Comparative analysis of the parameters of generators with circular and asymmetric oscillations

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Abstract. In the paper the calculation and comparative analysis of the technical characteristics and main parameters of a vibrator with circular oscillations with a driving force equal to 5 kN and a vibrating device with asymmetric oscillations with a similar driving force for two, three and four stages of vibration blocks with directional vibrations are performed based on the design methodology of vibration devices with asymmetric oscillations. The aim of this paper is to identify the positive and negative effects in the transfer of the vibrator with circular oscillations on the vibrating device with asymmetric oscillations. The paper uses a method for selecting rational ratios of static moments of debalances, which provides the highest coefficient of azimuth of the driving force of both individual stages of vibration blocks, and the coefficient of the total driving force of the entire device as a whole. This paper will be useful for manufacturers of vibration machines for construction and road vehicles.

1. Introduction

Modern rates of development of methods of design and creation of construction and road equipment and technology dictate the need to search for and implement ideas that significantly increase the speed of their work. The speed of work performed by machines, with high quality, becomes a priority factor when choosing machines and their manufacturers.

In the production of construction and road-building materials, construction and road construction works the use of vibration equipment, vibration devices, vibrators and vibration blocks plays a significant role in enhancing the speed of production.

According to the classification [1,2], vibrators and vibrating devices with circular and directional oscillations are used in the industry.

A significant way to increase the efficiency of vibration machines, and thus increase the speed of work performed, is their ability to work near the resonance [3,4]. However, as noted in a number of publications [5,6,7], creating conditions close to resonance is a much easier task than maintaining these conditions with stable output parameters over a long period of machine operation. Thus, the use of the resonance phenomenon in construction and road vehicles, or close to it, is currently problematic.

However, there is a method for generating mechanical oscillations that simulates conditions close to resonance to a high degree. This is a method for generating asymmetric oscillations by vibrating
devices consisting of vibration blocks with directed oscillations along a single line of action, Fig. 1, [8,9].

Figure 1. Scheme of debalance vibration blocks consisting of three stages of two-shaft vibration blocks with debalance shafts rotating in opposite directions.

The method of obtaining the total driving force for asymmetric oscillations is described in several sources [5, 6, 10, 11, 12]. Thus, the total effect of the asymmetry of the driving force estimated by the quantitative index – coefficient of asymmetry of the driving force \( k_a \), or, equivalently the coefficient of dynamic system with an asymmetric oscillations \( (k_d) \). Numerically, the coefficient of asymmetry of the driving force is the ratio of the amount of the driving force acting in one direction, usually in the direction of performing useful work \( (F_{u.w}) \) to the amount of the driving force acting in the opposite direction, i.e., in the direction of idle speed \( (F_{i.d.sp}) \):

\[
k_a = k_d = \frac{F_{u.w}}{F_{i.d.sp}}
\]  

It is found out [13] that the numerical value of \( k_a \) for a vibrating device with asymmetric oscillations consisting of two stages of vibration blocks with directional oscillations can be: \( k_a \leq 2.0 \). The numerical value of \( k_a \) for a vibrating device with asymmetric oscillations consisting of \( n \) stages of vibration blocks with directional oscillations can be: \( k_{a n} < n \). This means that with the correct and rational choice of the initial parameters of the vibration block of each stage, we can get an asymmetry coefficient of 2.0. If we deviate from the rational parameters, the value of the asymmetry coefficient of a two-stage vibrating device will be within the range of the numerical value \( k_a \) for a vibrating device with asymmetric oscillations consisting of two stages of vibration blocks with directional vibrations can be: \( k_a < 2.0 \). Similarly, for a multi-stage one: \( k_{an} < n \).

The aim of this work is to calculate the rational parameters of a vibrating device with asymmetric oscillations on the example of using the technical parameters of an industrial vibrator with circular oscillations consisting of two, three and four stages of vibration blocks with directional oscillations and to identify trends in quantitative and qualitative parameters in comparison with the basic sample.

