

STUDY OF THE DYNAMICS OF THE DRIVE OF THE MACHINE UNIT OF THE SEPARATOR FOR SEPARATION OF COTTON SEEDS

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ABSTRACT: The article presents the development of an effective, resource-saving design scheme for a separator, based on the analysis of existing separator designs used for separating cotton seeds. Theoretical studies have determined the influence of the rigidity of elastic elements on the impact vibrations of the shovel and have developed dynamic and mathematical models for the interaction of the machine units of the separator. Based on the numerical solution, the parameters of the working drum – such as torque and the laws of motion of angular velocities – along with the impact blade shafts and belt transmission under various technological resistances, are theoretically determined and substantiated. The laws governing the change in torque and angular velocities of the working drum are also determined. Additionally, the vibration characteristics of the impact blades are obtained, and recommended parameter values are selected based on the analysis of graphical dependencies, with a comparison between experimental results and theoretical studies.

KEY WORDS: aseparator, beater, shaft, drum, mesh, brush, rubber bushing, truncated cone.

1 INTRODUCTION

In the oil and fat industry, the key focus is on improving the energy and resource efficiency of machines and mechanisms used for extracting oil from cotton seeds,

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enhancing labor productivity, creating innovative designs, and improving the quality of manufactured products [1, 2].

Large-scale research and development efforts are being conducted worldwide to establish the scientific foundations for advancing the technology of oil extraction from cotton seeds, as well as the machines and mechanisms involved, their dynamic analysis, and the development of calculation methods [3, 4]. In this context, improving the design of the Bitter separator machine for producing high-quality oils from cotton seeds, analyzing the dynamics of interacting machine units based on the theory of machines and mechanisms, optimizing the technology for separating seed pulp into core and husk, and creating new, effective designs for impact shovels and working drums with mesh surfaces represent important scientific and technical challenges for the industry [4, 5].

An essential task in this area is the development of high-performance Bitter separator machines, the design of beaters for seed crushers, and the improvement of the working drum to increase the efficiency of feed products from cotton seeds [6, 7].

2 EFFICIENT SEPARATOR DESIGN FOR SEPARATING COTTONSEED RUSHANKA

The design of the separator for separating the cottonseeds consists of a housing 1, horizontally mounted two rotating mesh drums 2, inside which beater shafts 3 pass with beaters 4 mounted on them (Fig. 1a, Fig. 1b).

The essence of the design lies in the fact that in the design of the separator for separating the cotton seed rushanka (Bitter separator) contains horizontally installed two rotating mesh drums, inside which beater shafts with beaters mounted on them pass [1, 8, 9]. The beater shafts are installed eccentrically and the axes of the drums rotate in the opposite direction. Under the drums, there is a sieve, under which there is an inclined solid tray to remove the passage through the sieve from the machine, which moves back and forth in the direction of the roller. In this case, the beater shafts are made in the form of a pipe with a through hole, and the beaters are mounted on the shaft using rubber bushings and are fixed with a threaded connection. In this case, the beaters are mounted on the shaft in rows with alternating beater plates horizontally and vertically. In addition, the holes of the meshes of the drums are divided into three sections, differing in the size of the holes of the meshes, these hole sizes decrease from the beginning to the end of the drum, and the holes are made in the form of a truncated cone. In this case, the largest diameter of the conical holes of the screens is located on the outer surface of the drums. The taper of the holes decreases from the beginning to the end of the drum. It should be noted that the separator drive includes one electric motor and all working parts receive the corresponding movements from a common electric motor [5, 9].

In this case, the beater plate blades 9 are installed longitudinally and transversely

