A Formula for Calculating the Critical Load of the Needles Used in the Garment and Apparels Sewing Technology: Part 1: Pucarenko Technique

El Gholmy S. H., I. A. Elhawary

Department of Textile Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt
sh_gholmy@yahoo.com

Abstract: The sewing machines needle is an important and vital machines member. The general objectives of sewing needle is to penetrate the sewn materials either single layered or multiple layered fabrics and to carry the sewing thread via the sewn fabrics for loop formation during the penetration by the sewing needle, a resisting force at the free end of the needle is built up that subjects the needle to an axial compressive force this force can lead to the needles buckling in the elastic or plastic region of the needles metal [steel]. In both cases the sewing needle may be bent this will lead to produce a defective readymade garment or a downgraded quality clothing [1]. In the present work a Pucarenko technique has been applied for calculating the industrial sewing needle critical load $P_{cr.}$It was found that $P_{cr.}$ for an industrial sewing machine is 62 N (newton). The working resisting force during sewing process must be less than $P_{cr.}$ to avoid needles buckling this must be controlled by safety factor of elastic stability (m) where $m=P_{cr.}/P_W$, for jeans (denim) fabrics, where P_W =120 c N (woven fabric, 120 g/mt^2) when the needle free length changed from 45mm to 12mm, the critical load increased from 62N to 90N.The Pucarenko formula calculates only the stability factor **η** due to the different needle cross- section. The value of **η** changed about 0.0284% which can be neglected.

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1. Introduction:

The sewing machine needle is a major part of the sewing machine and its functions in general are: producing hole in the material, carrying the thread through the material and passing the needle thread through the loop **[1].**

The kinematics of the sewing needle during the process of stitch formation is important to obtain a good formed stitch. Increasing stitch velocity from 1000rpm to 4000 rpm the needle bar and the take-up lever velocity changed linearly, but the acceleration performed a non-linear function **[2].** Thus the needle penetration velocity was reduced by replacing the conventional slider-crank mechanism with a link drive mechanism. This reduced the needle velocity in the needle penetration area by 25% in comparison to the conventional slider –crank mechanism**[3]**.

A sewing machine needle is precision item and if it becomes misshapes in any way it will fail to form stitch properly. A bent needle may cause slip stitching. The reason why the needle became bent could be related to incorrect needle size for the fabric weight being sewn or to faulty operator handling. A needle where the point has become burred or damage in some way will almost certainly cause damage along the stitch line. Needles become deflected (buckled) during sewing by fabric that is too thick for the size of the needle. If the deflection is too severe, a larger size needle may be necessary. Needle can also become damaged as result of impacting a harsh material over a period of time, such as that used for denim jeans which are made up in a stiff state and then washed in garments form can require that the needles sewing it are changed every two hours. The ways in which the needles can strike and break fabric yarns and burst the loops in the knitted fabrics, have considered as one of the main reasons for the much critical damage. There for it is preferable to use needles with small size as it could be possible [1].Needle defection during sewing may cause uneven seam or thread breakage. It was measured by placing two gauges on the lateral sides of the needle, which was found correlated to needle eccentricity **[4].**

Needle heating, is another problem in stitch formation, which occurs as a result of friction between the needle and the sewn fabric. In high speed sewing of dense materials temperatures as 300◌̊C - 350◌̊C can be reached, it is possible that needle may suffer damage and lose hardness can easily be buckled. **[5].** A lot of suggestions have been written to reduce the friction between the needle and the material such as blowing an air current during the machine stitching; the production of jeans in cotton fabrics is typical of situation where high speed machines are used on a natural fiber and fabric and where considerable needle heat can be generated particularly on the long seam **[1, 5].**

Finally, we can say that to obtain a good looking seam, we have to measure forces acting on the needle during this process. Therefore, previous researches modeled the forces acting on the needle and gave some accurate results **[6-8].**

2- Review of literature:

Pucarenko et al. [9] has written the buckling formula of Euler for a bar subject to an axial compressive load:

$$y = A \sin n\pi \frac{x}{\ell} \quad , n = 1,2,3\,..\,etc\ .$$

Number of waves [single wave, double waves or triple waves ……etc],

$x = \frac{\ell}{2n}$ displacement of the compressed bar axis and A-amplitude of the waves constantly, the critical load Pcr formula is:

$$P_{cr} = \frac{\pi^2 E I}{(\gamma \ell)^2} = \eta \frac{E I}{\ell^2} \quad .... \quad .....(1)$$

Where:-

γ - Coefficient of the equivalent length, ℓ - Length of the bare (beam) between supports γ = 1 for simply supported beam, γ = 2 for cantilever, η - ideal stability factor & equals = $\frac{\pi}{\gamma}$, η =9.8696 for both simply supported beam and for a cantilevers .

