Evaluation of the Length Distribution of Needle Thread within the Take-up Disc Zone of a Lockstitch Machine

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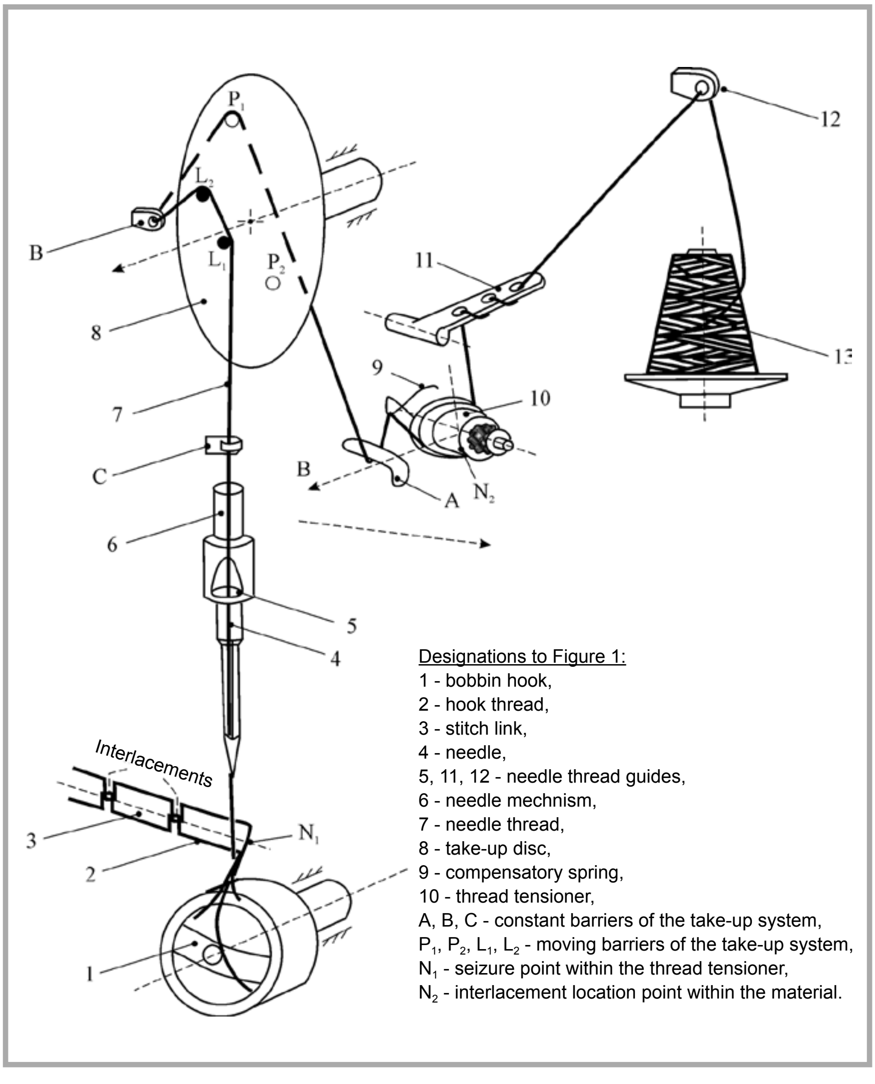
Abstract
Evaluation of the length distribution of needle thread during stitch formation is necessary to determine the dynamic characteristics of a sewing machine, and the thread needed in this process. In this study, physical and mathematical models of the take-up disc are developed. The thread length for the full rotation range is determined as the geometrical distance between the active frictional barriers. The algorithm of calculations is introduced and implemented alternatively by means of the languages Fortran and C++, as well as by genetic algorithms. The length distribution of the needle thread obtained was verified by using simulations of the sequence and geometry of the frictional barriers, as well as experimental research of the purpose-oriented model of the take-up disc prototype.

Key words: *lockstitch machine, take-up disc, working zone, algorithms, numerical calculations.*

General characteristic of the multibarrier take-up disc

The main function of the take-up mechanism of the lockstitch sewing machine (closed interlacement of stitch) is to create a stitch together with the needle and bobbin hook. We introduce two phases within the working cycle of the mechanism: the feeding of thread to the needle and bobbin hook, as well as the supplying of thread to the bobbin hook, which ends in the stitch tightening to create an interlacement. The dynamic stresses within the sewing thread are important during the stitch formation. The take-up disc (cf. ***Figure 1***), characterised by a multibarrier structure, can influence the thread control curve according to the technological requirements of the needle and bobbin hook.

Consequently, we can influence the dynamics of the interaction between the take-up disc and thread during the interlacement formation within the material package (the tightening of the stitch). Of course, we can select the barrier configuration of the take-up disc; primarily the configuration of the mobile frictional barriers on the take-up disc. A mechanism for controlling the thread capacity should be introduced into the process of machine stitch formation, because the thread length necessary for stitch link formation varies greatly in relation to the length within the link. The requirements for the take-up mechanism with respect to the thread needed by the needle and bobbin hook are formulated in [1, 2]. The



Designations to Figure 1:
1 - bobbin hook,
2 - hook thread,
3 - stitch link,
4 - needle,
5, 11, 12 - needle thread guides,
6 - needle mechnism,
7 - needle thread,
8 - take-up disc,
9 - compensatory spring,
10 - thread tensioner,
A, B, C - constant barriers of the take-up system,
P_1, P_2, L_1, L_2 - moving barriers of the take-up system,
N_1 - seizure point within the thread tensioner,
N_2 - interlacement location point within the material.