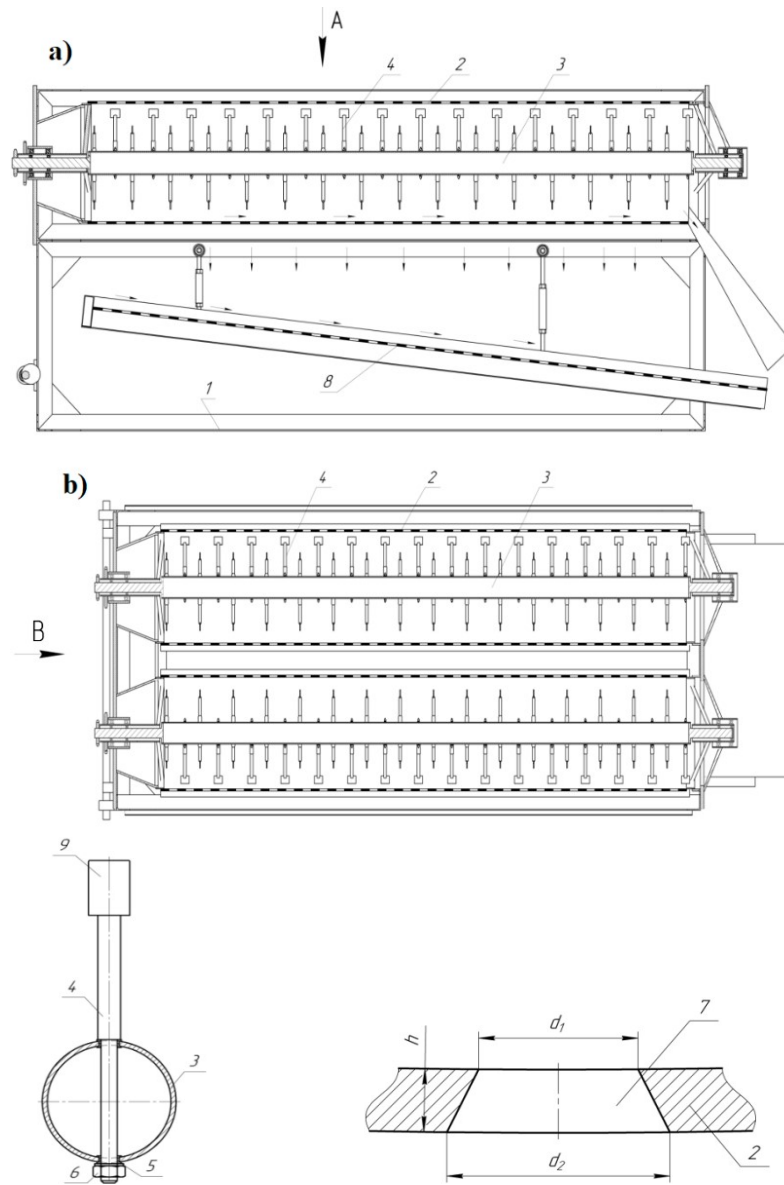


Figure 1. Scheme of a separator for separating cottonseed rushanka.

with alternating rows on the beater shafts 3 by means of rubber bushings 5 and a threaded connection 6. The holes 7 of the grids of the drums 2 are made in the form of a truncated cone. At the same time, along the length of drum 2, the holes are

distinguished by three sections, which differ in the size of the holes, decrease from the beginning to the end of the drums 2, and the holes 7 are made in the form of truncated cones and, accordingly, the taper is also made decreasing along the indicated three sections (the length of the sections is 1/3 of the drum length 2), has the ratio

$$(1) \quad k_1 = \frac{d_2 - d_1}{h},$$

where, d_1, d_2 – diameters of the bases of the truncated conical hole 7 of the mesh of the drum 2, h is the thickness of the mesh of the drum 2.

At the same time, for the first part $k_1 = 0.7$; for the second part $k_2 = 0.45$; for the third part $k_3 = 0.25$. Under the drums 2, a wind-driven sieve 8 is installed, which performs a reciprocating motion. All working bodies of the separator receive movement from one electric motor.

The design works as follows. Rushanka is served in both drums 2 in parallel. Inside the slowly rotating drums 2 (2 rpm), the rushanka is subjected to an intense action of the lamellar blades 9 beats 4, during which the core is released from the split into peeling cotton seeds. Taking into account that the lamellar blades 9 are rotated at an angle of 40° (degree) concerning the axis of the shaft 3, the flask is transported along the drum 2. It should be noted that as a result of the deformation of the rubber bushings 5 in the beaters 4 around the axis of the beater shaft 3, a series of angular oscillations arise, which leads to an increase in the additional impact impulse of the striker plate blades on the rudder. This leads to an increase in the efficiency of the release of the kernel from the cut cotton seeds. The separated core and small husks pass through the conical openings 7 of the mesh of drums 2 and fall on the windscreen 8, and large husks come out of the drums 2. The execution of hole 7 of the grid of drums 2 in the form of truncated cones eliminates their slaughter in all three zones for the extraction of kernels and small husks through hole 7. That is, in the first zone, larger kernels and husks stand out, and in the third zone, smaller kernels and husks. Shaking sieve 8 (with an area of 2.7 m^2) located under drum 2 receives reciprocating motion (250 vibrations per minute) from two eccentrics sitting on the main shaft (not shown in the figure) of the machine [7, 10, 13]. A feature of separating the core and husk on a shaking sieve 8 is that the particles of the husk, thanks to the down, adhere to lumps and go off the sieve further into the husk screw. The core goes through the passage and falls on the pallet, then into the core screw (not shown in the figure)