2. Materials and methods

The paper uses classical universal and special research methods. The first stage includes the creation and processing of databases of technical solutions in the field of generating asymmetric oscillations for use in construction and road equipment. Based on the obtained databases, we selected patents and printed works that contain elements of the design methodology for vibration devices with asymmetric oscillations. Design methods are classified according to the directions that reflect their significant differences. At the second stage, the design and creation of a calculation block for processing numerical values and parameters of harmonic and asymmetric oscillations are completed by the specialized pro-
gram Delpfy, which is designed to determine the optimal parameters of the vibrating device with asymmetric oscillations with an arbitrary number of vibration stages with directional oscillations. At the third stage, the method [10-13] was used to solve numerically and obtain rational parameters of the stages of vibration blocks included in a vibrating device with asymmetric oscillations in order to obtain the highest value of the asymmetry coefficient of the total driving force. Numerical calculations are performed using Excel spreadsheets included in the instrumental calculation apparatus.

3. Results

For comparative analysis, we take a vibrator with circular oscillations, widely used in industry IV-05-50 [14].

From the technological characteristics for further calculations and analysis, we take: the maximum driving force \( F = 5.0 \, \text{kN} \); oscillation frequency \( f = 50 \, \text{Hz} \) (\( n_0 = 3000 \, \text{rpm} \)); static moment of debalances \( M_{st,0} = 5.1 \, \text{kg} \cdot \text{cm} \), \( 0.051 \, \text{kg} \cdot \text{m} \); engine power \( N = 0.5 \, \text{kW} \); weight \( m_p = 15 \, \text{kg} \).

The paper does not imply any goals in the part – what vibrator is better. Each design is made to perform its own tasks and occupies its own market sector.

We check the calculated value of the driving force:

\[
F = m_0 \cdot r_0 \cdot \omega_0^2 = M_{ct,0} \cdot \omega_0^2 = 0.05 \cdot 314^2 = 5018 \, \text{N}
\]  

(2)

where \( \omega_0 = \frac{\pi n}{30} = \frac{314 \cdot 3000}{30} = 314 \, \text{s}^{-1} \) - angular speed of rotation of unbalanced shafts, \( m_0 \) - the total mass of debalances, kg.

We take 5.0 kN according to the technical characteristics. The projection of the driving force on the vertical axis is defined by the expression:

\[
F = m_0 \cdot r \cdot \omega_0^2 \cdot \cos(\omega_0^2 \cdot t + \varphi_0)
\]  

(3)

where \( t \) – current time, s; \( \varphi_0 \) – initial phase, deg.

The graph of changes in the value \( F \) within the period \( (T_0 = 1/50=0.02 \, \text{s}) \) is shown in Fig. 2a.

The result is obtained at the sum of the mass of the debalances: \( m_0 = 2.54 \, \text{kg} \), at the eccentricity: \( r = 0.02 \, \text{m} \) (2 cm) and at the speed of the debalance shaft \( n = 300 \, \text{rpm} \). If it is necessary to calculate the parameters of a vibration block with directional oscillations consisting of two rotating counterbalance shafts at the same initial parameters, we should take the mass of the debalances on each shaft (Fig. 1) equal to \( m_1 = m_0 / 2 = 1.27 \, \text{kg} \). The coefficient of asymmetry of the driving force is: \( k_a = \frac{F^+}{|F^-|} = \frac{5^+}{5^-} = 1.0 \), as the value of the driving force on the positive and negative sides of the graph is equal in magnitude to each other.

