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Geometric Characteristic of a Sewing Needle Applied in Clothing Manufacture Technology with Reference to Elastic Critical Statically Balance Loads – A Comparative Study

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Abstract

In this work a sewing needle of an industrial commercial sewing machine is investigated from the different points of view of geometrical and critical elastic statistical balance. The dimensions of the sewing needle are ℓ = 60 mm, and φ = 2.5 mm and 1.45 mm diameter for the two stepped needle. The needle is treated as a fixed – free end column, with two sections: I_0 (I_1) = 1.9615 (E – 12) m^4 and (I_2) = 2.0516 (E – 13) m^4. The upper partial length a = 31.2 mm, while the lower partial length b = 28.2 mm. The value of the critical load is 110 N, while the Euler load P_e = 1112 N, then γ = 3.1796. Another approach was used for a line diagram of the truncated cone of the sewing needle, where the critical load P_{cr} = 57 N, the Euler load P_e = 118 N, and γ = 3.13. For the line diagram of a sewing needle with a constant cross-section $\bar{\varphi}$ = 1.965 mm, I = 7.3185 (E – 13) m^4, $\frac{EI}{\ell^2}$ = 41.8778 N & η = 2.467. Then P_{cr} = 103 N, P_e = 413 N & $\gamma = \sqrt{\frac{P_e}{P_{cr}}}$ = 2. For a sewing needle with a constant cross-section and the penetration load is uniformly distributed, the geometric characteristic is found to be $\bar{\eta}$ = 7.839, γ = 1.22, $P_{cr} = P_{cr}(q\ell)cr$ = 328 N & q = 5472 N/m ($\cong$6 N/mm). The present work aims to open as yet untouched areas for more and intensive academic and experimental studies, in the field of how penetration forces affect critical loads. The work is the first step in the evaluation of the mechanics of the industrial sewing needle.

Key words: *geometrical, sewing needle, clothes, elastic line, critical loads, Euler loads.*

Introduction

The needle of a sewing machine is considered an important machine part. Its function is to carry the yarn via the sewn fabric to pass it into a loop. The sewing needle is a precision item, and any misshaping will cause failure in stitch formation. A bent sewing needle may cause the slip of the stitch. The reason for sewing needle bending could be related to several factors, such as bad handling, the size of the needle not being adapted to the sewn fabric etc. The sewing needle becomes deflected (buckled) during the sewing process because of too thick garments for the needle size, producing a rough fabric over a certain period etc [1].

Needle buckling (lateral deflection) during sewing may cause an uneven seam or thread breakage. The buckling could be checked experimentally with a critical load, where it may be related to needle eccentricity [1]. The effect of the lateral resistance of the fabric on the sewing needle was studied in research work [2, 3]. The critical buckling load of a sewing needle used in garment and apparel sewing technology, using the Pisarenko [4] approach for calculation of was published in a paper in Nature and Science, an online journal.

In the present work, the massive geometric characteristic of the sewing needle used in clothing manufacture technology will be obtained using different techniques of scientists of authority [5-8], etc.

Sherwet H. Elgholmy [9] in her lectures notes stated that sewing machines of different class are vital in ready-made garment and apparel manufacturing lines. Also, she described in detail the technology and mechanics of industrial sewing machines. In the same lecture notes, the organisation of a garment and apparel factory is written. Moreover, it was mentioned that the maintenance of a sewing machine is extremely important, especially for a new high speed machine.

Sultan and Hearle [10] measured the penetration force of a needle of a needle punching machine experimentally in the labs of Manchester University, UK. Nowadays, nonwoven fabrics play an important role in technical textiles.

