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DETERMINATION OF THE STABILITY AND STRENGTH OF A SEWING NEEDLE FOR LEATHER PRODUCTS

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Abstract: The theoretical calculations for application in engineering calculations of determining the stability of leather sewing needles, based on the theory of hardness, strength, durability of materials and stability of sewing equipment designed for sewing leather products are given in the article.

Introduction

The needle is the most important and, at the same time, the weakest element of the sewing machine. It must be very thin to avoid damage or tightening on the surface of the fabric. On the other hand, it must be very firmly fixed in order to hit the fabric in the same position. Deviation, which may be caused by the thread tension force or other causes, must be kept to a minimum in order to avoid disruption of the process.

Main part

The central crank-slider mechanism is the main mechanism that ensures the movement of the needle; duration of the working and idle strokes of the needle are the same. In a displaced mechanism, the duration of the working stroke of the needle is greater than the duration of the idle stroke. In order to reduce the heating of the needle during sewing, the crank mechanism is made with the top location of the connecting rod, since the average speed of the needle is lower than that of the mechanism with the bottom location of the connecting rod [2].

If the needle is chosen incorrectly, it may break. Needle breakage can also occur if the presser foot is in the wrong position, with a deformed needle. Thick seams and thick materials cannot be sewn with a fine needle. Putting a low-quality needle (blunt or deformed) in the sewing machine, as well as use low-quality threads is not allowed. A blunt, bent, or too fine needle for the material may cause skipped stitches in the seam.

During the sewing process the driving force Fd acts on the needle, which causes, upon contact with the fabric, resistance forces equal to the strength of the thread and the friction forces of the thread fibers on the surface of the needle. An analysis of the sewing process indicates that when using a ground needle without a bevel, with the same value of the driving force, the friction is almost two times less. Considering that the needle touches the threads of the fabric at high speed, that is, practically with a blow, the driving force will increase by the amount of the impact force, which will be equal to:

$$N=\frac{C_1 C_2 v_o}{C_1+C_2}, \quad (1)$$

If the puncture force P does not exceed a certain limit value P_{cr}, then the needle will experience where C_1, C_2 are the rigidity of the needle and the tissue material, respectively; v_o is the initial speed of the needle.

The transferred energy is:

$$A=Nvt=C_1 C_2 v_o^2 t, \quad (2)$$

where t is the impact time

In sewing machines, in order to ensure the vertical reciprocating movement of the needle, a drive is designed, which consists of an electric motor, a V-belt drive and a crank mechanism.

If the puncture force P reaches the limit value of the force $P=P_{max}=P_{cr}$, then the needle may be deformed. The needle rigidity coefficient can be determined by the following formula [4]:

$$C_1=\frac{ES}{l}=\frac{E}{\frac{l_1}{S_1}+\frac{l_2}{S_2}+\dots\frac{l_n}{S_n}}\geq(3\dots.16), \quad (3)$$

where E is the modulus of longitudinal elasticity of the needle material, MPa; l is the calculated length of the working part of the needle shaft, mm;

$l_1 \ldots . l_n$ are lengths of individual sections of the working part of the needle, mm;

$S_1 \ldots . S_n$ are sectional areas of individual sections of the needle, mm^2

The calculation for the needle blade is made. Since the flask is fixed in the needle bar, this part of the needle does not participate in the sewing process and does not experience longitudinal loads.

In order to determine the rigidity, stability and strength of the needle, it is necessary to know the cross-sectional areas in dangerous areas (Fig. 1).

The cross-sectional area in the first section, that is, in the region of the eyelet, can be defined as the area of two segments (Fig. 2):

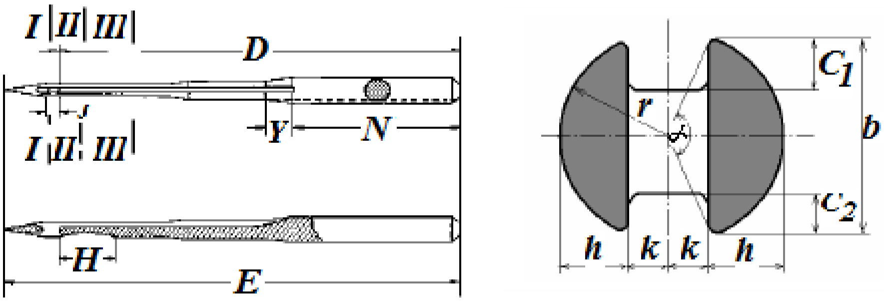


Fig. 1. Cross-sections of the sewing needle for the calculation of rigidity, stability and strength

$$S = 2 S_{сег}, \tag{4}$$

where S_{seg} is the area of the segment, which is determined by the formula:

$$S_{seg} = \frac{1}{2} r^2 \left(\frac{\alpha^o \pi}{180^o} - sin\alpha \right); \tag{5}$$

