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STUDY OF THE MOTION REGIMES OF A GRANULAR MEDIUM WITHIN A CONTAINER MOVING ALONG A COMPLEX SPATIAL TRAJECTORY

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The barreling process [1] which is the motion of machined (metal or polymer) parts together with a processing medium inside containers with different types of motion is a special type of processing of machining parts [2, 3] through their contact interaction with each other and with the components of the processing medium and the inner walls of the container. The outcome of the process involves either plastic micro-level deformation of the part surfaces or the removal and breakdown of certain structural elements of the components.

Various kinds of equipment [4] are used for barreling processes: machines with rotating vessels, vibrating machines, spindle, brush and rotary machines, machines with a complex space motion of working tanks.

Across our country, the most commonly utilized equipment includes machines with rotating containers and vibration-based systems, although these types are considered relatively inefficient. A more promising method entails employing barreling machines with containers performing complex spatial motion. In particular, this includes Turbula-type equipment, developed by the company Willy A. Bachofen (WAB, Switzerland) in 1966 [5].

In these machines, the working container performs a complex spatial motion, moving simultaneously along three mutually perpendicular planes while rotating around its own axis. This combined movement greatly enhances the agitation and circulation of the processing medium inside the container, which leads to a marked increase in processing efficiency and a reduction in energy expenditure. The overall design and appearance of the Turbula machine are illustrated in Fig. 1(a), whereas Fig. 1(b) depicts the kinematic diagram detailing the spatial mechanism responsible for this motion.

The Turbula is composed of a frame (1), a driving shaft (2), and a driven shaft (6). These shafts are mounted parallel to each other in the same plane and are connected by a double spatial joint, which includes a driving fork (3), a driven fork (5), and a working container (4). The container is fixed between the forks along geometrically perpendicular diametrical axes (7 and 8). The moving elements form a spatial six-link mechanism with rotational kinematic pairs A; B; C; D; E and F.

The motion of the processing medium was investigated using a test setup with the following geometric parameters: container length – 0.16 m, diameter – 0.12 m, and volume – 0.002 m³.

The transparent-walled working container was filled to 40% filling a portion of its total volume with particles having nearly identical mass, shape, and size. The behavior of the processing medium was examined within an angular velocity range of 1.1 to 5.3 rad/s. To observe the motion, high-speed video recording was carried out through the transparent container walls using a camera positioned in a vertical plane. By analyzing the footage in slow motion, the movement behaviors of the processing medium inside the container were identified.

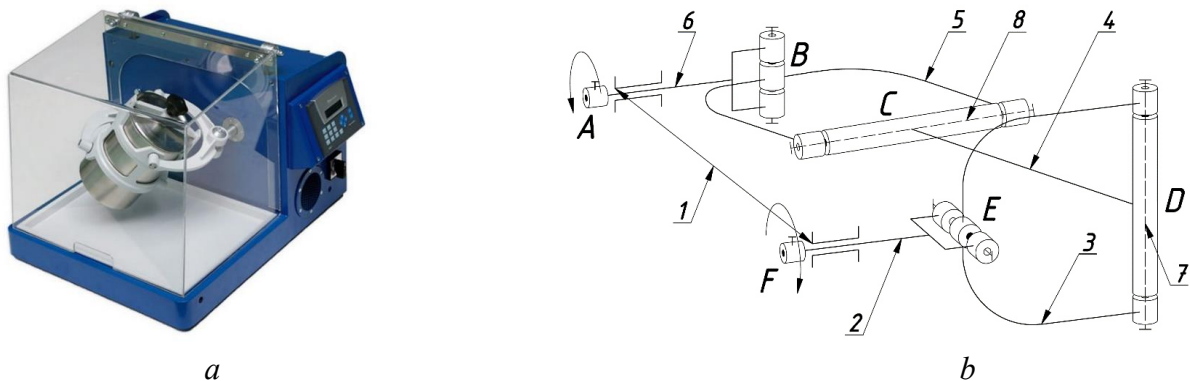


Figure 1 – Turbula machine: a - overall design and appearance; b – kinematic diagram of the spatial mechanism of the machine



Figure 2 – The photo of the test unit

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When the driving shaft rotates at an angular velocity of 1.0 rad/s, the movement of the medium predominantly resembles a cascading regime, as most particles remain remaining in contact, while rolling and sliding along the container surface and relative to one another. However, each time the driving shaft rotates through 180° , the section of the tank connected to the driven fork undergoes rapid downward acceleration, resulting in noticeable elements of a

waterfall-type motion. Selected snapshots illustrating the medium's movement at an angular velocity of 1,0 rad/s are shown in Fig. 3.