Figure 1. *View of the take-up disc in the lockstitch machine.*

thread required by the needle and bobbin hook of any sewing machine is the basis for designing the take-up mechanism controlling the needle thread capacity. The structure should secure the feeding of the thread portion during the process of stitch link formation without thread breakage for the assumed stitch length and material package thickness. Thread braking should be introduced at the end of stitch tightening by introducing the take-up mechanism. The take-up mechanism is experimentally verified by means of sewing tests.

The thread control curve of the take-up mechanism is used to design the take-up disc of a structure characterised by control points on the selected barriers. This property can be used to describe the control stages of the take-up mechanism corresponding to the appropriate wearing properties of textiles. The way to solve the problem is to model the thread control curve of the take-up disc according to the thread needed by the needle and bobbin hook [3].

An analytical description of the thread control conditions of the take-up mechanism can help to create special software to search for a take-up configuration for the assumed thread control curve. Thus a special system "Take-up disc 2.0" was developed in the C++ environment supported by components of the standard library VCL Borland. The system is based on classical genetic algorithms. The algorithm of the design cycle of the take-up prototype is shown in ***Figure 2*** and contains the identification of the thread required by the needle and bobbin hook, modelling of the thread control curve, determination of the take-up configuration, tests which evaluate the satisfactory operation of the take-up mechanism in assumed dynamic conditions, and evaluates the reaction of the take-up mechanism to the location of the selected barriers.

The result is the take-up configuration described by means of the number and locations of stationary (A, B, C) as well as mobile barriers (P_1; P_2; L_1; L_2), cf. ***Figure 3*** (see page 96). The locations of take-up frictional barriers is defined, respectively, by the polar coordinates: the distance to the rotation center (r) and the angle α between the needle line and the line connecting the rotation center and mobile barriers. The location of stationary barriers is described by means of coordinates (x,y) in the 2D Cartesian coordinate system. Analysing different take-up configurations, we were able to design a prototype of the mechanism, cf. ***Figure 4***.

According to the results obtained, we can influence some parts of the thread control curve. We used this fact in experimental tests of the lockstitch machine with the installed take-up prototype during the supplying of thread to the bobbin hook, stitch tightening, and the feeding of thread to the needle and bobbin hook.

References to the literature

Optimisation problems of the working conditions of sewing machines have been discussed in many publications [5-14]. Zajączkowski [5-7] discussed a mathematical model for the sewing machine and introduced the needle arm, as well as the hook and transport mechanisms. Structural parameters of the sewing machine are important for operation quality, and their optimization requires both a mathematical model and computer-oriented numerical calculations. Hence, Zajączkowski discussed the case of transport mechanism motion as well as zig-zag mechanism motion, both realised by means of triangular cams. The equations of motion obtained are solved numerically. For deeper discussion of vibrations generated within sewing machines, caused by the returnable motion of the working elements, we refer the reader once again to Zajączkowski [8-10]. Thus the vibrations are nonlinear and, consequently, can cause chaotic motion of the mechanism, due to inadequate selection of structural parameters.Optimal operating conditions for thread within sewing machines were developed in many papers by Więźlak and Elmrych-Bocheńska, cf. [11-14]. The authors proved the considerable level of thread destruction after stitch tightening, which is the basic operational element of bobbin hook thread of lockstitch machines. Technological conditions of the sewing process should be created with respect to minimal destruction of the thread, which was proved by means of the stitch tightening model in [12]. Więźlak and Elmrych-Bocheńska developed an optimal procedure which can help to theoretically model stitch tightening conditions. The problem was verified by using sewing tests. The real location of interlacement within the stitch link and corresponding strength loss of the thread after the stitch tightening was proved by the experimental results.

