ANALYSIS OF MATHEMATICAL MODEL OF SINGLE-STAGE FIBER CLEANER MACHINE AGGREGATE

[1]Shavkat Sadridinovich Xoldorov, [2]Ravshan Xasanovich Maksudov, [3]Aybek Palvanbaevich Mavlyanov, [4]Alisher Abdugappar ugli Abdusamatov

Junior lecturer, Tashkent institute of textile and light industry Republic of Uzbekistan, Tashkent[1],Professor, DcS., Ferghana State University Republic of Uzbekistan, Ferghana[2],Docent, PhD., Tashkent institute of textile and light industryRepublic of Uzbekistan, Tashkent[3],Basic doctorate, Tashkent institute of textile and light industry Republic of Uzbekistan, Tashkent[4]

ABSTRACT

The article was described a mathematical model of a single-stage fiber-cleaner machine aggregate, as well as the regularities of changes in the loading system, obtained at various values, angular velocity and productivity of the leading rotor of the saw cylinder based on the solution of the dynamics of the aggregate. A calculation system had been developed that takes into account the technological loading of the cotton fiber being cleaned.

Key words: cotton fiber, fiber-cleaner, saw cylinder, rotor, angular velocity, loading system, technological loading.

INTRODUCTION

Nowadays, in many cotton cleaning industries, three-drum fiber cleaners have been replaced by single-drum fiber cleaners. This is due to the need to prevent interruptions in the fiber cleaning process and improve the quality of fiber cleaning, as well as to simplify the services provided to fiber cleaning machines during production. Single-drum fiber cleaners are now installed instead of three-drum fiber cleaners, while maintaining the connection points of the fiber separator pipe. Therefore, the analysis of the mathematical model of a single-stage fiber cleaning machine aggregate and the development of the necessary calculation schemes for them is an important issue in the scientific and technological direction of the industry.

METHOD

The Lagrange's equations of the second kind were used to compile a system of differential equations describing the motion of the working bodies of a single-stage fiber cleaner [1]. In this case, angular displacements are taken for the generalized coordinates φ_r - for the rotor of the electric motor, φ_{sc} - for the saw cylinder. An asynchronous electric motor was taken into account in the form of a dynamic characteristic proposed by A.E. Levin [2]:

$$\frac{dM_m}{dt} = \left(\omega_c - P\frac{d\varphi_r}{dt}\right)\cdot\psi - \frac{M_m}{T_e}\ ; \tag{1}$$

$$\frac{d\psi}{dt} = \frac{2M_k - \psi}{T_э} - \left(\omega_c - P\frac{d\varphi_r}{dt}\right) - M_m;\ T_э = (\omega_c\cdot S_K)^{-1};\ \psi = \frac{S_K}{S}\left(M_m + T_э\frac{dM_m}{dt}\right);$$

where $M_m, M_c -$ driving torque and its critical value on the motor shaft; $\omega_c -$ the circular frequency of the network, $P -$ the number of pole pairs, $\varphi_r -$ the angular mixing of the motor rotor, $S_c -$ the critical slip, $T_e -$ is the electromagnetic time constant of the motor, ψ - an auxiliary variable.

In this case, for the machine unit of a single-stage fiber cleaner, we obtain the following system[3]:

$$\frac{dM_e}{dt} = \left(\omega_r - P\frac{d\varphi_r}{dt}\right)\cdot\psi - \frac{M_e}{T_e}\ ;$$

$$\frac{d\psi}{dt} = \frac{2M_k - \psi}{e} - \left(\omega_r - P\frac{d\varphi_r}{dt}\right) - M_e;\ T_e = (\omega_r\cdot S_c)^{-1};\ \psi = \frac{S_c}{S}\left(M_e + T_e\frac{dM_e}{dt}\right); \tag{2}$$

$$J_P \frac{d^2\varphi_r}{dt^2} = M_e - b\left(\frac{d\varphi_r}{dt} - U_{en}\frac{d\varphi_{sc}}{dt}\right) - c(\varphi_r - U_{en}\varphi_{sc});$$