The design allows for an increase in the efficiency of the released kernel from the cotton seeds cut into peeling, excretion, and their further transportation in the separator.

3

Calculation Scheme and Mathematical Model of the Machine Unit of the Separator

In the recommended design, the main working component is the beater shafts (drums) with lamellar blades mounted on the drum using rubber bushings. Since the beater blades are symmetrical, torsional vibrations occur due to the imbalance in mass. The beater drum itself is balanced by the symmetrical arrangement of the beater blades. At the same time, it is important to theoretically study the torsional vibrations of the beater drum, as these directly affect the process of separating cotton fibers. The beater screw drum receives its driving motion from the electric motor, reducer, and gear system [1, 10, 11]. However, to mitigate the torsional vibrations of the gearbox shafts and the motor rotor, a belt drive is used instead of gears. With this in mind, the design diagram of the machine unit, featuring the beater drum drive mechanism, is presented in the form of a two-mass system, as shown in Fig. 2.

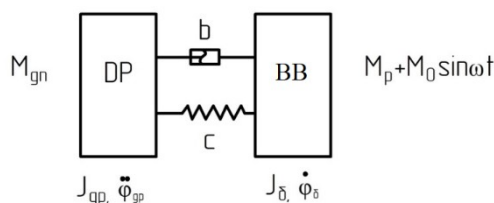


Figure 2. Calculation scheme of the machine unit with the beater drum drive mechanism.

To construct a mathematical model of the separator machine unit with the drum drive mechanism, the method of applying the Lagrange equations of the second kind was used [8, 11]. In this case, considering the fundamentally stable operating mode of the separator, the mechanical characteristics of the electric motor and its main working element [4, 8, 12]] are accounted for using the following expression:

$$(2) \quad M_{dr} = M_1 - M_k \frac{d\varphi_{dr}}{dt}.$$

where M_{dr} – driving moment in the drive shaft of the system [Nm], M_0 – constant and variable components of the driving moment, φ_{dr} – angular displacement of the drive shaft of the separator.

Using the known Lagrange equation of the second kind, according to the calculation scheme (see Fig. 2), we obtain the following system of differential equations describing the movement of the machine unit with the drive mechanism of the beater

drum in the form [1, 5, 13]:

$$\begin{aligned}
 M_{dr} &= M_1 - M_k \frac{d\varphi_{dr}}{dt}, \\
 (3) \quad J_{dr} \frac{d^2\varphi_{dr}}{dt^2} &= M_{dr} - b(\dot{\varphi}_{dr} - u_{db}\dot{\varphi}_b) - c(\varphi_{dp} - u_{db}\varphi_b), \\
 J_b \frac{d^2\varphi_b}{dt^2} &= u_{db}b(\dot{\varphi}_{dp} - u_{db}\dot{\varphi}_b) + u_{db}c(\varphi_{dp} - u_{db}\varphi_b) - M_p - M_0 \sin \omega t l
 \end{aligned}$$

where $J_{dr} - J_b$ – bringing the moments of inertia of the motor, gearbox shafts and beater drum, φ_{dp} – beater drum angular movement, c, b – stiffness and dissipation coefficients belt drive, u_{db} – elastic, transmission ratio, M_p, M_0, ω – constant components and amplitude, frequency of the variable component of the technological load from the separation of cotton seed coats, l – is the length of a shovel.

4 ANALYTICAL METHOD FOR SOLVING THE PROBLEM

It is known that the dissipative property of elastic transmission by absorbing energy, damping fluctuations of angular displacements and loads of the beater drum reduces the range of fluctuations of the angular velocity. Therefore, to estimate the maximum amplitude values $\dot{\varphi}_{dp}$ and $\dot{\varphi}_b$ coefficient of dissipation and non-negligible.

