

UDK 621

## ELIMINATION OF REDUNDANT CONSTRAINTS IN A RICE SORTING MACHINE WITH A CAM-TYPE ELASTIC ELEMENT IN THE TRANSMISSION MECHANISM

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**Abstract:** This article provides a detailed analysis of the operating principle and structure of a cam mechanism with a flexible element, which is used in the drive system of an eccentric rice sorting machine. The study reveals a change in the law of motion resulting from the deformation of the flexible cam during operation, in contrast to existing rigid cam mechanisms. It is substantiated that this deformation leads to the emergence of redundant constraints within the mechanism, which negatively impacts its operational process, accuracy, and efficiency. In light of this, methods for reducing and eliminating these redundant constraints are considered. Specifically, it presents the potential for improving contact conditions, ensuring even load distribution, and increasing the mechanism's reliability by replacing higher kinematic pairs with lower ones. Furthermore, the influence of the flexible element's deformation on the mechanism's geometric parameters is studied in-depth, and expressions are provided that account for dimensional changes in the main links, such as the rocker arm, connecting rod, and crank. These expressions are significant for the design and optimization of the mechanism, enabling calculations that more closely approximate real operating conditions.

**Keywords:** flexible element, formula, cam mechanism, kinematic diagram, coefficient, laws of motion, rocker arm, stiffness, redundant constraint.

### Introduction

Globally, achieving high yields in agriculture is not limited to just creating and cultivating new varieties. Along with this, the collection, high-quality processing of the harvested crop, and especially the organization of effective sorting of grain and seed, are of great importance. Therefore, developing modern sorting machines with high productivity, precision, and reliability, as well as improving existing designs, is one of today's pressing tasks.

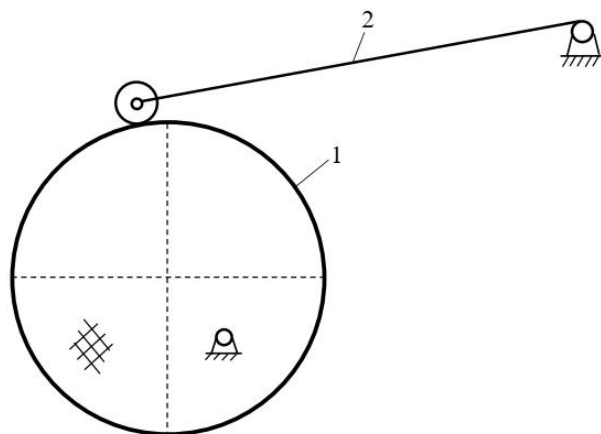
It is well-known that machines designed for sorting grain and seeds are structurally and functionally divided into stationary and mobile (portable) types. Industrial enterprises typically make extensive use of stationary sorting machines, which possess high capacity and the ability to operate continuously. Such devices ensure high efficiency when processing large volumes of grain products. Conversely, in agricultural holdings and farming systems, mobile sorting machines are more widespread due to their flexibility, ease of use, and transportability, allowing for the on-site processing of small to medium quantities of grain.[1]



Modern developments in the technical equipment used for processing grain products in the post-harvest period are focused on introducing energy-efficient technologies in accordance with international standards. As a result, modern sorting machines not only help to obtain high-quality products but also contribute to the rational use of resources [2].

### Methods.

In the general theory of machines and mechanisms, the structural analysis of planar mechanisms involves determining the degree of mobility by considering the number of links and kinematic pairs within the mechanism [3,4,5,6,7]. The transmission mechanism of the rice sorting device under consideration is a cam mechanism, which differs from existing cam mechanisms by its use of elastic elements [8, 9].