α^o is central angle corresponding to the segment, degree

From Fig. 2 it can be seen:

$$k = r - h = 0.45 - 0.3 = 0.15\, mm;$$

$$\frac{b}{2} = \sqrt{r^2 - k^2 = ¿ \sqrt{0.45^2 - 0.15^2 = ¿ 0.4243\, mm; \frac{\alpha^o}{2} = \arcsin \frac{b/2}{r} = \arcsin \frac{0.4243}{0.45} = 78.3806^o\, \alpha^o = 156.7611^o; ¿¿}}$$

$sin\alpha = 156.7611^o = 0.3946;$

$$S_{seg\,1} = 0.45^2 \left(\frac{156.7611 * 3.14}{180} - 0.3946 \right) = 0.2369\, mm^2.$$

The cross-sectional area in the first and section is equal to:

$$S_1 = \pi r^2 - S_{seg1} = 3.14 * 0.45^2 - 0.0994 = 0.5365\, mm^2.$$

The cross-sectional area in the second section is calculated according to Fig. 3, as a result it will be equal to:

$$S_2 = \pi r^2 - S_{seg2} = 3.14 * 0.45^2 - 0.0994 = 0.5365\, mm^2.$$

The cross-sectional area of the needle in the third section is equal to the cross-sectional area of the circle without the areas of the two grooves. In order to simplify the calculations, we will consider the cross-sectional areas of the grooves in the form of rectangles with side sizes shown in Figs. 4.

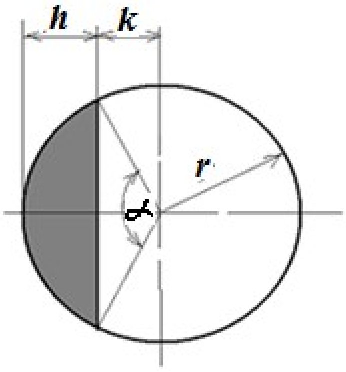
$C_1 = 0.4738\, mm^2$, $C_2 = 0.5365\, mm$.

It can be seen that the weakest section in the needle is the area in the eye area (thread hole). Let us calculate the moments of inertia for these sections of the needle. For an area in the form of a circle with a radius *r*, the moment of inertia of the section is equal to:

$$J = \frac{\pi r^2}{4}.$$

$J_1 = 0.0164\, mm^4$, $J_2 = 0.0543\, mm^4$, and $J_3 = 0.0502\, mm^4$

The calculation shows that the rigidity of the needle is quite high. For practical engineering calculations, when calculating the rigidity of the needle, it is possible not to break the needle into separate sections and determine the cross section and acting forces for each section, respectively. We take the weakest section (in the area with an eye for the thread) as the main one along the entire length of the working part of the needle, i.e., needle blade.



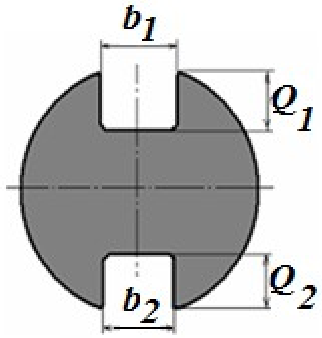


Fig. 1. Cross-sections of the sewing needle for the calculation of strength, rigidity and stability	Fig. 2. Sections of the sewing needle in the first section

In this case, the calculation formula will be significantly simplified, and the error will be quite insignificant (only about 1 ... 5%). With the value of the modulus of elasticity $E=2.1*10^5$ MPa, and angle $\alpha=150\ldots160^o$, the area of the weak section of the needle will be $0.4873\,mm^2$. In this case, the formula for determining the rigidity of the needle will take the following form:

$$C_1=\frac{0.28\,E*d^2}{l}>(3\ldots16) \quad (6)$$

The needle can be in stable and unstable equilibrium. If the needle is compressed along the geometric axis, gradually increasing the force, then at first it will be straight under the action of compressive stresses:

$$\sigma_{comp}=\frac{F}{S}, \quad (7)$$

where F is the needle compression force, N.