I) Sewing needle with a constant cross-section and with an axial concentrated load:

1. Needle with a constant (CSA) and with one axial concentrated load

Average $\varphi = \frac{2.5+1.43}{2} = 1.965\ mm$

$\therefore\ I = \frac{\pi \times (0.001965)^4}{64} = 7.3185\ (E-13)\ m^4$

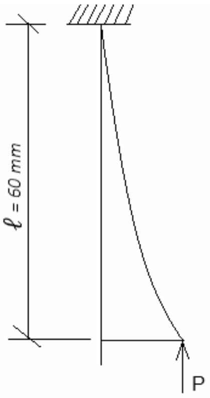
$\frac{EI}{\ell^2} = \frac{206\ (E+9) \times 7.3185\ (E-13)}{(0.06)^2} = 41.8778$ N

$\eta = \frac{\pi^2}{4} = 2.467$

$\therefore P_{cr} = 103.3128 \cong 103\ N.$

$P_e(Euler\ load) = 413.3173 \cong 413\ N.$

$\gamma = \sqrt{\frac{P_e}{P_{cr}}} = 2.0$



2. Sewing needle with a constant (CSA) average value i.e. I\ = constant (axial load is concentrated)

$\bar{\varphi} = \frac{2.5+1.43}{2} = 1.965\ mm$

$\therefore\ I^{\backslash} = \frac{\pi+\bar{\varphi}^4}{64} = 7.3185 \times 10^{-13}\ m^4$

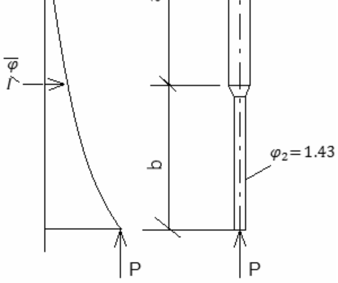
$EI^{\backslash} = 0.1508\ N.m^2$

$\frac{EI^{\backslash}}{\ell^2} = 41.878\ N\ \cong 42\ N.$

$\eta = \frac{\pi^2}{4} = 2.467$

$\therefore\ P_{cr} = \eta . \frac{EI^{\backslash}}{\ell^2} = 2.467\ \times 41.878$

$= 103.3\ N.$



N.B.

I – Inertia of needle cross-sectional area (CSA).

II) Sewing needle with a constant cross-section, where the penetration resistance is the distributed load:

1. Axial load uniformly distributed

$\gamma = 1.22$

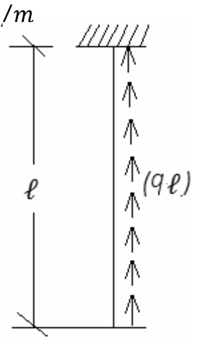
$\bar{\eta} = 7.839$

$P_{cr} = (q\ell)_{cr} = 7.839 \times \frac{EI}{\ell^2} =$

$= 7.839 \times 41.878$

$= 328.321\ N.$

$\therefore\ q_{cr.} = 5472\ N/m$



2. Axial load is halved and uniformly distributed

$\gamma = 1.486$

$\bar{\eta} = 4.47$

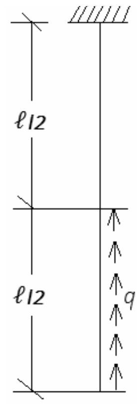
$P_{cr} = (q\ell)_{cr} = \bar{\eta} \times \frac{EI^{\backslash}}{\ell^2}$

