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Design development and parameters calculation methods of plastic diamond pattern bars on resilient supports in ginning machines

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Abstract. The article presents effective construction scheme and operating principle of plastic diamond pattern on bars on resilient supports of raw cotton cleaners for large weeds. Basic parameters of cleaning zone of the proposed construction are based on theoretical and experimental research. Production testing confirmed effectiveness of plastic diamond pattern bars use.

Keywords. Cleaner, raw cotton, diamond bar, resilient support, plastic mass, vibration, amplitude, frequency, saw cylinder, optimization, effect, weeds.

1. Introduction
In the current stage of the development of the cotton ginning industry, it is important to intensify the cleaning of raw cotton, to develop more sophisticated designs, to find new, effective ways of raw cotton cleaning from small and large weeds, and to select appropriate modes for moving operating elements of cotton cleaners. Raw cotton, which comes for its primary processing, contains large and small weeds. Weeds of less than 0.8 mm penetrate deeply into the fiber and are removed by means of strong shaking of raw cotton. Large weeds, mainly located on raw cotton surface, have weak adhesion to fiber and are easily separated from it [1, 2]. In the cotton ginning industry, research is aimed at innovative techniques and technology development to provide effective application of modern science and technology achievements as well as modernization. In this industry, development and research of effective, resource-saving and technological designs of operating elements and bars of cotton cleaners are of great importance. From the above brief analysis of the research in the field of raw cotton and cotton fiber cleaning, it can be concluded that most researches are focused on the development and modernization of operating elements of cotton cleaners from large weeds, based on application of optimization techniques. The matter of use of such alternative materials for bars and their geometrical parameters as plastic diamond pattern bars on resilient supports is insufficiently investigated.

Practically, there are no dynamic investigations that determine the basis for calculation of reliability, durability, endurance, etc. In addition, there are no investigations on vibration effect of operating elements on raw cotton, enabling efficient discharge of impurities [3, 4].

2. Theoretical part
In order to improve existing constructions and increase the cleaning effect, we developed a number of highly efficient designs of bar grilles that allow maximum possible preservation of natural qualities of cotton and seeds [5, 6].
According to design we recommend the plastic bars are installed in lateral segments by means of elastic sleeves, the thickness of which is selected as decreasing in the course of pulling the cotton. The construction works in the following way (fig. 1, a). Saw cylinder 4 grabs raw cotton with teeth, pulling them through the bars 2. At the same time the bars 2 fluctuate due to exposure of cotton pappus and deformation of elastic sleeves 3. Thickness of elastic sleeves 3 is selected as decreasing when pulling cotton and has a ratio of:

$$\Delta_1 = r_1 - R; \quad \Delta_2 = r_2 - R; \quad \Delta_n = r_n - R; \quad \Delta_1 > \Delta_2 > \ldots > \Delta_n$$  \hspace{1cm} (1)

where, \(R\) - bars radii; \(r_1, r_2, \ldots, r_n\) - external radii of elastic sleeves 3 of relevant bars 2; \(\Delta_1, \Delta_2, \ldots, \Delta_n\) - thickness of elastic sleeves 3 of relevant bars 2.

At the beginning of pulling zone raw cotton will be less friable and therefore due to greater thickness of elastic sleeves 3 the bars 2 in this zone will vibrate with greater amplitude and lower frequency, that allow not only to separate the weeds, but also to loosen the raw cotton. At the end of cotton pulling zone, due to less thickness of elastic sleeves 3 bars 2 vibrate with greater frequency and amplitude. This leads to separation of the weeds, located more deeply in stock.

Inter-bar gaps are also selected as decreasing in the course of pulling cotton and have a ratio of:

$$a_1 - a_2 = \Delta_1 - \Delta_3; \quad a_2 - a_3 = \Delta_2 - \Delta_4; \quad a_3 - a_4 = \Delta_3 - \Delta_5; \quad \ldots; \quad a_{n-1} - a_n = \Delta_{n-1} - \Delta_{n+1}$$  \hspace{1cm} (2)

where, \(a_1, a_2, \ldots, a_n\) - gaps between bars 2 in the course of cotton pulling.

Gaps difference between neighbouring bars 2 in the course of pulling cotton is selected according to (1, 2) equal to the difference of elastic sleeves 3 thickness respectively between even and odd neighbouring bars 2. In the course of pulling, cotton will be more divided on pappusses, and in order to reduce their loss through the gaps between bars 2, these gaps are made as decreasing according to displays (2). Recommended bar grid of fibrous material allows significantly increase the cleaning effect and reduce cotton pappus loss with discharged weeds.

