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## USING RECURSION ALGORITHM TO DETERMINE THREAD TENSION AND ITS COMPUTER IMPLEMENTATION

***Abstract.*** *The correctness of the assumptions made when building the model of interaction of the thread with the guide taking into account its physical and mechanical and structural characteristics and the possibility of using recursion in sequential determination of tension in areas of process equipment from the entrance area to the area of fabric and knitwear. In particular, it is found that the thread tension increases from zone to zone and reaches its maximum before the zone of formation. It is shown that excessive tension leads to disruption of the technological process and to thread breakage. Thus, there is reason to argue about the possibility, even at the initial stage of designing the technological process of fabric and knitwear, aimed at adjusting the tension of the thread in front of the area of fabric and knitwear by adjusting the geometric parameters and design of the thread feed system on process equipment and specific guides, which will minimize the value of the thread tension.*

***Keywords:*** *recursion; algorithm; thread; angle of coverage; guide; radius of curvature; tension.*

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## ЗАСТОСУВАННЯ АЛГОРИТМУ РЕКУРСІЇ ДЛЯ ВИЗНАЧЕННЯ НАТЯГУ НИТКИ ТА ЇЇ КОМП'ЮТЕРНОГО ВПРОВАДЖЕННЯ

***Анотація.*** *Підтверджена коректність зроблених допущень при побудові моделі взаємодії нитки з направляючою з урахуванням її фізико-механічних і структурних характеристик і можливість використання рекурсії при послідовному визначенні натягу по зонах технологічного устаткування від зони входу до зони формування тканини і трикотажу. Зокрема встановлено, що натяг нитки зростає від зони до зони і досягає свого максимуму перед зоною формування. Показано, що надмірне значення натягу приводить до порушення технологічного процесу і до обриву нитки. Таким чином, є підстави стверджувати про можливість, ще на початковій стадії проектування технологічного процесу виготовлення тканини і трикотажу, спрямованого регулювання натягу нитки перед зоною формування тканини і трикотажу за рахунок коригування геометричних параметрів і конструкції як системи подачі нитки на технологічному устаткуванні, так і конкретних направляючих, що дозволить мінімізувати значення натягу нитки.*

***Ключові слова:*** *рекурсія; алгоритм; нитка; кут охоплення; напрямна; радіус кривизни; натяг.*

**Introduction.** Under these conditions, mathematical modeling of the process of increasing the thread tension in the zones of technological equipment, the use of which creates the preconditions for the use of a computational experiment, which is based on the implementation of the corresponding algorithms and numerical methods on a computer, renders significant assistance [1–3].

Its use will allow at the initial design stage to determine the value of technological loads and improve the shape of the threading line on technological equipment, which will reduce the time of the technological process and increase the quality of the products [4–8].

The increase in the thread tension occurs due to frictional forces in the contact zone with the guides. The magnitude of the friction forces depends on the material of the thread and the guide, the ratio of their geometric dimensions (the radius of the cross-section of the thread and the radius of curvature of the guide in the contact zone) [4–8], the actual angle of coverage of the thread by the guide and the angle of the radial coverage of the thread by the surface of the guide, physico-mechanical and the structural characteristics of the thread, the tension of the thread in front of the guide [1, 5, 7].

The sequential passage of the thread along the guides, from the entry zone to the formation zone of fabric and knitwear, leads to a stepwise increase in tension. In this case, the output parameter of the tension after the previous guide will be the input parameter for the subsequent guide, which allows using recursion when determining the tension in front of the formation zone [1].

In this regard, the study on the computer implementation of the algorithm for determining the thread tension on technological equipment using recursion should be considered relevant [3–7].

**Formulation of the problem.** Taking into account the multifactorial dependence of the process of interaction of the thread with the guiding elements of the thread supply system of the technological equipment, the purpose of the work is to determine the tension of the thread in front of the zone of fabric and knitwear formation based on recursion.

**Research results.** At the break points of the threading line on the technological equipment, the thread interacts with the guides. The filling line can be divided into zones, each of which will contain one guide. Then the system of equations that describes the change in tension over zones will have the form

$$\begin{aligned} &P_1 = P_0 f_0(P_0), \\ &P_2 = P_1 f_1(P_1), \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &P_i = P_{i-1} f_{i-1}(P_{i-1}), \\ &i = 1, 2 \ldots n, \end{aligned} \tag{1}$$

where $P_0$ – the tension of the thread in the area of the entrance to the thread feeding system of the technological cars;

$P_1, P_2 \ldots P_i$ – thread tension when leaving the corresponding zone;

$f_0(P_0),\ f_1(P_1) \ldots f_{i-1}(P_{i-1})$ – functions that bind the thread tension to and after the guide in each zone;

$i$ – current zone number;

$n$ – number of guides in a specific threading system technological machine.