In the same work Pucarenko, Yakovlevand Matveev, **[9]**, it has been stated that the elastic stability factor η for n variable cross – sections of machine member is:

$$\eta = 2.467\left[\left(1-\frac{I_2-I_1}{I_1}\times\frac{(\ell-a_1)^2}{\ell^2}\right)\left(1-\frac{I_3-I_2}{I_2}\times\frac{(\ell-a_2)^2}{\ell^2}\right)\ldots\ldots\left(1-\frac{I_n-I_{n-1}}{I_{n-1}}\times\frac{(\ell-a_{n-1})^2}{\ell^2}\right)\right]\ldots(2)$$

The critical load is calculated by formula:-

$$P_{cr} = \eta \frac{E I_1}{\ell^2} \quad .... \ .... \ .... \ ....(3)$$

Where:

Inertia of the beam cross section at the completely fixed end.

Mutunskiand Movnin [10] have reported that the critical load for a machine member subjected to axial compressive load is:

$$P_{cr} = \frac{\pi^2 .EI_{\min}}{(\gamma \ell)^2} = \eta\left(\frac{E I_{\min}}{\ell^2}\right) \ldots.(3-a)$$

The critical stresses due to the critical load could be calculated by either formula.

$$\sigma_{cr} = \frac{\pi^2}{(\gamma \ell)^2} . \frac{E I_{\min}}{A} \quad .... \ .... \quad (4)$$

$$I_{\min} = i^2_{\min} \quad , A \ , \ i_{\min}$$

Radius of gyration or inertia radius of cross-section area A, or by formula:

$$\sigma_{cr} = \frac{\pi^2 E}{\lambda^2} \quad .... \ .... \ .... \ ......(5)$$

$\lambda = \frac{\gamma \ell}{i_{\min}}$ – *beam* Elasticity

imin = Imin / A,A – area of buckled beam cross-section.

Belyaev [11] has stated that the elastic line equation for the buckled beam axis depends on the number of wave in the beam, for single wave

$$y = a \sin \frac{\pi x}{\ell} \quad ....(6-a)$$

for double waves

$$y = a \sin \frac{2\pi x}{\ell} \quad ....(6-b)$$

$y = a \sin \frac{3\pi x}{\ell}$ for triple waves, or general formula is

$$y = a \sin \frac{\pi x}{\ell} \quad ....(6-c)$$

Where n=1, 2, 3……………,and a is the wave amplitude. In the same work Belyaev**[11]**, it was written that for conical machine member subjected to an axial compressive load, the critical load.

$$P_{cr} = \frac{\pi^2}{(\mu \ell)} . \frac{EI}{\ell^2} \quad ....(7)$$

where, $n = \frac{I_1}{I_2}$

μ -is calculated by special table, I1- inertia of the machine membercross- section at its free-end while I2 – the inertia of cross- section area at the fixed end. **Belyaev [11]** has mentioned that the critical stress in the buckled beam is:

$$\sigma_{cr} = \frac{\pi^2 E}{\lambda^2} \quad .... \ .... \ .... \ .... \ (8)$$

Where, E-mong's module and λ - beam elasticity. The critical stress σ_{cr} must be less than yield stress σ_y for steel 5. $\lambda \geq 85$ For cast-iron $\lambda \geq 80$

