ANALYSIS AND OPTIMISATION OF THE NEEDLE TRANSFER MECHANISM

Jaroslav Beran
***Karel Pejchar**
****Jiří Komárek**

Technical University of Liberec
Faculty of Mechanical Engineering
Department of Design of Textile Machine
Studentská 2, 461 17, Liberec 1, Czech Republic
jaroslav.beran@tul.cz
*Technical University of Liberec
Faculty of Mechanical Engineering
Department of Design of Textile Machine
Studentská 2, 461 17, Liberec 1, Czech Republic
karel.pejchar@tul.cz
**Technical University of Liberec
Faculty of Mechanical Engineering
Department of Design of Textile Machine
Studentská 2, 461 17, Liberec 1, Czech Republic
jiri.komarek@tul.cz

Abstract

The paper is concerned with an analysis and optimisation of the needle transfer mechanism by means of the software Pro/Engineer Wildfire 4 with the aim to reduce the noise at high r. p.m. of the machine. There has been carried out an optimisation of selected parameters of the mechanism with the aim to avert the vibration of the element that controls the moment of release of the needle during its transfer from one needle bar to the other one. Subsequently, there is carried out a sensitivity analysis of the effect of designing parameters of the mechanism upon the velocity of impact of the controlling element upon the machine frame. On the basis of the results of the analysis and optimisation, there have been proposed modifications of the design of the needle transfer mechanism, and subsequently, they have been verified experimentally by measuring the sound pressure on a functional model.

1 Introduction

The present trend in the development of sewing machines is to shorten the sewing times in the sewing process and to increase the productivity. Other parameters of the sewing machines manufactured nowadays are e.g. silent running, minimum vibrations, long service life of employed mechanisms and easy operation of the machine. The machine, a part of which is the needle transfer mechanism, operates in the velocity range of 100 – 250 r. p.m. At higher r. p.m., the sewing machine presents considerable vibrations and high levels of noise [2]. The object of this paper is to analyse the needle transfer mechanism and to optimise its dynamic behaviour, and subsequently, to realise modifications that should result in a reduction of the noise generated by this mechanism.

2 Analysis of the needle transfer mechanism

The needle transfer mechanism (fig. 1) forms a part of the system that allows imitating the hand stitch. Its task consists in providing for the transfer of the floating needle between two needle bars operating above the work table of the machine and below it. The floating needle is clamped by collets (item 12) in the needle bar, owing to the pressing force of the springs, items 11 and 15. The unlocking of collets is actuated during the movement of the needle bar by impact of its controlling element upon the machine frame before the dead centre of needle transfer, where the impact is damped by a rubber pad (item 10). The stop block can be seen in the figure 2. The jacket of the needle bar (item 2) goes on moving to the lower dead centre and completes the process of the needle transfer.

A mathematical model of the needle transfer mechanism has been devised by means of the system Pro/Engineer Wildfire 4.0 in the module Mechanism. The individual parts of the needle transfer mechanism are represented by means of rigid elements. The figure 1 shows the design of the needle transfer mechanism including two springs. These two springs are simulated by means of the functions SPRING and DAMPER. Another pliable element is the rubber pad mentioned above already. This pad is simulated by means of the functions FORCES and DAMPER. The mechanism of the needle bar and its proper function are provided by a system of stop blocks modelled by means of the function CAM, which allows simulating impact of bodies. The coefficients of restitution have been adjusted to such a value that the behaviour of the mathematical model would be as close as possible to the behaviour of the real mechanism which has been examined by means of a fast-speed camera.

