Optimization of vibrator parameters cotton bushes

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Abstract. The article presents issues related to the cultivation and harvesting of cotton in Uzbekistan, as well as the need to ensure a high-quality machine harvest. The purpose of growing plants to increase productivity from cotton bushes. Experimental studies of the simulation of the vibrator drive are carried out in laboratory conditions on a specially designed stand, consisting of two samples and made in full size. We conducted multivariate studies, i.e. mathematical planning of the experimental and obtained results adequately describes the technological process of the vibrator and allows to determine its parameters. The solution of mathematical models, with known input numerical values, made it possible to determine the rational parameters of the vibrator: the minimum unevenness of rotation of the carrier is $\Omega = 6.4829\%$; the maximum moment on the motor shaft is $M_{\text{max}} = 2.95825 \, \text{N m}$ and the degree of dynamism is $H = 684.8659 \, \text{rad/s}^2$.

1. Introduction

Currently, cotton in Uzbekistan is cultivated on an area of about 1.3 million hectares and the gross yield is about 4 million tons. Under favorable conditions and proper operation, one MX-1.8 cotton picker can collect about 100 tons of raw cotton per season. It follows that to collect at least slightly less than half the cotton crop of 1.5 million tons, it is necessary to have 15 thousand units of cotton harvesting machines. The production of so many cotton pickers should be based on a science-based approach. The layout of a domestic cotton picker differs significantly from the counterparts of foreign machines in layout and design and provides for a different, more efficient way of mounting it on a tractor - semi-mounted while releasing the latter for other seasonal agricultural work, which is an important factor for small farms and farms [1].

To date, the requirements of agricultural technology for the cultivation of cotton and the textile industry to biological raw materials have greatly increased, and in this aspect, the consensus to improve the working bodies, the development of new technological and technical solutions to increase the efficiency of the use of harvesting machines and cotton harvesting machines, in general, remain very urgent tasks.

The purpose of research.

Improving the efficiency of cotton-picking machines due to the use of a vibrator of plant bushes to increase the completeness of harvesting.

2. Materials and Methods

Experimental studies were carried out in laboratory conditions on a specially designed bench setup. The bench installation structurally included two mechanisms: the bush vibrator itself, made in full size, and the field bed model made in the form of wooden battens, on which field cotton bushes were installed through rubber bushings simulating the stiffness of the bushes in the soil [1, 2].
The following parameters are accepted as the main criteria determining the dynamic loads of the vibrator mechanism: rotation frequency of the carrier shaft, min\(^{-1}\); torque occurring in the area of the carrier shaft between the pulley from the electric motor and the carrier; the angular movement of the rocker arm, on which the working body is attached; the efforts arising in the working body from interaction with the stems of the bushes [3].

To conduct experiments and establish the numerical values of the above parameters, the following strain gauge structures were installed at the test bench: the carrier shaft rotation frequency was recorded using a reversible electric machine with permanent magnets like DPM-20-N1-03: the drive shaft torque was measured using 2PCV 10-200GB type strain gages with a base 10 mm, connected in a half-bridge circuit, the connection of strain gages was carried out through a current collector mounted on the end of the shaft. The angular displacements of the rocker arm were recorded using a TRM\(-\)type wire potentiometer (a spar traction angle sensor that allows angles to be recorded with an accuracy of 0.2 degrees) with a nominal value of 470 Ohms included in the circuit with an artificial midpoint with the same potentiometer. The efforts arising in the working body from interaction with the stems of the bushes were fixed by strain gauges assembled in a half-bridge circuit and glued to the lower beam arm at a distance of 10 mm from the support.

The measuring and recording equipment consisted of a multichannel amplifier at the carrier frequency of the UT\(-\)8 brand and a light-beam oscilloscope of the N145 brand.

Bench tests to study the force loading and vibrations of the cotton vibrator mechanism took place in two modes with an adjustable carrier speed of 745 and 1470 min\(^{-1}\). Before and after the tests, the tensiometric structures were calibrated to select the equipment parameters and establish the final calibration regression dependences of the deflection of the galvanometer beam to the corresponding value. The obtained regression dependencies were evaluated by the correlation coefficient and the adequacy of the regression lines to experimental data [4].