The following bar grid of fibrous material cleaner is developed, containing diamond pattern bars with the different number of faces that in the course of pulling fibrous material are selected so that each subsequent bar has one more face in the number of faces than the previous bar [5].
Construction consists of bars 1, which are rigidly installed, using elastic rubber sleeves 3, curved rods (not shown in the figure) 4 and rotating spiked roller 2 (included for explanation of operating of proposed bar grid). Bars 1 are of diamond kind. Each subsequent bar has one more edge in the number of edges than the previous bar 1 has. First bar 1 is four-sided, the second is five-sided one, the third bar 1, installed in the course of cotton pulling, is six-sided one and so on. In three sectional bar grid, each section has up to five bars 1, and then the last bar 1 will have 18-faces (fig. 1, б). During operation at the starting zone, raw cotton, clashing on the bars 1 with four faces, with great force is exposed to loosening and weeds separation. Further, when the number of bars 1 faces increases, interaction force between cotton and bars 1 faces reduces, but their frequency and interaction direction increase. This allows the effective separation of cotton and weeds, especially large weeds. Thus, the following relationship is maintained

$$K_i = K_{i-1} + 1$$

where, $K_i$ - number of faces of $i$ – bar 1. $K_{i-1}$ number of faces of $i-1$ – bar.

To improve productivity and cleaning effect, as well as to reduce cotton pappus loss, bar grid design is improved, using required sequence setup of round and diamond pattern bars in the course of pulling cotton. During operation, raw cotton (stock) is fed to spiked roller 3, teeth of which grab the
raw cotton and pull it along the bar grid. In operating area of spiked roller 3, cotton impacts cyclically on diamond pattern bars 1 and round cross-section bars 2 (fig. 1 b). In this case force and direction of impacts along the rotation of spiked roller 3 will be different due to different number of bars’ faces. At the same time, with an increase in the number of faces of the bars 1, the momentum force of the cotton impacts on the face of the bar 1 decreases, and, with the number of faces of the bars 1 decreasing. Such interaction of cotton with diamond (of different number) bars 1 facilitates release of impurities of varying weight and varying depth in cotton. Alternation of round cross-section bars 2 with diamond pattern bars 1 when interacting with fibrous material dramatically reduces of fibres, and allows changing the momentum force of interaction and motion law of fibrous material in the area of their pulling.

3. Results of theoretical researches on argumentation of plastic bars parameters.

For investigation of vibration and analysis of main parameters, taking into account random influence of cotton on plastic bars of raw cotton cleaner from large weeds, bar vibration equation is obtained:

\[
m \frac{d^2x}{dt^2} + \delta \frac{dx}{dt} + c_1x + c_2x^3 = M(F_{\alpha}) \pm \delta(F_{\alpha}) ,
\]

where \( m \) - reduced mass of plastic bar; \( \mu \) - constant coefficient of nonlinearity; \( c_1, c_2 \) – stiffness coefficients of resilient support, \( \delta \) – dissipation factor, \( m(F) \) –mathematical expectation of random resistance component of raw cotton.

Taking into account the initial angles \( t=0 \), \( \dot{X} = 0; \ddot{X} = 0 \), the solution was obtained, using PC: the average value of plastic bar axis displacement is \( X_{ср}=(1,4-1,6)\cdot10^{-3}m \), vibration amplitude will be \( \Delta X=(1,8-2,1)\cdot10^{-3}m \). High-frequency vibrations of the bar match the frequency of resistance force \( \delta(F_{\alpha}) \).

Fig. 2. shows fragments of displacement, speed and acceleration of the plastic bar on resilient support with nonlinear restoring force when \( m = 1,0 Hc^2 / M, \ c_1 = 0,8 \cdot 10^4 H / M, \ c_2 = 1,2 \cdot 10^4 H / M, \ M(F_{\alpha}) = 10,5 H, \)
\[ \delta F_{\alpha} = (0,7 \pm 1,0)H \]. It should be noted that frequency of the bar vibrations is (40…55) Hz. In this case the high-frequency component of bar vibrations is (147-178) Hz.

