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# DEVELOPMENT OF A PROCEDURE FOR DETERMINATION OF DAMAGE TO SEEDS AND COTTON FIBERS IN COTTON CLEANING MACHINES

***Fazil Veliev***✉
*Department of Engineering and Applied Sciences*[1]
*fazil-uzbekr@mail.ru*

***Esmira Mustafayeva***
*Department of Engineering and Applied Sciences*[1]

***Anatolii Mamontov***
*Department of Car and Tractor Industry*[2]

***Vadim Shevtsov***
*Department of Car and Tractor Industry*[2]

***Sergii Zinchenko***
*Department of Personnel Management and Labor Economics*
*Mariupol Institute of the Interregional Academy of Personnel Management*
*52 Hromovoi str., Mariupol, Ukraine, 87556*

***Anatoliy Rud***
*Department of Agroengineering and System Technology*
*State Agrarian and Engineering University in Podillya*
*13 Shevchenko str., Kamianets-Podilsky, Ukraine, 32316*

[1]*Azerbaijan State University of Economics (UNEC)*
*6 Istiglyaliyat str., Baku, Azerbaijan, AZ 1001*

[2]*National Technical University «Kharkiv Polytechnic Institute»*
*2 Kyrpychova str., Kharkiv, Ukraine, 61002*

✉**Corresponding author**

**Abstract**

Studies on the dynamic state of cotton raw materials when introducing working bodies of processing machines into it allow to draw the following proposition. Depending on the rate of penetration of the working body into the cotton medium and the density of the medium, in the formulas used to describe the state of the medium, the exponent y ρ can vary from 1.5 to 3. The exponent for density ρ is a measure of the compression and compaction of raw materials on the surface of the working body. The exponent of ρ is also related to the amount of damage to cotton fibers and seeds. For the first time, a cotton mass is considered as a compressible porous two-component medium consisting of a mixture of cotton fibers and air included in the composition of a porous medium, which is essential in dynamic processing processes, and it must be taken into account when planning technological modes. From experiments on the penetration of a splitter with a peripheral speed $u=3.5$ m/s into a cotton medium with a density of $\rho=150–350$ kg/m$^3$, it can be seen that a locally located «air cushion» appears in the close vicinity of the split end. The pressure in it increases by 1.5–2 times in comparison with the pressure of statistical compression of cotton fibers alone, without taking into account the influence of the air located in the pores of the system. The forces of compression of cotton fibers from the action of the splitter and the force of volumetric action on the fibers are comparable in the area of the «air cushion».

Using the general equations of the mechanics of the compressed medium, as well as experimental data, the fundamental equation of the dynamic state of the mass of raw cotton when the working body of the processing machine is introduced into it, such as the density of the medium, the speed of the working body, its external shape and the degree of surface treatment, is derived. The resulting equation can be used to describe the power stresses in a cotton environment in the technological processes of roller and saw ginning, and during cotton cleaning.

**Keywords:** damage to seeds, damage to fibers, density, compaction of raw materials, surface cleanliness, density of the medium.

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## 1. Introduction

The issue of preserving the natural valuable properties of raw cotton in the technological processes of the primary processing of cotton is invariably one of the main objects of attention when choosing the modes of technological processing operations. The results of studies on the dynamics of the state of cotton raw materials can be used to directly determine the relationship between these parameters and the value of damage to seeds and fibers [1–3]. This, in turn, makes it possible to control the state of the quality of raw materials processing and achieve optimal results in each particular technological process. In particular, it should be noted that in the work [1], studies were carried out on the introduction of a working body of a rotary type of installation that simulates the development of a cotton selection. The studies were devoted to the analysis of damage to raw materials when digging tunnels in the selection of raw cotton and the selection of the optimal parameters of the working bodies.

However, in [1], there is insufficient data on the forces and stresses arising inside the fibers during dynamic compression of the mass of raw materials, which cause deterioration in the quality or destruction of the fibers.

In works [4, 5], a formula was proposed for evaluating the dynamic state of raw materials, but only for a specific range of densities. Design features can be found in [6–9]. In particular, in the works [7, 8], the issues of fixing cotton flies on the splitting roller are highlighted and recommendations are given for the installation of two interlocked fixed brushes that provide a satisfactory fixing of the fibrous material on the splitter. The theoretical substantiation of the brush is carried out, taking into account the emerging forces on the basis of the theory of changing the momentum, taking into account the elastic properties.

