Study of needle seeding machine vibration system

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Abstract. Make analysis of the vibration system in the needle tray seeder and make plate’s vibration simplified as a single degree of freedom spring damping system under harmonic excitation forced vibration. Get the amplitude frequency characteristics of plate vibration. Make analysis of seed vibrating in the air, get the condition that seeds to be absorbed.

1. Introduction

Industrial seedling rearing is a new breeding technology that developed in 1960s and precision seeder is the key technology. Because of the advantages of saving seeds, not to hurt the root, seeding tidily, manageable and increasing production, tray seedling becomes the main means of industrial seedling.

Foreign researched on precision seeding from 1960s, for example, some famous companies, the Visser company from Holland, The Hamilton company from British and the Williames company from Australia and so on. In the initial stage, mainly study the mechanical sowing machine, Pneumatic seeder appeared in the early seventy's and now air-aspiration type is widely used. With the development of science and technology, hydraulic technology, pneumatic technology and electronic technology were applied to precision seeding equipment. The efficiency and the precision are improved. In recent years, research direction of precision seeding in foreign countries has shifted from the structure of the seeder to new seeding theory. And put forward some new seeding theory, such as fluid seeding and static seeding. In China, research on precision seeding technology started relatively late. The introduction of foreign technology began in late 1970s, mainly studied the tray precision seeding technology. And electromagnetic vibration precision seeder and vibrational air suction precision seeder were developed in 1990s. Although the tray precision seeding technology gets more and more attention, the problems of low efficiency and poor ability of adaption made that the utilization rate is not high in the actual. Therefore, the development of seeding equipment that can meet the needs of China has important practical significance to promote the industrial seedling technology in our country.

2. Classification of precision seeder

According to the working principle, Precision seeding machine can be divided into mechanical seeder, magnetic seeder and pneumatic seeder. The mechanical seeder’s structure is simple and has the advantage of, low cost, but the single grain sowing effect is bad, not suitable for precision seeding. The pneumatic seeder is divided into gas suction seeder and blowing seeder. Now the air suction type seeder is widely used.
It produces pressure difference by vacuum to adsorb seeds. It’s suitable for precision seeding and the seeds’ damage rate is low. According to the seeding form, the air suction type seeder can be divided into plate-type, needle type and Roller type, this paper discusses the vibration system in needle tray seeder.

3. The electromagnetic vibration exciter
When the seed resting on the plate, it’s mechanical properties is similar with granular material, and it’s characteristic was between solid material and liquid material. It’s not easy to be absorbed. In order to improve the adsorption properties of seed, the vibration exciter is used to make seeds remain vibration state. The adsorption performance of seeds is improved.

![Diagram of electromagnetic exciter structure](image)

**Figure 1.** Diagram of electromagnetic exciter structure

The electromagnetic vibration exciter structure is shown in Fig 1. It mainly consists of spring, shell, magnetic steel, flat, iron core and the drive coil. The working principle is that alternating current imports into coils in the magnetic field, Inductance stress produced by coils drive flat to vibration. Through vibration table control system and sensor signal feedback, Controllable vibration is produced. The vibration frequency has to do with voltage. So the amplitude and frequency of vibration can be controlled by regulating the voltage. When the input voltage is sinusoidal, the exciting force F is:

\[
F = \frac{1}{\mu_0 A_0} \left[ \frac{N_0 V_m \cos (2\pi\omega t)}{2\pi L_0 R_m \omega} \right]^2
\]

Among them, \(\mu_0\) — Permeability of vacuum; \(A_0\) — area of the Electromagnetic air gap; \(V_m\) — The amplitude of voltage; \(N_0\) — turns of the electromagnet coil; \(L_0\) — inductance of the electromagnet coil; \(R_m\) — Electromagnet reluctance; \(t\) — time; \(\omega\) — Excitation frequency.