A preliminary visual analysis of the oscillograms of bench experiments showed that in the static sense the parameters under study are random, i.e. in the process of interaction, the energy parameters vary both in amplitude and frequency. Therefore, all measured parameters were considered as random processes; for their study, we used the apparatus of the theory of random functions and statistical dynamics of agricultural aggregates.

Statistical data processing was performed on a personal computer using the DIASTA application software package [5]. The study of changes in loading parameters with time was carried out by correlation and spectral analysis of random processes. Statistical data processing was performed using the DADISP application package. Spectral densities and autocorrelation functions were evaluated by the fast Fourier transform (FFT) method [6].

3. Results and discussion

We have previously conducted a series of experimental studies to determine the dynamics of the power characteristics of the planetary-lever mechanism of the vibrator (Fig. 1), in particular: uneven torque; dynamic characteristics of the interaction of the planetary gear carrier with levers and force impact on the stems of cotton bushes [7, 8].
Figure 1. Scheme of the vibrator mechanism:

1 is satellite; 2 is connecting rod; 3 is shouldered rocker; 4 and 4’ are twin rods; 5 and 5’ are twin rocker; 6 and 6’ are working bodies; 7 is motionless wheel.

An analysis of the results and an interval estimation of the dispersion of the distributions showed that the random distribution of the measured parameters corresponds to the normal distribution law and with an increase in the carrier speed, the magnitude of the torque does not change and is within the standard deviation, but the average working force increases significantly by 1.98 times organ [1].

An analysis of the obtained results of evaluating the moments, numerical characteristics, and distribution parameters showed that the fluctuations of the torque in time strongly attenuate, and the fluctuations of the angle of rotation and effort on the working body act according to a harmonic law (table 1). This indicates that the drive and vibrator mechanism are stable with periodic exposure to plants.

Table 1. The results of the assessment of moments, numerical characteristics and distribution parameters

| Parameter                  | Mean | Dispersion | Standard deviation | Asymmetry | Excess |
|----------------------------|------|------------|--------------------|-----------|--------|
| Carrier speed 745 min⁻¹    |      |            |                    |           |        |
| Turn angle, hail           | 0.603| 3.07       | 1.75               | -0.613    | 2.39   |
| Part, gates, min⁻¹         | 753  | 126        | 11.2               | -0.304    | 2.32   |
The frequency distribution of the energy characteristics of the process revealed an increase in the amplitudes of oscillations at frequencies of 25, 37, 50, and 80 Hz. The highest spectrum of power is at a frequency of 25 Hz. This confirms that the effect on the bushes occurs precisely at this frequency. Higher frequencies arise from the influence of gears, while at different speeds of the carrier, the phases of the angle of rotation of the rocker arm do not coincide and in some positions, the angle of rotation is less than the limit, which can affect the process of hitting the bushes in these phases of rotation [2].

To establish rational parameters of the vibrator mechanism of shrubbery plants according to the criterion of minimum unevenness of work, a synthesis of the mechanism is carried out. Since the functional relationships between the parameters of the mechanism and its indicators are implicitly expressed, the solution of optimization problems is difficult. The application of the experimental design method significantly simplifies the search for a solution, since it allows one to obtain an explicit polynomial connection between the variable parameters of the mechanism and the target functions [8].

The minimum uneven operation of the vibrator mechanism was characterized by the uneven rotation of the carrier $\Omega$, the maximum moment on the motor shaft $M_{\text{max}}$, and the degree of dynamism N [2].

The following variables were taken as factors: the rotation frequency of the carrier $X_1$, the gear ratio of the planetary part $X_2$, the moment of inertia of the carrier with satellites $X_3$, the moment of inertia of the rocker arm 3 ($X_4$) and the moment of inertia of the rocker arm 5 ($X_5$).

The experiment was carried out according to the Hartley central orthogonal compositional plan with a semi-replica [9, 10] based on preliminary response data in the studied experimental area [2]. The selected factors and their variation levels are shown in table 2.

| Factor | $X_1$ (rad/s) | $X_2$ (i) | $X_3$ (kg m²) | $X_4$ (kg m²) | $X_5$ (kg m²) |
|--------|---------------|-----------|---------------|---------------|---------------|
| Main level | 151.77 | 3 | 0.170 | 0.0715 | 0.35 |
| Variation step | 75.89 | 1 | 0.085 | 0.039 | 0.15 |
| Lower level | 76.89 | 2 | 0.085 | 0.0325 | 0.20 |
| Top level | 22.66 | 4 | 0.255 | 0.1105 | 0.57 |

A check for the homogeneity of several adjusted dispersions showed that the hypothesis of the reproducibility of the experiment does not contradict the results of observing the response.

