OPTIMIZATION OF LIFT DEPENDENCE OF THE NEW STRUCTURE OF SMALL-DIAMETER KNITTING MACHINES

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Abstract

The paper is concerned with optimization of the new structure of small-diameter knitting machines, with the aim of analyzing dynamic behaviour of the system when employing new lift dependence of principal operating elements. The paper presents a proposal of such a lift dependence that might provide for elimination of impacts during transitions among the individual areas of lift dependence. This lift dependence employs the 7th degree polynomials for elimination of impacts. For the description of the mechanical driving system there has been employed the method of Lagrange equations of the second kind. The equations have been solved in the software Matlab and in its superstructure Simulink. As the result, courses of kinematic variables of the driving and technological systems of the machine have been obtained.

Introduction

The paper is focused on research and development of new types of drive of small-diameter knitting machines (*fig. 1*), taking advantage of modern, electronically governed drives. The development of mechatronic driving systems has brought the possibility of substituting intricate kinematic chains with simpler ones, and it allows governing the output element by changing the driving dependence. The paper deals in detail with employment of unit drives in relation to individual operating cycles of selected operating elements, producing jersey fabric. The operating elements in this case are the needle cylinder, the dial and the cutting disk. It is a new concept of drive, based on the system applied nowadays, which uses one driving unit for the drive of the whole system.

The design modifications of small-diameter knitting machines concern all components of these machines practically. In the endeavour to make the production as economic as possible, there appear a number of problems related with dynamic behaviour of the machine. The present small-diameter knitting machines are in an overwhelming majority equipped with one brushless servomotor, driving the needle cylinder, the dial and the cutting disk by means of mechanical transmissions, as well as with feeding of elastic thread by means of stepping motors, electromagnetic lever selection of needles and electro-pneumatic control of the cam system. The whole process is governed electronically by means of a programme.

1 Model of the new structure of the drive of small-diameter knitting machines

The principle of the drive of small-diameter knitting machines consists in the transmission of output on the knitting cylinder and the dial. These two components have the technological condition of mutual adjustment of their positions determined by the tolerance of their mutual slewing. The standard driving system has been used in practice for a number of years, and its concept consists in the drive by means of a chain of gear transmissions and shafts, starting from a brushless A.C. synchronous motor as the driving power unit; these issues are described in the study [3]. The newly devised structure of the drive complements the principal driving unit with two additional unit drives (*fig. 1*), employed separately for the drive of the dial and of the cutting disk. The basic precondition of this principle of the drive consists in its electronic interconnection with the main unit, which ensures the observation of technological conditions.

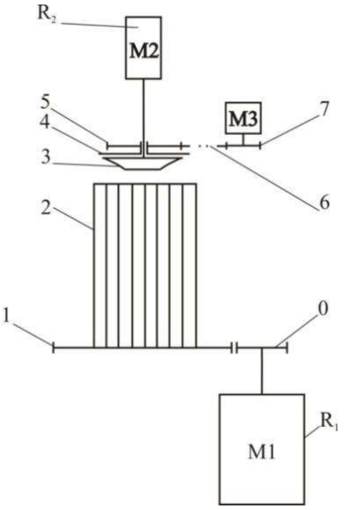

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Fig. 1: *Model of optimized drive*

The technological function of the drives consists in the movement of the needle cylinder (2), driven by a servo motor (M1) via a couple of gear wheels (0, 1). Furthermore, the dial (3) is driven by a servo motor (M2). Another inseparable part of the knitting system is the saw disk (4) driven by a stepping motor (M3) by means of an indented belt via a pair of pulleys (5, 7).