1-Eccentric elastic cam, 2-rocker arm (oscillating lever)

**Figure 1. Diagram of the elastic cam mechanism in the drive of a rice sorting machine**

Figure 1 shows a diagram of the cam mechanism in the drive section of the rice sorting device. According to this diagram, the elastic cam deforms sufficiently during operation, thus amortizing the motion. The law of motion differs from that of a rigid cam. It should be noted that when using the recommended elastic cam, the degree of mobility of the mechanism cannot be determined using existing formulas. This is because the condition for deriving the existing formula stipulates that the links of the mechanism are absolutely rigid [10,11,12]. The Somov-Malyshev formula applies only to a planar mechanism consisting of class 4 and 5 kinematic pairs [13].

$$W = 6n - 5P_5 - 4P_4 \quad (1)$$

where  $n$  is the number of movable links;  $P_4$ ,  $P_5$  are the number of fourth and fifth-class kinematic pairs, respectively.

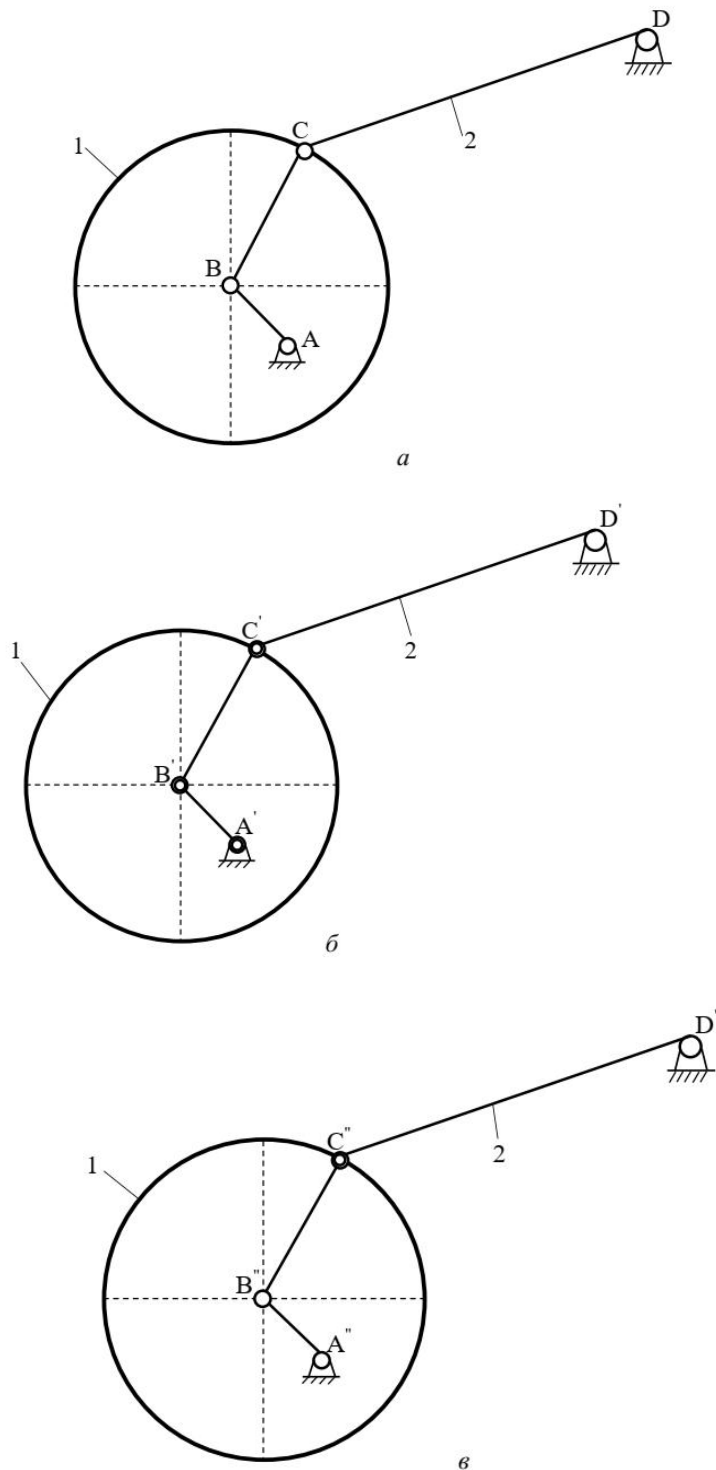


**Results**

Based on Formula (1), the degree of mobility of the mechanism under consideration cannot be calculated because the cam is flexible. The reason is that an additional degree of freedom arises. In this case, redundant constraints must be taken into account, according to [10].