$\frac{EI^{\backslash}}{\ell^2} = 41.878\ N$

$P_{cr} = 4.47 \times 41.878$

$= 187.194\ N. = (q\ell)_{cr}$

$\therefore\ q_{cr.} = 31120\ N/m$



3. Axial load right – hand triangle distribution (normal)

$\gamma = 1.388$

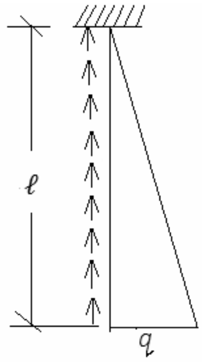
$\bar{\eta} = 5.123$

$P_{cr} = (q\ell)_{cr} = 5.123 \times \frac{EI^{\backslash}}{\ell^2}$

$= 5.123 \times 41.878$

$= 215\ N.$

$\therefore\ q_{cr.} = 3576\ N/m$



4. Axial load reversed right-hand triangle distribution

$\gamma = 0.782$

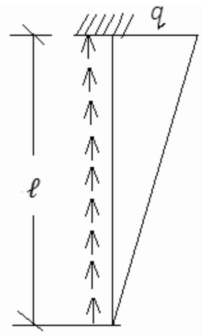
$\bar{\eta} = 16.128$

$P_{cr} = (q\ell)_{cr} = \bar{\eta} \times \frac{EI^{\backslash}}{\ell^2}$

$= 16.128 \times 41.878$

$= 675\ N.$

$\therefore q_{cr.} = 22514\ N/m$



5. Axial load triangle (left-hand) distribution

$I_X = I\ \left(\frac{\ell - X}{\ell}\right)^n$

$n = 0\ -\ 3$

$P_{cr} = \left(\frac{q_0\ \ell}{2}\right)_{cr} = \bar{\eta} \times \frac{EI^{\backslash}}{\ell^2}$

$\bar{\eta} = 6.59\ -\ 16.1$

$q = q_0 \frac{\ell - X}{2}$

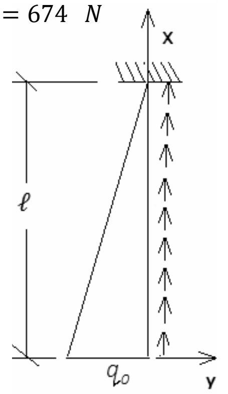
$P_{cr} = \left(\frac{q_0\ \ell}{2}\right)_{cr} = 16.1 \times \frac{EI^{\backslash}}{\ell^2}$

$= 16.1 \times 41.878$

$= 674\ N.$

$q_0 = 22475\ N/m$

$\therefore\ q_{max.} = q_0 = 674\ N$



6. Axial load is parabolic (left-hand)

$I_X = I\left(\frac{\ell - X}{\ell}\right)^n$

$n = 0 \; - \; 4$

$m = 2 - 5$

$$P_{cr} = \left(\frac{q_0\,\ell}{m+1}\right)_{cr} = \bar{\eta} \times \frac{EI^{\backslash}}{\ell^2}$$

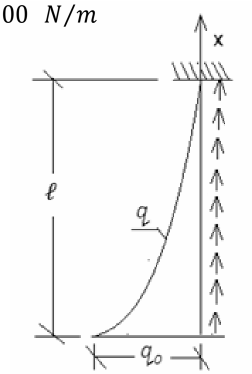
$q = q_0\left(\frac{\ell - X}{\ell}\right)^m$

For $m = 5$ & $n = 2$, $\bar{\eta} = 53.6$

$P_{cr} = 53.6 \times 41.878 = 2245 \; N. =$

$= \left(\frac{q_0\,\ell}{m+1}\right)_{cr} = \left(\frac{q_0\,\ell}{6}\right)_{cr}$

$\therefore \; q_0 = 224500 \; N/m$

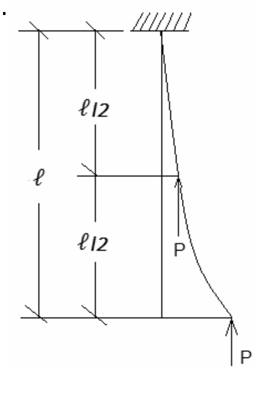


7. Axial loads are parabolic (right--hand), distribution with two concentrated vertical loads P

$P_{cr} = \frac{\pi^2}{2(3\pi - 2)} \times \frac{EI}{\ell^2}$

$= 2.09 \times 41.878$

$= 88 \; N.$



N.B.

All the machine cases for sewing needle loading by axial penetrating force may take place during needle travel from the top layer of the sewn fabric to the lower layer, and even after leaving the lower layer, to form the required stitch.