Ponomarev et al. [12] have found the critical load for a beam [cantilevers type] with a conical shape with inertia I1 at the free end and I2 at the fixed end . the formula is:

$$P_{cr} = 13.370 \frac{E I_2}{\ell^2} \text{.....(9)}$$

Where, L -the actual length of the cantilever. They applied the energy technique for the calculation where general equation of the total potential energy u_T for a buckled beam under an axial compressive load is calculated by formula

$$u_T = u_\circ + u - w \text{.......... ...(10)}$$

where: UT – total potential energy, u0- potential energy up to the buckling, w- the work done by external applied compressive forces during buckling and u- potential energy due to buckling. The potential energy due to buckling u is

$$u = \frac{1}{2EI}\int_\circ^\ell M^2 \, dx \text{.......... ....(11)}$$

M-bending moment

$$y''.dx, \; y = \sum_k a_k \sin\frac{\pi x}{\ell} \text{.......... (12)}$$

k- Section number of the buckled beam, and the work w is calculated by formula

$$w = P.\frac{1}{2}.\int_\circ^\ell y^2.dx \text{ ....(13)}$$

p- is the external force.

Elhawary [13] has introduced a simplified formula for calculating the critical load of the needles used in the needle punching machine. The derivation of these formula is based on the energy method .It was found that the critical load for the compound needle was 8.76N where as it was 14.75 for the simple needle, while the factor of safety of the elastic equilibrium (stability) of the needles either compound or simple was running from 1.6 to 2.7 that was considered to be a safe range of values.

Hussien, Nahrawyand Arafa**[14]**measured the needle penetration force on the fabric handle tester, using a modified jaw. It was found that the fabric weight and the use of a softener affect the needle penetration force. Also, the technology of needle manufacture had significant effect, especially, in knitted fabrics. **Ujevic et al. [15]** measured the needle force; the blade of the sewing needle was used as a sensor. It was found that sewing needle penetration forces increase proportionally with needle sizes.

Finally the critical stress σ_{cr} in the buckled needle as written by **Timoshenko [16]** is:

$$\sigma_{cr} = \frac{\pi^2 E}{\lambda^2} \text{ ....(14)}$$

Where: σ_{cr} - critical stress, E- young's modulus and λ - sewing needle elasticity = $\gamma\ell / i_{\min}$ (see nomenclature). The critical stress must be less than both of σ_y - yield stress & [σ]- design stress = σy: F.s c factor of safety:

$$\sigma_{cr} \le \sigma_y \le [\sigma] \text{ ....(15)}$$

In the workof Ponomarev,Buderman, Klikharev,Makyshin, Malinin and Foedosef**[12]** it has mentioned a formula for calculating a coefficient φ of decrease the design stress [σ] due to buckling where:

$$\left.\begin{aligned} \varphi &= 1 - 0.8\left(\frac{\lambda}{100}\right)^2 \quad \text{.....} \; \lambda \le 75 \\ &= \frac{3100}{\lambda^2} \quad \text{....} \; \lambda > 75 \end{aligned}\right\} \text{.......... (16)}$$

Nomenclature:

η - Ideal stability coefficient $= \pi^2 / \gamma^2$

$\mu \; or \; \gamma$ - Coefficient of the equivalent length

$\gamma\ell \, or \, \mu\ell$ - Equivalent length.

ℓ - Actual span length of the beam or of the machine member.

Pcr – critical load $= \frac{\pi^2 EI}{(\gamma\ell)^2} = \eta\frac{EI}{\ell^2}$

E- Young's modulus or modulus of elasticity in compression

I- Iinertia of the cross- section area of the beam

$\lambda = \gamma\ell / i_{\min}$ - beam elasticity, imin – min. radius of inertia of beam cross–section or radius of gyration.

$i_{\min}^2 = I_{\min} / A, A$ - Beam cross- section area

σ_{cr} - Critical stresses in the cross- section of the buckled beam

3- Mathematical approach:

3-1 Pucarenko et al. [9] technique:

According to Pucarenko et al. [9] technique the following formula will be applied for the industrial sewing needle of the sewing machine of the clothing technology manufacture:

3-1-1 The axial compressive critical load Pcr:

$$P_{cr} = \eta\frac{E I_1}{\ell^2} \text{ ....(17)}$$

Where:Pcr – critical load, η - stability factor, E- young's modulus = 206 Gpa for steel sewing needles material, I1- inertia of the needle cross- section and ℓ - is the total free length of the needle