Elongated brushes were recommended in [6, 9]. However, as shown by comparative tests, these brushes have inferior fixing properties, which negatively affects the technological reliability (entrapment of volatiles) and the cleaning effect of the machine.

The fragmentation of the available data regarding the influence of design and technological features does not allow assessing the dynamics of the state of cotton raw materials. Therefore, this study reveals the general laws that exist in the dynamic processes of processing between such parameters of raw materials as tension, the rate of introduction of the working body and the density of the raw material.

## 2. Materials and Methods

Earlier, on the basis of generalization of experimental studies on the compressibility of raw cotton [4, 5], a relation was obtained for the dynamic state of raw material in the form

$$\sigma = 10^{-3}(0.27+0.12V^2)\cdot\rho^{1.5}, \quad (1)$$

where $\sigma$ – bonding stress in the medium, N/m$^2$; $\rho$ – weight density of the medium, kg/m$^3$; $\rho$ – penetration rate of the working body, s.

Relation (1) was derived for the density range $\rho = 130–260$ kg/m$^3$.

For the direct application of formula (1) for applied technological purposes, the results of work [4] were used.

Here, data are given on the degree of mechanical damage to cotton seeds and fibers by the rotor of the working body of the installation, which simulates, under the conditions of the stand, the selection of a cotton cleaning of the 1st grade of machine harvest, normal humidity and contamination, laid with a bulk density of $\rho = 150$, 200, 250 kg/m$^3$.

The actual damage $D$ % of seeds by the working body was determined as the difference between the crushing obtained after cotton cleaning and before election:

$$D = D_2 – D_1,$$

where $D$ – fragmentation of seeds by the working body, %; $D_2$ – fragmentation of seeds after selection, %; $D_1$ – initial fragmentation, %.

From relation (1) for density $\rho=150$ kg/m$^3$, it can be obtained that:

$$(10^{-3}\cdot 150^{1.5}=1.5),$$

$$\sigma=0.40+0.18V^2. \quad (2)$$

In the last expression, the stress $\sigma$ in the medium is a function $V^2$ of the penetration rate of the working body, and the density of the medium $\rho$ in an implicit form goes into the coefficients of expression (2).

On the other hand, the pattern $D$ of seed crushing is possible according to the experimental data in **Table 1** for different values of velocities $V$ can be represented as:

$$D=b+aV^2, \quad (3)$$

where the previously unknown constant coefficients $a$ and $b$ can be determined using two different values of the splitting speed of the splitting roller $V$. In this case, the values of damage $D$ from table are used from the **Table 1** for the same $V$.

**Table 1**

Data on seed damage by the rotor of the working body

| **Weight density $\rho$, kg/m$^3$** | **Roller speed $V$, m/s** | **Seeds damage by the working body experimentally $D$ %** | **Damage determined theoretically, $D$ %** |
|---|---|---|---|
| 150 | 2 | 0.3 | 0.26 |
| | 4 | 0.3 | 0.29 |
| | 8 | 0.42 | 0.44 |
| | 12 | 0.73 | 0.68 |
| 200 | 2 | 0.38 | 0.38 |
| | 4 | 0.42 | 0.42 |
| | 8 | 0.65 | 0.62 |
| | 12 | 1.00 | 0.94 |
| 250 | 2 | 0.45 | 0.44 |
| | 4 | 0.5 | 0.5 |
| | 8 | 0.65 | 0.74 |
| | 12 | 1.3 | 1.14 |

Proceeding in this way, for the density of the raw material $\rho=150$ kg/m$^3$, it was obtained according to (3):

$$D=0.25+0.003V^2. \quad (4)$$

In the last expression, the density of the medium $\rho=150$ kg/m$^3$ comes out implicitly through the coefficients $a=0.003$ and $b=0.25$. **Fig. 1** shows the calculations (3) for $\rho=150$, 200, 250 kg/m$^3$ and $V=2$, 4, 8, 12 m/s.

Let's now exclude the values of the velocity $V^2$ 2 from (2), (3) and finally obtain the following relation for the value $D$ of seed crushing:

$$D=0.25+0.015\sigma, \quad (5)$$

where now $D$ is expressed explicitly as a function of $\sigma$ of the force stress in the medium, and also implicitly depends on the density $\rho=150$ kg/m$^3$ through the coefficients of expression (5).

