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ORIGINAL ARTICLE

The Application of the Secant's Equation to the Sewing Machine Needle

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Limitation of technological load to critical load

Abstract The sewing needle of the industrial sewing machines is an essential element. Its' target is to penetrate the sewn fabric layers by a penetrating axial compressive force, which, coincides with the sewing needle geometrical axis. Author wise, it will cause stress on the needle's cross section. Practically, there is always a shift – eccentricity- between the effective action line of the force and the sewing needle geometrical axis. In the present work a mathematical approach has been carried out to study the mathematical relationship between the eccentricity $\left(\frac{ec}{r^2}\right)$ and the penetration force (P_a), taking into consideration the critical load (P_{cr}) (Euler load) of the sewing needle. This relationship is named the ''Secant formula'', where it was computerized and graphed. It was found that; the limiting values for the $\left(\frac{ec}{r^2}\right)$ was 0.7 and for the ratio P_a/P_{cr} was 0.8 to make the needle to run in its design stress 538 MPa (steel). When the ratio P_a/P_{cr} was equal to unity, the sewing needle max stress σ_{max} changed from 101 MPa to 58 GPa i.e. the working penetration force P_a must be far enough from the critical load by about 20%. The required value of P_a must be equal or less than 0.8 P_{cr}. This work focused on the static case.

1. Introduction

The sewing machine needle is an important and vital machine member. The general objective of the sewing needle is to penetrate the sewn materials either single layered or multiple layered and to carry the sewing thread via the sewn fabrics for loop formation. During the penetrations of the sewing needle, a resisting force at the free end of the needle is built up, this subjects the needle to an axial compressive force. This force can lead to the needle buckling in elastic or plastic region of the needles material [steel]. In both cases the sewing needle may be bent. This will lead to the production of a miss stitch and a low sewing seam quality [1].

Hussien et al. (2009) developed the fabric hand tester to measure the penetration force of the sewing needle [2]. ElGholmy and Elhawary studied a formula for calculating the critical load of the needle used in the garment and apparels sewing technology [3]. In all these studies the subjection of the sewing needle to axial compressive forces act along the centroid axis of the needle was assured. But in real-life situation, often we come across the needle with an eccentric loading in such case, the line of action of the penetrating force does not pass through the centroid of the needle cross section.

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The mechanics of the columns and machine members subjected to axial compressive forces with all the associated phenomena have been studied extensively by several scientists [4–6].

Elhawary [7] has studied the mechanics of the needle used in the needle punching machine for the production of nonwoven fabric. The piercing load of such needle is an axial compressive force.

Sultan and Hearle [8] studied and evaluated experimentally the punching force machine. They found the average value of the punching force (working force) to be 6 N. The factor of stability of the needle ranges from 1.63 to 2.74.

Lemov [9] in this work has studied a predictive model for the penetration force of a woven fabric by a needle. Consequently he developed a formula for estimating the value of the penetration force that depends upon so many factors such as; weave pattern, fabric count and crimp. The predictive force was checked experimentally. The max measured value of the penetration force was 46 C–12 CN for plain weave (with different tightness and density) and for sateen 8/3 respectively. It was also reported that the needle during fabric penetration causes radial displacement of threads. From this point of view this displacement of the threads will react as an elastic reaction on the needle i.e. spring effect. This, of course, will affect the elastic stability of the needle itself during the sewing process.

Kawamura [10] stated that; in the sewing operation a needle could be deflected by factor as sewing fabric structure. Lui [11] has written that; the max load that a perfectly eccentrically loaded column can carry is the Euler load. In reality, however, because of material yielding, the Euler load is seldom reached and the maximum carrying-load-capacity of an eccentrically loaded column will fall far under the Euler force.

Thus the aim of this research work is to use the "Secant formula", to study the mathematical relationship between the eccentricity $\left(\frac{ec}{r^2}\right)$ and the penetration force (P_a), taking into consideration the critical load (Euler load) of the sewing needle.

2. Mathematical approach

Referring to Fig. 1, the elastic line of the needle due to the technological eccentric load could follow:

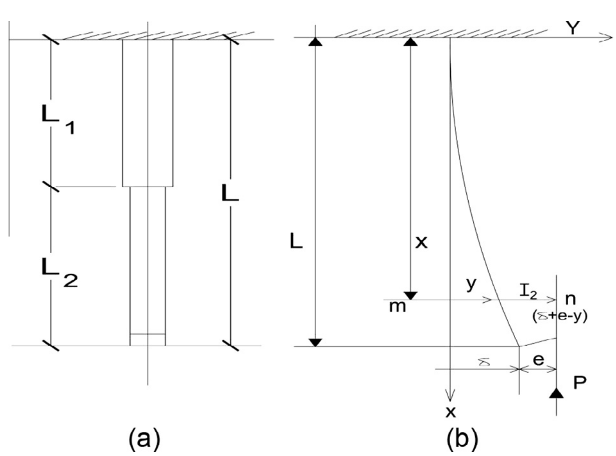

Fig. 1 An elastic line of a sewing needle.

$$\mathcal{Y} = (\delta + e)(1 - \cos\lambda X) \quad (1)$$

where

X – Instantaneous lateral displacement of the needle (vertical axis).

$\mathcal{Y}$ – The horizontal axis parallel to the sewing needle axis.

$$\lambda - \text{const} = \sqrt{P/EI} \quad (2)$$

P – Axial and actual axial compressive load on the sewing needle due to sewing technology.

E – Young's modulus.

I – Minimum inertia of the sewing needle cross section.

EI – Minimum bending stiffness of the needle.

e – Technological load-penetrating needle force eccentricity i.e. the shift between the needle geometrical axis and the technological force active line.

δ – The lateral displacement of the lower free end of the industrial sewing machine's needle.

The lateral movement of the sewing needle (lower end) could be calculated by:

$$\because\ \mathcal{Y} = (\delta + e)(1 - \cos\lambda X)$$

By putting $x = \ell$

$$\therefore\ \mathcal{Y} = (S + e)(1 - \cos\lambda\ell)$$

$$\therefore\ \mathcal{Y} = e\frac{(1 - \cos\lambda\ell)}{\cos\lambda\ell} \quad (3)$$

Return back to Eqs. (1) and (3), Then:

$$\mathcal{Y} = e\frac{(1 - \cos\lambda x)}{\cos\lambda\ell} \quad (4)$$

Eq. (4) represents the equation of the sewing needle elastic line (deflection curve), that equation can give the lateral displacement instantaneously for any distance at the sewing needle length.

The last formula (4) represents the equation of the needle elastic line (deflection curve). By using this equation the deflection at any cross section of the sewing machine's needle can be calculated.

In case of the needle of the industrial sewing machine, the value $\lambda\ell$ is small in comparison with unity and it is sufficiently accurate to take:

$$\cos\lambda\ell = 1 - \frac{1}{2}\lambda^2\ell^2 \quad (5)$$

Using this quantity of $\cos\lambda\ell$ and neglecting the value $\lambda^2\ell^2/2$ in the denominator of expression (3), as being small in comparison with unity, We obtain:

$$\delta = \frac{e\lambda^2\ell}{2} = \frac{P_e\ell^2}{2EI} \quad (6)$$

This represents the value of the lateral deflection at the needle's free end by the applied couple $P \cdot e$ due to load eccentricity e. Hence the use of the approximate expression (5) is equivalent to neglecting the effect of the deflection upon the magnitude of the bending moment and taking instead a constant moment equal to $P_a \cdot e$.

In case of relatively long sewing needles, the value $\lambda\ell$ is not small and δ is calculated by Eq. (3). In this way it was found