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Design of Rapid Cooling Ejection Device for Biological Samples

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Abstract

A test bench for ultra-fast cooling of biological samples in ultra-low temperature cooling medium is designed. In order to systematically study the dynamic process of small biological samples at the microscopic scale, through the triggering control of the catapult, the small samples are ejected into the cryogenic liquid nitrogen at a very high initial velocity, so that the ejection of small samples can be carried out infinitely. Speed regulation. The spring-loaded catapult uses collision contact to eject a small sample carrier into the supercooled liquid nitrogen at a certain initial speed, and conducts motion simulation and data analysis on the test device.

Keywords

Rapid cooling; Catapult; Cryogenic liquid nitrogen; Stepless speed regulation.

1. Introduction

Rapid cooling has a wide range of applications in the vitrification preservation of small biological samples in a low-temperature environment, fixation under an electron microscope, and the preparation of new materials such as amorphous or microcrystalline materials. The rapid cooling process of small biological samples has the characteristics of small sample size, fast movement speed, and rapid temperature drop (from normal temperature to minus 200°C) in a very short time (millisecond level) [1]. How to systematically study the dynamic process of small biological samples at the microscopic scale has always been a concern of cryogenic engineering research. Due to the limitations of equipment and small samples, the design of the catapult needs to solve the following problems:

(1) Higher ejection speed is required;

(2) The ejection device is small in scale and can realize stepless speed regulation.

The solution to the problem:

(1) Adopt a spring-type ejector to obtain sufficient ejection speed through the characteristics of the spring itself and the amount of compression of the spring;

(2) Using the principle of spiral amplification, the structure adopts adjusting nuts to realize stepless speed regulation.

2. The structure design of the catapult

As shown in Figure 1, the ejection device adopts a collision type ejection, and the front end of the ejection rod is used as a striker. In order to improve the stability of the spring, the power spring is sleeved on the ejection rod, and the ejection rod functions as a guide rod. The shell of the catapult adopts a three-stage connection of tailstock, upper sleeve and lower sleeve, and a window is opened in the lower sleeve[2]. The main purpose of the three-stage connection is to facilitate the installation and disassembly of the spring, guide sleeve, and fine-tuning nut. A window is opened in the lower sleeve. The position of the window is the position of the fine-tuning nut, which is convenient for

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manual adjustment of the fine-tuning nut. In the design of braking and shock absorption of the catapult, the catapult rod is a slender rod, and the tensile stress is obviously better than the compressive stress. In braking, tension braking should be used, and a rubber block is provided at the tail of the catapult for impact braking. In order to improve the stability of the system during a collision, a shock-absorbing spring is provided at the front end of the ejection rod to absorb a part of the energy before the impact and reduce the impact of the ejection rod on the system during braking.