At the same time, from the second equation of system (4), having solved it with respect to the displacement φ_b and twice prodeffenmerusia, we obtain [6, 7, 14]

$$\begin{aligned}
 \varphi_b &= \frac{J_{dp}}{c} \frac{d^2\varphi_{dp}}{dt^2} + \varphi_{dp} - \frac{M_{dp}}{c}, \\
 (4) \quad \frac{d\varphi_b}{dt} &= \frac{J_{dp}}{c} \frac{d^3\varphi_{dp}}{dt^3} + \frac{d\varphi_{dp}}{dt} - \frac{1}{c} \frac{dM_{dp}}{dt}, \\
 \frac{d^2\varphi_b}{dt^2} &= \frac{J_{dp}}{c} \frac{d^4\varphi_{dp}}{dt^4} + \frac{d^2\varphi_{dp}}{dt^2} - \frac{1}{c} \frac{d^2M_{dp}}{dt^2}.
 \end{aligned}$$

From the resulting system (4), substituting the first and third equations into the second equation (3), we can obtain the following equation [2, 13, 15]

$$(5) \quad \frac{J_{dp}J_b}{c} \frac{d^4\varphi_{dp}}{dt^4} + (J_{dp} + J_b) \frac{d^2\varphi_{dp}}{dt^2} = M_{dp} + \frac{J_b}{c} \frac{d^2M_{dp}}{dt^2} - M_p - M_0 \sin \omega t.$$

Taking into account the working area of the mechanical characteristic of an asynchronous electric motor [8, 14, 16], according to (2), we rewrite equation (5) in the following form:

$$(6) \quad \frac{J_{dp}J_b}{c} \frac{d^3\omega_{dp}}{dt^3} + \frac{J_bM_k}{c} \frac{d^2\omega_{dp}}{dt^2} + (J_{dp} + J_b) \frac{d\omega_{dp}}{dt} + M_k\omega_{dp} = M_1 - (M_p - M_0 \sin \omega t).$$

From the analysis of the obtained (4), it can be noted that the law of rotational motion of the drive shaft of the separator is a differential equation of the third order. In this case, it is important to determine the fluctuations of the angular velocities φ_{dr} and $\dot{\varphi}_b$ in the steady state of the separator.

The characteristic equation of the corresponding differential equation (5) has the form [10, 17]:

$$(7) \quad \frac{J_{dp}J_b}{c}p^3 + \frac{J_bM_k}{c}p^2 + (J_{dp} + J_b)p + M_k = 0.$$

Moreover, in equation (7) all coefficients are positive and, accordingly, the first-order determinants are also positive. Therefore, the solution depends on the sign of the second-order determinant:

$$(8) \quad D_2 = \begin{vmatrix} \frac{J_bM_k}{c} & M_k \\ \frac{J_{dr}J_b}{c} & J_{dr} + J_b \end{vmatrix}.$$

Then, we have:

$$(9) \quad D_2 = \frac{J_bM_k}{c}(J_{dr} + J_b) - \frac{M_kJ_{dr}J_b}{c} = \frac{J_b^2M_k}{c} > 0.$$

That is, all first and second order determinants are positive.

5 ANALYSIS OF THE ANGULAR DEFORMATION OF THE ELASTIC TRANSMISSION OF THE MACHINE ASSEMBLY OF THE SEPARATOR

In the recommended separator for separating cottonseed towels during operation, the technological resistance changes according to a harmonic law. Therefore, these loads lead to fluctuations in the angular velocity of the beater drum. In this case, angular deformations of the elastic transmission (belt transmission) occur. Therefore, it is important to study these deformations according to [16, 18]:

$$\Delta\varphi = \varphi_{dr} - \varphi_b,$$

or

$$(10) \quad \begin{aligned} \varphi_b &= \omega_{dr}t - \Delta\varphi, \\ \dot{\varphi}_b &= \omega_{dr} - \Delta\dot{\varphi}. \end{aligned}$$

Usually in steady state given the large reduced moment of inertia of the drive shaft J_{dr} , its angular velocity fluctuates sharply, therefore:

$$(11) \quad \ddot{\varphi}_b = -\Delta\ddot{\varphi},$$

where $\Delta\varphi$ – angular deformation in the belt drive.

