters selection of different components of propellant, and the optimal granulation scheme optimization design of multi-component pyrotechnic propellant granulation was completed. The design scheme of intelligent particle forming system for mixed pyrotechnics is shown in Fig. 1.

![Fig. 1 Pyrotechnic intelligent particle forming system](image)

3.2. Mechanical system

The working principle of the intelligent particle forming system for mixed pyrotechnic composition is to extrude the composition from the barrel by extrusion, make the composition into strips of the same thickness through the sieve hole of the screen. At the same time, the barrel is moved laterally to cut the strip medicine into cylindrical medicine granules with uniform length. The particles are vibrated to drop and collected automatically after drying.

The whole set of equipment consists of a granulating screen accumulation device, a granulating screen X-axis servo shifting device, a granulating screen Y-axis servo shifting device, a granulating
screen Z-axis servo shifting device, a cold air drying device, and a knock-off device. Pharmaceutical particle collection and weighing device, collection tray shift device, granulation screen collection device, etc. The design of the whole set of equipment and the selection of accessories are in compliance with relevant safety standards and industry standards. The equipment can realize the safety and automatic granulation of multi-variety mixed medicines. The layout of each station of system is shown in Fig. 2.

The first station is the screen stacking station. Before production, the screen frame is manually installed into the guide rail of the upper screen mechanism by the operator. During production, the screen frame is successively dropped into the granulating track through a group of combined air cylinders.

The second station is granulation station. Six groups of cartridge filled with medicine are loaded manually. The cartridge is a material cartridge composed of rod and piston structure. The piston is equipped with a conductive rubber liner for extruding the mixing agent. The discharge cylinder drives the cartridge to move from 0° to 90° and the z-axis motion device is made of an electric push rod. When the discharge barrel is at 90° position, the electric push rod will extrude the medicament in the cartridge evenly without residual medicament. The cartridge moving device is composed of x-axis servo motion system and y-axis servo motion system. When the z-axis cartridge is extruded from the cartridge, the x-axis and y-axis motion system drives the screen to shear and pelletize.

The third station is the air drying station. After setting the working time according to the process requirements by an axial flow fan, the reagent particles on the screen are dried at room temperature.

The fourth station is the finished product collection station. The weight of the reagent particles is measured by the explosion-proof electronic scale. When the specified weight is reached, two pneumatic motors drive eight blanking rubber hammers on the cam mechanism respectively. At the same time, the reagent on the screen is knocked. After the particles are dried, the receiving bucket is used to collect them. After the collection is full, the rodless cylinder is used to drive the clamping cylinder to move the collecting plate out of the equipment, waiting for manual removal.

The fifth station is the screen collection station. The used screen frames enter the collection mechanism in sequence. A group of cylinders are used to clamp the two screen frames at the same time. The z-axis cylinder is used to drop the screen frame into the collection vehicle and wait for the collection vehicle to be removed manually.
The design complies with relevant national standards and quality control specifications, combines advanced automation technology at home and abroad, and uses advanced technology and high-tech devices to ensure continuous and reliable production lines. Such as the automatic control system adopts advanced industrial programmable controller (1756-171) to realize the automatic control of equipment. The main components are products of Rockwell, Turck, Schneider and other international famous companies, and the corresponding sensors are imported devices with reliable performance [4].

A variety of measures are used in safety design to ensure production safety. The electrical equipment on the production line is all explosion-proof equipment, and the explosion-proof grade reaches dⅡBT4. Each inductive input signal of the production line is input to the controller through the safety barrier to form the intrinsic safety control loop. The whole machine and its components are conductive connected, so that the equipment system, components (parts) and the grounding system can be reliably connected, leaving no isolated conductor, so that the static electricity can be effectively discharged; the interlocking of input and output signals is integrated in the control program of the equipment, so as to effectively prevent the occurrence of wrong action, ensure the reliability of process action, and eliminate the potential safety hazard

3.3. Technology Electrical control system

The electrical control system is mainly composed of Rockwell PLC and its extended function module, P + F safety barrier, Rockwell inverter, servo control system, intrinsically safe switch, temperature sensor, secondary instrument, time relay, intermediate relay, explosion-proof control button, explosion-proof indicator light, explosion-proof door control switch and other electrical components.

The console in the control room is equipped with control buttons, secondary instruments, time relays, indicator lights and other electrical components, which can control the remote start and stop operation of each station in the system. Remote setting and monitoring equipment operation time, speed, weighing weight and other process parameters. At the same time, the console has the functions of self-locking, interlock, fault alarm, upper and lower limit alarm of process parameters, error self-diagnosis, automatic stop, and timely display of equipment fault alarm information.

PLC and its extended function module, safety barrier, frequency converter, servo control system and other electrical components are installed in the electrical cabinet in the control room. Through the internal control program of PLC, the automatic production function of mixed pyrotechnics particle forming system in the designated area can be realized. The electrical control system configuration diagram is shown in Figure 3.

![Fig. 3 Schematic diagram of electrical control system configuration](image-url)
4. Design and calculation of the system
The working conditions of x-axis and y-axis displacement devices are as follows: the nut runs at a uniform speed \( v = 0.05 \text{m/s} \), the acceleration time \( T_1 = 3 \text{S} \), the deceleration time \( T_2 = 3 \text{S} \), the screw load \( F_1 = 200 \text{N} \), there is no other external force except the load in the horizontal direction of the screw, and the effective stroke of the driving servo motor is \( L_1 = 1 \text{m} \).