$$J_{sc} \frac{d^2\varphi_{sc}}{dt^2} = U_{en} b\left(\frac{d\varphi_r}{dt} - U_{en}\frac{d\varphi_{sc}}{dt}\right) - U_{en}c(\varphi_r - U_{en}\varphi_{sc}) - M_{tr};$$

$$M_{tr} = M_1 + M_0 sin\alpha t$$

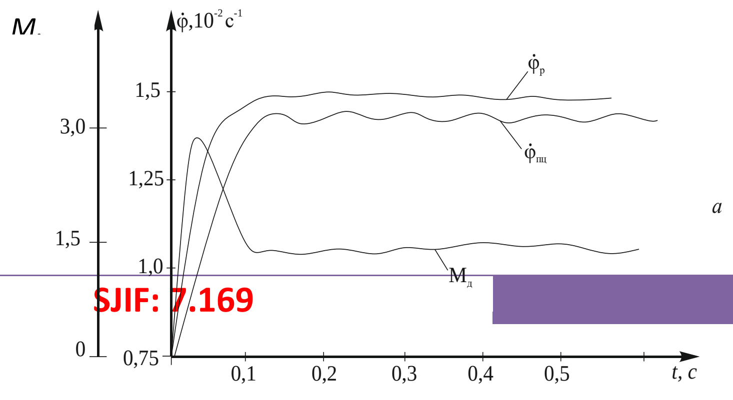
where J_r, J_{sc} - the reduced moments of inertia of the masses on the rotor of the engine and on the shaft of the saw cylinder of the fiber cleaner, *c*, *b* - the coefficients of circular stiffness to dissipation of the elastic transmission of the machine unit, $M_{tr.} -$ the technological resistance from the cleaned cotton fiber.

System (4.2) was solved numerically on a PC using well-known programs [4], taking into account the following calculated values of the parameters of a single-stage fiber cleaner: 4A100S4U3 engine; $P = 3{,}0\ kW, n = 1500\ rpm; \omega_r = \dot{\varphi}_r = 157\ c^{-1}; \omega_{sc} = \dot{\varphi}_{sc} = 157\ s^{-1}; U_n = 220\ volt; \delta = 0{,}81$. $cos\alpha = 0{,}88$; $M_c = 32{,}7\ Nm; M_H = M_c/2 = 16{,}35$ Nm; $f = 50\ Hz; \omega_H = 149{,}1\ s^{-1}; S_H = (\omega_0 - \omega_H)/\omega_0 = 0{,}052; S_c = 0{,}189; P = 2; C = (102 \div 140) Nm/rad; b = (3{,}5 \div 3{,}8) Nm \cdot s/rad; J_P = 0{,}817\ kgm^2; J_{sc} = 2{,}19\ kgm^2$.