III) Sewing needle with a variable cross-section (theoretical approach):

This study will be applied to a commercial needle used in the sewing technology of ready – made garments and apparel. The model of calculation is shown in ***Figure 1*** and ***Figure 2*** (two-stepped section sewing needle). The database is: ℓ = 60 *mm*, *a* = 31.2 *mm* & *b* = 2.8 *mm*, φ_1 = 2.5 *mm* & φ_2 = 1.43 *mm*. According to Pisarenko [4], the following calculations are carried out: I_1 = 1.915 (E – 12) m^4, I = 2.051 (E – 13) m^4, a/ℓ = 0.52, & $\frac{I_1 - I}{I}$ = 0.97631, then (using interpretation) $\bar{\eta}$ = 0.93 (special table).

$$\therefore \; P_{cr} = \bar{\eta}.\frac{EI_1}{\ell^2} =$$

$$= \frac{0.9763 \times 206 \times 10^9 \times 1.9165 \times 10^{-12}}{(0.06)^2} =$$

$$= 109.7 \; N. \cong 110 \; N. \qquad (1)$$

A) Pisarenko method [4]:

I) Sewing needle with a variable cross-section:

a) Commercial needle Schmitz, system Dxy Geometric – characteristic:

- $I_1 = 1.9165\;(E - 12)\; m^4$
- $I = 2.0516\;(E - 13)\, m^4$
- $a/\ell = 52\;\%$
- $\frac{I_1 - I}{I} = 1.7113$, by Interpretation

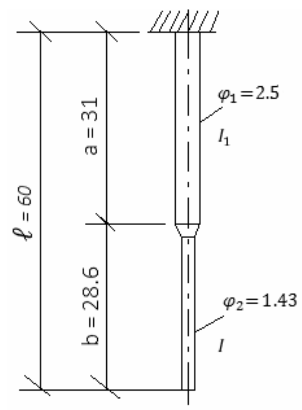
$\frac{I_1 - I}{I} = \frac{1.7113 + 0.7662}{2} = 0.97631$

$= \bar{\eta}$ …… by special table c [4]

$$\therefore \; P_{cr} = \bar{\eta}.\frac{EI_1}{\ell^2} =$$

$$= \frac{0.9763 \times 206 \times 10^9 \times 1.9165 \times 10^{-12}}{(0.06)^2}$$

$\cong 110 \; N.$



In the preceding calculation; it is assumed that:

$$\bar{\eta} = 2.467{:}\left[\frac{\ell - a}{\ell} + \frac{\ell - a}{\ell}.\frac{I}{I_1} + \frac{1}{\pi}\left(\frac{I}{I_1} - 1\right).\sin\frac{\pi a}{\ell}\right]$$

This formula was enhanced by different values and tabulated in a special table [4]. From ***Equation (1)***, γ = 3.1796, then:

$P_e(Euler\ load) = 1112 \; N.,$

$$\sqrt{\frac{P_e}{P_{cr}}} = 3.179 = \gamma$$

B) Chen technique [7]:

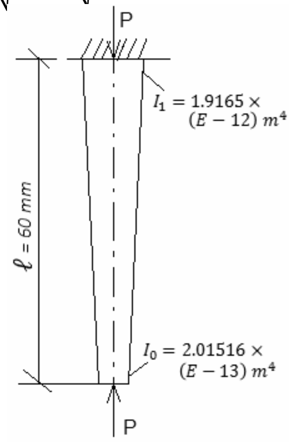
- $I_0 = 2.0151\;(E - 13)\; m^4$
- $2\, I_0^{\backslash} = I_1 = 1.9165\;(E - 12)\; m^4$
- Ratio $= \frac{I_1}{I_0} = 9.5104$
- $\frac{EI_0}{\ell^2}$=11.53 N

$\therefore \; P_{cr} = 1.0336 \times 11.5311 \cong 12 \; N.$

The Chen scheme will be considered as a virtual sewing needle

$$P_e(Euler\ load) = \frac{\pi^2}{(1)^2}.11.53 = 118 \; N.$$

$$\gamma = \sqrt{\frac{P_e}{P_{cr}}} = \sqrt{\frac{118}{12}} = 3.13$$



N.B.