The driving systems employed nowadays do not utilize the individual machine parts realizing the knitting process with maximum efficiency. The newly devised drive allows increasing its efficiency by optimization of the operating diagram of the machine. The knitting cylinder participates in the knitting process incessantly meanwhile the cutting disk during max is 50% of the overall knitting time. The dial itself is (without the saw disk) during several revolutions only, namely for a period of several seconds. When comparing conventional systems of drive and the optimized drive with separated motions, the optimized one shows an economy of energy of about 30 %. [4]

During the non-reversible rotation of the cylinder, there are knitted the welt, the leg, the foot and the extra courses. However, for knitting the reverse heel and toe, it is necessary to change to reversible operation, when the machine runs at reduced r. p.m. When knitting the heel and the toe, the drive of the dial and cylinder performs reverse swinging motion in both senses of the rotation. From the dynamic point of view, the knitting of reverse heel and toe is considered to be the least favourable state [1, 3].

The dial of the knitting machine (the rib dial) is a rotary disk with spreaders, seated in radial grooves. The spreaders are governed by means of fixed cams.

The drive of the dial of the knitting machine is realized by a system of gear wheels and shafts, providing not for the dial drive only, but for its proper setting with respect to the movement of the needle cylinder, too. For a proper function of the machine, as well as for accurate setting of the dial of the knitting machine with respect to the needle cylinder, the following construction conditions for the seating of the dial must be observed: The seating of the dial of the knitting machine must secure its alignment with the needle cylinder; the maximum allowed value of misalignment is 0.05 mm. When dismounting and subsequently remounting some parts of the drive of the needle cylinder or of the dial of the knitting machine, the accurate re-seating of the dial with respect to the needle cylinder must be respected strictly. Another requirement concerning the accuracy of adjustment is mutual slewing of the cylinder and the dial of the knitting machine with tolerance ±0.05 on the diameter 100 mm.

2 Lift dependence of the knitting system

When devising the new lift dependence, from the point of view of reduction of dynamic forces, it is suitable to employ the so-called shock-free course, provided by the polynomial 4-5-6-7, where the angle of slewing of the needle cylinder (*fig. 1*) is a function of displacement of a fictitious cam within one period of time, when the cylinder performs a symmetric motion from the rest position with return to the same position. The basic form of motion dependence consists of segments with uniform rotary motion, with reversation in limit positions along transition curves (*fig. 2*) chosen conveniently. These segments are represented by suitably chosen polynomials; in case of curvilinear motions, they are polynomials of the7th degree, so-called 4-5-6-7, and the remaining linear sections with requirements of constant velocity are represented by a linear function. For the synthesis of knitting mechanism, the initial values of the lift dependence must be established first. When devising the lift dependence, the set of evaluated data from the measuring serves as input parameters, indicating the required position in time. The output value for synthesis of the mechanism will be the function $\gamma(\psi)$ where γ stands for the angle of slewing of individual elements of the drive, and ψ is the angle of the fictitious cam, related to individual time sections of one period.