Then, at a certain load F_{cr}, called critical, the needle will suddenly begin to bend sharply, the stresses in it will increase rapidly, and there will be a danger of destruction. This phenomenon is called stability loss [3]. In this case, the forms of the bend of the needle can be varied (Fig. 5).

The critical force in this task will be equal to such an axial force that the needle can be in a slightly bent state.

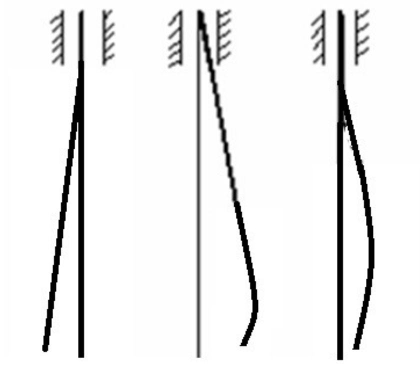


Fig. 5. Shapes of needle bends under longitudinal load

For small deflections of the needle, the differential equation of the bent axis in the following form can be used:

$$EJ\,y^{n} = -M = -Fy\,, \tag{8}$$

where E is the modulus of elasticity of the needle material, MPa; J is the moment of inertia of the cross-sectional area; y is the coordinate of the center of gravity of the sectional area element, mm; M is the moment of inertia force. The minus sign on the right side of the equality shows that the moment of force tends to increase the negative curvature of the elastic line.

Equation (8) can be rewritten as:

$$\frac{d^2 y}{d x^2} + ky = 0\,, \tag{9}$$

$$k = \sqrt{\frac{F}{EJ}}, \tag{10}$$

General solution of equation (9):

$$y = K_1 sinkx + K_2 coskx\,, \tag{11}$$

where K_1, K_2 are arbitrary constants determined from the boundary conditions:

$$\text{at} \quad x = 0,\, y(0) = 0\,, \tag{12}$$

$$\text{at} \quad x = l,\, y(l) = 0\,, \tag{13}$$

From condition (12) it follows that $K_2 = 0$; condition (13) can be satisfied only if:

$$K_1 sinkl = 0, \tag{14}$$

Equation (12) has two solutions: $K_1 = 0$ and $sinkl = 0$. When $K_1 = K_2 = 0$, the displacements y are identically equal to zero and the needle retains a straight shape. This case does not satisfy the conditions of the problem, since a curved needle is considered.

Therefore, the needle can only bend if sin $kl = 0$where n is an arbitrary integer.

$$sinkl = 0 \tag{15}$$

$$kl = \pi n \tag{16}$$

From equality (8) it follows that with a small force F, while the value of the needle will retain a straight shape. When: $k = \sqrt{\frac{F}{FJ} < \frac{\pi}{l}}$,

$$F = F_{кр} = \frac{\pi^2 EJ}{l^2} \tag{17}$$

This force, corresponding to $n = 1$ is called the Euler force or the first critical force [3]. In this case, the needle will bend along the half-wave of the sinusoid:

$$y = K_1 \sin \frac{\pi - x}{l}, \tag{18}$$

In (18) value K_1 corresponds to the maximum bend of the needle. The value of K_1 can be determined more precisely from the differential equation for the bent axis of the beam:

$$y = \frac{1}{EJ} \int \left(\int M_x dx + K \right) dx + D, \tag{19}$$

where $K, D$are arbitrary constants determined from the boundary conditions.

When $n > 1$, the elastic line of the needle is transformed into a curve that includes n half-waves. However, these unstable forms of equilibrium are of no practical importance, since already at $n = 1$the needle loses its efficiency.

The value of F_{cr} depends on the conditions of fixing the needle, the nature of the loading and the shape of the sections (moments of inertia) of the needle. In the general case, the Euler formula (17) can be represented as:

$$F_{кр}=\frac{\pi^2 EJ}{(\mu l)^2}, \qquad (20)$$

Where μ is the length reduction factor, depending on the shape of the bend of the end of the needle.

Let us determine the critical force F_{cr}, N, according to the Euler formula (20) for the weakest section of the needle (in the area with the eye):

Conclusion

According to the obtained formulas, a calculation of sewing needle was made according to the criteria of rigidity, strength and stability based on the theory of strength, resistance of materials, and stability of the rods.

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