4. Analysis of plate vibration system
The seeds’ vibration is produced by the vibrating plate, Plate vibration system belongs to the mechanical vibration system. Vibration plate can be regarded as forced vibration of single degree of freedom. The mechanical model of vibration plate vibration system as shown in Figure 2.
In harmonic exciting force, $F = F_0 \cos(\omega t + \varphi)$, the motion equations of the system is:

$$m\ddot{x} + c\dot{x} + kx = F_0 \cos(\omega t + \varphi) \quad (2)$$

Make that: $2\xi\omega_n = 2\alpha = \frac{c}{m}, \omega_n^2 = \frac{k}{m}, h = \frac{F_0}{m}, B = \frac{\delta_{st}}{\sqrt{(1-\lambda^2)^2 + 4\xi^2\lambda^2}}, \theta = \arctan \frac{2\xi\lambda}{1-\lambda^2}, \lambda = \frac{\omega}{\omega_n}, \delta_{st} = \frac{F_0}{k}$

The equation can be written as:

$$\ddot{x} + 2\xi\omega_n\dot{x} + \omega_n^2 x = h \cos(\omega t + \varphi) \quad (3)$$

The general solution of differential equation is:

$$x_1 = e^{-\xi\omega_n t}(C_1 \cos \omega_d t + C_2 \sin \omega_d t) \quad (4)$$

The special solution is:

$$x_2 = B \cos(\omega t + \varphi - \theta) \quad (5)$$

Among them, B—amplitude in the forced vibration, $\theta$—The phase difference between the forced vibration response and excitation force, $\delta_{st}$—static deformation, $\lambda$—vibration frequency and natural frequency ratio, $\omega$—The working frequency of vibration exciter, $\omega_n$—natural frequency of the vibration, $k$—spring rate, $c$—damp, $\xi$—damping ratio.

Make the initial conditions of vibration system as $x(0) = x_0, \dot{x}(0) = v_0$, the full solution of equation is:

$$x = B \cos(\omega t + \varphi - \theta) + e^{-\xi\omega_n t}\left(x_0 \cos \omega_d t + \frac{v_0 + \xi\omega_n x_0}{\omega_d} \sin \omega_d t\right)$$

$$-Be^{-\xi\omega_n t}\left[\cos(\varphi - \theta) \cos \omega_d t + \frac{\xi\omega_n \cos(\varphi - \theta) - \omega \sin(\varphi - \theta)}{\omega_d} \sin \omega_d t\right]$$

(6)
Formula 3.5 is seed plate’s complete response in harmonic excitation, which consists of three parts. The first is plate’s steady-state harmonic vibration. Its frequency is equal to the frequency of exciting force, while the phase lags angle $\theta$ than the exciting force. The second is damped free vibration, independent of the excitation force. It depends on the initial conditions of the system. The third one is the accompanying free movement. The amplitude has to do with the exciting force. Through formula 3.5 we can make the analysis that because of the damping, free vibration and accompanying free vibration will disappear as time passes, and finally only steady forced vibration $x = B \cos(\omega t + \varphi - \theta)$, survives. Make a further discussion about it. Let $\beta = \frac{1}{\sqrt{(1-\lambda^2)^2 + 4\xi^2\lambda^2}}$, so the formula $B = \frac{\delta_{st}}{\sqrt{(1-\lambda^2)^2 + 4\xi^2\lambda^2}}$ can be written as $B = \beta \delta_{st}$. $\beta$ is the coefficient of dynamic magnification. It’s the function of two variables, frequency ratio and damping ratio. If make the damping ratio as parameter, you can draw $\beta - \lambda$ curves, as shown in Fig 3.

![Figure 3. Amplitude-frequency characteristics of the plate’s vibration](image)

As can be seen from the graph, plate’s vibration is concerned with both vibration parameters and structure of the system, and it has following characteristics:

When $\lambda \ll 1$, the vibration frequency is far less than the natural frequencies and $\beta$, coefficient of dynamic magnification, is close to 1. $B$, amplitude, is equal to $\delta_{st}$, static deformation. The plate’s amplitude is proportional to the exciting force and is inversely proportional to the system’s stiffness.