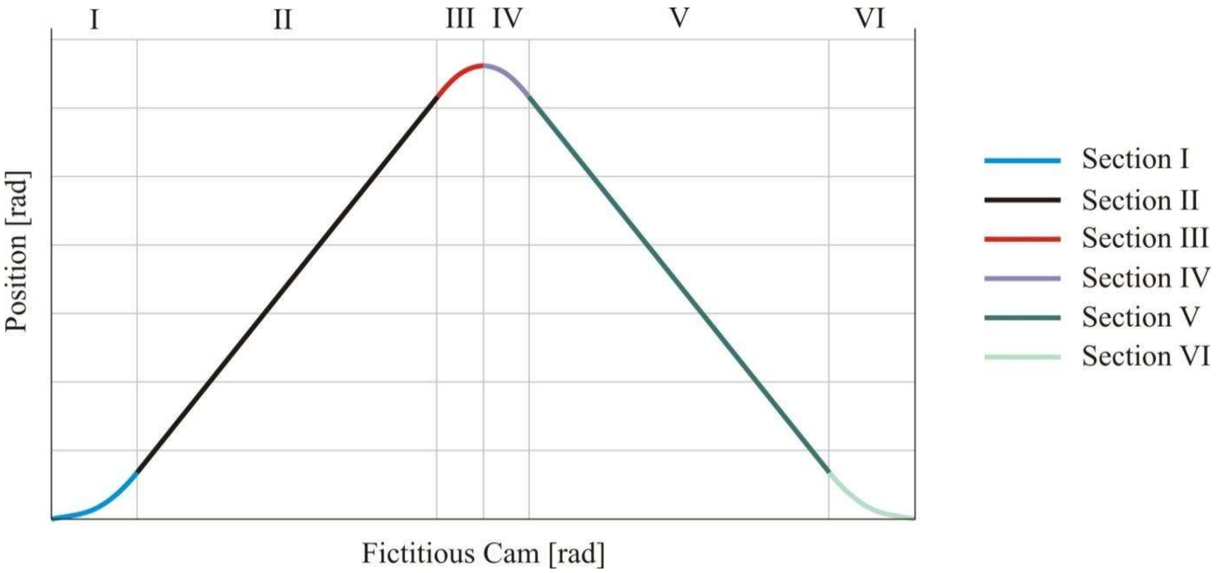

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Fig. 2: *Lift dependence*

The lift dependence (*fig. 2*) of rotary elements of the knitting mechanism consists of a total of 6 areas. In the transition areas (intervals I, III, IV and VI) it is described by means of the polynomial 4-5-6-7 (see set of equations 1-4), in the remaining areas (intervals II, V) it is described by means of a linear function, i.e. by a linear function (see set of equations 5-9).

2.1 Compiling the equations of the lift dependence

The equation describing the polynomial applies to the segments *I, III, IV* and *VI* and is expressed by the set of equations (1 – 4).

$$\gamma(\psi) = C_0 + C_1 \cdot \psi + C_2 \cdot \psi^2 + C_3 \cdot \psi^3 + C_4 \cdot \psi^4 + C_5 \cdot \psi^5 + C_6 \cdot \psi^6 + C_7 \cdot \psi^7 \quad (1)$$

ψ – angle of slewing of fictitious cam [rad],

γ – angle of slewing of the mechanism [rad],

C_n – constants

In the equation (1) there figure eight constants, for the establishment of which eight boundary conditions must be found. By calculating successive derivatives of this relation, we obtain four equations more. Another precondition is the fact that the cam revolves at constant velocity.

Equations of the polynomial 4-5-6-7

$$\begin{aligned}\Omega(\psi) = C_1 \cdot \omega + 2C_2 \cdot \omega \cdot \psi + 3C_3 \cdot \omega \cdot \psi^2 + 4C_4 \cdot \omega \cdot \psi^3 + 5C_5 \cdot \omega \cdot \psi^4 + \\ + 6C_6 \cdot \omega \cdot \psi^5 + 7C_7 \cdot \omega \cdot \psi^6\end{aligned} \quad (2)$$

$$\begin{aligned}\varepsilon(\psi) = 2C_2 \cdot \omega^2 + 6C_3 \cdot \omega^2 \cdot \psi + 12C_4 \cdot \omega^2 \cdot \psi^2 + 20C_5 \cdot \omega^2 \cdot \psi^3 + \\ + 30C_6 \cdot \omega^2 \cdot \psi^4 + 42C_7 \cdot \omega^2 \cdot \psi^5\end{aligned} \quad (3)$$

$$\begin{aligned}\delta(\psi) = 6C_3 \cdot \omega^3 \cdot + 24C_4 \cdot \omega^3 \cdot \psi + 60C_5 \cdot \omega^3 \cdot \psi^2 + 120C_6 \cdot \omega^3 \cdot \psi^3 + \\ + 210C_7 \cdot \omega^3 \cdot \psi^4\end{aligned} \quad (4)$$

Equations of the linear fiction

$$\gamma(\psi) = C_{10} + C_{11} \cdot \psi \quad (5)$$

$$\Omega(\psi) = C_{11} \cdot \omega \quad (6)$$

$$\varepsilon(\psi),\ \delta(\psi) = 0 \quad (7)$$

Ω – angular velocity [rad.s^{-1}],

ε – angular acceleration [rad.s^{-2}],

ω – angular velocity of fictitious cam [rad.s^{-1}],

δ – impact [rad.s^{-3}]

The constants $C_0 – C_7$ are established from the sets of eight equations with eight unknowns, and the constants $C_{10} – C_{11}$ from four equations with four unknowns.