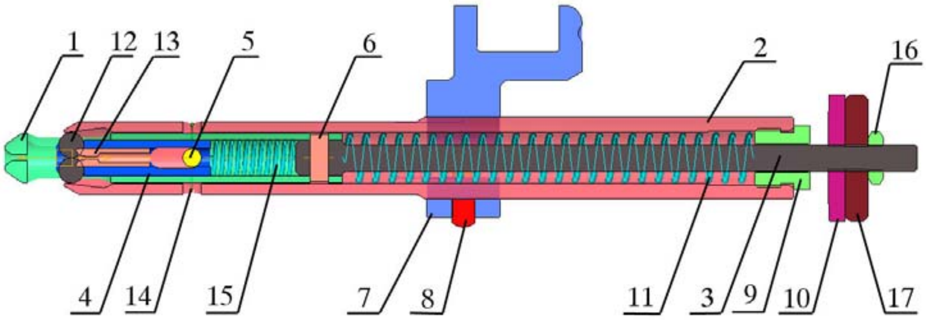

Figure 1 Sectional view of the needle transfer mechanism

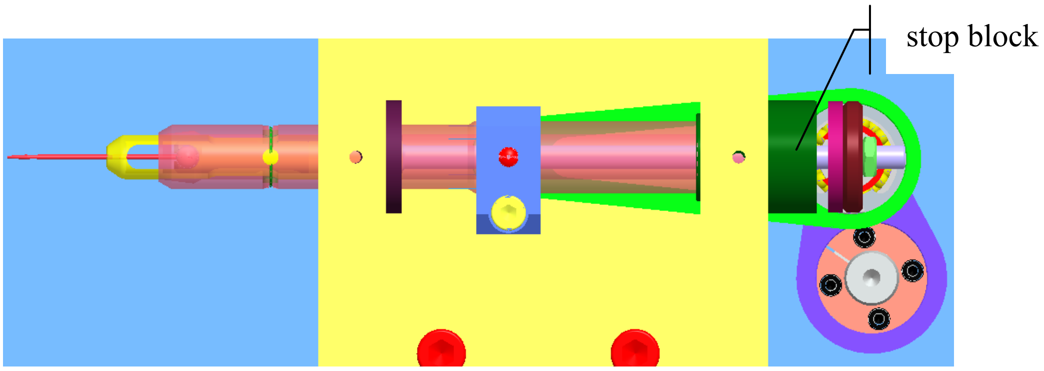

Figure 2 Newly proposed crank mechanism

The needle transfer mechanism performs the rectilinear reverse movement that has been realised by a cam mechanism in the existing machine. The newly proposed functional model of the machine consists of crank mechanism with servo-drive converting the rotary swinging motion into rectilinear reverse movement – see figure 2. In the following diagram 1 there is shown the dependence of the position of the needle bar on the time. The time value 0.24 sec.

corresponds to one cycle of the needle mechanism for the machine regime of 250 r. p.m. In the following section, we shall deal with the first passage from the upper position of the needle bar to the lower one, because in this area there exist the highest values of the acceleration, and during this movement impacts and noise are generated in particular.

The values of stiffness of the springs *K1* and *K2*, items 11 and 15, have been taken over from the work [1]. The values of intrinsic damping of the springs B1 and B2, items 11 and 15, and of intrinsic damping of the rubber pad B3 have been taken over from the work [3]. The resulting values of stiffness of the springs and their intrinsic damping are shown in the table No. 1 below.

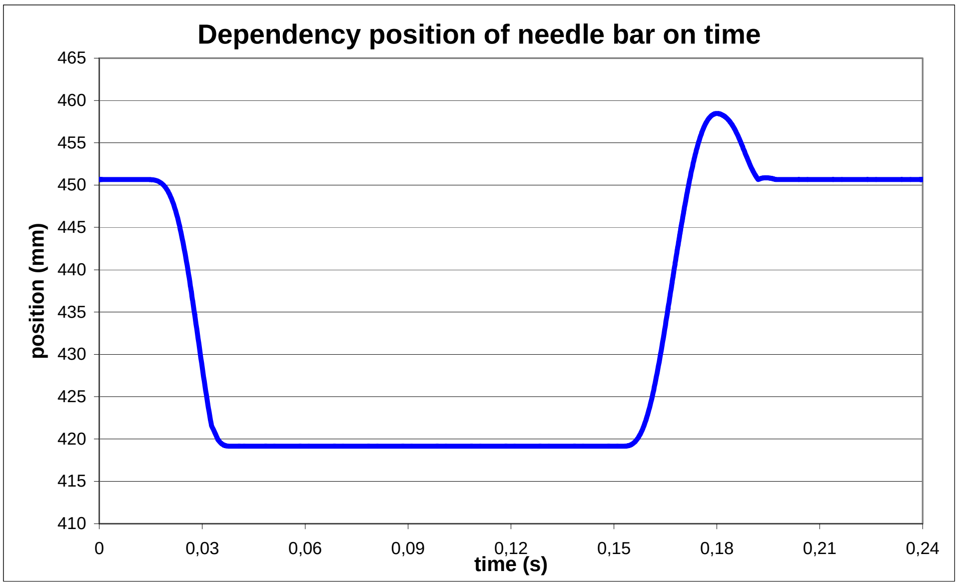

Diagram 1 Dependence of the position of the needle bar on time

Table 1 Values of stiffness and intrinsic damping of the springs

	Stiffness *K* [N/mm]	Intrinsic damping *B* [N.s/mm]
Spring item 11	0,899	0,013152
Spring item 15	0,69	0,03322
Rubber pad item 10	-	0,0285

