Adaptive centrifuge vibration damping module for biofuel production

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Abstract. The present study considers the problem of obtaining promising renewable energy sources, in particular biofuel. Biomass is the main fuel for green energy accounting for two-thirds of renewable energy. Industry further development depends on improvement of used equipment and technologies. Biofuel usually contains significant amounts of harmful impurities that need to be isolated. The paper deals with the problems of centrifuge operation for the biofuel production. In particular, the most significant operation problem is the residual rotor imbalance which causes torsional oscillations that negatively affect the biodiesel production process and centrifuge reliability. A new technology for damping torsional vibrations of centrifugal device rotating system is described as well as adaptive module device for its implementation is developed. The module main feature is vibrations adaptive level of the rotor elements interaction with external environment. Computer simulation of the module operation process in ANSYS Fluent program was carried out. Data on the module efficiency depending on various factors in the dynamics of its work are obtained. The most effective device configuration is determined.

1. Introduction

Currently, the world fuel and energy complex movement vector, in all its areas, is aimed, among other things, at the development of alternative energy sources and strengthening environmental resistance to harmful anthropogenic impacts [1]. The involvement of renewable raw materials or biomass in energy production is particularly promising [2]. This feedstock can be used directly for the production of electricity or heat, or it can be used for the production of gaseous, liquid, or solid fuels, with bio-diesel, bioethanol, and biogas being considered the most promising [3]. In particular, demand for diesel fuel is growing. One of the many reasons for this success is environmental policies of many countries and organizations that specifically promote fuels derived from renewable raw materials [4]. The transition to environmentally friendly and resource-efficient energy is one of the priority areas of the Russian science and technology strategy [5].
Centrifugal devices have found their use in various industries: from electric power and petrochemistry to metallurgy [6-7]. Decanter centrifuges are used in biofuel and biogas production processes [8]. Centrifuges are used at many stages of biodiesel preparation, in particular for: isolation of glyceric water from fatty acid ester; washing of precipitated salts; processing of raw materials before esterification; isolation of small substances from biodiesel; phase separation, etc. [9].

Centrifugal devices while in operation produce vibrations that adversely affect the reliability of these devices, affect the processes in which they are used, its personnel and other technical facilities located nearby [10]. The nature of the vibrations that arise is different but leads to one consequence - a decrease in equipment reliability, breakdown of structural parts or even failure of the device which leads to significant material costs and a decrease in productivity and production efficiency [11].

Additional difficulties in the breakdown of centrifugal devices are the features of these machines [12]. For example, at present, fast-moving rotors with an angular velocity of several tens and hundreds of thousands of revolutions per minute are increasingly used. These can be gas turbine engines with high specific power, compressors and pumps, centrifuges with high-quality separation of mixtures into component parts, etc. In this equipment the main way of technical progress is to increase the speed of their main working body – the rotor.

Despite the successes achieved in accurately balancing the rotors and using elastic-damper supports the main problem of fast-rotating rotors remains strong vibration due to residual imbalance. Residual imbalance of centrifuge rotors occurs, for example, due to the accumulation of solids during the periodicity of separation process or influence of mixture granulometric composition and its physicochemical properties, for example, adhesion. In addition, residual imbalance accumulates as centrifuge parts, in particular bearing units and screws, wear out. This process can cause dynamic stability loss and accidents during centrifuge operation [13-14].

Since residual imbalance of the centrifuge rotor is inevitable, adaptive monitoring and vibration protection of this equipment type are important tasks.

2. Model of adaptive module for damping centrifuge vibrations
Siberian Federal University Biofuel compositions laboratory has been developed a technology for damping torsional vibrations of centrifugal devices. This technology is based on the installation of the developed adaptive module, the design of which is shown in figure 1, centrifuge rotor.

![Figure 1. Module diagram in operating position: 1 – rotor; 2 – vibration damping module; 3 – module housing; 4 – piston micromovement drive; 5 – spring; 6 – medium resistance element (fin); 7 – casing.](image-url)
The developed technology is based on the rotational speed of the rotor 1 transmission of force to the micromovement drive 4 (module 2), as well as the creation by the element 6 of the force of resistance to rotation, depending on the speed of the rotor 1, by means of an external environment located in the casing 7. The force effect on the micromovement drive 4 is obtained by changing the inertia forces of the rotor when changing the number of revolutions. To create resistance force to rotation a viscous medium is used while this force is created by moving the micromovement drive 4 with resistance element 6, which is caused by the forces of pressure and viscous friction of the medium increasing or decreasing the area and forces of the resistance element 6 interaction with the medium with an increase or decrease in the number of rotor revolutions 1, respectively.