Ratio $= \frac{1.9165\;(E-12)}{2.0151\;(E-13)} = 9.5608$

$\because \; P_{cr} = 12 \; N.$ For ratio 2 I_1/I_0= 2

$\therefore \; P_{cr}^{\backslash}$(modified) $= \frac{9.5608}{2} \times 12 =$

$= 57.364 \cong 57 \; N.$

Case study

For more explanation, we will make a case study of # 5 (axial load triangle left – hand distribution):

From the database of our sewing needle, we can state the following:

$\ell = 60 \;\; mm = 0.06\, m$ &

& $\bar{\varphi} = 1.965\, mm = 0.001965\, m$

a) Inertia of the needle cross-section

$$I^{\backslash} = \frac{\pi \; \bar{\varphi}^4}{64} = \frac{\pi \; \times (0.001965)^4}{64} =$$

$= 7.3185 \; \times (E - 13)$

b) Bending stiffness of the needle (EI)

$$\frac{EI^{\backslash}}{\ell^2} = \frac{206\;(E+9) \;\times 7.3185\;(E-13)}{(0.06)^2}$$

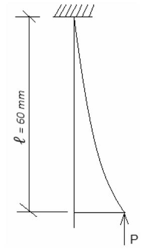
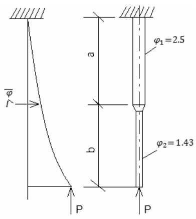
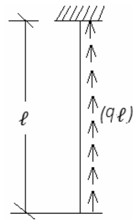
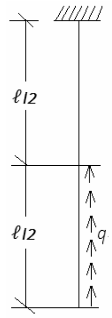
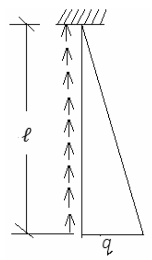
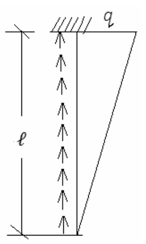
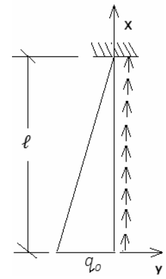
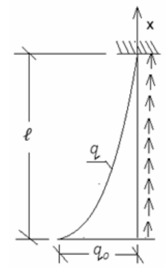
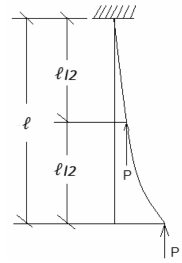
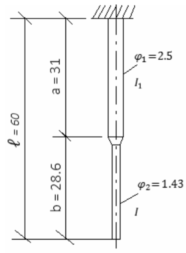
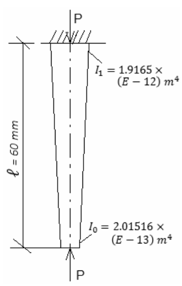
$= 42.0$ *N.*

According to [5], $\bar{\eta} = 6.59 - 16.1$

$P_{cr} = \left(\frac{q_0\,\ell}{2}\right)_{cr} = \bar{\eta} \times \frac{EI^{\backslash}}{\ell^2} =$

$= 16.1 \; \times 41.8778 = 674\, N.$

Table 1. *Comparative values of sewing needle geometric characteristics concerning buckling mechanics.*