The model comprises the pliability of the rubber pad. The course of the force necessary for the compression of the rubber pad has been established experimentally in the work [1]. In the record, there can be seen the expected non-linear behaviour of the rubber pad during its compression. The course of the acting force has been approximated by a polynomial of third degree (1).

$$F(x) = -693{,}79x^3 + 1515{,}4x^2 + 236{,}1x + 11{,}246 \qquad (1)$$

Increased r. p.m. of the machine are accompanied with vibrations of the controlling element of the needle bar that controls the moment of release of the needle during its transfer from one needle bar to the other one. The vibrations bring an increase of the impact velocity of the controlling element as a consequence, and hence, an increase of kinetic energy at the impact on the machine frame. This phenomenon has an adverse effect upon the service life of the parts, and naturally, upon the noise level of the mechanism. From the effected analysis there follows that the existing springs of the mechanism are not dimensioned for high r. p.m. of the machine sufficiently. The diagram 2 displays the velocities of the jacket of the needle transfer mechanism and the velocities of the controlling element for two different regimes. At the operating regimes up to 160 r. p.m., the vibrations of the controlling element do not come up yet, and at the regime 250 r. p.m., the difference of the velocities of the jacket and of the controlling element is Δv = 0.56m/s. The impact velocity of the controlling element attains the value 2.68m/sec. in this case.

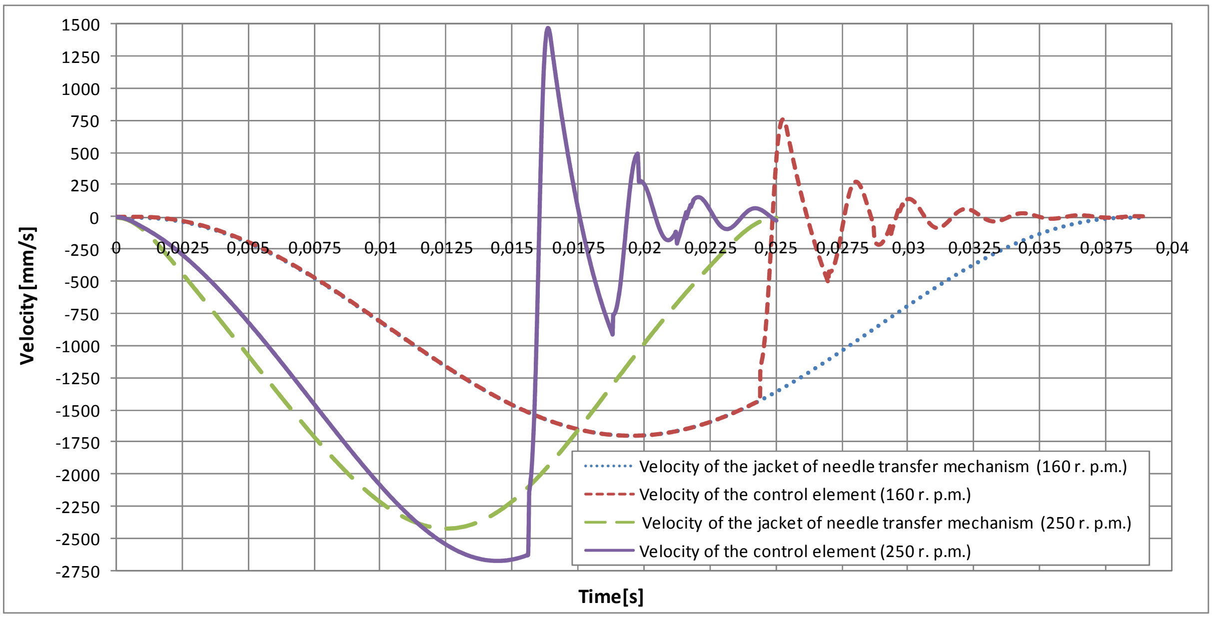

Diagram 2 Time behaviours of velocities of the elements of the needle transfer mechanism for the regimes 160 r. p.m. and 250 r. p.m.