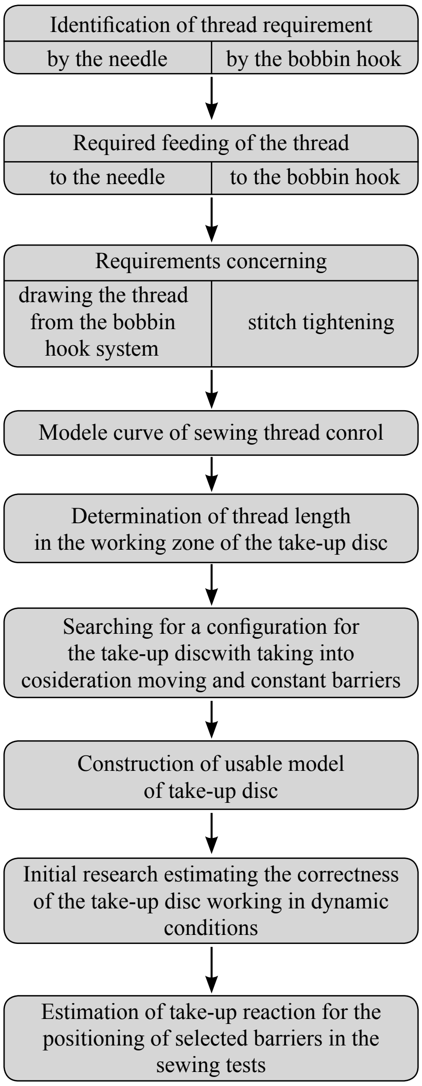


Figure 2. *Algorithm for designing a multi-barrier take-up disc.*

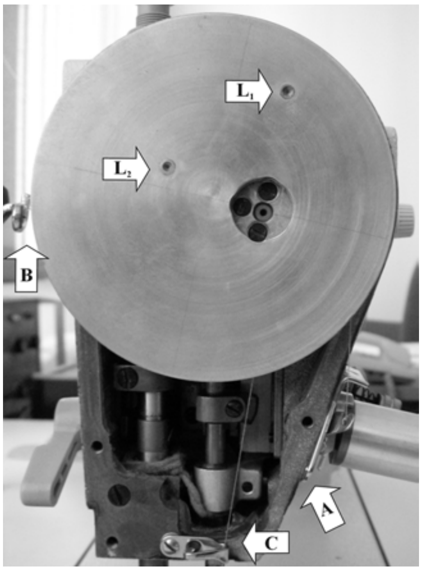


Figure 4. *Prototype of a take-up disc installed on a sewing machine; A, B, C – stationary barriers; L_1, L_2 – mobile barriers.*