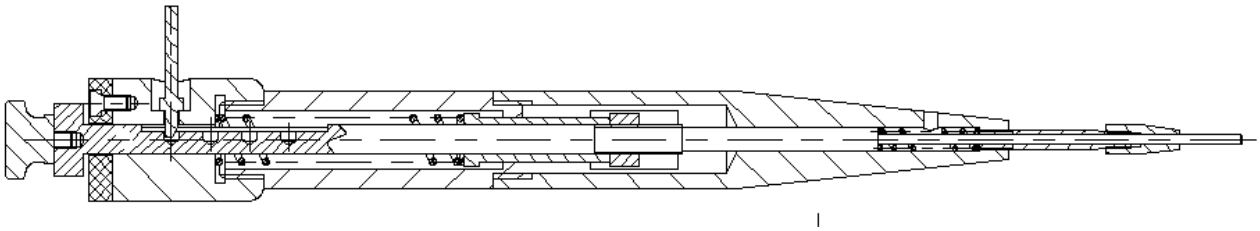

Figure 1. Schematic diagram of the catapult project

This paper proposes the design of stepless speed regulation in different gears. The specific plan is as follows: According to the speed range and the working stroke of the spring, the working stroke of the spring is divided into 3 ranges (four gears), and the adjustment nut is designed as a fine-tooth fine-tuning nut, so that the fine-tuning range covers the gear distribution and achieves continuous speed , Stepless speed regulation is divided into gears. The tongue-shaped lock is connected by the trigger system. The advantage of the tongue-shaped lock is that the ejection rod can only move in one direction. This will not only ensure that the ejection rod can be lifted up to reach each hole, but also can prevent the ejection rod from sliding down (locking). In addition, the trigger lever can be triggered manually by a mechanical type, or can be triggered by an electromagnet. To prevent the ejection rod from rotating and the hole position cannot correspond to the tongue-shaped lock head, a guide groove is provided on the ejection rod. In order to improve the stability of the ejection, a needle sleeve is designed at the front end of the ejector to play a guiding role. A safety lock nut is designed at the front end of the needle sleeve. When the ejector is not working, use the lock nut to lock the ejection rod.

3. Design calculation of power spring

The test device designed in this paper is to systematically study the dynamic process of small biological samples at the microscopic scale. The key is the design of the power spring. The test device must provide sufficient power.

3.1 The spring's elasticity coefficient

According to the elastic potential energy equation $E = \frac{1}{2}k\chi^2$,and the kinetic energy theorem $U = \frac{1}{2}mv^2$, the energy conversion at the moment of collision E=U. so: $k = \frac{mv^2}{\chi^2}$.

3.2 Spring design requirements and original conditions

Maximum load when the spring is working $P_m = k\chi$;

Minimum load when the spring is working $P_{\min} = 0\ N$.

Spring categories: catapult work frequency is not very high, the spring under cyclic loading generally in the following, should choose the Ⅲ spring class load.

End structure: For the stability of fine-tuning and the accuracy of ejection, the end face can be ground and tightened, and the support ring is designed as one ring.

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Spring material: Grade C carbon steel wire material is selected according to the working environment and working load [3].

3.3 Spring related parameters

Initial calculation of spring stiffness $P' = \frac{P_m - P_{\min}}{h}$;

Working limit load P1: the number of static load or cyclic load is less than 103, the class III load spring is selected, then $P_1 \geq P_m$.

Spring diameter d, middle diameter D, allowable stress τ_p, single-turn stiffness P_d', single-turn deformation f1, maximum spindle diameter Dmax, minimum spindle diameter Dmin. As shown in Table 1.

Table 1. Compression spring calculation table

d(mm)	D(mm)	τp(MPa)	P1(N)
1.0	8	980	40.63
f1(mm)	Pd′ (N▪mm-1)	Dmax(mm)	Dmin(mm)
2.106	19.3	7	11

3.4 Spring stability check

If the ratio b of the height of the compression spring to the diameter is relatively large, when the axial working load increases to a certain value, the spring will bend in the lateral direction, causing the spring to lose its stability[4]. In order to ensure the normal use of the spring, the ratio b of the height to the diameter of the spring is required to meet the following requirements when designing the spring:

(1) Free rotation at both ends: $b \leq 2.6$;

(2) One end fixed, one end rotating: $b \leq 3.7$;

(3) Fixed at both ends: $b \leq 5.3$.

When the ratio b of the height to the diameter of the compression spring is larger than the above value, it should be checked according to the following formula:

$$P_c = C_B P' H_0 > P_n$$

Critical load of spring P_c, instability coefficient C_B [5].

4. Kinematics simulation of catapult

In order to more clearly design the operating state of the device, the non-moving parts are set as fixed links, the moving parts are defined as movable links, and the trigger rod, ejection rod, power spring, small sample and their solid connected parts are defined It is a movable link. Then define the movement relationship (motion pair) of each movable link, and define the ejection rod, trigger rod, and small sample as the sliding pair [6]. Because UG motion simulation defaults that all links are rigid links, it is impossible to simulate the compression process of the spring. Here, the spring connector can be set to display the spring motion symbol. After defining the connecting rod, define the driving mode. The main motions include pulling the ejection rod up and down, the triggering reset motion of the trigger rod, and the ejection motion of a small sample. Here you need to apply the step function (time displacement equation).

The step equation of trigger device: STEP(time, 0, 0, 0.5, 2) +STEP (time, 2, 0, 2.1, -2) +STEP (time, 4.5, 0, 4.55, 2) +STEP (time, 5, 0, 5.01, -2) +STEP (time, 6, 0, 6.5, 2) +STEP (time, 8, 0, 8.01, -2) +STEP (time, 8.05,0,8.3, 2) +STEP (time, 10, 0, 10.1, -2) +STEP (time, 12, 0, 12.05, +2) +STEP (time, 12.1, 0, 12.15, -2).

