Estimation of two- and three-stage vibration device's parameters with asymmetric oscillations in terms of system's dynamic factor

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Abstract. The paper shows the advantage of the efficiency of asymmetric directed oscillations in front of symmetrical directed oscillations for the implementation of several technological operations. The method is given for calculating the system's dynamic factor of two- and three-stages' vibrators with directed asymmetric oscillations. Some recommendations are analyzed for the ratios of the unbalances' static moments for a two- and three-stage vibrating device. Rational values of the system's dynamic factor of two- and three-stage vibrating devices are obtained.

1. Introduction

Vibration, as an operation, takes place in many technological processes. Vibration equipment, which is used to generate forced oscillations, has a diverse range of design solutions. Most of the vibrating devices and vibrators are concentrated in the class of plate vibrators [1, 2, 3]. Plate vibrators generate circular and elliptical oscillations. By installing in parallel two equivalent vibrators with circular oscillations, directional oscillations are obtained along the line of driving force's action. However, such designs require a significant increase in power and synchronization of their work. This requires quite complex analytical and technical solutions [4, 5, 6].

Improving the design of plate vibrators and vibrating devices is conducted in two directions. In the first direction, directional vibrations of the single-shaft vibrator are obtained with the possibility of changing the direction of the driving force's action within 360° [7]. In the second direction, asymmetric oscillations are created by changing the values of the driving force's components in the direction of the useful work and in the direction of idling [8, 9]. The work is devoted to the implementation and development of the second direction for the improvement of vibration devices.

2. Materials and methods

While preparing this article, the authors used modern methods of scientific research. The authors performed analysis of the patent situation; analysis of the market of plate vibrators and vibration mechanisms; analytical studies of parameters characterizing the vibrators' work; elements of processes’
programming and modeling. The market of plate vibrators and vibration mechanisms is represented by a number of manufacturers and suppliers, for example, Brecon (Bosch), Italvibras, FRIEDRICH Schwingtechnik, Knauer engineering GMBH, AVITEQ, Netter, OLI, OMB, Somai, Venanzetti, Wurges Vibrationstechnik, Derrick, Martin engineering, Visam. Inventions’ patenting is conducted quite intensively in the field of vibrating devices' improvement [10].

3. Evaluation of asymmetric oscillations' efficiency using the dynamic factor

By asymmetric vibrations of vibratory devices, the authors mean the process in which the components of the driving force periodically directed in opposite directions differ significantly from one another in the module. As a rule, the component with a large value of the module is directed toward performing useful work, and with a smaller one - in the opposite direction, in the idling direction. The action of the driving force's components is carried out alternately through each half-cycle of the oscillation. In this case, the dynamic factor \( k_d \) is estimated by the dependence:

\[
k_d = \frac{|F_u|}{|F_i|},
\]

where \( F_u \) is the driving force (component) in the direction of the performance of the useful work, \( F_i \) - the driving force (component) in the direction of idling. \( F_i \) has a negative sign with respect to \( F_u \).

The value of ratio (1) can vary from 1.0, with a symmetric driving force up to several units. The larger the value of \( k_d \), the less energy is expended in the direction of idling. This means that the less energy is needed to compensate for the driving force's component in the idling direction. Currently, the role of the compensator of the driving force's idling component is most often carried out by an additional inert mass, which is called the load. Asymmetric vibrations either completely abolish the need to apply the load or significantly reduce its mass.

Asymmetric oscillations can be obtained, first of all, by installing at least two groups of shafts with imbalances. Each group of parallel shafts, called the "stage", has its own rotation frequency of the unbalanced shafts. The vibration mechanism can have 2, 3, 4, 5, 6 and more stages, if necessary. With an increase in the stages' number, the magnitude of the dynamic factor also increases. Obviously, in the near future, the two- and three-stage vibrating devices will be in great demand in the practice of application. The ratio of the rotation frequencies of unbalanced shafts' adjacent stages is recommended to be taken as multiple, for example: 1:2; 1:2:3, and so on. The dynamic factor's magnitude of a vibrating device with asymmetric oscillations can be regulated by the mass of unbalances \( m \) and their eccentricity \( r \), which ultimately reduces to the ratio of the static moments of the unbalances of each stage: \( m_1r_1, m_2r_2, m_3r_3, \) etc.