As a result of the calculations, the estimates of the regression coefficients, variances and correlation moments of the calculated estimates are determined. The statistical significance of the obtained estimates and regression coefficients was checked using the $t$-criterion [11].

Thus, the following mathematical models are obtained for:

uneven rotation of the carrier $\Omega$:

$$
\delta = 7.525 - 0.805X_1 + 0.873X_2 - 3.681X_3 + 3.313X_4 - 0.806X_1 + 2.23X_2X_3 + 0.267X_1X_4 + 0.401X_2X_5 + 0.705X_3X_4 - 1.046X_5X_6 + 0.093X_4X_5 - 6.316X_1X_2 - 1.993X_1^2 - 3.54X_2^2 - 1.415X_4^2 + 7.710X_4^2 + 3.010X_5^2;$$

\[1\]
2) maximum torque on the motor shaft $M_{max}$:

$$M_{max} = 10.521 + 3.423X_1 - 0.638X_2 - 0.292X_3 - 1.866X_4 + 1.595X_5 + \nonumber \\ \ + 0.495X_1X_2 + 1.153X_1X_4 - 1.926X_2X_4 + 1.092X_2X_5 + 0.705X_4X_5 - \nonumber \\ \ - 0.488X_2X_5 + 0.581X_1X_3 + 0.963X_3X_4 - 1.077X_3X_5 + 1.619X_4X_5 - \nonumber \\ \ - 2.204X_1^2 - 0.685X_2^2 - 0.315X_3^2 + 1.589X_4^2 + 0.477X_5^2;$$

3) degree of dynamism $H$:

$$H = 2964.85 + 1604.76X_1 - 828.65X_2 - 635.75X_3 + 758.12X_4 + 222.42X_5 + \nonumber \\ \ + 735.71X_1X_2 - 510.23X_1X_3 + 461.10X_2X_4 + 310.46X_3X_4 - 576.45X_3X_5 + \nonumber \\ \ - 48.17X_1X_4 - 228.97X_2X_4 + 134.98X_2X_5 - 58.34X_3X_5 - 993.03X_4X_5 - \nonumber \\ \ - 449.08X_1 - 944.53X_2 + 25.66X_3 + 1615.45X_4^2 + 353.48X_5^2;$$

Testing the hypothesis about the adequacy of mathematical models and the significance of individual coefficients was determined by sample variances using the Fisher $F$-test [12].

The method of finding the optimal parameters (uneven rotation of the carrier $\Omega$, the maximum torque on the motor shaft $M_{max}$ and the degree of dynamism $H$) is based on multidimensional optimization using the Hook-Jeeves configuration method, which is based on finding the minimum of the function along the lines of discontinuity of derivatives under the assumption that the displacements in the space under study successful in the early stages of the search can lead to success in the later stages. The Hook-Jeeves method is based on the assumption of the unimodality of the objective function and is intended to find the minimum function of many variables [6, 12].

4. Conclusions

1. The increased requirements of agricultural technology for the cultivation of cotton and the textile industry to biological raw materials are a consensus on the modernization of harvesting machines for cotton harvesting machines.

2. The solution of the obtained mathematical models, with known input numerical values: carrier rotation speed $X_1=75.89$ rad/s, planetary gear ratio $X_2=3$, carrier moment of inertia with satellite $X_3=0.101$ kg·m$^2$, rocker inertia moment 3, $X_4=0.05785$ kg·m$^2$ and rocker 5, $X_5=0.275$ kg·m$^2$, will determine the rational parameters of the vibrator, in particular:

- the minimum unevenness of rotation of the carrier is $\delta=6.4829\%$;
- the maximum moment on the motor shaft is $M_{max}=2.95825$ N·m;
- the degree of dynamism is equal to $H=684.8659$ rad/s$^2$.

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