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The time-displacement curve is shown in Figure 2:

Figure 2. Trigger time-displacement curve

The step equation of the ejection rod: STEP (time, 0, 0, 2, 8) +STEP (time, 4.5, 0, 4.6, -8) +STEP (time, 6, 0, 10, 16) +STEP (time,12, 0, 12.1, -16).

The time-displacement curve is shown in Figure 3:

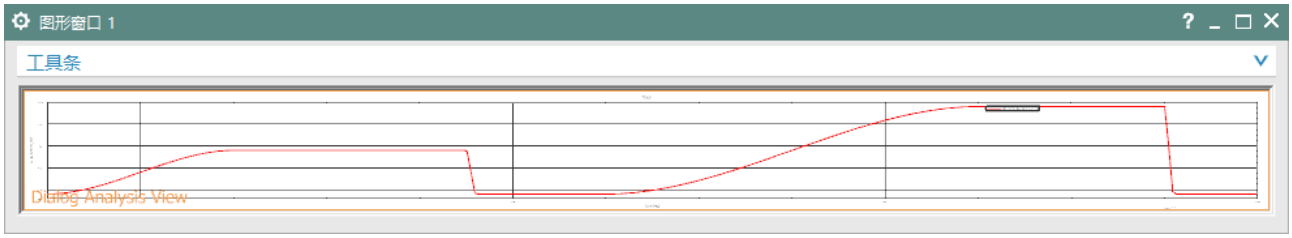

Figure 3. Ejection lever time-displacement curve

The step equation of the sample: STEP (time, 4.6, 0, 4.7, 43.681) +STEP (time, 6.5,0, 8, -43.681) +STEP (time, 12.1, 0, 12.2,43.681).

The time-displacement curve is shown in Figure 4:

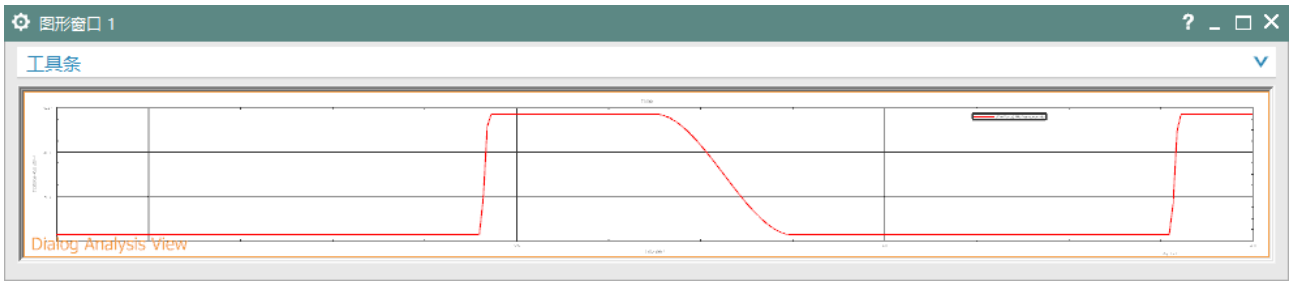

Figure 4. Sample time-displacement curve

Solution selection is often 13s, with 300 steps, and other default values. Then click solve. After solving, you can choose to click animation to view the motion form. The step function used in this paper simulates the motion, but only the motion form (displacement change based on time change).

The significance of this simulation is to understand whether the motion form of the ejection mechanism can meet the actual motion demand, verify whether the mechanism design is reasonable by motion simulation, verify whether there is interference in the ejection process, etc., so as to improve the reliability of the design, and optimize the design of the mechanism by motion simulation.

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5. Conclusion

The size of biological samples is small, so the cooling rate should be fast enough and the temperature should be low enough. By designing special catapult spring, the immersion rate of small samples can be improved, and the cooling rate can be improved. The ejection device realizes that the ejection speed can be adjusted in a wide range, the structure is simple, the cost is low, and the driving mode is very simple.

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