The low-frequency component corresponds to the frequency of forced oscillation speed serrate drum unit, and the high frequency component corresponds with the number in the grate section. Fig. 2 shows that, at forced vibrations, bar deviates in average by value \( X_{ср} = (1,4 - 1,6) \cdot 10^{-3}m \), and vibrations amplitude at calculated values of parameters is \( \Delta X = (1,8 - 2,1) \cdot 10^{-3}m \). For metal bars on resilient support under operation [4] the vibrations amplitude is \( \Delta X = (2,2 - 2,5) \cdot 10^{-3}m \). Comparison of the results shows that in the proposed design of plastic bars the vibrations amplitude is increased by (10-15)% due to low weight of the bar.

Values \( \dot{X} \) and \( \ddot{X} \) change accordingly. Amplitude of speed vibrations reaches the value of 0.6 m/s - 1.25m/s, and amplitude of accelerations vibrations at the calculated parameters of the system changes within (6,5-10) m/s². Frequencies of speed and accelerations vibrations correspond to high-frequency component of process load from cotton.

Fig. 2a graphically shows the dependences of changes of displacement, speed, and acceleration amplitude due to increase in bar grille mass. It is known that with mass increase in the vibration system the great strength is required for its agitation, i.e. with increase in mass, amplitude of the plastic bar oscillations reduces. With increase in bar mass from 0.7 Nc2/m to 1.5 Nc2/m the vibrations
The amplitude of the plastic bar decreases from $1.85 \times 10^{-3} m$ till $0.65 \times 10^{-3} m$ according to non-linear rule. Considering the vibration system, it should be noted that with increase in the bar mass the reducing speed and acceleration are also nonlinear. It is especially important that the intensity of the decrease in the amplitude $\Delta X$, $\Delta \dot{X}$ and $\Delta \ddot{X}$ of the vibrations decreases with increasing mass. This is due to the nonlinear rigid characteristic of resilient support.

In the course the process of raw cotton cleaning from large weeds limiting of bars vibration amplitude is of great importance, as these vibrations have a direct impact on width of gap between the bars and saw cylinder. Researches have revealed that increase in rigidity coefficient $C_i$ of the resilient support leads to proportional reduction of vibration amplitude of the plastic bars. To provide plastic bars vibrations with amplitude $(0.6 \pm 1.2) \times 10^{-3} m$ the non-linear component of elastic rigidity coefficient of resilient support must have the value of $(0.8 \pm 1.0) \times 10^4$, and rigidity coefficient of $c_i=(1.2 \pm 1.4) \times 10^4 H/m$. The change of thickness of the rubber bushing is up to $2.0 \pm 2.5 \times 10^{-3} m$ (for NO-68 rubber).

Fig. 2b graphically shows dependences of displacement, speed and acceleration change for plastic bar on resilient supports with nonlinear rigidity in variations of load from raw cotton. With increase in cotton resistance from 8.5 to 20 N (average value), the bar displacement increases from $0.65 \times 10^{-3}$ to $2.6 \times 10^{-3} m$.
To prevent pappus loss between bars due to large vibrations amplitudes of the bars and shortening of the process gap between the spiked roller and bars, on the experiments results the plastic bars amplitude should not exceed $\frac{10}{4} \cdot 10^{-3} m$. With increase in bar load the intensity of resilient supports deformation decreases that causes reduction of the bars vibrations amplitude (see figure.2c). Comparison of researches results with investigations of metal bar on resilient support shows that the amplitude of speed vibration and acceleration $\dot{X}$ and $\ddot{X}$ in recommended variant is $(10+13)\%$ more than in cylindrical bars. This means that momentum force of plastic bars, influencing on raw cotton is $(12+15)\%$ more than in existing cleaner bars. Recommended values for plastic bars mass are $(1,1\div1,3)$ NC2/m.

Thus, in order to provide vibrations amplitude less than $(1,0\div1,4) \cdot 10^{-3} m$, it is recommended the parameters with values of $c_2 = (0,8\div1,0) \cdot 10^4$ H/m, $c_1 = (1,2\div1,4) \cdot 10^4$ H/m, $F_0 = (15\div20)$ H, $Pr = (5,0\div7,0)$ t/h. It is known that rotary overspeed of saw cylinder more than $(31\div35)$ rad/s leads to raw cotton pappus dragging by saw cylinder and pappus inclination angle increases and without interaction with the bars, pappus passes through cleaning zone. In order to argumentate pappus exclusion, we shall consider calculation model (Figure. 3) and compose differential equation of seed cotton pappus vibration:

$$m_1l_1^3\ddot{\beta} + m_1(\omega_0 + \omega_1 \sin K_{s} t)^2 \cdot \left[ \sqrt{l_1^2 + R^2 \sin^2 \varphi + R \cos \varphi} \right]$$

$$\cdot R \sin \varphi + m_1gh_1 + \sqrt{l_2^2 + R^2 \cos^2 \varphi} \cdot F_0 \theta_0 \frac{\partial^2}{\partial t^2} l_1 = 0 \quad (5)$$