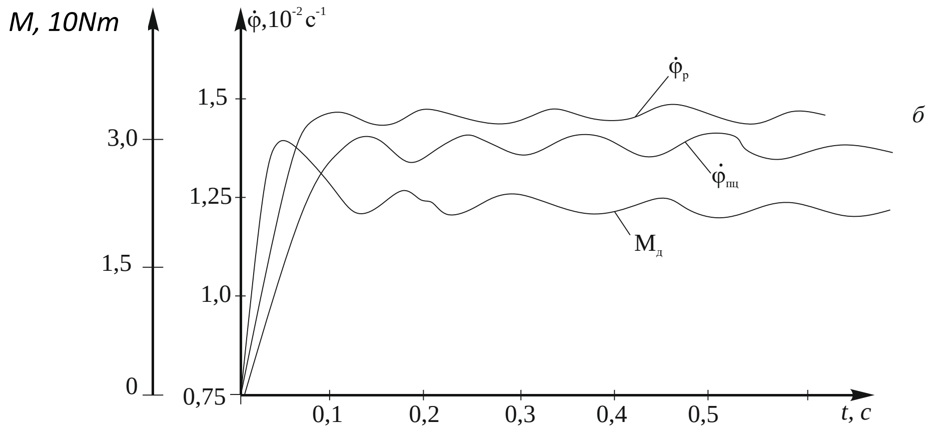
RESULT

Based on the solution of system (4.2) on a PC using the above technique and standard programs, the regularities of changes in the angular velocities of the electric motor rotor, saw cylinder, as well as the torque on the electric motor shaft are obtained, which are shown in Figure 1. The analysis of the obtained regularities shows that the fluctuations $\dot{\varphi}_r$ and $\dot{\varphi}_{sc}$, as well as M_e, $M_0 sin\alpha t$, depend on the change in $M_{t.r.}$. Arising from the frequency of supply of cotton fiber to the cleaning zone according to the value of $M_0 sin\alpha t$. With an average technological load of 12.5 Nm, the angular speed of the engine rotor decreases on average to $(1{,}44 \div 1{,}46) \cdot 10^2 s^{-1}$, and the angular speed of the saw cylinder decreases to $(1{,}34 \div 1{,}37) \cdot 10^2 s^{-1}$. With an increase in the technological load to 24.5 Nm, the average values of the angular velocities decrease $\dot{\varphi}_r = (1{,}38 \div 1{,}41) \cdot 10^2 s^{-1}$, $\dot{\varphi}_{sc} = (1{,}38 \div 1{,}41) \cdot 10^2 s^{-1}$.

Based on the processing of the obtained regularities, graphical dependences of the change were built, which are shown in figures 2-5. In figure 2 shows graphs of changes in the average values of angular velocities and the range of their oscillations from the technological load. Analysis of the graphs shows that the increase in $\Delta\dot{\varphi}_r$ and $\Delta\dot{\varphi}_{sc}$ from the technological load will be significant for small numerical values of the moments of inertia $J_r = 0{,}68\ kgm^2; J_{sc} = 2{,}1\ kgm^2$. The increase in the moments of inertia of the motor rotor and the saw cylinder leads to the alignment of the movement of the system. It should be noted that some fluctuations $\Delta\dot{\varphi}_r$ and $\Delta\dot{\varphi}_{sc}$ allow the intensity of cleaning cotton fibers, due to the occurrence of angular accelerations, thereby to the impulsive force effects of saws on the fibers. Therefore, the recommended values are: $J_r = (0{,}45 \div 0{,}55)\ kgm^2; J_{sc} = (1{,}8 \div 2{,}0)\ kgm^2$.

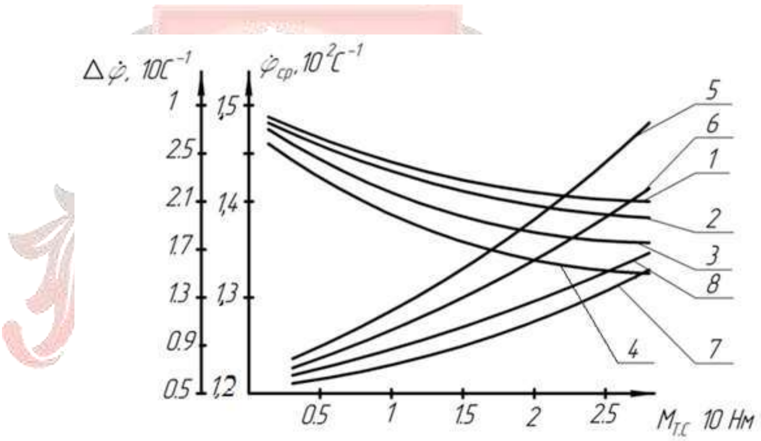


$when\ M_{tr} = 12{,}5\ \boldsymbol{Nm}$



$when\ M_{tr} = 25\ \boldsymbol{Nm}$

Fig. 1. Regularities of changes in the angular velocities of the engine rotor, saw cylinder and torque M_e on the engine shaft



$1{,}2\ - \Delta\dot{\varphi}_r = f(M_{tr.})$; $3{,}4\ - \Delta\dot{\varphi}_{sc} = f(M_{tr})$; $5{,}6\ - \Delta\dot{\varphi}_{sc} = f(M_{tr.})$;

$7{,}8\ - \Delta\dot{\varphi}_r = f(M_{tr})$; 1,2,5,6 – when $J_P = 0{,}68\ kgm^2$;

$J_{sc} = 2{,}1\ kgm^2$; 3,4,7,8 – when $J_P = 1{,}21\ kgm^2$; $J_{sc} = 3{,}25\ kgm^2$.