In order to be able to describe the behaviour of the examined system, it is necessary to compile a suitable mathematical model, which will describe its behaviour during an operation cycle with maximum possible precision [1]. In the software Matlab there has been devised a program for the definition of the lift dependence with respect to the boundary conditions. Subsequently, the course values have been inserted into the mathematical model [1]. In the model there are considered elastic couplings among individual elements forming the knitting system. In view of geometrical properties of the needle cylinder, its body is considered as two halves connected by an elastic element. The drive of the saw has not been incorporated into the mathematical model, because of its low mass parameters and the impossibility to exert an influence on it from construction and technological points of view.

3 Results

Once the calculated constants have been inserted into the equations, we obtain new equations for lift dependencies, velocities and accelerations. The evaluation of results is presented in the charts in the figures 3-7, representing these quantities entered by means of discrete values.

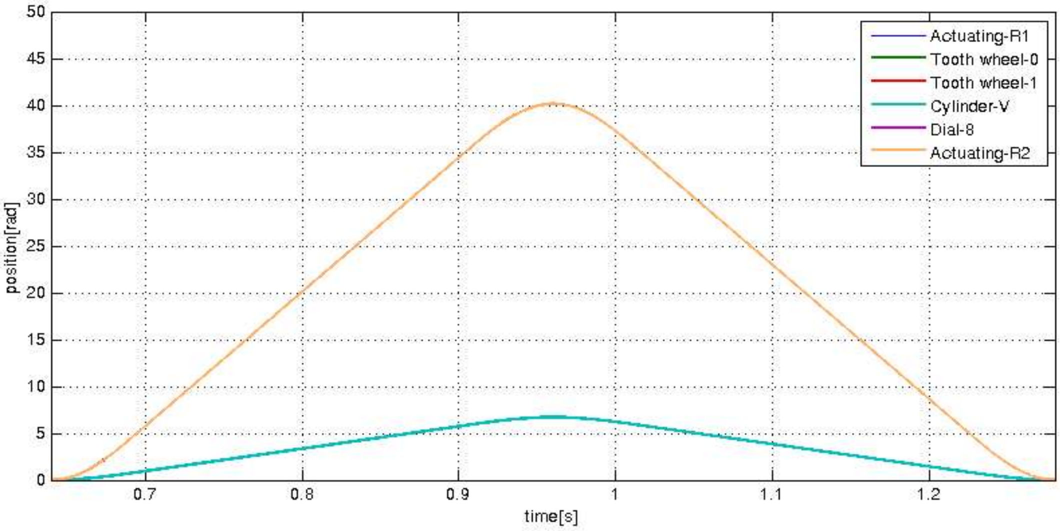

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Fig. 3: *Course of the position*