Relation (5) indicates a direct connection between the value of seed crushing $D$ and stresses at a given density 150 kg/m$^3$.

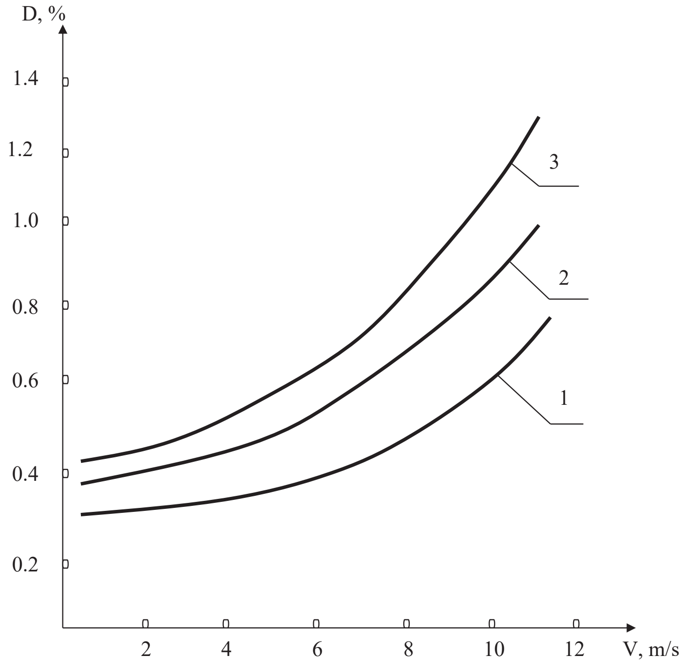


**Fig. 1.** Dependence of damage *D* % of cotton seeds on the penetration rate of the splitting of the splitting roller into the raw and its density ρ: 1 – density $\rho=150$ kg/m$^3$; 2 – density $\rho=200$ kg/m$^3$; 3 – density $\rho=250$ kg/m$^3$

Repeating all the above reasoning for the densities of the medium $\rho=200$, 250 kg/m$^3$, let's obtain for these densities the relations:

$$\sigma=f(V^2, \rho),$$

$$D=f(V^2, \rho),$$

$$D=f(\sigma, \rho),$$

similar to (2), (3), (5), which were derived at $\rho=150$ kg/m$^3$.

All the results obtained with such actions are listed in **Table 2**. It is seen that there is an analogy between a formula of the type (2):

$$\sigma=f(V^2, \rho),$$

for stress σ in the medium during the introduction of the working body and the regularity for crushing seeds (4) in the form $\sigma=f(V^2, \rho)$.

Based on (2) and (4), it is possible to express in a direct form the relationship between stress σ and seed crushing *D*, excluding $V^2$ from these expressions. Then let's obtain the required dependence (5) in the form $D=f(\sigma, \rho)$, **Table 2**.

In the results of studies (**Table 1**), carried out in this section of the work, regression coefficients were obtained.

On the basis of the experimentally determined value of the compressibility of cotton samples of different weight density, the speed of sound in such media and the frequency of sound vibrations were determined.

In addition, with the help of experimental data on the compressibility of cotton raw materials, a fundamental relationship has been derived that describes the dynamics of the state of the cotton environment and connects the force stresses within the environment with the rate of its loading and density.

**Table 2**

Dependences of the size of seeds crushing $D$ on the speed $V$, stress σ and density ρ

| Density ρ, kg/m$^3$ | 150 | 200 | 250 |
|---|---|---|---|
| Stress $\sigma=f(V^2, \rho)$, kg/cm$^2$ | $\sigma=0.40+0.18V^2$ | $\sigma=0.73+0.33V^2$ | $\sigma=1.13+0.50V^2$ |
| Seeds crushing, % $D=f(V^2, \rho)$ % | $D=0.25+0.003V^2$ | $D=0.36+0.004V^2$ | $D=0.42+0.005V^2$ |
| Seeds crushing, % $D=f(\sigma, \rho)$ % | $D=0.25+0.015\sigma$ | $D=0.35+0.012\sigma$ | $D=0.41+0.010\sigma$ |

These results are of both independent theoretical interest and can find their direct practical application in the technological processes of primary processing of cotton when substantiating the modes of optimal dynamic efforts in raw materials.