Fig. 2. Graphical dependences of changes in average angular velocities and their amplitude of oscillations on the technological resistance of the cleaned fiber.

$$1\ - M_e = f(M_{tr.}); 2 - M_e = f\left(\frac{J}{J_{calc}}\right); 3 - \Delta M_e = f(M_{tr.});$$

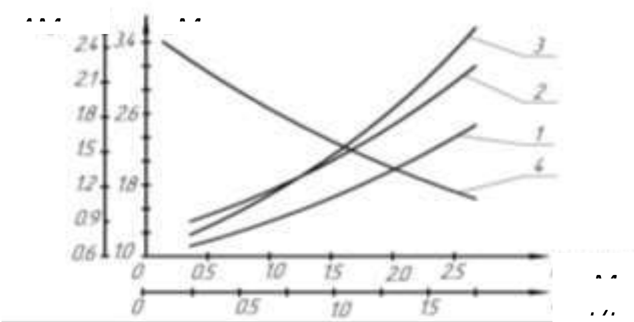
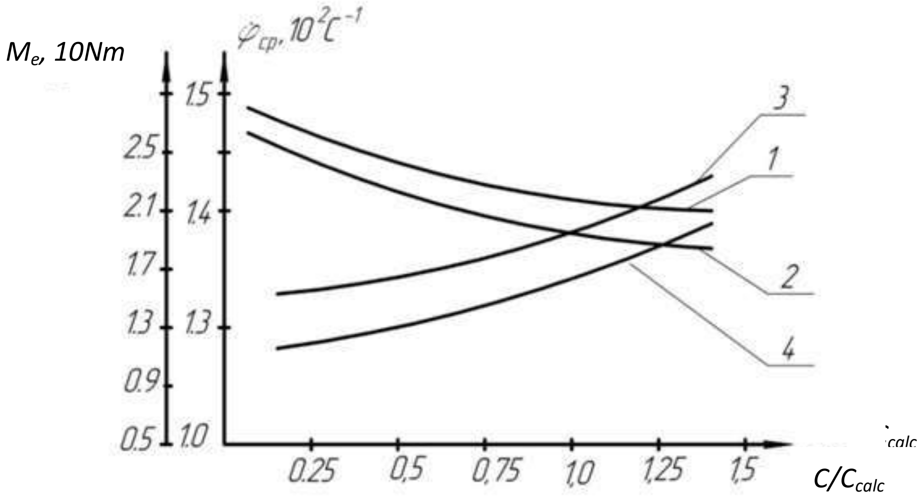


Fig. 3. Regularities of the change in the torque and the amplitude of oscillations on the electric motor shaft from changes in the technological load and the relative moment of inertia.

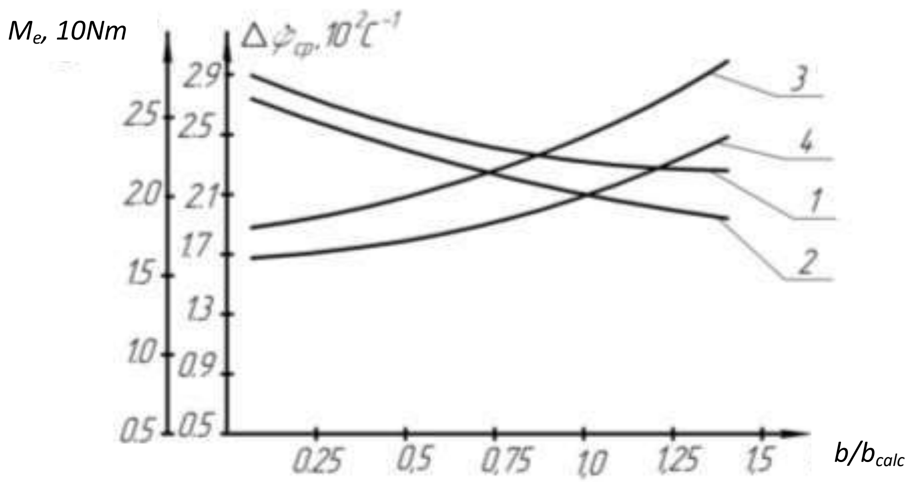


$1-\Delta\dot{\varphi}_r = f(\mathrm{C}/\mathrm{C}_{calc.})$; $2-\Delta\dot{\varphi}_{sc} = f(\mathrm{C}/\mathrm{C}_{calc.})$;

$3-M_e = f(\mathrm{C}/\mathrm{C}_{calc.})$, $when\ n_r = 1{,}2\ t/h$; $4{-}M_e = f(\mathrm{C}/\mathrm{C}_{calc.})$,

$when\ n_r = 2{,}5\ \mathrm{t}/h$.