3-1-2 The stability factor η general formula is:

$$\eta = 2.467 \cdot \left\{1-\left(\frac{I_2-I_1}{I_1}\right)\times\left(\frac{(\ell-\ell_1)^2}{2}\right)\right\}\cdot\left\{1-\left(\frac{I_3-I_2}{I_2}\right)\times\left(\frac{(\ell-\ell_2)^2}{2}\right)\right\}$$

$$\cdot\left\{1-\left(\frac{I_4-I_3}{I_3}\right)\cdot\left(\frac{(\ell-\ell_3)^2}{2}\right)\right\}\times\ldots\ldots\ldots\ldots\left\{1-\left(\frac{I_n-I_{n-1}}{I_{n-1}}\right)\times\frac{(\ell-\ell_{n-1})^2}{2}\right\}\ \ldots\ldots\ldots\ldots 18$$

Where, I1, I2, I3 & I4 – cross sectional sewing needle area's inertias respectively from section1 to 4. $\ell_1, \ell_2, \ell_3, \ell_4 \,\&\, \ell$ - Lengths of the different sewing machine needle sections and the total length of the needle respectively.

3-2 Critical load Pcr calculation:

3-2-1 Actual configuration of sewing machines needle: [four sections]

As shown in fig. (1), the sewing needle has four sections: shark, blade, scarf with eye and tip. Therefore the general formula of **Pucarenko [9]** will be applied with needles data bases from table (1):

$$\eta = 2.467 : \left\{1-\left(\frac{1.0417\times10^{-14}-2.4850\times10^{-13}}{2.4850\times10^{-13}}\right)\times\left(\frac{(0.045-0.015)^2}{2}\right)\right\}.$$

$$\left\{1-\left(\frac{7.8125\times10^{-16}-1.0417\times10^{-14}}{1.0417\times10^{-14}}\right)\times\frac{(0.045-0.040)^2}{2}\right\}.$$

$$\left\{1-\left(\frac{1.9175\times10^{-16}-7.8125*10^{-16}}{7.8125\times10^{-16}}\right)\times\frac{(0.045-0.04)^2}{2}\right\}$$

Using formula (2):

$$\eta = 2.467 : \{1+0.9581\times4.05\times10^{-7}\}\,.\,\{1+0.925\times1.25\times10^{-5}\}$$

$$.\,\{1+0.754546\times5\times10^{-7}\}$$

$$= 2.467 : \{1.000000388\}.\{1.000012\}.\{1.000000373\}$$

$$= 2.467 \times 1.000016$$

$$= 2.467 / 1.000016$$

$$= 2.46696$$

$\therefore$ using formula (1)

$$P_{cr} = 2.46696\times\frac{206\times10^9\times2.4850\times10^{-13}}{(0.045)^2}$$

$$= 62\ N.$$

3-2-2 Modified configuration of the sewing machine's needle [3- sections]

By using formula (14):

$$P_{cr} = \eta\,\frac{E\ I_1}{\ell_4^2}$$

By using formula (2):

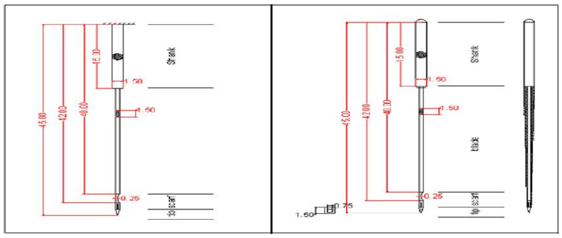

Figure (1) four parts of sewing needle

Table (1) geometrical characteristic of sewing needle:

Section	I (m4)	ℓ
Shark	$I_1 = 2.4850\times10^{-13}\ m^4$ $[\varphi = 1.5\ mm]$	$\ell_1 = 0.015\ m$
Blade	$I_2 = 1.0417\times10^{-14}\ m^4$ $= \frac{w\times t^3}{12}\begin{bmatrix}, w = 1.0\ mm \\ t = 0.5\ m\end{bmatrix}$	$\ell_2 = 0.040\ m$
Scarf	$I_3 = 7.8125\times10^{-16}\ m^4$ $= \frac{w\ t^3}{12}\begin{bmatrix}w = 0.6\ mm \\ t = 0.25\ mm\end{bmatrix}$ $I_3' = w_1 t_1^3/12 - w_2 t_2^3/12\ (eye) - negle$	$\ell_3 = 0.042$
Tip (point)	$I_4 = \frac{\pi\ \varphi^4}{64},\ \varphi = 0.25\ mm$ $= 1.9175\times10^{-16}\ m^4$	$\ell_4 = 0.045\ m$
		total $\ell = 0.045\ m$

