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A Theoretical Substantiation of a Grain Cleaner with a Compound Motion of the Operating Device

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ABSTRACT

The agrarian complex is an important part of the economy of a state that provides food to the population. Grain cleaners are an important part of this complex; however, most of them have already exceeded their working life. Necessary quality in grain processing is achieved via multiple passes through the processing line. This situation increases grain loss, causes grain damage, and increases the cost of postharvest handling. The drawback of these machines is that they use a sieve with a crank gear, which reduces the quality of grain cleaning. It is possible to improve the effectiveness of sieves by using a sun and planet gear. The research investigates the characteristics of a grain cleaner with a sun and planet gear, which was designed at the S. Seifullin Kazakh Agrotechnical University Mechanical Engineering Department. A set of complementary methods (including analysis, design, and mathematical modeling) was used to achieve the set goal. A system of first order differential equations and their transformation into logarithmic spiral equations was investigated. The mechanism under consideration significantly increases effectiveness due to the lack of alternating stress, which enables increasing the angular velocity.

KEYWORDS
Grain cleaner, alternating motion of sieves, sieve with sun and planet motion, logarithmic spiral equation, seed processing

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Introduction

Grain production is a crucial area of the agro-technical complex; it has the biggest impact on the supply of food to the population and the development of forage resources for several branches of the agro-industrial complex (Bilde, 2015; Matveev, Valieva, Kislov, & Trubetskaya, 2016; Sheidler, Musser, Finamore, & Teijido, 2014).

One of the most labor-intensive and important operations in grain production is its postharvest primary (to the basic conditions of industrial grain) and seed cleaning (Bilde, 2015; Sheidler et al., 2014; Stan & Linde, 2014).

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However, flaws in the design and wear of the main equipment prevents farms from conducting postharvest handling properly and in a timely fashion.

Outdated grain cleaners have been replaced by new ones for many years, since no significant progress has been made in the design of new efficient grain cleaners of local manufacture or the development of improved grain cleaning techniques (Liang, Li, Xu, & Zhao, 2016; Mingjie, Wei, & Jianguo, 2012; Stahl, 2015). Therefore, farms lack efficient grain cleaners, which causes significant damage due to loss of grain during postharvest processing, even with high crop yields.

One of the crucial problems facing manufacturers of competitive grain cleaners is the substantiation of rational designs and equipment for current technologies of cleaning and separation of grain seeds, which would achieve good results at minimum cost; in the future, this will ensure that efficient agricultural machinery for postharvest handling of grain are designed and manufactured (Bischoff, 2015; Claerhout, 2015; Johnson, Rizzo, Schmidt, Stott, & Unrau, 2015).

Presently, the creation of new machines is mostly aimed at improving conventional principles, making basic constructions more complex, and increasing their specific amount of metal and energy-intensity, which does not improve their technological reliability and specific indexes of their performance standard (Bayhugulova, Sh.K. Eskhozhin & Capov, 2015; Jing, 2013; Capov & Shepelev, 2010b). This is because existing conventional methods of development and design of production processes and equipment (grain cleaners and processing lines) are based on a traditional sequence of processing steps and the use of existing basic machines. It is impossible to improve postharvest cleaning and separation of grain without implementing advanced technologies and creating next-generation grain cleaners (Eskhozhin & Bayshugulova, 2015; Capov & Shepelev, 2010a; Linenk, Tuktarov, & Akruchin, 2012).

Therefore, it is necessary to solve the problem at hand by optimizing the rational set of particular operations and parameters of grain cleaners that determine the sequential and step-by-step efficient cleaning schemes. They should ensure the achievement of set indexes while minimizing the total reduced cost of cleaning and production.

Aim of the Study

This study aims to investigate the characteristics of a grain cleaner that was designed at the S. Seifullin Kazakh Agrotechnical University Mechanical Engineering Department.

Research question

What allows sieves to achieve high angular velocities?

Method

The theoretical and methodological framework of the research includes the theory of regulation of sustainable development of agrarian production under diverse business patterns and integrative development of agricultural companies, as well as studies of Kazakh and foreign specialists in agrarian production and mechanical engineering.