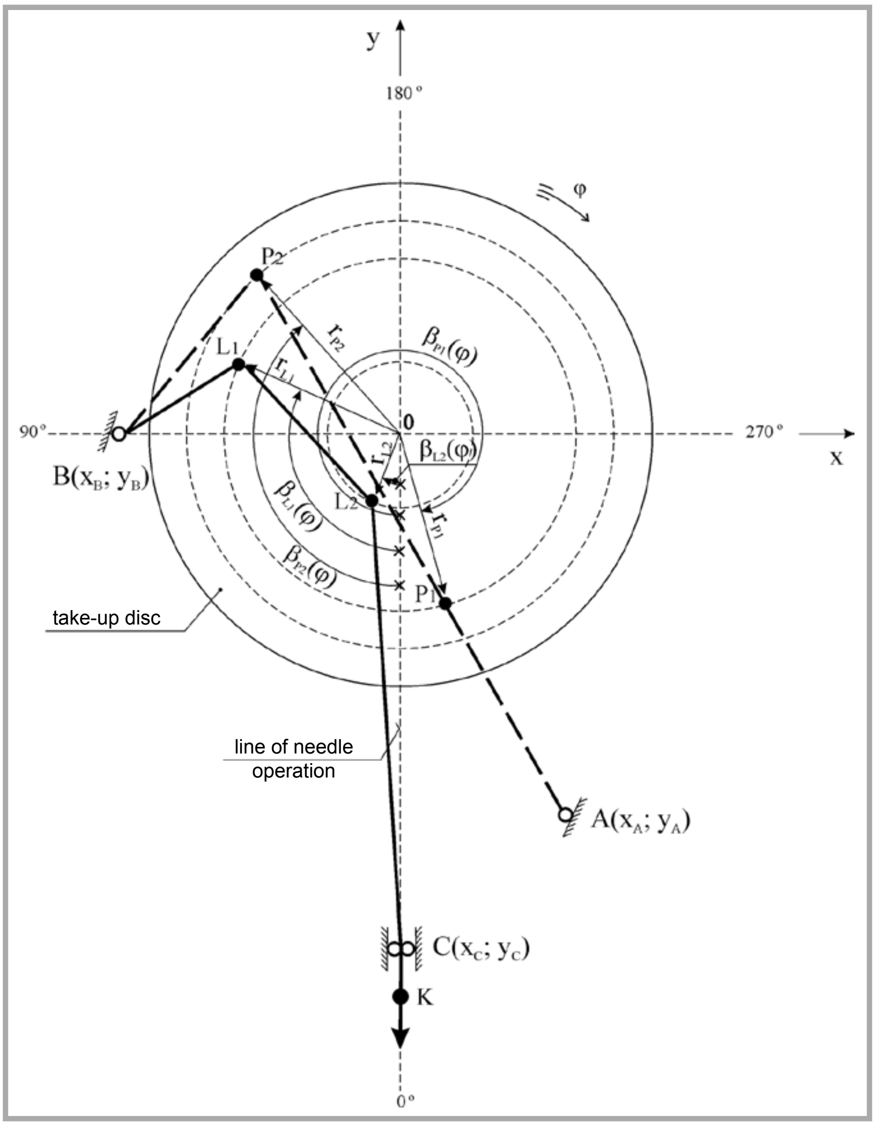


Figure 3. *Sewing thread in the working zone of the take-up disc.*

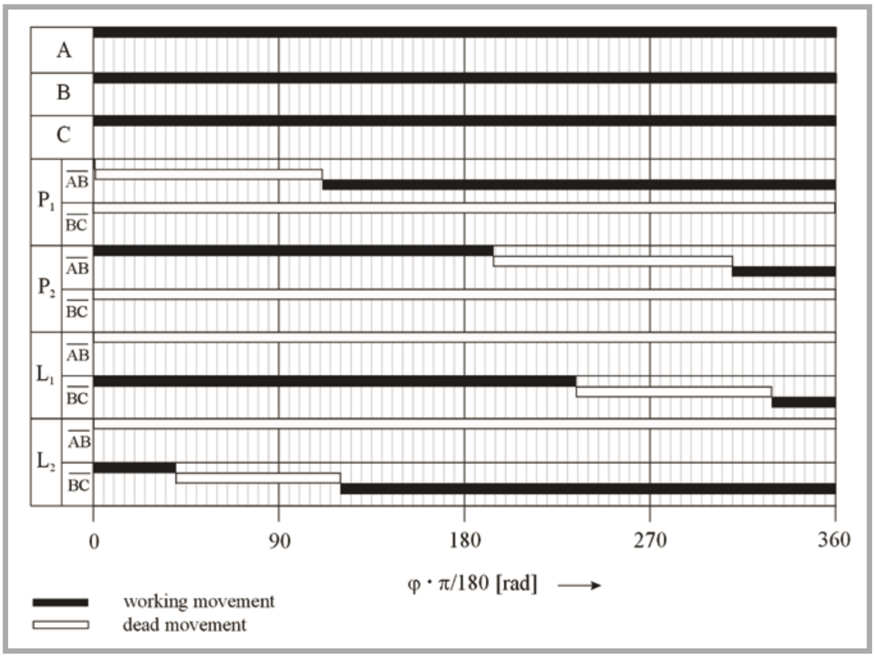


Figure 5. *Activity cyclogram of the take-up disc with mobile barriers (P_1, P_2, L_1, L_2) and stationary barriers (A, B, C).*

Classic programming in different languages is in common use in engineering practice. Detailed information has been appeared in many papers, for example concerning the Fortran language cf. Chrobak [15], the C++ language cf. Sokół [19]. Genetic and evolutionary algorithms are rarely used. Simulation of the evolution of species requires another procedure. Thus we should introduce random generation of the initial population, as well as the reproduction (i.e. mutation and crossing) and selection of the population etc., cf. Davis [16]. Other general problems concerning optimisation by using genetic algorithms are discussed by Goldberg [17] and Michalewicz [18], for example.

Main goal of the paper

The main goal of the paper is to determine the length characteristics of needle thread within the working zone of the take-up disc. The independent variable is now the angle of rotation of the disc. Thus two different methods of computer-oriented programming are implemented:

- Genetic algorithms, which determine the thread length as minimization of the fitness function by means of the last squares method. The Input data are thus: (i) the coordinates of locations of stationary barriers for the take-up system, (ii) the thread control curve of the take-up disc created by means of the thread required by the needle. Genotypes describe the locations of the barriers and are randomly generated. Consequently, the fitness correlation between the theoretical configuration of the mechanism and the real existing take-up disc should be estimated. The population selection is based on the defined thread requirement of the needle. The worst fitted genotypes are eliminated, whereas the accepted genotypes create a set of fenotypes.
- Classical programming, which determines the thread length as the geometrical distance of the active barriers of the take-up disc. Let us first define the number and sequence of the active mobile barriers. Next, the needle thread length can be calculated as the distance between the frictional barriers of the take-up disc. The coordinates necessary are the predefined input data or are alternatively calculated within the plane 2D Cartesian coordinate system.

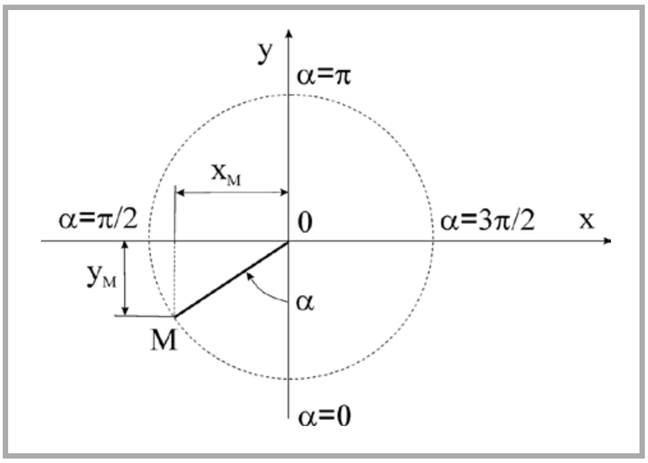


Figure 6. *Characteristic rotation parameters of the mobile barriers; M – mobile barrier (P_1, P_2 or L_1, L_2); O – rotation center; α – variable rotation angle.*

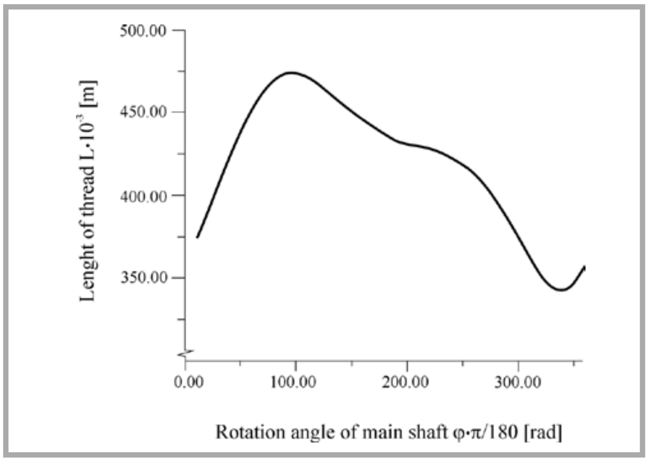


Figure 8. *Needle thread length in the take-up disc zone.*

The results obtained are double verified by means of the following methods:

- Geometrical simulation of the barriers sequence of the take-up disc by using the professional graphical program AutoCad. The internal functions as well as the precise location coordinates can help to check the values of thread length calculated and the shape of thread length characteristics obtained.
- Experimental research of the purpose-oriented model of the take-up disc prototype located at the Department of Clothing Technology. A wide spectrum of experiments during stitch tightening can be realised. Thus we can determine the thread required by the needle as well as the dynamical characteristics of stitch formation.