3 Optimisation of the stiffness of the spring of the transfer mechanism

The vibrations of the control element of the transfer mechanism are influenced by the strength of the spring item 11 - fig. 1 primarily. By increasing the stiffness of this spring, it is possible to suppress the vibration of the control element, thus reducing the difference in velocities of the jacket and of the control element. However, the produced strength of the springs must not be too high; otherwise, the servo-motor driving the crank mechanism would have to generate a higher torque in the lower position of the mechanism. By means of a mathematical model, there has been found such a value of spring stiffness at which no vibrations of the controlling element might occur for the regime 250 r.p.m. By the effected sensitivity analysis there has been found the value of stiffness of the spring item 11 $K1$ = 1.235 N/mm. When setting up this value of stiffness, the velocity of the jacket of the transfer mechanism coincides with the velocity of the control element, namely up to the moment of its impact upon the stop block. This velocity is represented in the diagram 4.

4 Sensitivity analysis – reduction of kinetic energy of the control element

An integral part of the needle transfer mechanism is the stop block which provides for opening of the collets. After the impact of the rubber pad upon the stop block, the controlling element of the needle mechanism is brought to a halt. The kinetic energy of the controlling element of the needle transfer mechanism at the drop upon the stop block is determined by the relation

$$E_K = \frac{1}{2} m v^2, \tag{2}$$

where m is the mass of all parts of the controlling element and v is the impact velocity of the controlling element. From the relation it can be seen that it is possible to reduce the kinetic energy through a reduction of the mass, however, it is more effective to reduce the impact velocity. A reduction of the velocity is achieved by shortening the length of the inner cylinder – see fig. 3, which forms a part of the controlling element. Thanks to this alteration, the moment of the impact is transferred to an area where the impact velocity attains considerably lower values – see the diagram 4.

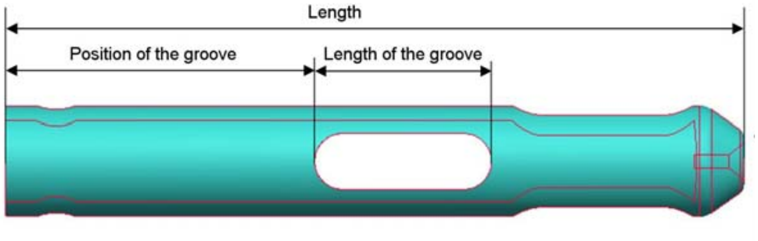

Figure 3 Inner cylinder

The table 2 shows the results of sensitivity analysis for the optimised stiffness of the spring item 11, namely the resulting values of the impact velocity of the controlling element and the values of kinetic energy for individual values of the shortened groove.

Table 2 Table of results of sensitivity analysis – impact velocity and kinetic energy at the impact

Shortening of the groove [mm]	Length of the part [mm]	Length of the groove [mm]	Position of the groove [mm]	Weight [g]	Regime 250 r. p.m.	
					Impact velocity [m/s]	Kinetic energy [J]
0	58,8	14,1	24,6	10,60	2,157	0,102826
1	59,8	13,1	25,6	11,15	2,061	0,095043
2	60,8	12,1	26,6	11,7	1,952	0,086303
3	61,8	11,1	27,6	12,24	1,826	0,076422
4	62,8	10,1	28,6	12,79	1,682	0,065622
5	63,8	9,1	29,6	13,34	1,524	0,054511

In the following diagram 3 there is shown the decrease of kinetic energy due to designing alteration of the inner cylinder in order to optimise the stiffness of the spring, item 11.

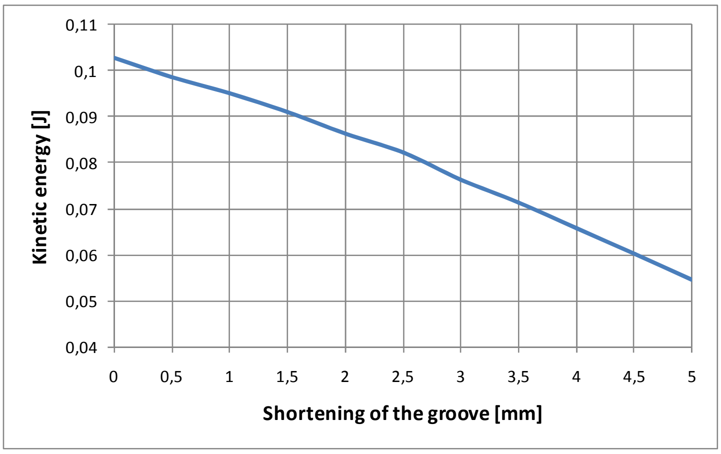

Diagram 3 Sensitivity analysis of the effect of shortening of the groove of the inner cylinder upon the kinetic energy

In the diagram 4 there is shown the time behaviour of the velocity of individual parts of the transfer mechanism for the regime 250 r. p. m during the movement from the upper position of the needle mechanism to the lower one, because the impact of the controlling element upon the stop block occurs in this phase. The blue curve represents the velocity of the jacket of the needle bar of the transfer mechanism – see item 2, figure 1. The violet curve shows the velocity of the controlling element of the original design with original stiffness of the spring, item 11. The red curve represents the velocity of this element for the optimised stiffness value of the spring, item 11 $K = 1.235$ N/mm. The diagram also includes a green curve, which stands for the modified design of the controlling element in accordance with the table 2, with the groove shortened by 5mm.