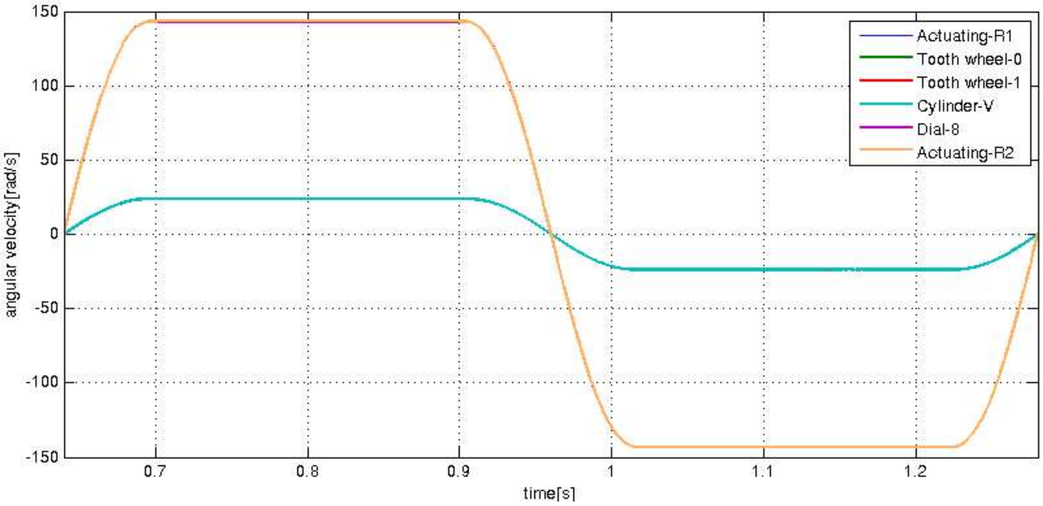

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Fig. 4: *Course of the velocity*

The *fig. 3* shows the lift dependence of the basic reverse motion in dependence on the angle of the fictitious cam. The first and second time derivatives are shown in the *figs. 3* and *4*.

When compiling the equations, there are given requirements on the slope of the linear section, which must correspond to the set constant velocity, prescribed technologically by the knitting process. Moreover, there is pre-determined the length of transition areas and the overall lift, following from technological requirements. In the places of link-up of individual segments, there is required the continuance to the second derivative.

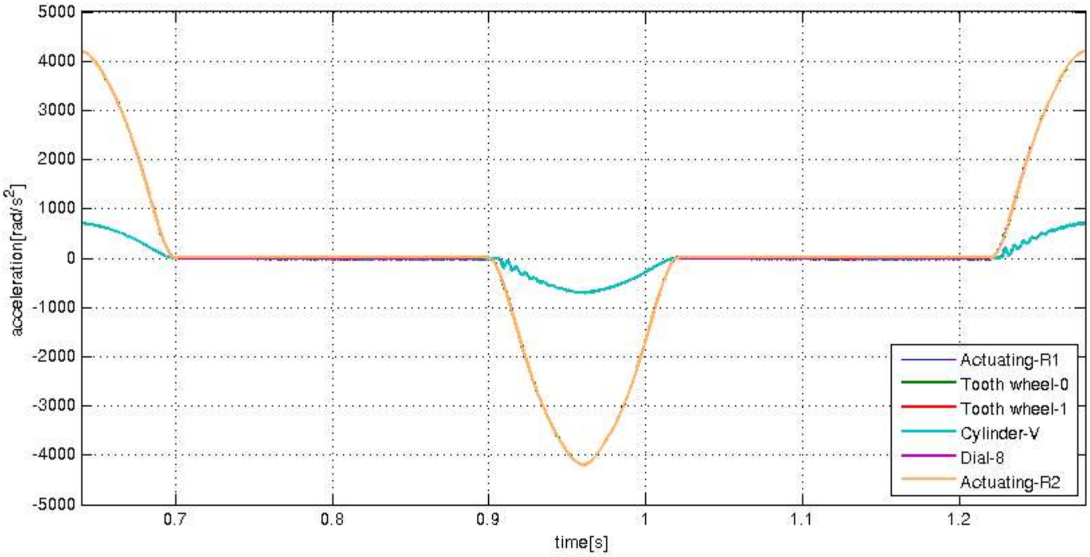

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Fig. 5: *Course of the acceleration*

In comparison with the original lift dependence, where the lifting function was constituted by a polynomial of the 3rd degree, study [1], a reduction of the acceleration has come about, owing precisely to the employment of the polynomial 4-5-6-7. This decrease is important from the point of view of its effect on the overall dynamic behaviour of the system, where the main contribution is the reduction of peak values in the areas of transition among polynomials.