Thus, for a two-stage vibration mechanism, the ratio of the static moments of the first and second stage of shaft's groups in the interval from six to one and up to ten to one is recommended [8].

The program developed by the authors makes it possible to estimate the dynamic factor's magnitude from the ratio of the stages' unbalances' static moments. The program is designed for seven stages of the vibration mechanism. Vibration devices with two and three stages are considered in this paper.

Table 1 shows the dynamic factor's calculation of a two-stage vibration device. In table 1 the following parameters are adopted for clarity: the eccentricity of the unbalance (radius) equal to one; the ratio of the unbalanced shafts' rotation frequencies being 1: 2: 3; mass value \( m_i \) equal to 10.

As a result of the calculation, there is largest dynamic factor \( k_d = 2.04 \). The magnitude of the driving force's useful component is 0.85 kN, and the magnitude of the idling component one is 0.42 kN. The dynamics of the driving force's magnitude within one period is shown in Fig. 1.

| pi Vibrator number | Mass (kg) | Radius (cm) |
|-------------------|-----------|-------------|
| 3.1416            | 10        | 1           |
|                   | 1.39      | 1           |

Table 1. Calculation of the dynamic factor of a two-stage vibration device with asymmetric oscillations according to the recommendations [8]
Let the magnitude of the useful driving force, which is 0.85 kN, be the initial task for the realization of the useful work.

The most advantageous ratio of the static moments of the first and second stages, $m_1r_1$ and $m_2r_2$, is: 7.19, which is included in the interval of 6:1 ... 10:1; however, it differs significantly from the boundary values. At a static moments’ ratio equal to 6: 1 and 10: 1, $k_d$ is equal to 1.96.

For a three-stage vibration mechanism, ratio 100:16.64:3.68 of the static moments of the first, second and third stage groups of shafts is recommended [8].

Setting this ratio of static moments and using the parameters of the previous example, the authors obtain the results given in table 2. The data of table 2 are reduced in areas of recurrence or evidence.

| T  | Start phase (deg) | Speed (rpm) | 500  | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 |
|----|-------------------|-------------|------|------|------|------|------|------|------|
| 0.12 |                   | dt          | R (m) |      |      |      |      |      |      |
| 0.006 | fi0 (rad)         | w (1/s)     | 52.36| 104.72| 157.08| 209.44| 261.8| 314.16| 366.52|

| №  | t   | Amount |
|----|-----|--------|
| 0  | 0.000 | 0.55  | 0.30  | 0.85  |
| 1  | 0.006 | 0.52  | 0.25  | 0.77  |
| 2  | 0.012 | 0.44  | 0.09  | 0.54  |
| 3  | 0.018 | 0.32  | -0.09 | 0.23  |
| 4  | 0.024 | 0.17  | -0.25 | -0.08 |
| 5  | 0.030 | 0.00  | -0.30 | -0.30 |
| 6  | 0.036 | -0.17 | -0.25 | -0.42 |
| 7  | 0.042 | -0.32 | -0.09 | -0.42 |
| 8  | 0.048 | -0.44 | 0.09  | -0.35 |
| 9  | 0.054 | -0.52 | 0.25  | -0.27 |
| 10 | 0.060 | -0.55 | 0.30  | -0.24 |
| 11 | 0.066 | -0.52 | 0.25  | -0.27 |
| 12 | 0.072 | -0.44 | 0.09  | -0.35 |
| 13 | 0.078 | -0.32 | -0.09 | -0.42 |
| 14 | 0.084 | -0.17 | -0.25 | -0.42 |
| 15 | 0.090 | 0.00  | -0.30 | -0.30 |
| 16 | 0.096 | 0.17  | -0.25 | -0.08 |
| 17 | 0.102 | 0.32  | -0.09 | 0.23  |
| 18 | 0.108 | 0.44  | 0.09  | 0.54  |
| 19 | 0.114 | 0.52  | 0.25  | 0.77  |
| 20 | 0.120 | 0.55  | 0.30  | 0.85  |