The research took the abstract-logical and analytical approach and used methods of design, optimization, and mathematical modeling of production processes.

Data, Analysis, and Results

One of the crucial features of modern grain cleaners is the alternating motion of their sieves, which generates alternating stress on the drive and driven shafts, the housing of the sieve boot, and the chassis of the grain cleaner. This stress reduces the durability of parts and the reliability of the machine in general, requires massive counterweights, and increases the metal and energy rate (Capov & Shepelev, 2010a). A new principle of grain cleaning and separation is offered to solve this problem. The goal of the offered theoretical principle is to improve the performance of grain cleaners through compound motion of the operating device. This is achieved by replacing the crank gear with the sun and planet gear (Capov & Shepelev, 2010b).

The offered machine was designed at the S. Seifullin Kazakh Agrotechnical University Mechanical Engineering Department (Figure 1). An innovation patent was received for the machine (Bayhugulova, Sh.K. Eskhozhin & Capov, 2015).

Figure 1. Operating devices of the grain cleaner

The purpose of the machine is to improve the quality of grain mixture separation and the performance of the operating sieve, which is achieved by avoiding alternating stress and centrifugal load thereon (Bayshugulova, Eskozhin, & Carov, 2015).

The flowchart of the sieve with a sun and planet motion is presented in Figure 2. Planet holder 1 rotates axis of sieve 0_1 at an angular velocity of ω around center 0. Satellite 3, which envelops sun gear 4, is mounted on the axis of sieve 2, while sieve 2 rotates around center 0_1. Grain enters the sieve from bowl 5.