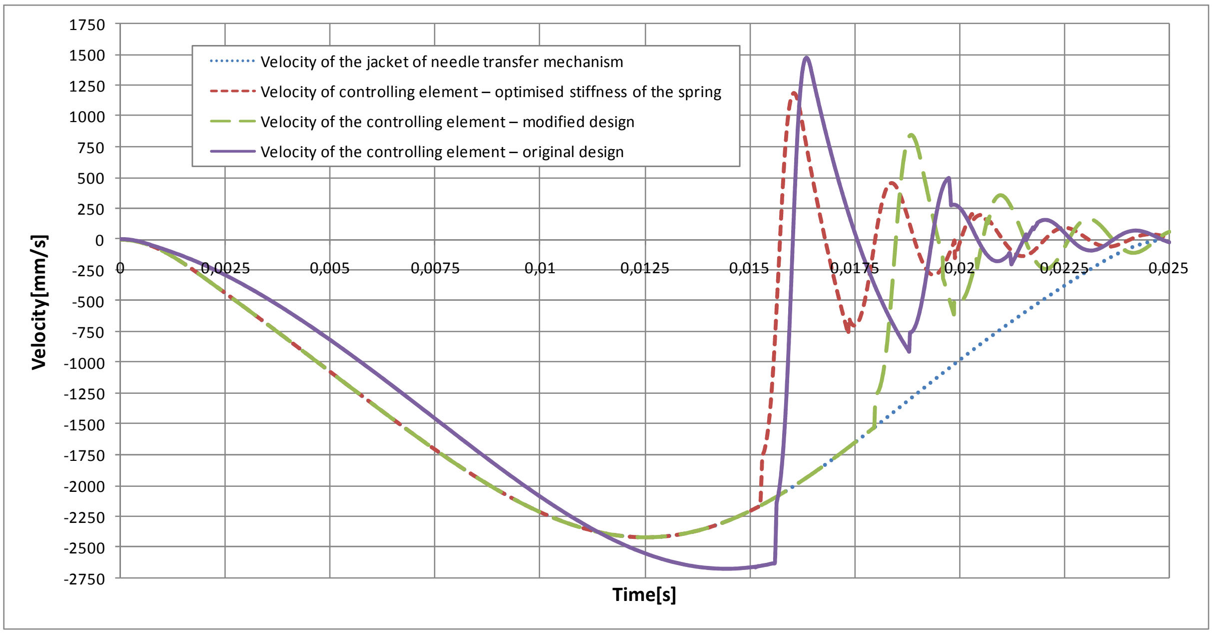

Diagram 4 Kinematic conditions of velocities of individual parts of the needle transfer mechanism for the regime 250 r. p.m.

The table 3 compares the values of kinetic energy at the impact of the original needle transfer mechanism, where vibrations of the controlling element occurred, and of the mechanism with optimised stiffness of the spring and modified inner cylinder.

Table 3 Reduction of kinetic energy

	Impact velocity [m/s]	Impact energy [J]
Original mechanism	2,676	0,158261
Optimised mechanism	1,524	0,054511

5 Experimental verification of the optimisation of the needle transfer mechanism

The aim of experimental measuring has been a verification of results of the needle transfer mechanism. For this purpose, there has been performed measuring of the sound pressure in the proximity of the needle transfer mechanisms both of the original mechanism and of the optimised one. It has been a comparative measurement, not pretending to obtain standard values of sound pressure. For measuring the sound pressure there has been employed a measuring apparatus manufactured by Brüel & Kjaer with the dual-channel analyser 2144 and microphone type 4165. The following diagram 5 shows the overall levels of sound pressure measured on a functional model at the regime 250 r. p.m. The value A/L stands for the overall level given by the sum of energies in individual frequencies. The value W stands for the overall level weighted by the filter A. The filter A is suitable for the analysis of sound pressure in audible frequencies; it respects the properties of human hearing. The measured results and differences in sound pressures are summarised and compared in the table 4.