Mathematical model. Thread length determined directly as a geometrical distance

A mathematical model can be defined as a set of correlations which describe needle thread length during stitch tightening. The classical model determines the thread length as the geometrical distance of the selected active barriers to the take-up disc. Let us assume that the thread has an inelastic structure, as we have to calculate the thread needed by the needle. Thus the feeding of the thread portion should be determined as the geometrical distance during stitch formation. The barriers mentioned are thus: the thread braking apparatus (A), the barrier (-s) on the right-hand side of the take-up disc (P_1 or P_2 or P_1+P_2 simultaneously), the thread divider (B), the barrier (-s) on the left-hand

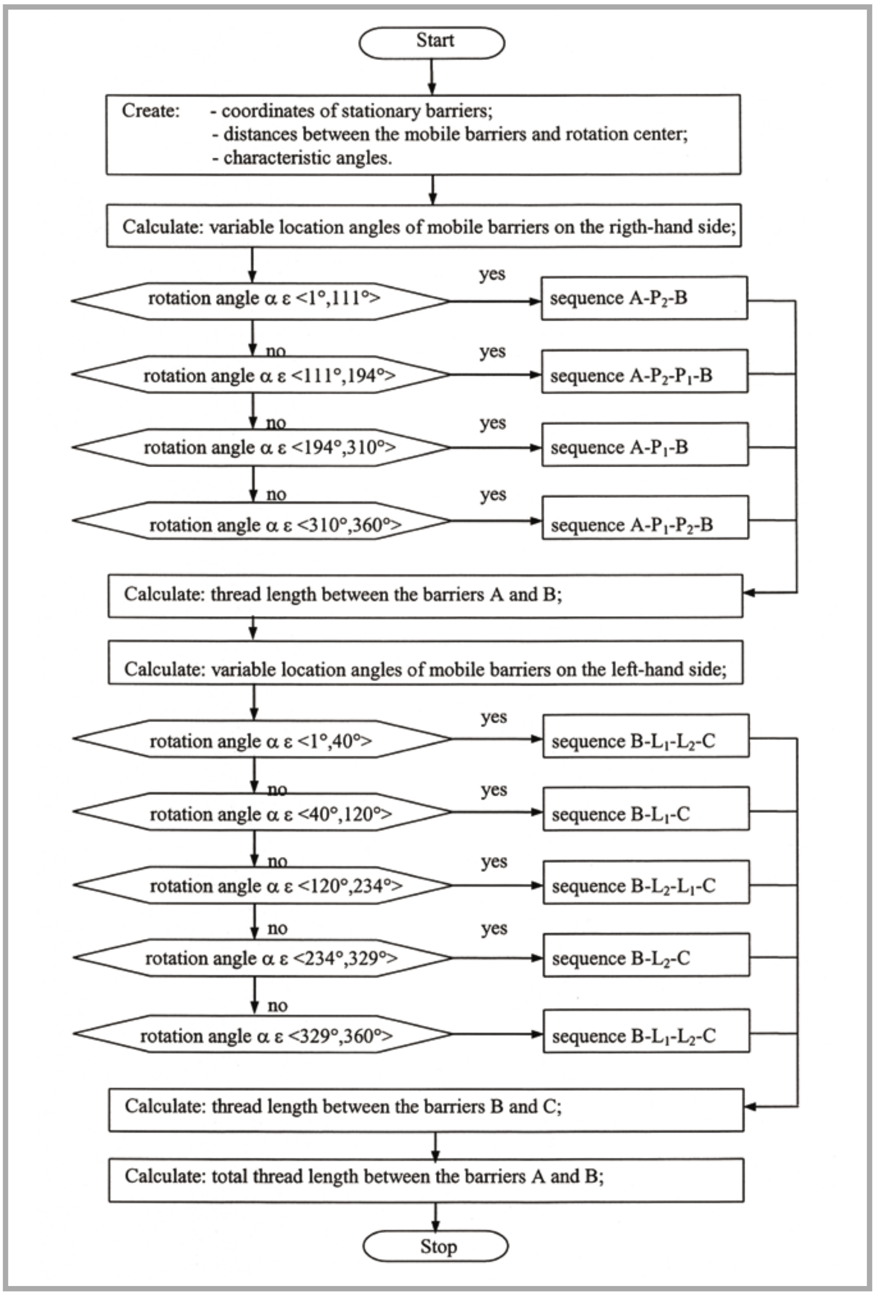


Figure 7. *Block diagram for thread length calculations directly determined as a geometrical distance.*

side of the take-up disc (L_1 or L_2 or L_1+L_2 simultaneously) and the thread-guide for the needle thread within the take-up disc zone (C). It follows easily that the needle thread come into contact with both mobile frictional barriers or alternatively only one mobile barrier on the each side of the take-up mechanism for the full rotation range. The number and sequence of the active barriers in contact with the thread can be determined by means of a cyclogram (cf. ***Figure 5*** see page 96). The cyclogram is based on the graphical simulation of the take-up disc rotation in different programs (for example AutoCad), as well as on the experimental determination of the activity range of the rotation angles for the mobile barriers on both sides of the mechanism. It can help to define the sequence of frictional barriers for the thread.