Then the first equation of system (3) takes the following form:

$$(12) \quad J_b \Delta \ddot{\varphi} + c \Delta \dot{\varphi} = M_p - M_0 \sin \omega t.$$

Using the well-known method [16] of solving (12), we get:

$$(13) \quad \Delta \varphi = \frac{M_p - M_0 \sin \omega t}{c} + c_1 \cos \sqrt{\frac{c}{J_b}} t + c_2 \sin \sqrt{\frac{c}{J_b}} t,$$

where c_1, c_2 – integration constants.

Taking into account the following initial conditions, at $t = 0$, $\Delta \varphi = 0$:

$$(14) \quad c_1 = -\frac{M_p + M_0 \sin \omega t}{c}, \quad c_2 = 0.$$

In this case, the angular deformation of the belt transmission of the drive of the beater drum of the separator is determined from the expression:

$$(15) \quad \Delta \varphi = \frac{M_p - M_0 \sin \omega t}{c} \left(1 - \cos \sqrt{\frac{c}{J_b}} t \right).$$

According to this (14) solution of the problem of angular oscillations of the belt from the drive transmission of the beater drum of the separator, it can be noted that the frequency and amplitude of oscillations will be:

$$(16) \quad A = \frac{M_p + M_0 \sin \omega t}{c}, \quad \varphi_p = \sqrt{\frac{c}{J_b}}.$$

6 DETERMINATION OF VIBRATIONS OF THE TRANSMISSION BELT OF THE MACHINE UNIT, TAKING INTO ACCOUNT DISSIPATION

In the system (2) of equations obtained above, the dissipation of the elastic element is proportional to the angular velocity and, taking into account (10), we obtain [3, 16, 18]:

$$(17) \quad J_b \Delta \ddot{\varphi} + b \Delta \dot{\varphi} + c \Delta \varphi = M_p + M_0 \sin \omega t.$$

In this case, the roots of the characteristic equation according to (16) according to the well-known technique:

$$(18) \quad \varphi_{1,2} = -\frac{b}{2J_b} \pm \sqrt{\frac{b^2}{4J_b^2} - \frac{c}{J_b}}.$$

It should be noted that in this machine unit, the transient process in the steady state will be aperiodic [16–18], and then oscillatory. Taking into account that the damping of the belt is sufficient, let us consider the transient process of the movement of the beater drum as an oscillatory one.

Then we obtain solution (17) in the following form:

$$(19) \quad \Delta\varphi = \frac{M_p - M_0 \sin \omega t}{c} + (1 - \cos \beta t + c_2 \sin \beta t) \exp\left(-\frac{b}{2J_b}t\right),$$

$$\text{where } \beta = \sqrt{\frac{c}{J_b} - \frac{b^2}{4J_b^2}}.$$

Taking into account the initial conditions, the integration constants c_1 and c_2 are determined, we get [8, 18]:

$$(20) \quad \Delta\varphi = \frac{M_p - M_0 \sin \omega t}{c} \left[1 - e^{-\frac{b}{2J_b}t} \cos(\gamma + \beta t)\right],$$

where $\gamma = \arctan(b/2sp)$.

Analysis (20) shows that when taking into account the dispensation coefficient of the transmission belt of the machine unit of the separator, the transient process in the steady operation mode of the beater drum attenuates with a frequency β with a phase shift α . The maximum angular deformation will be equal to:

$$(M_p - M_0 \sin \omega t) \frac{1}{c}$$

Then the recommended values of the coefficient of circular stiffness of the beater drum transmission belt:

$$(21) \quad c = \frac{(M_p - M_0 \sin \omega t)}{\Delta\varphi\varphi_{max}}.$$

Numerical solution of the problem of determining the parameters of the elastic transmission of the separator. The numerical solution of the problem was carried out with the following initial values of the parameters of the machine unit:

$$\begin{aligned} P &= 2.2 \text{ kW}; & n &= 250 \text{ rpm}; & \omega_p &= 26.17 \text{ rad/s}; \\ \omega_b &= 7.33 \text{ rad/s}; & \eta_r d &= 0.95; & c &= (150 \div 350) \text{ Nm/rad}; \\ b &= (2.5 \div 4.5) \text{ Nms/rad}; & M_r &= (100 \div 180) \text{ Nm}; & J_{dr} &= (0.637 \div 0.91) \text{ kgm}^2; \\ J_b &= (0.31 \div 0.4) \text{ kgm}^2 \end{aligned}$$