Investigations of the degree of mechanical damage to the cotton fiber by the rotor of the working body were carried out in laboratory conditions from a bench installation (**Fig. 2**).

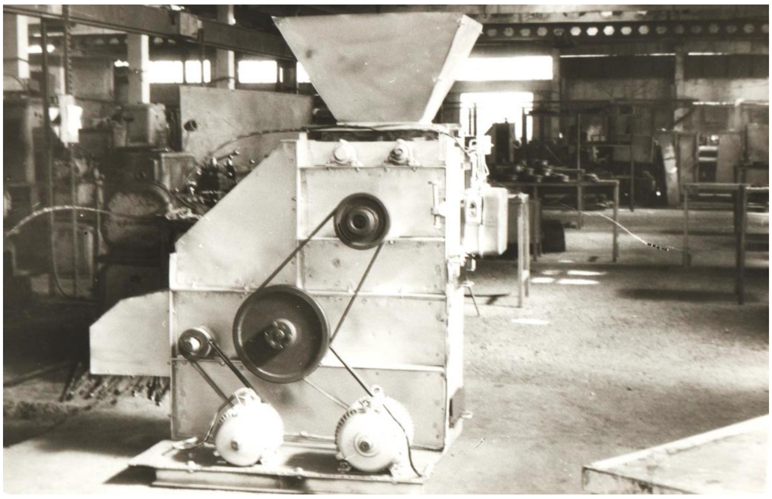

**Fig. 2.** Bench installation for studying the degree of mechanical damage to cotton fiber

## 3. Results and discussion

### 3. 1. Results of the study of the degree of mechanical damage to cotton fiber by the rotor of the working body

The results of mechanical damage to fibers by the rotor of cotton cleaning machine based on the experimental data obtained on the bench installation are presented in **Table 3**.

**Table 3**

Results of mechanical damage to fibers by the rotor of cotton cleaning machine

| Density ρ, kg/m$^3$ | Damage to fibers by a roller *P* % for splitting processed according to the 6th class of cleanliness | Damage to fibers by a roller *P* % for splitting processed according to the 2nd class of cleanliness |
|---|---|---|
| 150 | 0.68 | 1.9 |
| 200 | 0.9 | 2.4 |
| 250 | 1.25 | 3.7 |

The circumferential speed of rotation of the roller was $V=8$ m/s with a volumetric weight equal to $\rho=150, 200, 250$ kg/m$^3$ for two types of splitters, processed according to the 6$^{th}$ and 2$^{nd}$ class of surface cleanliness, respectively.

The analysis of fiber damage was carried out according to the formula:

$$P=P_2-P_1,$$

where $P$ – the number of fibers damaged by the roller in %; $P_2$ – the number of fibers with mechanical damage in cotton after selection in %; $P_1$ – the number of fibers with mechanical damage in the original cotton in %.

Analysis of experimental data from **Table 3** and the curves plotted from these results (**Fig. 2**) indicates that the amount of fiber damage is proportional to the value $\rho^2$ for splitting a cotton cleaning machine with a smooth surface, 6 cleanliness class. And for splitting with a roughly processed surface, 2 classes of cleanliness, the amount of fiber damage is proportional to the value of $\rho^{2.5}$ density.

Therefore, the regularity of damage to cotton fibers for smooth splitting of grade 6 cleanliness can be described as:

$$P=b+a\rho^2, \tag{6}$$

where the constant coefficients $a$ and $b$ are calculated on the basis of the experimental data in **Table 3** according to $P$.

To find two unknowns $a$ and $b$, a system of two equations is drawn up.

For example, for a splitter with a surface of the 6th grade of purity at a density of $\rho=150$, 200 kg/m$^3$, it was experimentally found that the damage $P$ of the fibers was, respectively, $P=0.68$ % and $P=0.9$ %.

Then:

$$0.68=b+a150^2, \tag{7}$$

$$0.90=b+a200^2.$$

Let's compose several such systems for different values of P and solving them, let's find that the average value of the coefficients is $a=0.14\cdot10^{-4}$; $b=0.36$.