Solution (5), taking into account [11] will be.

$$\frac{d^2 h_1}{dt^2} + \frac{R h_1}{l_1} (\omega_o + \omega_1 \sin K_{s} t)^2 + \frac{g}{l_1} - h_1 = 0 ; \quad \beta = \frac{h_1}{l_1}$$

$$h_1 = h_\infty \cos f_{c0} t + \frac{\nu_0^2 l_1}{R\omega^2 + g} \sin f_{c0} t \quad (6)$$
Analysis (3) shows that at the starting moment when t=0, value \( h_1 = h_0 \) the deviation angle of pappus fibers strand deviates from the radius of spiked roller by 600...620. Taking into account the pappus strand length of 0.022 m, the \( h_0 \) will be 0.019 m. Accordingly, to provide deviation angle of cotton pappus of less than 56÷63 and rotary speed of saw cylinder of 31.4 rad/s the design shutdown is selected within \( h_1 = (0.018 \pm 0.621) \) m.

4. Experimental part.

Experiments were conducted in production environment of cotton gin. Measurement of load, bars vibrations was conducted both for plastic bars on resilient supports and for serial bars. When conducting experiments according to the rigidity coefficients values the following rubber were selected: SKF 32, SPF 26, SPF 260, 1847, NO-68, 1318, and their characteristics were also studied. It was chosen the SKF 32 rubber with rigidity coefficient of \((2 \pm 2.2) \cdot 10^4\) N/m and the sleeves were manufactured from it by vulcanization method. Accordingly were studied the properties of such plastics as PVC-polyvinylchloride, PP-polypropylene, PE-polyethylene, PA-polyamide. It was choosen the PA plastic consisting of antipyrene (fireproof), anti-static substance (not charged), glass fiber and basalt fiber of 3.5 mm to increase strength when impacts. Load displacements on axes \( X \) and \( Y \) were measured using strain gauge sensor, and recorded on a computer, using modulator, digital converter. Figure 4 shows diagram of measurements of bars displacement (loading) and overview of the measuring instrumentation [7].

Figure 3. Analytical model (a) and diagram of spiked roller (b) rotary speed
Figure 5 presents oscillograms of plastic bar vibrations on axes X and Y. Thus, at spiked roller rotation speed of 300 rad/s, machine performance of 5.0 t/h and bars rubber bearings rigidity of $1.8 \times 10^4$ N/m the vibration amplitude of the plastic bar on Y axis reaches $0.55 \times 10^{-3}$ m, and on X-axis the bar does not actually vibrate. With increase in performance of cotton cleaner up to 7.0 t/h and rotation frequency of the spiked roller 310 rad/s and with stiffness of rubber supports $c=1.4 \times 10^4$ N/m, the vibrations amplitude of plastic bar increases up to $0.6 \times 10^{-3}$ m on X axis, and on Y axis vibrations amplitude of plastic bar on resilient support reaches $3.0 \times 10^{-3}$ m.

Obtained oscillograms were processed based on computer software oscillograms, and graphic dependences were built (fig. 6). On the basis of results analysis, it was revealed that the existing metal bars do not vibrate. Plastic bars on rubber bushes of X-axis vibrate with low amplitude $(0.2÷6.3)$ mm, on Y-axis, bar vibration amplitude reaches $(2.5÷3.1)$ mm, and vibration frequency is $(6.5÷15.5)$ Hz, that is much less than rotation frequency of the spiked roller, and reaches $(70÷80)$ Hz. When increasing rigidity coefficient of the rubber support from $1.2 \times 10^4$ N/m to $2.8 \times 10^4$ N/m, oscillation amplitude of plastic bar on X axis decreases from $0.67 \times 10^{-3}$ m to $0.18 \times 10^{-3}$ m, and on Y axis, it decreases from $2.25 \times 10^{-3}$ m to $0.58 \times 10^{-3}$ m (Fig.5).

