THE 3rd BUCKLING PHASE OF A SEWING NEEDLE INTERACTION WITH THE HEAVY MULTILAYERED FABRICS

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Abstract: *In the present work the interaction between the lower end of the sewing needle and the sewn multilayer having massive fabrics is studied. The sewing needle lower end just penetrate the top layer of the cloth starts to be surrounded by fabrics and yarns that activate as fixer to the needle end. As the industrial lower end travels downward, the fixation is increased so that the needle became a column fixed-fixed ends. In the present work, it is a summed that the industrial sewing needle has a constant cross-section (CSA with $\bar{\varphi}$ = 1.965 mm). Actually the needle is a bar with variable (CSA) that could be transferred to a column with constant (CSA). By the way this problem is more complicated. The future vision of this work is to build stand in the laboratory to verify the different values of the critical loads.*

Keywords: *sewing needle, penetration phase, column, restrained ends, buckling load, Euler and critical, equivalent length coefficient, elastic stability η.*

1 INTRODUCTION

In the clothing manufacture technology, a sewing process is running via a sewing needle reciprocating motions in the vertical direction through a driving mechanism irrespective of its kinematic chain, the end of the sewing needle penetrates the sewn layers of the fabric, starting from the top layers to underneath the lower layer, causing a looping of the sewn thread to connect or to fix the layers to each other. This will enable people to have ready-made garments or apparel [1, 2].

Figure 1 shows the different phases of the sewing needle lower-end, penetration vertically in the layers of the cloth layers. During penetration from the top layer to the lowest layer, the sewing needle lower end is subjected to different degrees of resistance [1, 2]. The resistance of the fibers, yarns and fabrics is presented by a virtual constrains: start from zero to the third degree level as illustrated in exhibit (Figure 1).

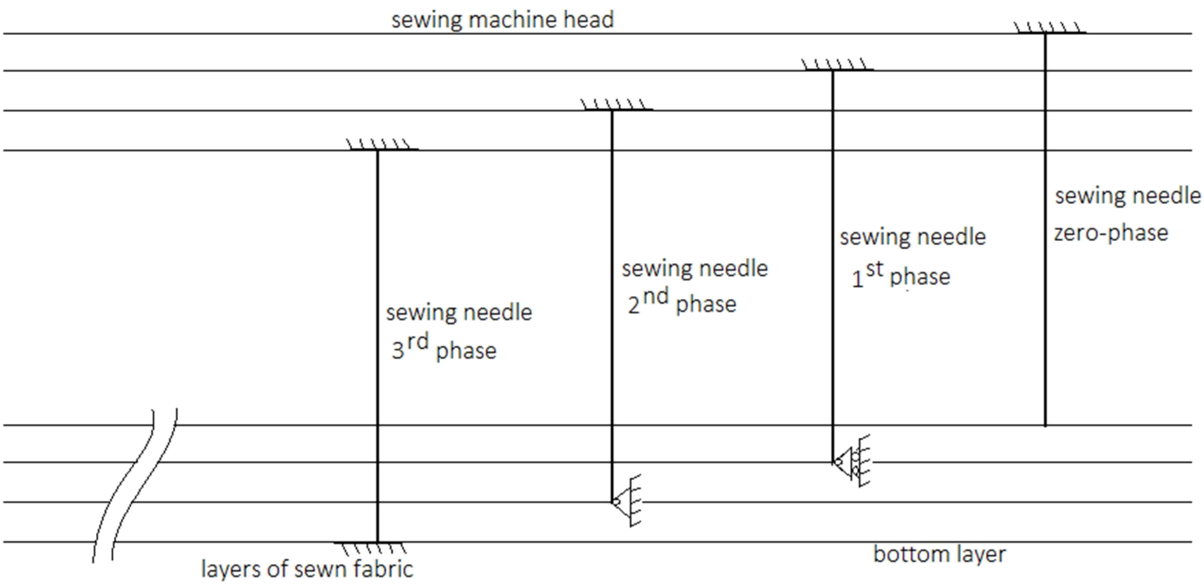

Figure 1 Different phases of a sewing needle penetration in the sewn fabric layers
zero-phase - the sewing needle is fixed-free end column (cantilever); 1st phase - the sewing needle is fixed-hinged (movable) end column-beam; 2nd phase - the sewing needle is fixed-hinged (angular) end column-beam; and 3rd phase – the sewing needle is fixed-fixed end column-beam

In addition, it was done extensive study on a standard commercial needle with two stepped sections with $\overline{\varphi}$ = 1.965 mm, EI = 2.52 N.m^2, length ℓ = 60 mm. It was found that for zero penetration, buckling load P_{cr} = 104 N, while Euler load P_e = 415 N consequently $\gamma = \sqrt{\frac{P_e}{P_{cr}}} = 2$ [1].

Also, the 1st & 2nd phase of sewing needle penetration in the multi-layered sewn fabric were studied. It was found the axial critical compressive force F_{cr} = 848 N, while the Euler load F_e = 415 N & equivalent length $\lambda = 0.699$ [2].