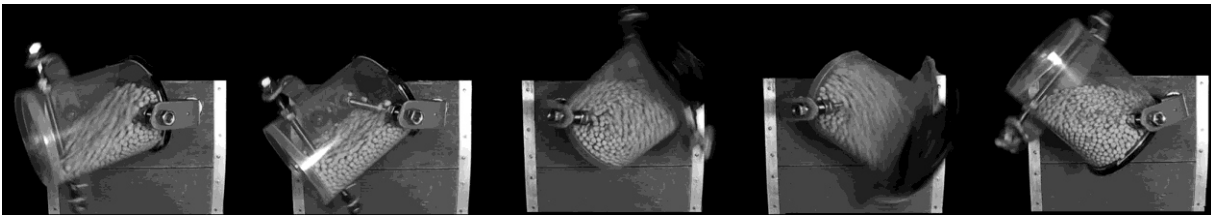


Figure 3 – Some fragments of the displacement of the processing medium at an angular velocity of 1,0 rad/sec

If the angular velocities of the driving shaft are 2,0, 3,1, and 4,3 rad/sec, two modes of motion of the processing medium are observed simultaneously: cascade and waterfall. When moving to the container end positioned at the connection point with the driven fork, almost the entire processing medium freely flies, implementing the waterfall mode of motion (Fig. 4a). When moving in the opposite direction (Fig. 4b), the processing medium flows while sticking to the container walls in the cascade mode of motion. This is because of the fact that the part of the tank that is connected to the driving fork moves relatively uniformly, without sharp accelerations and decelerations. The total mode of motion is a combination of the cascade and the waterfall modes.

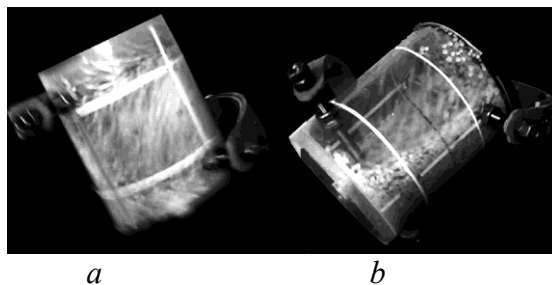


Figure 4 – Mixed mode of movement: a – waterfall mode of motion; b – the cascade mode of motion

As the angular velocity rises to 5,4 rad/s, the motion pattern approaches a waterfall regime. However, the intensity of the processing medium's movement varies depending on its direction along the container. As the medium travels toward the end connected to the driving fork, its movement is significantly weaker than in the opposite direction. The behavior of the processing medium at an angular velocity of 5,4 rad/s is illustrated in Fig. 5.

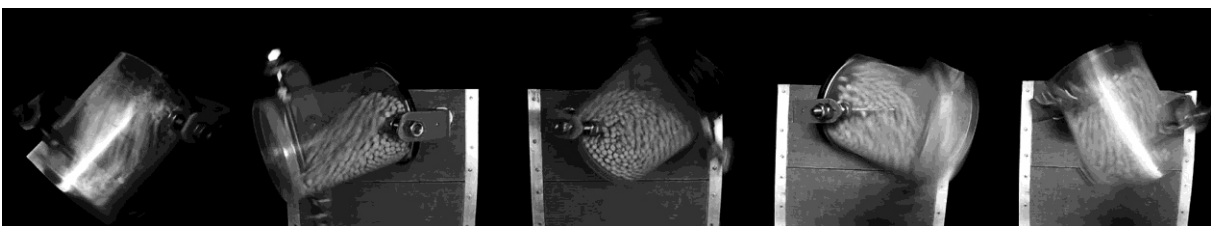


Figure 5 – Motion of the processing medium at an angular velocity 5,4 rad/sec

The experiments revealed that the sudden acceleration of the portion of the working container attached to the driven fork causes the processing medium

to move with varying intensity along the length of the container. As a result, the medium's motion differs when traveling from one end to the other, even if the driving shaft maintains a steady angular velocity within the investigated range. This indicates that the dynamics of the medium are strongly influenced by the localized acceleration of the container, leading to asymmetrical movement patterns in opposite directions.

It was established that the combination of uniform rotation of the driving shaft and non-uniform rotation of the driven shaft leads to conditions in which the processing medium moves with varying intensity along the container. As a result, two motion regimes – cascade and waterfall – occur simultaneously. Such a combined режим is not appropriate for all barreling operations. In practice, most processes should be carried out under a single motion regime; for example, grinding and polishing are more effective in cascade conditions, whereas the separation of parts from molds is better achieved under a waterfall regime. Therefore, it is necessary to develop a drive system capable of ensuring uniform motion the level of motion at both ends of the tank.

In conclusion, the behavior of the processing medium in a barreling machine of the “basic” design, which performs complex spatial motion, has been investigated. It was shown that the non-uniform angular velocity of the driven shaft causes uneven motion intensity of the processing medium between the opposite ends of the container. Consequently, this type of processing режим is suitable only for a limited range of barreling operations.

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