4.1. Screw speed check
Limit speed of screw rod [5]:
\[
[n] \leq \alpha \times \frac{60 \lambda^2}{2^{\frac{1}{2}} \eta} \sqrt{\frac{Eg}{rA}} = \frac{f}{L} \times 10^7 \tag{1}
\]
\( \lambda \): safety coefficient (\( \alpha = 0.8 \); \( E \): elasticity (\( E = 2.1 \times 10^4 \text{kgf/mm}^2 \)); \( l \): Minimum secondary moment of screw shaft section (\( l = \frac{\pi}{64} dr^4 \text{mm}^4 \)); \( dr \): diameter of screw shaft tooth base (\( dr = \text{mm} \)); \( g \): gravitational acceleration (\( g = 9.8 \times 10^3 \text{mm/s}^2 \)); \( r \): Material density (\( r = 7.8 \times 10^{-6} \text{kg/mm}^3 \)); \( A \): Area of screw shaft section (\( A = \frac{\pi}{4} dr^2 \text{mm}^2 \));
\( L \): installing distance (\( L = 1520 \text{mm} \)); \( f \): The coefficient determined according to the screw installation method (Fixed +support, \( f = 15.1, \lambda = 3.927 \))

Screw speed:
\[
[n] \leq \frac{60 \lambda^2}{2^{\frac{1}{2}} \eta} \sqrt{\frac{Eg}{rA}} = \frac{f}{L} \times 10^7 = 15.1 \times \frac{22.8}{1520^2} \times 10^7 = 1490 \text{rpm} \tag{2}
\]
Rotation speed used by screw: \( n = \frac{\omega}{\omega} = 600 \text{rpm} \)

4.2. Calibration and screw load
According to the manual of ball screw, Rated static load of ball screw pairofSFA2505Coa=4658kgf=45648.4N; Rated dynamic loadCa=1650kgf=16170N; Actual usage loadF1=200N<Ca.

4.3. Screw drive torque calculation
4.3.1. Load torque.
\[
TL = \frac{FPB}{2\pi \eta} = \frac{4 \times 0.005}{2 \times 0.14 \times 0.9} = 0.036 \text{Nm} \tag{4}
\]
Limit speed of screw rod:
\[
F: \text{Axial load}(F = FA + F1 (\sin \alpha + \mu \cos \alpha) = 4 \text{N}); \mu: \text{Friction coefficient}(\mu = 0.02); FA: \text{external force}(FA = 0); F1: \text{load}(F1 = 200 \text{N}); PB: \text{lead screw}(PB = 0.005 \text{M}); \eta: \text{Mechanical efficiency}(\eta = 0.9)
\]

4.3.2. Calculation of starting torque.Linear motion platform and load inertia:
\[
J_L = m \left( \frac{PB}{2\eta} \right)^2 = 0.1293 \times 10^{-4} \text{kgm}^2 \tag{5}
\]

Screw inertia:
\[
J_B = \frac{\pi}{32} rLBDB^4 \times 3.14 \times 7.8 \times 10^{-6} \times 1.52 \times 0.025^4 = 4.5817 \times 10^{-4} \text{kgm}^2 \tag{6}
\]

Inertia of coupling:
\[
J_C = \frac{1}{8} MCxDC^2 = \frac{1}{8} \times 0.0342 \times 0.289 \times 10^{-4} \text{kgm}^2 \tag{7}
\]

Total load inertia:
\[
J = J_L + J_B + J_C = 0.1293 \times 10^{-4} + 4.5817 \times 10^{-4} + 0.289 \times 10^{-4} = 5 \times 10^{-4} \text{kgm}^2 \tag{8}
\]
\( m \): Load mass (\( m = \frac{F1}{g} = \frac{200}{9.8} = 20.4 \text{kg} \)); \( PB \): lead screw (\( PB = 0.005 \text{M} \)); \( r \): Material density (\( r = 7.8 \times 10^{-6} \text{kgf/mm}^3 \)); \( LB \): screw length (\( LB = 1.52 \text{M} \)); \( DB \): screw diameter (\( DB = 0.025 \text{M} \)); \( MC \): mass of coupling (\( MC = 0.02 \text{kg} \)); \( DC \): diameter of coupling (\( DC = 0.034 \)).
4.3.3. Calculation of starting torque.

\[
TS = \frac{2m}{60t_1} \left( 2 \times 3.14 \times 100 \times (0.64 \times 10^{-4} + 5 \times 10^{-4}) \right)
\]

\[
J_m: \text{Inertia of motor rotor (} J_m = 0.64 \times 10^{-4} \text{kgm}^2) \]

\[
T = (T_k + T_g) \times S = (0.0036 + 0.012) \times 1.5 = 0.0234 \text{Nm} (S=1.5)
\]

(9)

(10)

4.3.4. Calculation of shaft end strength. Minimum machining diameter of screw shaft end of SFA2505d=17mm

Maximum torque:

\[
[T] \leq \frac{\sigma [\sigma] \times 0.017 \times 55 \times 10^6}{5} = 54.043 \text{Nm}
\]

\([\sigma]: \text{yield Strength of Materials ([} \sigma] = 55 \times 10^6 \text{Pa}); T < [T]
\]

(11)

5. Conclusion

In this paper, through the research and development of automatic particle forming equipment for pyrotechnics safety, from manual and semi-automatic production to fully automatic man-machine isolation production, the automatic granulation production of multi-component high-energy pyrotechnics is realized, and the production efficiency is improved.

The equipment can be used in the production of tungsten series, magnesium series, boron series, zirconium series delay composition, ignition composition, etc. It can not only increase the power of the composition particles, but also enhance the safety level to meet the index requirements. In view of the incomparable advantages of granular multi-component high-energy pyrotechnic composition over powder pyrotechnic composition, the research on granulation technology of mixed pyrotechnic composition conforms to the development trend and needs of the times.

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