Figure 2. a - Graph of changes in the magnitude of the projection of the driving force \( F=5.0 \, \text{kN} \) on the vertical axis \((Yr, \, \text{kN})\) of the vibrator with circular oscillations within the period \((T_0 = 1/50=0.02 \, \text{s})\); b - Graph of the change in the projection of the total driving force \( F=5.0 \, \text{kN} \) on the vertical axis \((Yr, \, \text{kN})\) of a two-stage vibration device with asymmetric oscillations within the period \((T_0 = 0.03 \, \text{s})\).
In accordance with the method for a vibrating device with asymmetric oscillations consisting of two stages of vibration blocks with directed oscillations [13], we divide the total driving force \( F = 5.0 \) kN into two components: \( F_1 = 3.33 \) kN and \( F_2 = 1.67 \) kN. The rotation speeds of the unbalanced shafts are accepted: \( n_1 = 2000 \) rpm and \( n_2 = 4000 \) rpm. The static moments of debalances are determined from ratios:

\[
M_{st1} = \frac{F_1}{\omega_1^2} \quad \text{and} \quad M_{st2} = \frac{F_2}{\omega_2^2}
\]  

(4)

The initial parameters for calculating a two-stage vibrating device with asymmetric oscillations are summarized in table 1.

**Table 1.** Initial parameters for the calculation of the two-stage vibrating device with asymmetric oscillations.

| Constants | Parameter      | \( \pi \) | 1 | 2 |
|-----------|----------------|----------|---|---|
| \( \pi \) | Weight (kg)    | 3.1416   | 1.9 | 0.475 |
|           | Radius (cm)    |          | 2 | 1 |
|           | Init. phase (deg.) | 0 | 0 |
| \( T \)  | Speed (rpm)    | 0.03     | 2000 | 4000 |
|          | Ri (m)         |          | 0.02 | 0.01 |
|          | \( \phi_i \) (rad) | 0.00 | 0.00 |
| dt       | \( \omega_i \) (1/s) | 0.0015 | 209.4 | 418.88 |

Here, \( T = 0.03 \) s, the period of debalance oscillation at \( n = 2000 \) rpm; \( dt = 0.0015 \) s - the time, duration, length of time, by dividing the duration of the period on 20 segments; \( \phi_i \) = the initial phase of the i-th vibration unit composed of the vibration device with asymmetric oscillations; \( Ri \) is the eccentricity of debalances of the i-th vibration unit composed of the vibration device with the asymmetric oscillations; \( \omega_i \) – the angular velocity of rotation of the debalance shafts.

The calculation results are shown in table 2.

**Table 2.** Results of calculating parameters of a two-stage device with asymmetric oscillations.

| №  | t    | F1   | F2   | Sum  |
|----|------|------|------|------|
| 0  | 0.000| 3.33 | 1.67 | 5.00 |
| 1  | 0.002| 3.17 | 1.35 | 4.52 |
| 2  | 0.003| 2.70 | 0.52 | 3.21 |
| 3  | 0.005| 1.96 |-0.52 |1.44 |
| 4  | 0.006| 1.03 |-1.35 |0.32 |
| 5  | 0.008| 0.00 |-1.67 |-1.67|
| 6  | 0.009| -1.03|-1.35 |-2.38|
| 7  | 0.011| -1.96|-0.52 |-2.47|
| 8  | 0.012| -2.70| 0.52 |-2.18|
| 9  | 0.014| -3.17| 1.35 |-1.82|
| 10 | 0.015| -3.33| 1.67 |-1.67|
| 11 | 0.017| -3.17| 1.35 |-1.82|
| 12 | 0.018| -2.70| 0.52 |-2.18|
| 13 | 0.020| -1.96|-0.52 |-2.47|
| 14 | 0.021| -1.03|-1.35 |-2.38|
| 15 | 0.023| 0.00 |-1.67 |-1.67|
The asymmetry coefficient of the total driving force is:

\[ k_a = \frac{5.0}{|2.47|} = 2.02 \text{ kN} \]. Total weight of required debalances is 2,375 kg.

The graph of the change in the projection of the total driving force on the vertical axis is shown in Fig. 2 b.