$$\eta = 2.467 : \left\{1+(0.9581)\,\frac{(0.044-0.015)^2}{2}\right\}.\left\{1+0.925\times\frac{(0.044-0.040)^2}{2}\right\}$$

$$= 2.46598$$

$$\therefore P_{cr} = \eta\,\frac{206\times10^9\times2.485\times10^{-13}}{(0.044)^2}$$

$$= 2.46598\times26.442$$

$$= 65\ N.$$

3-3-3 Modified configuration of the sewing machine's needle [2-sections]

by applying formulas (14) &(15) then:

$$\eta = 2.467\left\{1+0.9581\times\frac{(0.042-0.015)^2}{2}\right\}$$

$$= 2.467\{1.0003492\}.\left\{1+0.925\,\frac{(0.042-0.040)^2}{2}\right\}$$

$$= 2.467 / 1.00034939$$

$$= 2.466138$$

$$\therefore P_{cr} = 2.46614\times\frac{206\times10^9\times2.48125\times10^{-13}}{(0.042)^2}$$

$$= 72.0\,N$$

3-3-4 Modified configuration of the sewing machine's needle [one section]:

By applying both of formulas (14)&(15):

$$\eta = 2.467 : \left[1 - \frac{I_2 - I_1}{I_1} \times \frac{(\ell - \ell_1)^2}{2}\right]$$

$$= 2.467 : \left[1 + 0.9581 \times \frac{(0.040 - 0.15)^2}{2}\right]$$

$$= 2.467 / 1.000299$$

$$= 2.46626 .0$$

$$P_{cr} = 2.466261 \times \frac{206 \times 2.850 \times 10^{-4}}{(0.040)^2}$$

$$= 90 \ N$$

The summary of calculations that concern the critical load of the sewing machine's needle are tabulated in table (2). It is shown from the table that the actual sewing needle has the minimum critical load due it's more length as explained by equation or formula (1). On the contrary for the virtual sewing needle with one section (shank), the critical load Pcr is the highest because it has the shortest free length, as shown by Euler formula (1).The high critical load Pcr for the short sewing machine needle will enhance the value of the safety elastic stability factor m where:

$$m = \frac{P_{cr}}{P_{w0}}$$

Table (2) summary of calculation for Pcr values

	Type of sewing needle	The critical load Pcr .(N)*
1	Actual needle (4- section)	62
2	Virtual sewing needle (3 section)	65
3	Virtual sewing needle (2-section)	72
4	Virtual sewing needle (one section)	90

N- new tons - force unit due to S.I organization

Where, Pcr – critical of the sewing needle i.e. the load after which the sewing needle will lose its straight configuration and Pw is the working load, established during needle penetration the sewn fabric. Therefore the modern clothing technology manufacturers recommended the application in the industrial sewing machines, the short needle [1]. And the overlock machine needle is the shortest needle as this type of machine has the maximum speed. According to the high stability elastic safety factor m, the probability of elastic or plastic buckling of the needle is too negligible. These will lead to less bent or defective needle that will enhance the sewn fabric quality and sew ability.

From table (2) it will be noted that decreasing the sewing machine needle from 45 mm to 15 mm will increase the critical load Pcr from 90 N to 62 N i.e. by about 45% i.e. the critical load Pcr is too sensitive for the free length (ℓ) of the sewing needle.

The formula (2), concerns the stability elastic factor (η), gives different values for (η) with the change of sewing machine's needle configuration. For example for the longest sewing needle, $\eta = 2.46696$ while for the virtual shortest needle $\eta = 2.46626$ i.e. the difference is about 0.0284% that means it could be neglected. Therefore the main item in calculating Euler formula of Pcr is the free length of the sewing needle. By the way, the highest resisting force on the sewing needle tip [conical] part penetrating the sewn layered fabric takesplace for jeans [denim] cloth during garments production [1].