After that, (6) can be written explicitly as follows:

$$P=0.36+0.14\cdot10^{-4}\rho^2. \tag{8}$$

This is the desired regularity for calculating the damage of fibers $P$ by a spike with a surface of 6th cleanliness class at a speed of penetration into the medium $V=8$ m/s.

Let's now turn to the study of experimental data on fiber damage by a spike, the surface of which is roughly processed according to the 2nd cleanliness class. Here, to describe damage, it is necessary to use the expression:

$$P=b+a\rho^{2.5}. \tag{9}$$

To find the previously unknown values of the coefficients $a$ and $b$, it is possible to use the reasoning just given in relation to the splitting with a surface of the 6th grade of purity.

However, in order to avoid a scatter of values when determining the coefficient $a$, it is more convenient to first determine graphically the value of the coefficient $b$ from (**Fig. 3**).

Then it is possible to assume that $b=1.4$.

At the same time, based on systems of equations similar to (7), it was obtained that the average value of the coefficient a will be $a=(0.19–0.20)\cdot10^{-5}$.

Based on this, formula (9) for a coarsely processed splitter of 2nd cleanliness class explicitly takes the form:

$$P=1.4+0.19\cdot10^{-5}\rho^{2.5}. \tag{10}$$

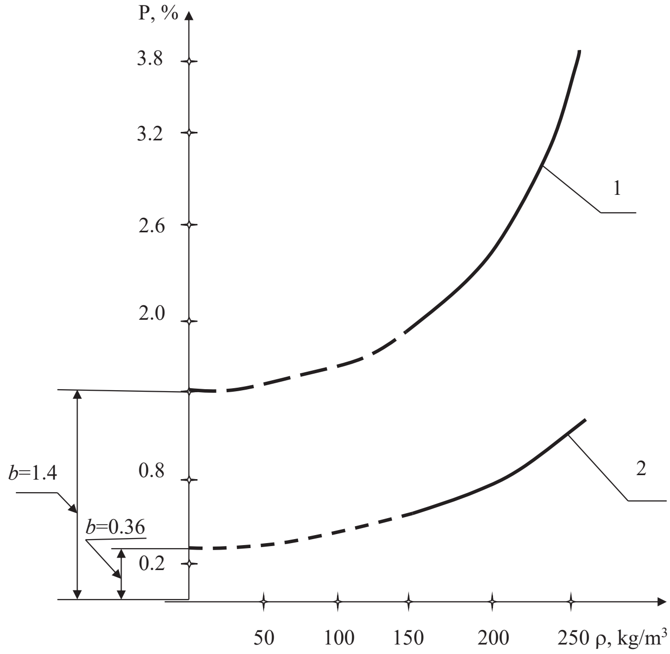


**Fig. 3.** Dependence of the damage *P* % of fibers on the degree of surface treatment of the splitter of the reel and the density of the raw material ρ at $V=8$ m/s of the working body: 1 – splitter of the 2nd class of surface cleanliness (rough); 2 – splitter of the 6th class of surface cleanliness (smooth)

The last relation is a regularity *P*, which describes the damage to the fibers by the surface of a cleaver of 2nd cleanliness class, the density of the cotton medium is included in (8) as a factor, and is also implicitly present in the coefficients *a* and *b*.

All the indicated values $\rho^2$, *a*, *b* for a smooth splitting are numerically less than the analogous values $\rho^{2.5}$, *a*, *b* for a roughly processed splitting surface.

**3. 2. An example of calculating damage to seeds**

Below is an example of calculating the damage to seeds by the working body of a tunnel machine with metal splitters.

In [8], experimental data on damage to seeds by a valuable working body with splitters with a diameter of 12 mm on connecting strips for digging tunnels in selection of raw cotton are given, **Table 4**. The speed of introduction of the working body $V=2$ m/s.