Max 0.55 0.30 0.00 0.00 0.00 0.00 0.00 0.85
Min -0.55 -0.30 0.00 0.00 0.00 0.00 0.00 -0.42

$k_d = 2.04$
Figure 1. Dynamics of the change in the driving force's magnitude (Yr) within the same period of the two-stage vibration device: 1 and 2 – the graph of the change in the driving force of the 1st and 2nd stages, 5 – the graph of the reserve fifth stage, "Sum" – the summary graph of the change in the driving force.

Table 2. Calculation of the dynamic factor of a three-stage vibration device with asymmetric oscillations according to recommendations [8]

| Vibrator number | 1     | 2     | 3     |
|-----------------|-------|-------|-------|
| Mass (kg)       | 10    | 1.664 | 0.368 |
| Radius (cm)     | 1     | 1     | 1     |
| Start phase (deg)| 0    | 0     | 0     |
| Speed (rpm)     | 500   | 1000  | 1500  |

| №   | t, t | Amount          |
|-----|------|-----------------|
| 0   | 0.000| 0.55 0.36 0.18 1.09 |
| 10  | 0.060| -0.55 0.36 -0.18 -0.36 |
| 20  | 0.120| 0.55 0.36 0.18 1.09 |
| Max |       | 0.55 0.36 0.18 1.09 |
| Min |       | -0.55 -0.36 -0.18 -0.36 |

$k_d = 3.027$

With an increase in the dynamic factor from 2.04 to 3.03, there is an increase in the total value of the driving force from 0.85 to 1.09 kN, which is higher by 28%.

Using the recommendations of the ratios of static moments [8], the authors calculate the total driving force of 0.85 kN and the dynamic factor of 3.04, Table 3.

Table 3. Calculation of the dynamic factor of a three-stage vibration device with asymmetric oscillations according to the recommendations [8]

| Vibrator number | 1     | 2     | 3     |
|-----------------|-------|-------|-------|
| Mass (kg)       | 7.798 | 1.298 | 0.287 |
| Radius (cm)     | 1     | 1     | 1     |
### Table

| №   | Amount | t | Speed (rpm) |
|-----|--------|---|-------------|
|     |        |   | 500         | 1000 | 1500 |
| 0   | 0.000  | 0.43| 0.28 | 0.14 | 0.85 |
| 10  | 0.060  | -0.43| 0.28 | -0.14 | -0.28 |
| 20  | 0.120  | 0.43| 0.28 | 0.14 | 0.85 |
| Max | 0.43   | 0.28 | 0.14 | 0.85 |
| Min | -0.43  | -0.28 | -0.14 | -0.28 | 3.04 |

In this case, the ratio of static moments is 100:16.49:3.647. This ratio of static moments is fairly close to optimal for three-stage vibration devices with asymmetric oscillations.

### Figure 2

Dynamics of the change in the driving force's magnitude (Yr) within the same period of the three-stage vibration device: 1 and 2 – the graph of the change in the driving force of the 1st and 2nd stages, 5 – the graph of the reserve fifth stage, "Sum" – the summary graph of the change in the driving force.

### 4. Conclusion

Asymmetric oscillations for a number of technological machines can have a number of significant advantages over machines with directed oscillations with a symmetric driving force. The effect of the asymmetry of the driving force can be estimated by the dynamic factor – the ratio of the value of the useful component of the force to the value of the idle one. The two-stage vibration mechanism achieves a dynamic factor within two units, and a three-stage one – within three units. Figures 1 and 2 show the significant difference in the time of action and in the magnitude of the maximum of the useful force and the idling force. Thus, in a two-stage vibration device, the ratio of the time of action of the useful force and the idling force is 0.72 s and 0.28 s, respectively, and for the three-stage – 0.48 and 0.52. This important remark can be the basis for choosing the number of stages for a particular technological process and the design of the vibrator.
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