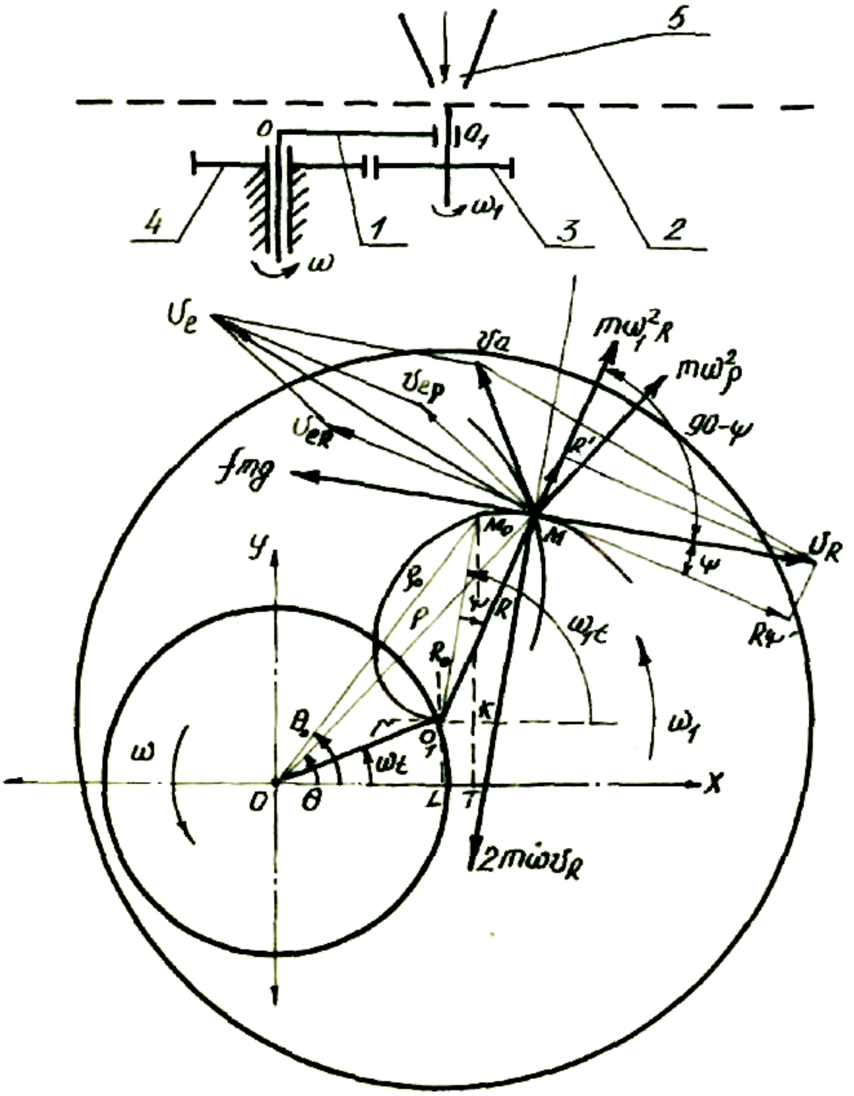

Figure 2. Sieves with a sun and planet motion.

The motion equation for sieve point M_0 was calculated from the following equations:

$X = OL + LT$

$Y = O_1L + M_0K$

From which it follows that

$X = r\cos\omega t + R_0\cos\eta\omega\, t,$
$Y = r\sin\omega t + R_0\sin\eta\omega t.$ (1)

$\rho = \sqrt{r^2 + R_0^2 + 2rR_0\cos(1-\eta)\omega t}\,;$

$tg\theta_0 = \dfrac{r\sin\omega t + R_0^2 + 2rR_0\cos(1-\eta)\omega t}{r\cos\omega t + R\cos\eta\omega t}.$ (3)

$\frac{\omega_1}{\omega} = \eta$ is the coefficient that characterizes the planet holder angular velocity to sieve angular velocity ratio.

Consider a material point (grain) located in the sieve in a sun and planet motion. Without relative motion, material point M together with the sieve ends up in position M_0 after t time. However, due to the relative motion, while slipping across the sieve, it will move to position M at the same time.

The following designations are introduced:

V_{er} is the velocity of the point in transitional motion in regards to point 0_1;
$V_{e\rho}$ is the velocity of the point in transitional motion in regards to point 0;
V_e is the transitional velocity of point M_1;
V_R is the transitional velocity of point M;
R' is the radial component of relative velocity;
R_φ is the tangential component of relative velocity;
V_a is the absolute velocity of the material point;
$\prec = \mathrm{M_0 0_1 M}$ is the relative slip angle;
$m\omega_1^2 R$ is the centrifugal force of transitional motion around point 0_1;
$m\omega^2\rho$ is the centrifugal force of transitional motion around point 0;
$2m\omega' V_R$ is the Coriolis force;
fmg is the frictional force;
$\omega' = (\omega + \omega_1)$ is the total angular velocity at point M.

Based on the figure, the assumption is that the angle between the relative velocity and its tangential component is approximately equal to the relative slip angle.

At 00_1M: $\prec 0_1 = [90 - (\omega_1 t - \varphi) + (90 + \omega t)] = \pi - \omega_1 t + \omega t + \varphi;$
$\prec 0 = \theta - \omega t$
$\prec M = [\pi - (\prec 0_1 + \prec 0)] = \omega_1 t - \theta.$

The effective force equation projected onto natural axes is built according to D'Alembert's principle (Bayshugulova, Sh.K. Eskozhin, 2015):

$m\omega_1^2 R + m\omega^2\rho\cos(\omega_1 t - \varphi - \theta) - 2m\omega_R' \cdot \cos\varphi - fmg\cos(90-\varphi) = 0.$
$m\omega^2\rho\sin(\omega_1 t - \varphi - \theta) + 2m\omega' v_R\sin\varphi - fmg\sin(90-\varphi) = 0.$ (3)

Reduce all members by m:

$\omega^2\rho\cdot\cos(\omega_1 t - \varphi - \theta) - 2\omega' v_R\cos\varphi - fg\sin\varphi = -\omega_1^2 R.$
$\omega^2\rho\cdot\sin(\omega_1 t - \varphi - \theta) - 2\omega' v_R\sin\varphi - fg\cos\varphi = 0.$ (4)

The relative velocity can be expressed through its components:

$$V_R = \sqrt{R^{12} + R^2\varphi'^2} = R\sqrt{1+\varphi^2} \quad (5)$$

Then:

$$\frac{R'}{V_R} = \sin\varphi \qquad \frac{R\varphi}{V_R} = \cos\varphi. \quad (6)$$