$$W = 6n - 5P_5 - 4P_4 + q \tag{2}$$

where q is the number of redundant connections



1-cam, 2-rocker arm a-kinematic pairs in a completely rigid state; b-3 kinematic pairs are equipped with flexible elements; v-one kinematic pair is equipped with a flexible element

**Figure 2. A substitute mechanism for the cam mechanism in the drive of a rice sorting machine**

When the cam in the considered mechanism is absolutely rigid;

$$q = W - 6n + 5P_5 + 4P_4 = 3 \quad (3)$$

Accordingly, in the theory of machines and mechanisms, the method of replacing higher kinematic pairs with lower kinematic pairs is applied.

The replacement schemes for the proposed eccentric cam mechanism are shown in Figure 2. In the first scheme, variants with absolutely rigid links (crank, connecting rod, rocker arms) were taken for the kinematic pairs. In this case, no elastic elements were involved in the kinematic pairs. According to formula (3), there will be three redundant constraints.

In the diagram shown in Figure 2-b, flexible elements are used in 3 kinematic pairs in the substituted part of the eccentric cam mechanism, whereas in diagram 2-v, a flexible element is used in only one kinematic pair. The difference between them is that in variant a, the lengths  $l_{AB}$ ,  $l_{BC}$ , and  $l_{CD}$  do not change [14]:

$$l_{AB} = const; \quad l_{BC} = const; \quad l_{CD} = const; \quad (4)$$

In option b, accordingly:

$$\begin{aligned} l_{AB} &= l_{AB} \pm \Delta l_{AB}; \\ l_{BC} &= l_{BC} \pm \Delta l_{BC}; \end{aligned} \quad (5)$$

$$l_{CD} = l_{CD} \pm \Delta l_{CD}$$

For the circuit diagram in Figure 2v:

$$\begin{aligned} l_{AB} &= const; \\ l_{BC} &= l_{BC} \pm \Delta l_{BC}; \\ l_{CD} &= l_{CD} \pm \Delta l_{CD} \end{aligned} \quad (6)$$

In this case, the values of  $\Delta l_{BC}$  and  $\Delta l_{CD}$  are small, but their values in expression (5) can be



significantly larger. In general, based on the results presented, this is determined by the following expression, taking into account the number of elastic elements used in the links and kinematic pairs of planar mechanisms.

$$q = W - 6n + 5P_5 + 4P_4 - K \quad (7)$$

where  $k$  is the coefficient that determines the number of flexible elements.

For option b:

$$q = W - 6n + 5P_5 + 4P_4 - K = 1 - 18 + 20 + 0 - 3 = 0 \quad (8)$$

For version V:

$$q = 1 - 18 + 20 + 0 - 1 = 2 \quad (9)$$

is formed.

**Discussion.** The issues of reducing and eliminating excessive constraints in kinematic pairs by replacing the cam mechanism in the drive of a rice sorting machine with alternative mechanisms have been analyzed above. The analyses show that when the mechanism is composed of three kinematic pairs, excessive constraints can be completely eliminated. This theoretically optimizes the mechanism's degree of freedom, simplifies its operation, and reduces excessive stresses. However, this configuration is not recommended for use in the mechanism because the values of the lengths  $l_{AB}$ ,  $l_{BC}$ , and  $l_{CD}$  constantly change due to the deformation of the kinematic pairs. The reason is that, as a result, the laws of motion for the crank, connecting rod, and rocker arm become dependent on the stiffness of the elastic element, making them difficult to determine.

### Conclusion.

Based on the analysis conducted, it can be concluded that among the alternatives for replacing the cam mechanism, the V-variant is selected as the most optimal solution. In this variant, the mechanism is equipped with only one kinematic pair featuring a compliant element, which allows for the preservation of a stable and predictable law of motion while significantly reducing redundant constraints.

This approach ensures the structural simplicity of the mechanism, simplifies calculation processes, and increases its reliability in practical application. As a result, the efficiency and long-term performance of the rice sorting machine's drive are improved.

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