Using a recursive approach to determining the tension of the thread in front of the zone of fabric and knit formation, in which the output tension after the guide in the previous zone will be the input value of the tension in front of the guide in the next zone (see Fig. 1), we represent equations (1) in the form

$$P_n = P_0 \prod\nolimits_{i=0}^{n} f_i(P_i). \tag{2}$$

Figure 1 shows a block diagram of the computer implementation of the algorithm for determining the thread tension on technological equipment using recursion. Let us dwell on the decoding of individual blocks. Block 1 corresponds to the beginning of the algorithm execution. In block 2, constant values are set: a, n1 – constant coefficients for a given type of thread; B – coefficient of bending stiffness of the thread; r is the radius of the cross-section of the thread.

The bending stiffness coefficient of the thread is determined by the formula

$$B = EI, I = \pi(2r)^4 / 64, \quad (3)$$

where $E, I$ – respectively, the modulus of elasticity of the thread in tension and the moment of inertia of the cross section of the thread.

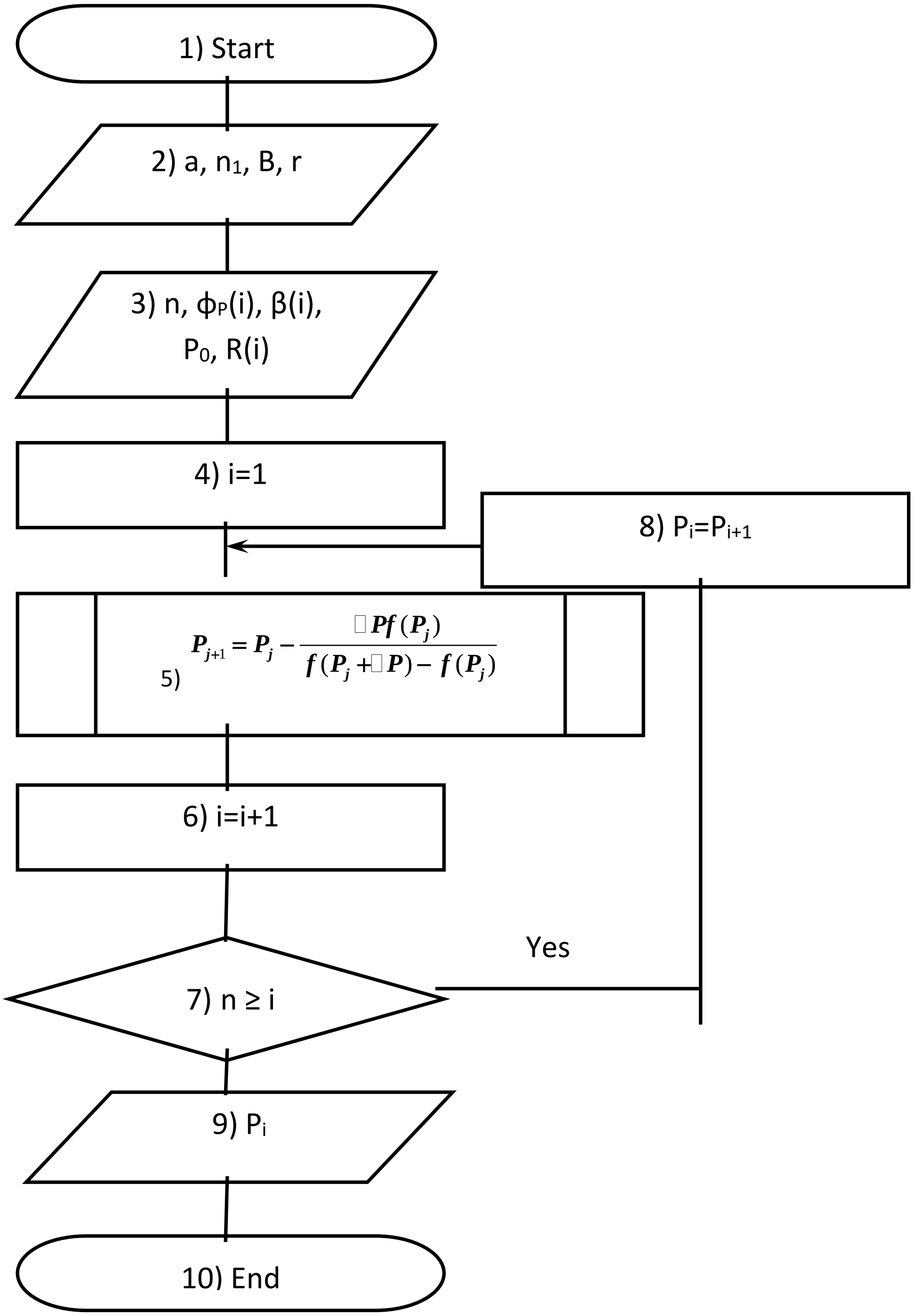


*Fig. 1.* **Block diagram of the computer implementation of the algorithm for determining the thread tension using recursion**

Block 3 sets the number of guides in the yarn feeding system of a particular technological machine, the value of the initial yarn tension in the entry zone.

Also, in block 3, for each -th guide, arrays are formed: for the calculated angles of the thread of the guides $\varphi_P(i)$; for angles of radial yarn wrap around the guide surface $\beta(i)$; for radii of curvature of guides $R(i)$.

In block 4, the first rail is selected. Block 5 is used to call the subroutine for calculating the roots of the transcendental equation $f(P_k) = 0$. The fact is that the dependence that connects the tension of the thread before and after the guide is a system of two transcendental equations (see 4.2). To determine the root, we used a modified Newton method (tangent method), which consists in the fact that for the function $f(P_k) = 0,\ (k = 1, 2 \ldots \mathrm{n})$, instead of calculating the derivative $df(P)/dP$, at each iteration step, its approximate value is found

$$\frac{df(P_j)}{dP} = \frac{f(P_j + \Delta P) - f(P_j)}{\Delta P} = \frac{\Delta f(P_j)}{\Delta P}, \Delta P = \varepsilon,\ j = 0, 1, 2 \ldots,$$

where $\varepsilon$ – given error in calculating the root.

Then the recursive formula for constructing the iterative dependence $\{P_j\}$ will look like

$$P_{j+1} = P_j - \frac{\Delta P f(P_j)}{f(P_j + \Delta P) - f(P_j)}. \tag{4}$$