Based on oscillograms processing, graphical dependences of the variation in the vibrations of bars of both variants along the X and Y axes from the change in load from the raw cotton to be cleaned, which are presented in Fig. 6. $\Delta X$ and $\Delta Y$ are nonlinear. Value of $\Delta Y$ is important for the plastic bar that
directly affects cleaning of raw cotton from large weeds. So, when increasing load from 5.0 N to 23.0 N, the vibration amplitude in the current version of bar $\Delta X$ and $\Delta Y$ does not exceed $0.5\cdot10^{-3}$ m. At that, vibration amplitude of the plastic bar on resilient supports on X-axis reaches $1.0\cdot10^{-3}$ m, and on Y axis it reaches $3.15\cdot10^{-3}$ m. At that, plastic bars vibrate vertically with an amplitude of $1.575\cdot10^{-3}$ m with frequency for 6.5-15.5 times higher than rotation frequency of the spiked roller. It means that during operation of the cleaner with one turnover of spiked roller, the raw cotton pappus, pulled by saw cylinder, in average 6.5-15.5 times clashes on the bar, i.e. frequency of forced vibrations of plastic bars reaches 70-80 Hz.

It is necessary to manufacture the rubber support of the plastic bar from SKF 32 rubber with rigidity coefficient of $(1.6\div2.0)\cdot10^4$ N/m. Rotation frequency of saw cylinder is within $(3.0\div3.15)\cdot10^2$ rad/s.

The following regression equations are based on planning of full-factorial experiments [8]:

for I-class cotton Namangan -77

$$Y= 84.08 + 0.96X_1 - 1.28X_2 - 0.76X_3 - 2X_1X_2 - 0.34X_1X_3 + 0.27X_1X_2X_3$$

for II-class cotton Namangan -77

$$Y= 80.1 + 0.33X_1 - 1.24X_2 - 1.87X_3 + 0.4X_2X_3 - 1.56 X_1X_3 + 0.73X_2X_3 + 0.37 X_1X_2X_3$$

The input factors are: $X_1$-rubber rigidity of $10^4$ N/m, $X_2$- machine capacity Pr, ton/h, $X_3$-bar gap $\delta$, $10^{-3}$ m; output parameter - effect of cotton cleaning. Analysis of results, obtained during full factorial experiment, allows to recommend the following values for the selected key factors: performance, t/h – 5.0; rubber rigidity - $2.0\cdot10^4$ N/m; gap between the bar and spiked roller – 16 mm. At these values the efficient operation of raw cotton cleaner is observed, i.e. the cleaning effect is above 90%.

5. Results

Recommended diamond plastic bars on resilient supports were installed on the lines of universal cleaning complex of ginning factories in Tashkent region. Production test results are presented in Table 1.

**Table 1. Production test results**

| Indications, % | After cleaning unit with the recommended plastic bars | After cleaning unit with serial plastic bars |
|----------------|------------------------------------------------------|------------------------------------------|
|                |                                                     |                                          |

Figure 6. Regularity of change
|                                |     |     |
|--------------------------------|-----|-----|
| Cotton, Humidity, (%)          | 8.9%| 8.9%|
| Content of weeds, (%)          | 4.6/2.75 | 4.6/3.3 |
| Cleaning Effect, (%)           | 93.4 | 77.1 |
| Mechanical damage of seeds     | 1.89 | 2.82 |
| Free fiber                     | 0.08 | 0.19 |
|                                | 0.11 | 0.21 |

6. Conclusions

Based on the analysis of the construction of cotton cleaner bar grilles for large weeds, new effective schemes for low-weight construction of plastic bars on resilient supports was developed. A mathematical model, of the vibrations of plastic bars on resilient supports with nonlinear rigidity characteristics, was made. It was shown that increase in mass of the plastic bar reduces displacement vibration amplitude, speed and acceleration of the bar according to non-linear regularity of (1.1÷1.3) \( \frac{He^2}{m} \). Formulas were obtained to determine the distance and angle of cotton pappus deviation with variable rotation of the spiked roller and use of the plastic bar. During experiments the oscillograms were obtained, characterizing vibrating movement laws of the plastic bars on resilient supports when changing the load from raw cotton to be cleaned, rigidity coefficient of rubber bushings (supports) and rotation frequency of the spiked rollers. A mathematical model was developed that adequately describes cleaning process of raw cotton from large weeds in the form of regression equations. Use of plastic bars on resilient supports in raw cotton cleaners for large weeds helps to improve cleaning effect up to 17%, mechanical damage of seeds is reduced to 1%, and free fiber by 0.18% compared to serial variant.

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