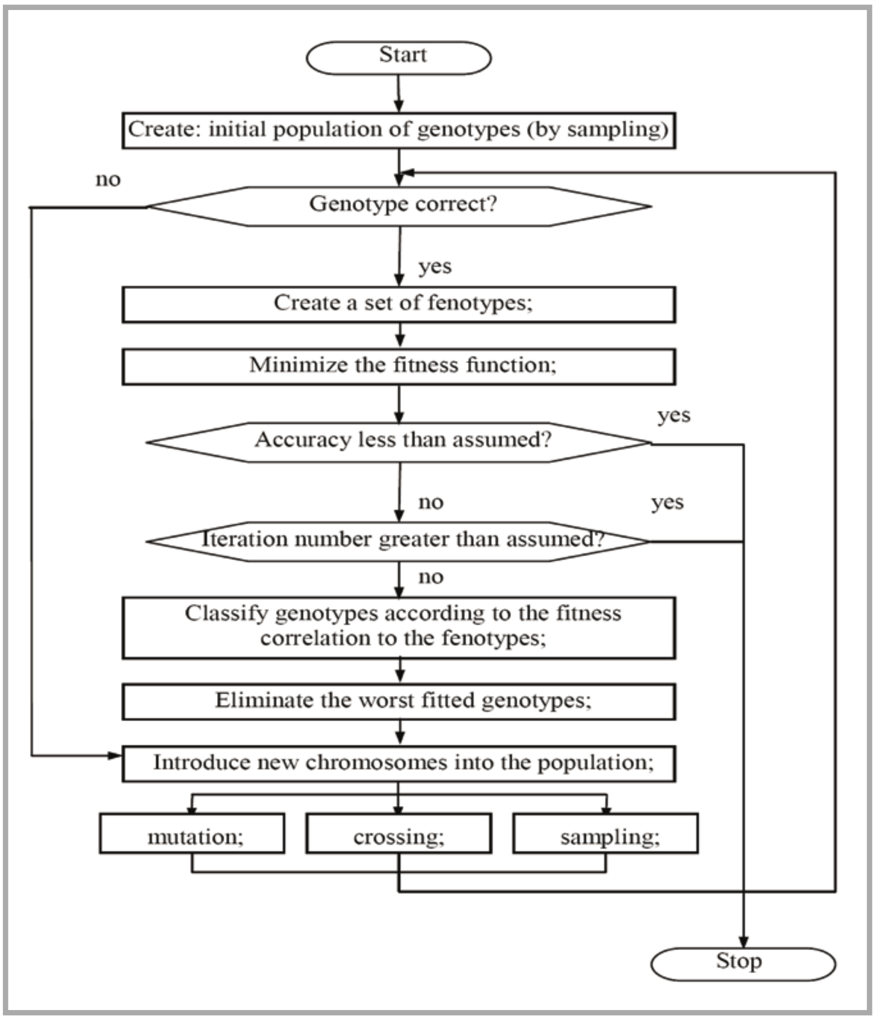


Figure 9. *Block diagram for the thread length calculation determined by means of genetic algorithms.*

The take-up disc configuration is characterised by the locations (i.e. the coordinates) of the rotation center (O) prescribed, the thread braking apparatus (A), the thread divider (B) and the thread-guide (C). The coordinates of the mobile barriers P_1; P_2; L_1; L_2 are unknown and should be determined as a function of the rotation angle. The location of mobile barriers within the 2D stationary Cartesian coordinate system can be described by means of the constant distance to the rotation centre O and the variable rotation angle (cf. also ***Figure 6***).