A feature of solving the problem of angular deformations of the elastic element of the machine unit with the separator drive mechanism is that $\Delta\varphi_{\max}$ is determined

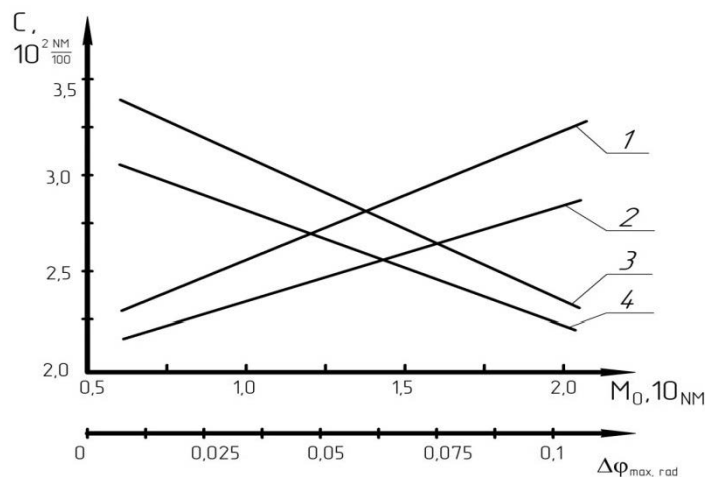


Figure 3. Dependences of the change in the coefficient of circular fluidity of the elastic element of the machine assembly of the separator from the increase in the constant component of the technological load and the maximum angular deformation: 1,2 — $c = 1(M_0)$; 3,4 — $c = 1(\Delta\varphi_{\max})$; 1,3 — $M_p = 175 \text{ Nm}$; 2,4 — $M_p = 105 \text{ Nm}$; $2.24 \times 10^2 \text{ Nm/rad}$.

by varying the values of the coefficients of angular stiffness and dissipation of the belt (coupling), and then the maximum value of the deformation is specified. According to (20), graphic dependences of the change in the circular stiffness of the belt (an elastic element of the coupling) are plotted with a change in the values of the technological load and the range of angular vibrations of the beater drum, which are shown in Fig. 3. Analysis of the obtained graphical dependencies shows that with an increase M_0 from $0.75 \times 10 \text{ Nm}$ before $2.0 \times 10 \text{ Nm}$ the circular coefficient of belt fluidity increases linearly from $2.4 \times 10^2 \text{ Nm/rad}$ before $3.35 \times 10^2 \text{ Nm/rad}$ at $M_p = 175 \text{ Nm}$ at $M_p = 105 \text{ Nm}$ value C will increase from 2.11 Nm/rad before 2.72 Nm/rad . According to hydration $\Delta\varphi_{\max}$ from 0.013 rad before 0.1 rad at a load of 175 Nm , the coefficient of circular stiffness decreases from $3.41 \times 10^2 \text{ Nm/rad}$ from $2.35 \times 10^2 \text{ Nm/rad}$ and at a load of 105 Nm , then the value of C decreases according to a linear pattern from $3.0 \times 10^2 \text{ Nm/rad}$ before $2.24 \times 10^2 \text{ Nm/rad}$.

At the same time, the values $\Delta\varphi_{\max}$ directly providing the necessary changes in the angular velocity of the beater drum, that is, the occurrence of conditional acceleration, ensuring the separation of the seeds of cotton towels due to the additional impulsive, impact impact on them of the lamellar blades of the beater drum. Therefore, the recommended values:

$$c = (185 \div 215) \text{ Nm/rad}; \quad \Delta\varphi_{\max} = (0.065 \div 0.12) \text{ rad}$$

7 CONCLUSIONS

An effective design scheme of a separator for separating cottonseeds has been developed, theoretical studies have substantiated the parameters of the beater drum drive. It has been revealed that in order to increase the technological load from the separation of cotton seeds, it is considered expedient to increase the circular rigidity of the belt drive of the machine unit.

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