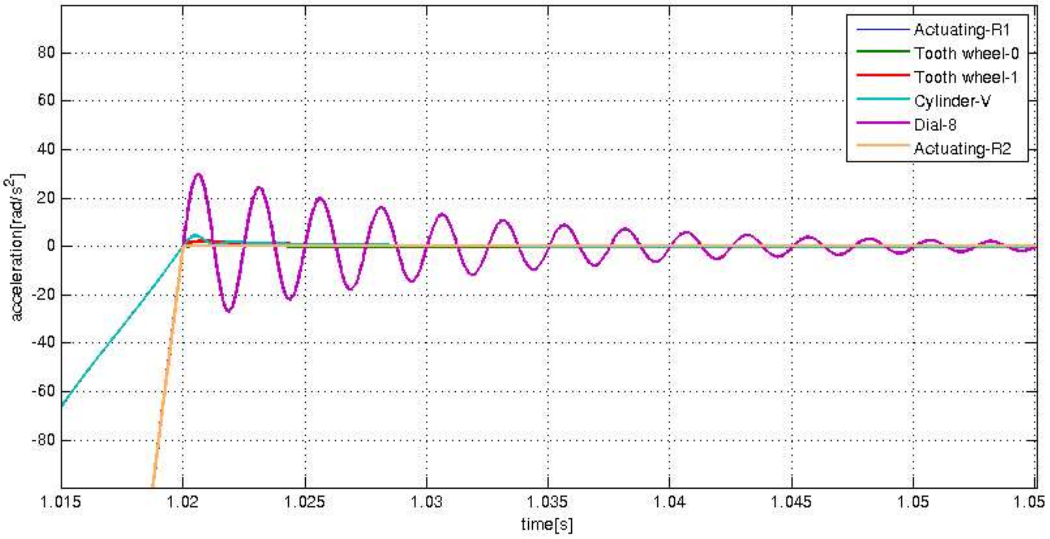

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Fig. 6: *Detail of the course of acceleration A*

The *figs. 6* and *7* show the details of the courses of acceleration in identical transition areas, where in the case visualized in the *fig. 6* there is employed the original course of the lift [1].

The fig. 7 represents the same detailed area, however, for the case of the lift dependence analyzed above. As can be seen from both of the cases, vibrations in these areas have been suppressed.

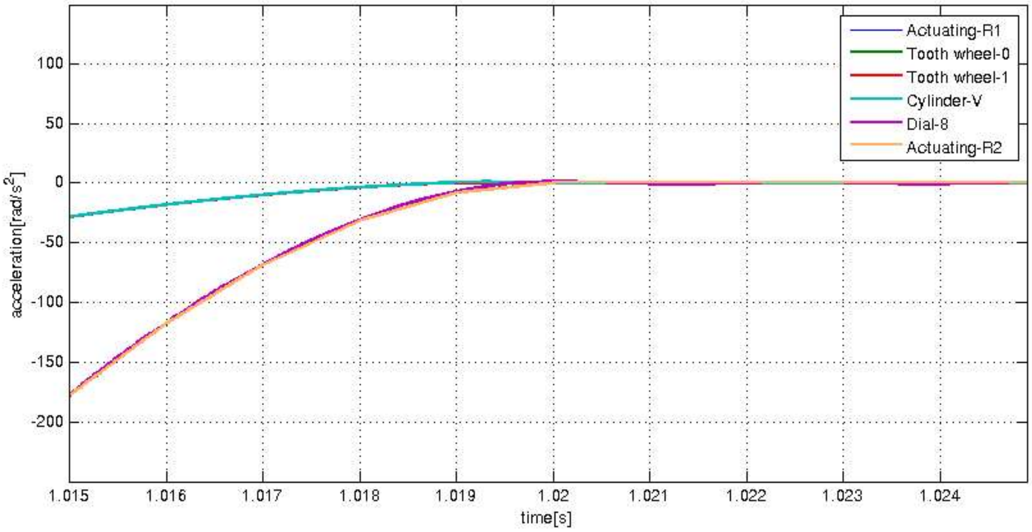

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Fig. 7: *Detail of the course of acceleration B*