$$x_M = x_O - OM \sin\alpha \, ; \; y_M = y_O - OM \cos\alpha \tag{1}$$

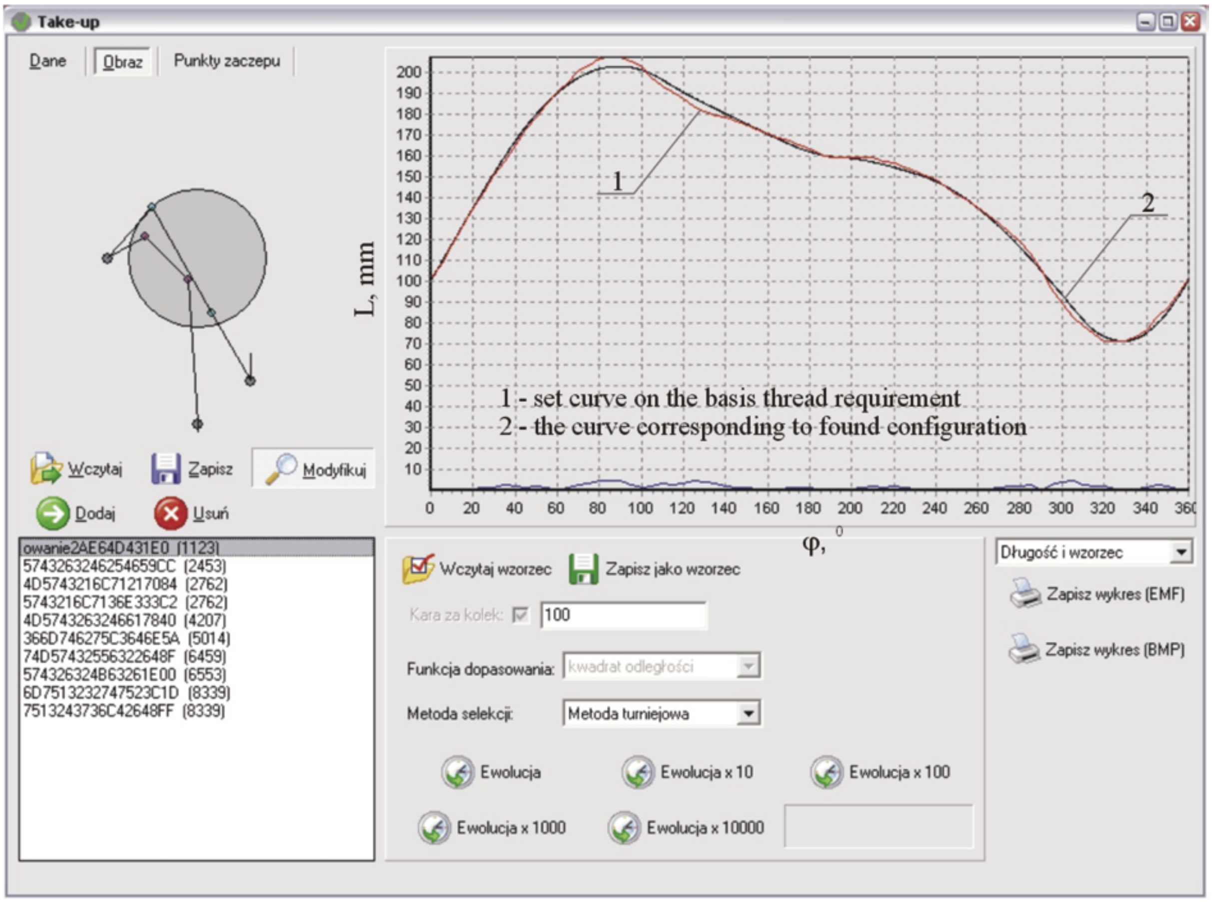
where α is the variable rotation angle $\alpha \in <0,2\Pi>$[rad]; O is the rotation center, and M denotes the mobile frictional barriers which can be alternatively P_1; P_2; L_1 or L_2. The length OM is different for each mobile barrier and for P1 equal to OM = 40,6 mm; P_2: OM = 49,3 mm; L_1: OM = 40,6 mm; L_2 OM = 16,8 mm. The above defined physical model does not contain the diameters of mobile frictional barriers and can be characterised by the following components of the thread length

$$L = \sum_{k=1}^{KB} L_k \, ; \; L_k = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2}$$

where k is the index of the particular segment; i and j are the end-point indexes of each segment, which are stationary and mobile barriers, respectively; KB is the number of segments (i.e. components of the geometrical distance), which depends on the variable rotation angle of the take-up disc.

Thus the influence of the diameters of mobile barriers is neglected in the mathematical model presented. The diameter has negligible values $d = 3 \cdot 10^{-3}$ m. Introducing the diameter of the barriers, after numerical calculations at some selected points, we obtain a difference of 1.5% in relation to the values for d = 0. The difference obtained is negligible; however, the calculations are relatively complicated and time-consuming. It also follows that the diameters of mobile frictional barriers are not included in the existing model of the take-up disc.

The algorithm of calculations of the needle thread length is shown in ***Figure 7*** (see page 97). At first, the input data should be introduced, i.e. the coordinates of stationary barriers within the 2D Cartesian coordinate system, the radiuses of the mobile barriers, and the activity range of rotation angles for each barrier. Next, the variable rotation angles of the mobile barriers on the right-hand side of the take-up disc are calculated. Physically speaking, each particular value of rotation angle secures an adequate sequence for the mobile barriers (cf. ***Figure*** *7*). Consequently, the thread length is determined as the geometrical distance between the stationary barriers A and B. The total length is a sum of length components in the prescribed number of segments between the points of the coordinates calculated, cf. ***Equation (2)***. The distances are calculated, respectively, for the left-hand side of the take-up disc by means of the same strategy. The variable rotation angles of the mobile barriers are calculated and the activity sequence of the frictional barriers is analyzed. The thread length between the stationary barriers B and C can be calculated as the geometrical distance according to ***Equation (2)***. Finally, the needle thread length is a sum of



owanie2AE64D431E0 (1123)
5743263246254659CC (2453)
4D5743216C71217084 (2762)
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366D746275C3646E5A (5014)
74D57432556322648F (6459)
574326324B63261E00 (6553)
6D7513232747523C1D (8339)
7513243736C42648FF (8339)

Kara za kolek: ☑ 100
Funkcja dopasowania: kwadrat odległości
Metoda selekcji: Metoda turniejowa
Długość i wzorzec

Figure 10. *Modelling of the thread control conditions of the take-up disk in a sewing machine by the Take-up disc 2.0 system.*

the values for the left-hand side and right-hand side, respectively.