Formula (4) was used to numerically determine the tension for the -th rail. In block 6, the transition to the next guide is carried out. Block 7 is used to check the number of the guide with a given number of guides to the thread feeding system of the technological machine. If the condition is met $n \geq i$ there is a return to block 5. In this case, in block 8, the reassignment is carried out $P_i = P_{i+1}$, when the tension value after the previous rail is assigned to the tension value before the subsequent rail. In the case when the condition $n \geq i$ the transition to block 9 is not performed, where the tension of the thread in front of the zone of formation of the fabric or canvas is fixed. Block 10 corresponds to the end of the algorithm execution.

The expressions for determining the stiffness angles are

$$\gamma_{0i} = \arccos[1 - \frac{B}{2P_{i-1}(R_i + r)^2}],\ \gamma_{1i} = \arccos[1 - \frac{B}{2P_i(R_i + r)^2}].$$

The actual angle of coverage of the thread can be determined from the expression

$$\phi_i = \phi_{Pi} - \arccos[1 - \frac{B}{2P_{i-1}(R_i + r)^2}] - \arccos[1 - \frac{B}{2P_i(R_i + r)^2}],$$

where $\phi_{Pi}$ – calculated value of the angle of coverage – th guide.

The thread tension linkage function before and after the guide will look like

$$f_{i-1}(P_{i-1}) = e^{a[\frac{P_{i-1}-\frac{B}{2(R_i+r)^2}}{R_i}]^{n_1}\phi_i} + \frac{B}{2P_{i-1}(R_i+r)^2}\{1-e^{a[\frac{P_{i-1}-\frac{B}{2(R_i+r)^2}}{R_i}]^{n_1}\phi_i}\}.$$

**Conclusions.** On the basis of the developed block diagram, a computer implementation of the algorithm for determining the thread tension on technological equipment using recursion is carried out. The studies carried out have established that the tension of the thread in front of the formation zone is influenced by the number of guides on each specific technological machine.

On the basis of the developed theoretical model, a computational experiment was carried out to determine the tension and the bond function of the thread tension before and after the guide, taking into account the radius of curvature of the guide, the angle of the guide thread, the angle of the radial thread, physical, mechanical and structural characteristics of the thread. It has been established that the value of the crimp of the thread's coverage of the guides and the crimp of the radial coverage of the thread by the surface of the guide are determined by the geometric parameters and the design of both the filament feeding system on the technological equipment and specific guides.

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