The resulting moment due to tangent stresses occurring on the surface can be mathematically expressed by the following formula

$$M = \gamma \cdot \omega$$

where: $\gamma$ is coefficient of viscous damping at torsion; $\omega$ is the angular rotor velocity on which the module is fixed.

The module operates as follows. In the initial position, the medium resistance element 6 is hidden. As the number of revolutions of the rotor 1 with the module 2 increases the centrifugal force received by the piston 4 causes its displacement inside the housing of the module 3 from the center to the periphery along the guide. This displacement is controlled by the spring 5 the movement of which is limited by the module housing 3.

When the piston is displaced, the resistance element to the medium 6 is extended to an amount equal to the compression value of the spring 5, which is proportional to the perceived centrifugal force and is regulated by its rigidity. Thus, the area of the active pressure on the module and the moment of resistance are proportionally increased. In the case of decreasing the number of revolutions the reverse process occurs that is the area of the current pressure on the module and the moment of resistance proportionally decrease.

To determine the most effective parameters of the module, simulation was carried out in ANSYS Fluent program. The performance indicator is the force of resistance to rotation expressed in the value of negative torque and pressure on the resistance element. To determine these parameters all studies were conducted on a simplified design model.

Figure 2 shows the calculated finite-element model of the adaptive module for damping torsional centrifuge vibrations.
The study was conducted as the medium resistance element was extended: in the initial position; nominated halfway; in the final position. And also for various configurations of the module, in particular when the module 2 (fig. 1) vibration damping is rotated by 15°, 30° and 45°. Simulations were also carried out on the resistance element that has a surface relief.

For the convenience of comparing, the values of pressure $P$ and resistance moment $M$ relative values characterizing the conversion effect were used. They were obtained by formulas

\[
P_i = \frac{P_{ni}}{P_1},
\]

\[
M_i = \frac{M_{ni}}{M_1},
\]

where $M_{ni}$ и $P_{ni}$ – numerical values of resistance moment and pressure on medium resistance elements obtained during simulation; $i$ is the simulation sequence number (1 in the initial position, 2 in the position where the medium resistance element is extended half, 3 in the final position). At the same time, $M_1$ and $P_1$ were taken to be equal to one.

### 3. Simulations results

The simulation results as the resistance element is extended are presented in table 1. Figure 3 shows the calculation models illustrating the pressure distribution.

| Parameter | Extension level |
|-----------|-----------------|
|           | original | half | full |
| $P_{ni}$  | 1       | 1.33  | 1.64 |
| $M_{ni}$  | 1       | 1.29  | 1.71 |

The simulation results when rotating the vibration damping module by 15°, 30° and 45°, as well as when applying relief to the surface of the resistance element are presented in table 2, and the calculation models in figure 4.
Table 2. Numerical ratios of desired parameters in different medium resistance element transformations.

| Parameter        | Transformation            | Original form | Rotate the element by 15° | Rotate the element by 30° | Rotate the element by 45° | Surface relief applying |
|------------------|----------------------------|---------------|---------------------------|---------------------------|---------------------------|-------------------------|
| Pressure         |                           | 1             | 1.51                      | 1.77                      | 1.83                      | 1.82                    |
| Resistance moment|                           | 1             | 2.08                      | 3.02                      | 3.14                      | 2.95                    |

Figure 4. Simulation results when rotating the vibration damping module by 15°, 30°, 45° when applying relief.

The simulation data show the following:

- Increasing extension of the resistance element relative to its initial position increases the pressure and resistance moment generated by it, which indicates an increase in the resistance force to rotation of the centrifuge rotor.
- Increasing counter torque generated by the medium resistance elements is influenced by the position of vibration damping module (rotation angle) and presence of surface relief.
- The highest rotational resistance force of the centrifuge rotor will be achieved by setting the rotation angle of vibration damping module to 45°.
- The value of the resistance moment when adding relief to the surface of medium resistance element is almost 3 times.

4. Conclusion
A new protection technology against vibration of centrifugal devices rotors is proposed and investigated. For this purpose, an adaptive module device has been developed which uses the dynamic interaction of the resistance element and a viscous medium to dampen vibrations.
Device operability and efficiency was confirmed by simulations in ANSYS Fluent software. According to the simulation results it was revealed that the best configuration of the device combines the rotation angle of the damping module by 45° and the application of the surface relief to the medium resistance element. Using such configurations, as the study showed, the resistance moment to rotation will increase by 3 times, an increase in pressure on the resistance element by 1.8 times.

Thus, it can be concluded that the vibration of centrifugal devices rotating systems can be significantly reduced by using the developed technology and adaptive module, thereby improving the reliability of centrifuges for biofuels production and stabilizing their operation.

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