Fig. 5. Graphical dependences of changes in the average angular speeds of the engine rotor, saw cylinder and engine load on the relative value of the belt drive stiffness coefficient.



$1-\Delta\dot{\varphi}_r = f(b/b_{calc.})$; $2-\Delta\dot{\varphi}_{sc} = f(b/b_{calc.})$;

$3-M_e = f(b/b_{calc.})$ and $n_r = 2{,}5\ \mathrm{t}/h$;

$4{-}M_e = f(b/b_{calc.})$ and $n_r = 1{,}25\ t/h$.

Fig. 5. Graphical dependences of changes in the range of angular velocities and engine load on the relative value of the dissipation coefficient of the elastic transmission.

Figure 3 the graphs of changes in M_e and ΔM_e from variations in $M_{tr.}$, as well as from changes J/J_{calc}. It can be seen from the graphs that with an increase in $M_{tr.}$ from 0.45 Nm to 2.7 Nm, M_e and ΔM_e increase according to a nonlinear pattern. An increase in J/J_{calc}. also leads to an increase in M_e, but ΔM_e is significantly reduced. This means that with an increase in the mass of the system, the unevenness of the loading decreases. It is important to study the influence of the elastic-dissipative properties of the belt transmission on the changes in $M_e, \dot{\varphi}_r$ ва $\dot{\varphi}_{sc}$.

Figure 4 shows the dependences of the average changes in the angular velocities of the engine rotor, saw cylinder, as well as the engine load on the coefficient of circular stiffness of the belt. An increase in the belt stiffness factor leads to a decrease in $\Delta\dot{\varphi}_r$ to $1{,}38\cdot10^2\ s^{-1}$ and $\Delta\dot{\varphi}_{sc}$ to $1{,}34\cdot10^2\ s^{-1}$ and an increase in the load M_e to *(23 ÷ 24) Nm*, thereby to additional power consumption engine. Therefore, to ensure $\Delta\dot{\varphi}_{sc} = (1{,}6 \div 2{,}0)\ s^{-1}$, allowing an increase in the effect of cleaning cotton fiber, the recommended values are: $C/C_{calc} = (0.75 \div 0.90)$.

Figure 5 shows the graphs of the change in the torque on the motor shaft and the range of angular velocities of the saw cylinder and the engine rotor from the change in b/b_{calc} of the belt. It is known that an increase in the dissipation coefficient leads to a rapid damping of free oscillations of systems, a decrease in the time of transient processes in technological machines, but this leads to additional power consumption. An analysis of the graphical dependencies in fig. 5 shows that an increase b/b_{calc} from *0.25* to *1.5* leads to an increase in M_e from *15.5 Nm* to *23.5 Nm* with a purifier capacity of 1.25 t/h. With an increase in the productivity of the cleaner up to 2.5 t/h, the load M_e reaches up to *(28 ÷ 29) Nm*. In this case, the swing of oscillations $\Delta\dot{\varphi}_{sc}$ of the saw cylinder decreases from $28\ s^{-1}$ to $19\ s^{-1}$. Recommended values are $b/b_{calc} = (0.5 \div 0.75)$ [5].

CONCLUSION

A calculating system and a mathematical model of the machine aggregate of a single-stage fiber cleaner was compiled, taking into account the dynamic mechanical characteristics of the asynchronous electric motor, the inertia of the system, the elastic-dissipative parameters of the flexible transmission, as well as the technological loading from the cotton fiber which cleaning. Graphical dependences of the change in the average angular velocities and their amplitude of oscillations on the technological resistance of the cleaning fiber were constructed.

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