4-Conclusions& Recommendations

From the above mathematical approach, the following conclusions can be drawn for actual & virtual sewing industrial machine's needles.

1-The coefficient of the equivalent length of the sewing needle $\gamma = 2$. The elastic ideal stability factor η of Euler formula Pcr for sewing needle $= \frac{\pi^2}{\gamma^2}$ i.e $\eta = 2.4674$ where it is assumed the sewing needle has a constant cross- section.

2-The elastic stability factor η *is* 2.46696 for the actual sewing machine needle, [the longest needle 4 sections], while η *is* 2.46626 for the shortest virtual needle [one section] only. The difference between them is too negligible.

3-The main factor in calculating **Pucarenko et al. [9]**Pcr is the free length of the sewing machine needle.

4-In **Pucerenkoand Yakovlev and Matveev.[9]** formula (2) for calculating the elastic stability factor η, the second part of the formula that decrease or increase the value of η ideal for sewing needle with constant cross-section, has a title effect on the value of η ideal and could be neglected.

5-Seemingly, the **Pucarenko et al. [9]** formula (2) for calculating the critical load on the actual sewing machine needle [5- sections: shank, blade, scarf, eye & point] is enough for the industrial applications. The eye section is neglected.

It is recommended to try with another techniques, for calculating the critical load Pcr. such energy techniques **[9]** also, it is recommended to carry out an experimental work for finding or exploring the actual critical load for actual sewing machine needle and then calculating the safety factor of the elastic stability m.

Reference:

1- Carr H. and Latham B. the technology of clothing manufacture, British library, UK, 1988.
2- Lojen D, and Gotlih K. Computer Simulation of Needle and Take-up Lever Mechanism Using the ADAMS Software Package, Fibres and Textiles in Eastern Europe, 2003, Vol.11, No. 4(43).
3- Golith K. Sewing Needle Penetration Force Study, International Journal of Clothing Science and Technology, Vol.9, No.3, 1997, P. 241-248.
4- Tanaka M, Yasumori K, Kamata Y. Needle Deflection and Sewablity on Lochstitch Sewing Machine, Journal of the Textile Machinery of Japan Vol. 48,No.3, (1995-3)
5- Golith K, Lojen D,.Vohar B. Optimizing of needle velocity using the link drive mechanism in a sewing machine. Fibre and Textile in Eastern Europe, Vol. 15, No. 1(60), 2007.
6- Lomov S. A Predictive Model for the Penetration Force of a Woven Fabric by Needle, International Journal of Clothing Science and Technology, Vol.10, No.2, 1998, P. 91-103.
7- Vobolis J, Juciene M, Punys J, Vaitkevicius V. Influence of Selected Machine and Martial Parameters on the Stitch Length and Its Irregularity, Fiber and Textile in Eastern Europe, Vol. 11, No. 3(42), 2003.
8- Zajaczkowski J. Applying Brent's Method for Calculating the Forces Acting on Sewing Manipulators, Fiber and Textile in Eastern Europe, Vol. 11, No. 4(43), 2003.
9-Pucarenko G.C,Yakovlev A.P,Matveev V.V.A text book of the strength of material, NaykovaDynamka press,Kiev, 1975
10- Mutunski A.N.,Movnin M.C.Technical Mechanics, Moscow, 1955.
11- Belyaev N.M, Strength of Material, Nayka press, Moscow, 1976.
12- PonomarevC.A, Buderman V.A, Klikharev K.K, Makyshin V.M,Malinin N.N, Foedosef V.U. The Principle of the New Method for the Design of Machines, Mashguz press, Moscow, 1952.
13-El hawary I.A, A simplified Formula for Calculating The Critical Load of The Needles Used in The Needle – Punching Machine, J. text institute, 1988,80 NO 4.
14- Hussien S, NahrawyA.,ArafaA, Development of a needle penetration force measurement device, 6th international conference of textile research division N R C, Cairo, Egypt, April 5-7 2009.
15. Ujevic D. Rogale M. KartalSajatovic B, Impact of Sewing Needle and Thread on the Technological Process of Sewing Knitwear, Fibres and Textiles in Eastern Europe, 2008, Vol.16, No. 4(69).
16- Timoshenko C. P., Mechanics of Materials MirPub., Moscow, 1976.

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