Conclusion

The paper is concerned with devising suitable lift dependence for the new structure of the driving system of small-diameter knitting machines. The presented lift dependence is a reaction to shortcomings of the original solution, where polynomial of the 3rd and a linear function have been used for the whole course of the solution. The principle consists in employing this dependence for a fictitious servo drive, which excites cinematically a dynamically flexible system, described by Lagrange equations of the second kind [1, 2]. The outputs are the indicated courses of cinematic variables. When comparing the courses, the most important benefits have been obtained in the transition areas with constant velocity, where we succeeded in suppressing practically completely the impacts generating transition oscillating phenomena. In these areas precisely, the course employed originally [1] has exerted a negative influence on the technological process of knitting and dynamic behaviour of the machine.

Acknowledgements

The paper has been elaborated in the frame of the solution of the grant project 1M0553.

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OPTIMALIZACE ZDVIHOVÉ ZÁVISLOSTI NOVÉ STRUKTURY MALOPRŮMĚROVÉHO PLETACÍHO STROJE

Článek je zaměřen na optimalizaci nové struktury maloprůměrového pletacího stroje s cílem analyzovat dynamické chování soustavy při použití nové zdvihové závislosti základních pracovních členů. Obsahem článku je návrh této zdvihové závislosti, která zajišťuje eliminaci rázů při přechodu mezi jednotlivými oblastmi zdvihové závislosti. Zdvihová závislost využívá polynomů sedmého stupně pro eliminaci rázů. K popisu dynamického systému pohonu je použita metoda Lagrangeových rovnic druhého druhu. Rovnice byly řešeny v software Matlab a jeho nadstavby Simulink. Výstupem jsou průběhy kinematických veličin pohonné a technologické soustavy stroje.

OPTIMIERUNG DER HUBABHÄNGIGKEIT DER NEUEN STRUKTUR BEI DER WIRKMASCHINE FÜR KLEINE DURCHMESSER

Der Artikel konzentriert sich auf die Optimierung der neuen Struktur bei der Wirkmaschine für kleine Durchmesser mit dem Ziel, das dynamische Verhalten des Systems bei der Verwendung der neuen Hubabhängigkeit der grundlegenden Arbeitsglieder zu analysieren. Der Artikel beinhaltet den Entwurf dieser Hubabhängigkeit, die für die Beseitigung der Stöße beim Übergang zwischen den einzelnen Bereichen der Hubabhängigkeit sorgt. Die Hubabhängigkeit nutzt die Polynome vom siebten Grad zur Beseitigung der Stöße aus. Zur Beschreibung des dynamischen Antriebssystems wird die Methode der Gleichungen der zweiten Art von Lagrange angewandt. Die Gleichungen wurden in der Software Matlab und derer Anbau Simulink gelöst. Die Ausgänge sind die Verläufe der kinematischen Größen des Antriebs- sowie des Technologiesystems der Maschine.

OPTYMALIZACJA PRZEBIEGU FUNKCJI RUCHÓW NOWEJ STRUKTURY MASZYNY DZIEWIARSKIEJ MAŁEJ ŚREDNICY

Artykuł jest poświęcony optymalizacji nowej struktury maszyny dziewiarskiej małej średnicy, w celu przeprowadzenia analizy zachowań dynamicznego układu z zastosowaniem nowych zależności posuwów podstawowych elementów roboczych. Treścią artykułu jest opracowanie tej zależności ruchów, która zapewnia eliminację uderzeń przy przejściu między poszczególnymi obszarami funkcji ruchów. Funkcja ruchu wykorzystuje wielomian siódmego stopnia dla eliminacji uderzeń. Do opisu układu dynamicznego napędu zastosowano metodę równań Lagrange drugiego rzędu. Równania były rozwiązywane w programie Matlab i jego nadbudowie Simulink. Wynikiem są przebiegi wielkości kinematycznych układu napędowego i technologicznego maszyny.