The above algorithm can help to formulate a numerical program in the Fortran and C++. The thread length is shown in ***Figure 8*** (see page 97) as a function of the rotation angle. The length characteristic has the same shape as the reference diagrams, see [20].

Mathematical model. Thread length determined by means of a genetic algorithm

The thread length can be determined by means of genetic algorithms (GA), which is a different calculation technique. GA describe the evolution of species and do not contain memory. All information is coded, analysed and converted within the genes of a chromosome, described as the floating point numbers, cf. as reported by Davis [16], Goldberg [17], and Michalewicz [18].

The main idea of GA is to optimise the fitness function. The function is described by means of different correlations, but the most used is the least squares method. Thus we have to minimise the "distance" between the state variable for a real structure and that for calculation model. This discrete correlation has the following form:

$$G = \sum_{i=1}^{N} \frac{1}{2} \left(\Phi_i - \Phi_{im} \right)^2 \rightarrow \min \, ; \qquad (3)$$

where Φ_i is the state variable for real structure, Φ_{im} is the state variable for the calculation model, and N denotes the number of points which are used to evaluate the fitness function. The state variables are now the thread lengths in the 2D Cartesian coordinate system. The Real structure is a sum of the configurations of the take-up mechanism, which secures the assumed shape of the thread needed by the needle for the material package prescribed. The thread control curve is assumed at the beginning of calculations and is the state variable for a real structure. Mathematical models are consecutive accepted genotypes, i.e. configurations of the take-up disc which create particular lengths of the needle thread. They are randomly generated at the beginning of calculations and the shape obtained is evaluated from a physical point of view by means of minimisation of the fitness function ***Equation (3)***. The worst fitted genotypes are eliminated, whereas the accepted genotypes create a set of fenotypes. The genetic algorithm is shown in ***Figure 9***.

Let us first create the initial population of genotypes by means of simple sampling. We introduce the initial set of configurations of the take-up disc which is described as the floating point numbers. Physically speaking, the genotypes should be verified in each calculation step. The genotypes eliminated should be reconstructed and a new genotype is determined alternatively by means of mutation (i.e. the random noise of a gene within the chromosome), the crossing of two chromosomes and the simple sampling of a new gene. Next, the improved genotype should be verified from a physical point of view. The genotypes accepted create a set of fenotypes, i.e. the accepted configurations of the take-up disc. Our next goal is to minimise the fitness function cf. ***Equation (3)***. Let us compare the shape of thread required by the needle for a particular genotype with the thread control curve. Thus the least squares method in the discrete form is minimised in some particular points with the assumed accuracy. If the accuracy is less than the assumed at the beginning of calculations, the procedure is stopped. If the accuracy is greater, we evaluate the number of iterations. If the number is less than the assumed, we change the existing genotypes by means of selection. The genotypes are classified and the criterion is the fitness correlation to the corresponding fenotypes. The worst fitted genotypes are eliminated, and new chromosomes are introduced into the population. Physically speaking, we introduce new mobile frictional barriers into the take-up disc configuration. We have a few methods to apply: (i) mutation of the chromosome, i.e. perturbation of the gene by means of the perturbation function prescribed, (ii) the crossing of two existing chromosomes as the pattern population with the introduced cross-section and creation of the children population, and (iii) the sampling of a new chromosome. The complete population should be physically evaluated and the calculation sequence is repeated again.

Summarizing, we have two exit criterions:

- The accuracy is less than the assumed. The procedure is stopped immediately and the length characteristic obtained is optimal.
- The number of iterations is greater than the assumed. Thus, the characteristic calculated is best fitted to the thread control curve prescribed, but not the optimal one.

The interactive menu of the GA program is shown in ***Figure 10*** (see page 99). The characteristic of the needle thread length obtained is also presented here.

Conclusions

1. The current model supports the theoretical description of all the effects. That is why the results obtained indicate the same length characteristics of needle thread within the take-up disc zone for both methods used – classical programming and GA. The same shapes are obtained by the following double experimental verification: (i) simulations of the sequence and geometry of frictional barriers in the program AutoCad and (ii) experimental research of the purpose-oriented model of the take-up disc prototype. The length characteristics are the same as the reference diagrams published in other papers. We conclude from above that the algorithms and methods introduced are correct.
2. Both calculation algorithms are relatively simple and correct. We can also apply and introduce both calculation methods. Practically speaking, practical implementation is a question of personal choice.
3. Both algorithms are universal and can be applied to describe the more complicated configurations of geometry as well as the sequences of the frictional barriers of the take-up disc. Thus the problem can be much more complicated and depends on the realisability of the program implemented and software limitations.
4. The characteristics of the thread length within the take-up disc zone obtained are important parameters as they describe the dynamics and maintenance of sewing machines. Thus the thread required by the needle can be implemented into the physical model of thread deformation during stitch tightening. This will be the topic of the next publication, which is in progress.

Acknowledgment

This research work was supported for the 2nd Author by the Ministry of Education and Science, Grant No. 3 T08E 087 28.

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Received 29.06.2007 Reviewed 9.05.2008