Table 4 Comparison of overall levels of sound pressure

Operating regime	250 r. p.m.	
Overall levels of sound pressure (dB)	A/L	W
Original cylinder	105,74	80,8
Modified cylinder	102,68	76,4
Reduction of overall levels of the sound pressure (dB)	3,06	4,4

The results of the measuring confirm a marked improvement, achieved by the modification of the inner cylinder and optimisation of the stiffness of the spring. This modification has brought a decrease of the overall level of sound pressure by 4 dB approximately.

6 Conclusion

In this paper, there has been analysed the needle transfer mechanism both by means of the software Pro/Engineer and experimentally. There has been carried out an optimisation of stiffness of the spring of the needle transfer in order to avert the vibrations of the controlling element. By means of a mathematical model there has been established the theoretical velocity of the impact of the rubber pad upon the stop block. There has been carried out a sensitivity analysis of the effect of the modification of designing dimensions of the inner cylinder upon the kinetic energy of the controlling element at its impact upon the machine frame. On the basis of this sensitivity analysis there has been altered the design of the inner cylinder, and there has been effected measuring of the sound pressure, which has shown a considerable reduction. The experimental analysis has also confirmed that the designing alteration of the inner cylinder has exerted no effect upon the process of the needle transfer.

Literature

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[3] PEJCHAR, K., BERAN, J.: Optimisation of the needle bar mechanism. /Entry in the collection of papers/. Liberec, TUL 2009

Prof. Ing. Jaroslav Beran, CSc.
Ing. Karel Pejchar
Ing. Jiří Komárek

ANALÝZA A OPTIMALIZACE MECHANISMU PŘEDÁVÁNÍ JEHLY

Článek pojednává o analýze a optimalizaci mechanismu předávání jehly pomocí softwaru Pro/Engineer Wildfire 4 s cílem snížit hluk při vysokých otáčkách stroje. Je provedena optimalizace vybraných parametrů mechanismu s cílem zamezit kmitání členu, který řídí okamžik uvolnění jehly při jejím předání z jedné jehelní tyče na druhou. Následně je provedena citlivostní analýza vlivu konstrukčních parametrů mechanismu na rychlost dopadu řídícího členu na rám stroje. Na základě výsledků analýzy a optimalizace jsou navrženy konstrukční úpravy mechanismu předání jehly a následně experimentálně ověřeny měřením akustického tlaku na funkčním modelu.

ANALYSE UND OPTIMIERUNG BEIM NADELÜBERGABEWERK

Der Artikel behandelt die Untersuchung und Optimierung beim Nadelübergabewerk mittels der Software Pro/Engineer Wildfire 4 mit dem Ziel, den Lärmpegel bei hoher Maschinendrehzahl zu reduzieren. Es wird eine Optimierung der ausgewählten Werksparameter vorgenommen, wo das Ziel gesetzt wird, die Schwingung im Augenblick der Nadellösung bei ihrer Übergabe aus einer Nadelstange in die andere steuernden Glied zu verhindern. Anschließend folgt die Empfindlichkeitsanalyse der Auswirkung von Werkskonstruktionsparametern auf die Geschwindigkeit des Steuergliedeinfalls auf den Maschinenrahmen. Anhand von den Untersuchungs- und Optimierungsergebnissen werden Konstruktionsanpassungen beim Nadelübergabewerk entworfen, die anschließend durch Messung des Schalldrucks beim funktionsfähigen Modell versuchsmäßig überprüft werden.

ANALIZA I OPTYMALIZACJA MECHANIZMU PRZEKAZYWANIA IGŁY

Artykuł jest poświęcony analizie i optymalizacji mechanizmu przekazywania igły za pomocą oprogramowania Pro/Engineer Wildfire 4, dokonywanej w celu obniżenia hałasu przy wysokich obrotach maszyny. Przeprowadzona jest optymalizacja wybranych parametrów mechanizmu w celu eliminacji wibracji elementu, który określa moment zwolnienia igły podczas jej przekazywania z jednego prowadnika igły na drugi. Następnie jest przeprowadzona analiza wrażliwości wpływu parametrów konstrukcyjnych mechanizmu na prędkość opadania elementu sterującego na ramę maszyny. Na podstawie wyników analizy i optymalizacji zaproponowano zmiany konstrukcyjne mechanizmu przekazywania igły, które następnie eksperymentalnie sprawdzono pomiarami ciśnienia akustycznego na działającym modelu.