Transform equations (4) with equations (6):

$$\omega^2\rho\cos(\omega_1 t - \varphi - \theta) - 2\omega' R\varphi - tg\sin\varphi = -\omega_1^2 R.$$

$$\omega^2\rho\cdot\sin(\omega_1 t - \varphi - \theta) + 2\omega' R' - tg\cdot\cos\varphi = 0. \quad (7)$$

This creates a system of first order differential equations, which characterizes the relative motion of a material point on the surface of a horizontal sieve in sun and planet motion.

The solution of the obtained equations is laborious (Shipachev, 1990).

Therefore, the following transformation is performed:

From the second equation of (7):

$$2\omega' = \frac{1}{R'}[tg\cos\varphi - \omega^2\rho\sin(\omega_1 t - \varphi - \theta)]. \quad (8)$$

Insert (8) into the first equation of (7).

$$\frac{R\varphi'}{R'} = \frac{\omega^2\rho\cdot\cos(\omega_1 t - \varphi - \theta) + \omega_1^2 R - fg\sin\varphi}{tg\cos\varphi - \omega^2\rho\sin(\omega_1 t - \varphi - \theta)}. \quad (9)$$

Designate the right side of (9) as follows:

$$\frac{\omega^2\rho\cos(\eta\omega t - \varphi - \theta) - tg\sin\varphi + \eta^2\omega^2 R}{tg\cos\varphi - \omega^2\rho\sin(\eta\omega t - \varphi - \theta)} = A \quad (10)$$

All variables included in (10) depend on ω and η.

By changing their value, it is possible to make it so that $A = const$. At that, equation (9) is written as follows:

$$\frac{R'}{R\varphi'} = tg\varphi = \frac{1}{A} = const \quad (11)$$

The integration of this equation produces $R = R_0 e^{A\varphi}$.

The result is a logarithmic spiral equation. This means that the material point moves in a logarithmic spiral before overtail. The parameters of the spiral depend on A and φ. At $A = const$, the smaller the $\prec \varphi$, the more turns the spiral has and the longer the period during which the material point is located on the sieve. At that, the grain mass is cleaned and separated.

Discussion and Conclusion

The lack of alternating stress enables setting high angular velocities of sieves, which increases effectiveness significantly. Laboratory trials of the experimental rig proved its efficiency.

The offered machine improves the quality of grain mixture separation and performance of the sieve, which is achieved by avoiding alternating stress and centrifugal load thereon, thus making the mechanism more stable. This also extends the working life of the mechanism and makes it more cost-effective.

In their concepts of new grain cleaners, designers try to reduce the centrifugal load on the sieve. One of the ways is to use a linear motor (Linenk et al., 2012). The advantages of this mechanism are as follows:

- Stable operating modes
- Possibility of regulating kinematic parameters
- Ability to adjust technological parameters
- Ability to visually observe the separation process

However, this model is inefficient from the financial perspective, since it increases power consumption significantly. It also makes the assembly of grain cleaners with a linear motor inconvenient and complicated. The replacement of a crank gear with a sun and planet one is a more effective solution.

Thus, the offered model of a grain cleaner with a sun and planet gear is a more cost-effective and technologically advanced solution. In addition, a system of first order differential equations was investigated, which characterizes the motion of a material point on the surface of a horizontal sieve in sun and planet motion; said equations produced a logarithmic spiral equation after transformation.

Implications and Recommendations

The conclusion based on the above calculations is that the design and modernization of grain cleaners with the offered grain cleaning and separation principle based on a sieve with a sun and planet motion will improve the effectiveness of grain cleaning and increase the working life of the machine. In addition, this technology significantly increases effectiveness due to the lack of alternating stress, which enables increasing the angular velocity of sieves.

Accurate results were obtained by solving a system of first order differential equations and transforming them into a logarithmic spiral equation.

The offered technical solution can be used to design new grain cleaners and modernize existing models.

Disclosure statement

No potential conflict of interest was reported by the authors.

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