**Table 4**

Seed damage from bulk density and cotton varieties

| No. | Cotton grades | Bulk density ρ, kg/m$^3$ | Damage to seeds, % | | | |
|---|---|---|---|---|---|---|
| | | | Initial damage $P_1$, % | After digging a tunnel $P_2$, % | Experimental damage growth *P*, % | Theoretical damage growth $P_t$, % |
| 1 | 108-F, 1-grade | 120–150 | 2.08 | 2.11 | 0.03 | 0.03 |
| 2 | 108-F, 2-grade | 300–350 | 2.7 | 3.12 | 0.42 | 0.43 |
| 3 | 4227, 4-grade | 300–350 | 3.15 | 3.68 | 0.53 | 0.01 |

**Table 4** the increase in seed damage *P* % is defined as the difference between the initial damage $P_1$ % and the subsequent $P_2$ % damage after digging the tunnel:

$$P=P_2-P_1.$$

For the calculation, let's use the formula (6):

$$P = b + a\rho^3. \tag{11}$$

Analysis of the experimental data given in **Table 4** suggests that for the density of the raw material ρ in the case under study it is necessary to choose the exponent in the form of a cubic dependence $\rho^3$. Then, based on (11), according to the data on damageability $P$ for cotton grade 108-F from **Table 4** compiles a system of two equations to determine the desired coefficients $a$ and $b$:

$$0.03 = b + a150^3, \tag{12}$$

$$0.42 = b + a350^3.$$

From (12) it is possible to find that; at $b = 0$, let's determine $a \approx 1 \cdot 10^{-8}$. Thus, in an explicit form, the expression for the theoretical determination of the degree of damage to seeds, expression (11) will now be written as:

$$P = 10^{-8}\rho^3. \tag{13}$$

Let's note that the high exponent of the density of the raw material $\rho^3$ indicates a large compression and compaction of the raw material at the ends of the splitters of the chain conveyor when digging tunnels in the seleciton of raw cotton.

When introducing the working bodies of processing machines into a cotton environment, one should expect the appearance of the effect of compressibility of the environment. This significantly increases the pressure, density and temperature in raw cotton. This effect is described by a system of three equations interconnecting the pressure, density and speed of movement of a part of the compressible medium.

This leads to an increase in pressure and density, as well as an increase in the degree of mechanical microdamage to the elements of the raw material, which have arisen in contact with the hard surface of the splitting roller.

To describe the process of damage to the components of the cotton environment (fibers, seeds), it is necessary to use a closed system of four equations. These equations relate such parameters of the environment as the force stress in it, the speed of movement of the working body in the environment, the density of raw materials, as well as the amount of damage to the natural components of the environment.

For the reliability of the conclusion of the type of connections existing in a mechanical system of this kind, it is necessary to widely take into account the experiments confirming the regularity of the assumptions and assumptions that are inevitable at the initial stage of the study of this complex problem. To date, the solution of such a complex system of four equations has been possible only for some particular technological processes.

The exponent at the factor $\rho^2$ or $\rho^{2.5}$ in (8) and (9) shows the degree of surface treatment of the splitters of a cotton cleaning machine. At the smooth surface of the splitter, the contact area is small, the mass of raw materials flows freely around the splitter, while being little compacted on its surface. For a splitter with a rough surface, the contact area is large, as a result of which the flow around the splitter is difficult [8, 10]. This results in a high compaction of the cotton medium on the surface of the splitter.

These factors are the reason for the increased damage to the fibers of the raw material when using a coarsely processed splint in comparison with a smooth surface.

In this regard, it is important to note the following circumstance. The assumptions made that the process parameters and properties of the medium are deterministic quantities impose restrictions on the results obtained. It is obvious that uncontrolled deviations in the rate of penetration of the working body, the difficulty of accurately estimating the weight density of the medium and the appearance of the effect of its compressibility, will lead to obtaining results that differ from the calculation. A way to overcome this limitation can be the representation of process parameters and properties of the environment by fuzzy numbers described by membership functions. At the same time, the estimation of the modal values of the named variables and the compactness of the uncertainty body [11] will make it possible to obtain results that are closer to the real conditions of the process.

## 4. Conclusions

For splitters of the same external shape, with their equal speed of penetration into the raw material, for a roughly processed splitting surface, the exponent for the density $\rho$ is 2.5 and it is greater than that of a smoothly machined splitting surface, where the exponent is 2. In this regard the damage of fibers and seeds in a splitter with a roughly processed surface is the same as in a smoothly processed splitter.

On the basis of the obtained equation of the dynamic state of the cotton environment and experimental data, an analytical expression is derived to describe the damage to cotton fibers and seeds. The calculation results for damage by the obtained method are close to the experimentally determined ones.

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