The asymmetry coefficient of the total driving force for the calculation of a three-stage vibrating device with asymmetric oscillations is: \( k_a = 3.01 \text{ kN} \). The total weight of required debalances is 3.56 kg. The values of the components of the total driving force have the following values: \( P_1 + P_2 + P_3 + P_4 = 2.5 + 1.67 + 0.83 = 5.0 \text{ kN} \).

A graph of the change in the value of the projection of the total driving force on the vertical axis is shown in Fig. 4 a.

**Figure 3.** a - Graph of changes in the projection of the total driving force \( F=5.0 \text{ kN} \) on the vertical axis (Y, \( \text{kN} \)) of a three-stage vibrating device with asymmetric oscillations within a period (\( T_0 = 0.04 \text{ s} \)); b - Graph of the change in the projection of the total driving force \( F=5.0 \text{ kN} \) on the vertical axis (Y, \( \text{kN} \)) of a four-stage vibrating device with asymmetric oscillations within the period (\( T_0 = 0.06 \text{ s} \)).

The asymmetry coefficient of the total driving force for the calculation of a four-stage vibrating device with asymmetric oscillations is: \( k_a = \text{kN} \). The total weight of required debalances is 4.0 kg. The values that make up the total driving force have the following values: \( P_1 + P_2 + P_3 + P_4 = 2.0 + 1.5 + 1.0 + 0.5 = 5.0 \text{ kN} \).

The graph of the change in the value of the projection of the total driving force on the vertical axis is shown in Fig. 3 b.
4. Summary
Based on the results of calculations, we can present a table of comparative parameters of vibration devices for obtaining a driving force of 5 kN, acting in the direction of performing useful work $F_{u,w}$, table 3.

**Table 3. Results of the comparative parameters of the vibration devices.**

| №  | Parameter                                      | Basic sample | Number of stages of the vibration device |
|----|-----------------------------------------------|--------------|------------------------------------------|
| 1  | Component of the driving force, $F_{u,w}$ kN  | 5.0          | 5.0  5.0  5.0  5.0                       |
| 2  | Component of the driving force acting in the direction of idle speed, $F_{idl,sp}$ kN | 5.0          | 2.47  1.66  1.25                        |
| 3  | Asymmetry coefficient of the driving force, $k_a$ | 1.0          | 2.02  3.01  4.0                         |
| 4  | Total weight of debalances, $\sum m_q$       | 2.54         | 2.375  3.56  4.002                      |
| 5  | Oscillation period, T, s                     | 0.2          | 0.3  0.4  0.6                           |
| 6  | Time of action of the force $F_{u,w}$, s      | 0.01         | 0.011  0.012  0.016                     |
| 7  | Time of action of the force $F_{idl,sp}$, s   | 0.01         | 0.019  0.028  0.044                     |

The value of the driving force component in the direction of idle speed, at the accepted parameters of individual stages of vibration blocks with directional oscillations, is reduced from 5.0 kN to 1.25 kN. The asymmetry coefficient of the driving force, which increases from 1.0 in the basic sample to 4.0 in a four-stage vibration device, with a small degree of conditionality, can be considered a coefficient that evaluates the effect of the system resonance. The time of action of the force $F_{u,w}$ does not change significantly, about 9 ... 10% when changing the number of stages. It is noteworthy that with the increase of number of stages increases the total weight of debalances. However, the method allows, within a static moment of debalances to reduce the total weight of them by increasing the radii of the displacement of the centers of gravity of respective debalances.

The comparative calculations show that in necessary and justified conditions [15, 16], in which it is necessary to have high values of the driving force in the direction of performing useful work and low values of the driving force in the direction of performing idle speed, it is justified to switch to the design, creation and use of machines with vibration devices that generate asymmetric oscillations. The method presented in the paper allows selecting the main technological and design parameters of vibration blocks of a multi-stage vibration device that provide the highest coefficient of asymmetry of the total driving force.

5. References
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