When $\lambda \approx 1$, the vibration frequency is close to the natural frequency. $\xi$, damping ratio, has great influence on $\beta$, coefficient of dynamic magnification. When damping increases, amplitude decreases. In the range of $\lambda \approx 1$, a smaller electromagnetic force can make large amplitude.

When $\lambda \gg 1$, the vibration frequency is higher than the natural frequency. As the exciter frequency is big, the vibration direction changes rapidly. Plate’s displacement is too late to change, so no matter how big the electromagnetic force is, the plate can only get very small amplitude.

Damping effects the vibration characteristics only in the Resonance range, that is, the range where the Vibration exciter’s frequency is close to the natural frequency. As you can see from Figure 3, when
\( \lambda \ll 1 \) or \( \lambda \gg 1 \), \( \beta \) curve is more intensive and has little change. So in this case, we can take it as the undamped condition.

In above, plate’s vibration frequency depends on the frequency of electromagnetic vibration exciter. The amplitude of plate’s forced vibration is influence by the exciting force, Excitation frequency, Vibration system’s stiffness, quality and the damping of system. Take the vibration system’s quality into consideration, mainly the Vibration system performance’s stability influenced by seed weight’s change. Usually, reduce the impact on the plate’s vibration by increasing the system rigidity, reduce the system natural frequency and the frequency ratio.

5. Vibration of seeds

Under the action of plate’s vibration, Seeds remain vibration state, reducing the friction among each other and easy to be adsorbed. But different seeds have different shape, size and the basic characteristics of other materials and parameters are also different, in addition to impact and collision among seeds. The seed’s force and motion state is very complicated and It is difficult to accurately analyze the specific movement of seeds. Therefore, only makes the theoretical hypothesis and make less error on the basis. Now analysis the single seed that keep vibrating:

Here is a force diagram when Seeds remain vibration in the air:

![Figure 4. Force diagram for seed.](image)

Seeds remain vibrating in the air, acted on by three forces. They are Adsorption force acts on the seed \( F \), the buoyancy of the air \( F_1 \) and The seed itself gravity \( G \)

\[
F = \frac{1}{2} \rho_1 C Sv^2
\]

\[
F_1 = \rho_1 g V_2
\]

\[
G = \rho_2 g V_2
\]

Among them, \( \rho_1 \) — The density of air, \( C \) — coefficient of drag, \( S \) — front face area, \( v \) — velocity of seed, \( \rho_2 \) — The density of seed, \( V_2 \) — Volume of seed.

In order to make the seeds remain in the air without falling, its force shall meet the following conditions:

\[
F_1 + F \sin \alpha \geq G
\]
The buoyant force is small, can be neglected, so it is:

$$\frac{1}{2} \rho_i C S v^2 \sin \alpha \geq \rho_s g V_z$$  \hspace{1cm} (9)$$

For spherical seeds, suppose its Radius is \(r\), so seed area is \(\frac{1}{2} \pi r^2\) and \(S = \frac{1}{8} \pi r^2\). Accordingly, seed volume can be estimated to be \(\frac{4}{3} \pi r^3\). So there is:

$$\frac{1}{2} \rho_i C \frac{1}{8} \pi r^2 v^2 \sin \alpha \geq \rho_s g \frac{4}{3} \pi r^3$$

$$v^2 \geq \frac{64}{3} \frac{rg\rho_s}{\rho_i C \sin \alpha}$$

$$v \geq \sqrt{\frac{64rg\rho_s}{3\rho_i C \sin \alpha}}$$  \hspace{1cm} (10)$$

We can get the conclusion: as long as the adsorption velocity is greater than \(v\), seeds can be adsorbed.

6. Conclusions

Make analysis of the vibration system in the needle tray seeder, introduces the working principle of electromagnetic vibration exciter and make plate’s vibration simplified as a single degree of freedom spring damping system under harmonic excitation forced vibration. Get the amplitude frequency characteristics of plate vibration. Through the force analysis of seed vibrating in the air, get the condition that seeds to be absorbed by the gas needle. Lay the foundation for further analysis of seed movement.

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