	Parameters					Line diagram
	γ	η	$P_{cr.}$, N	$P_{cr.}$ (q_{cr}), N	q_{cr}, N/m	
I) CSA with an axial concentrated load:	2	2.467	103	–	–	
	2	2.467	103.3	–	–	
II) CSA with an axial distributed load:	1.22	7.839	–	328.3	5472	
	1.486	4.47	–	187.194	31120	
	1.388	5.123	–	215	3576	
	0.782	16.128	–	675	22514	
II) CSA with an axial distributed load:	1.277	6.59-16.1	–	674	22475	
	0.429	53.6	–	2245	224500	
	2.173	2.09	–	88	–	
III) Variable CSA	3.179	0.9763	110	–	–	
	3.13	1	12 (57)	–	–	

Legend:

1 – $\eta = \left(\frac{\pi}{\gamma\ell}\right)^2$, $\bar{\eta} = \left(\frac{\pi}{\gamma}\right)^2$,

2 – Sewing needle with constant CSA (cross sectional area) for both concentrated and distributed axial loads.

3 – Sewing needle with variable CSA for constant axial loads only, but with distributed variable loads (none-till now 2019).

4 – Pisaranko two-stepped needle (accurate solution $P_{cr.}$ = 110 N), while approximated $P_{cr.}$ = 103 N i.e % error = 7%.

A summary of calculations is exhibited in ***Table 1***.

Conclusions & future visions

From the sewing needle line diagrams and different techniques of calculations of the interaction between the penetration load distribution and the critical load, the following conclusions and future aims can be obtained:

1. Results of the sewing needle geometric and force analysis are as follows: $I = 27.3185\ (E-13)\ m^4$, $EI/\ell^2 \cong 42\ \ N.,\ \ \eta = 2.467$, $P_{cr.} \cong 103\ \ N,\ P_e(Euler\ load) =$ $= 413\ \ N.,\ \gamma = \sqrt{\frac{P_e}{P_{cr}}} = 2.$
2. A sewing needle with a constant cross-section and with a distributed penetration force has the following values of geometric characteristics:
   a) Uniformly distributed: $\gamma = 1.122$, $\bar{\eta} = 7.839$, $P_{cr}(q\ell)_{cr} = 328\ \ N.$, $q(load\ intansity) = 5472\ \ N/m.$
   b) Right-hand triangle distribution: $\gamma = 1.388$, $\bar{\eta} = 5.123$, $P_{cr}(q\ell)_{cr} = 215\ \ N.$, $q_{cr.} = 3576\ \ N/m.$
   c) Reversed right-hand triangle distribution: $\gamma = 0.782$, $\bar{\eta} = 16.128$, $P_{cr}(q\ell/2)_{cr} = 675\ \ N.$, $q_{cr.} = 72514\ \ N/m.$
   d) Parabolic distribution of the penetration force for $m = 5,\ n = 2$, $\bar{\eta} = 53.6$, $P_{cr} = (q_0\ell/6)_{cr} =$ $= 2245\ \ N.,\ q_0 = 224500\ \ N/m.$
3. For a sewing needle with a variable cross-section:
   a) Two-stepped needle $\overline{\eta} = 0.97631,\ P_{cr} = 110\ \ N.$, $\gamma = 3.179,\ P_e = 1112\ \ N.$, $I_1 = 1.9165\ (E-12)\ m^4$, $I = 2.0516\ (E-13)\ m^4$, $a/\ell = 0.52$.
   b) One-stepped sewing needle: $I_1 = 1.9165\ (E-12)\ m^4$, $I_0 = 2.0516\ (E-13)\ m^4$, *Ratio* = 9.5104, P_{cr} = 12 *N.*, P_e = 118 *N.*, γ = 3.13, P_{cr} *modified* = 57 *N.*
4. The future aim is to build a stand to verify the calculated value via experimental ones.
5. The sewing needle can be treated as a fixed free end column, w. r.t strength of material science.
6. Values of sewing needle geometric characteristics depend on numerous factors: the boundary condition, cross-sectional area distribution, buckling load, either concentrated or distributed etc.

N.B.

The analyses and calculations are sourced via Pisarenko G. C. [4], but with a particular reference to the sewing needles of industrial sewing machines.

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