Groz-Beckert has reported and graphed the distribution of the penetrating force during sewing process as shown in Figure 2. At the start of the free need touch the top layer of the fabric (zero penetration) an impact force is generated = 25 N (the highest value). Due to continuity of penetration, the resisting force on the needle drops to 6 N. Finally at the end of penetration when the needle extruding from the lower layer of the sewn fabrics the penetration force drops to zero lower end is outside fabric, but visually the value of force = 10 N due to the increase of needle cross-section. This means that the sewing needle has different phase during its penetration in the sewn fabric [3].

In the work [4] it has been mentioned the use of Pisarenko technique what could be applied for calculating the critical load of the sewing needle with variable CSA (Cross-sectional area). In the work [5], it has been explained the balancing of the multiproduct garment production line using the simulation technique. The study was applied on the production line consists of 12 class 301 single needle sewing machine, eight class 504 overlock-stitch machine and six class 401 chain – stitch machines. This means that the study solved the problem mainly via sewing department [5].

The industrial sewing machine could be divided to four categories as: half-automatic, mechanical class, basic sewing machine and automatic transfer line [6]. Concerning the elastic compressive balancing load of sewing needle (as slender column), the machine detail, the energy method - critical & Euler loads - could be applied [7-10], etc.

Finally, if the needle is not changed regularly, it can cause major quality problems. The needle is subject to the most use of all machine parts as it penetrates the material at speed of 5000-6000 stitches/min for lockstitch and 8000-10000 stitches/min for chain stitch. The friction caused by the penetration between needle and fabric causes an extreme heat with the needle temperature of 250-300°C. When the fabrics are stitched together, the impact of the needle as it penetrates the fabric can cause needle buckling and distortion of the yarns and fibers. A smaller diameter needles reduces the mechanical forces exerted on the yarn. The mechanical strain on the yarns increases if the needle is damaged. The damage can cause the fibers to rupture which reduce the seam strength significantly [11].

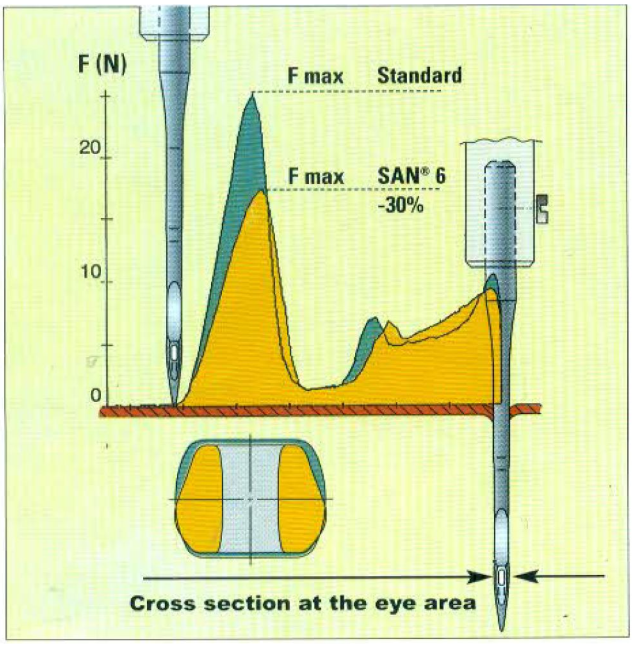

Figure 2 Phases of the sewing needle free end – interaction with the sewn layers of fabric [3]; the blue color refers to the standard needle in the chart; the orange color refers to the SAN 6 needle in the chart, both needle are Groz-Beckert made

2 THEORETICAL APPROACH

Figure 3a shows an industrial sewing needle where it is fixed – fixed ends during its travel form the top layer of multilayer to the bottom layer of sewn fabric (heavy type). The loads on the needle as it buckles are shown in the figure. From Figure 3b it could be seam that the loads balancing requires that:

$$P.X + F.y - M_A = M_0 \quad (1)$$

As it is well known that the resisting moment M_0 is:

$$M_0 = -EI.X^{\backslash\backslash} \quad (2)$$

The differential formula for equilibrium (balancing) of the sewing needle can be written as:

$$X^{\backslash\backslash} + \lambda^2.X = -\frac{F}{EI} + \frac{M_A}{EI} \quad (3)$$

where: $\lambda^2 = -F/EI$.

The solution of the formula (3) has a general solution that consists of a complementary part and a particular part satisfying the entire equation. Thus the general solution of formula (3) is:

$$X = A\sin\lambda y + B\cos\lambda y - {}^{F.y}/_{P} + {}^{M_A}/_{P} \quad (4)$$

From boundary conditions of the sewing needle:

$$\left.\begin{matrix} X(0) = 0 & X^{\backslash}(\ell) = 0 \\ X(\ell) = 0 & X^{\backslash}(\ell) = 0 \end{matrix}\right\} \quad (5)$$

Then where *y=0*, we have:

$$B = -{}^{M_A}/_{P};\ A = {}^{F}/_{P\lambda} \tag{6}$$

By substituting of formula (6) in equation (4), we will have:

$$X = {}^{F}/_{P\lambda} \sin\lambda y - {}^{M_A}/_{P} \cos\lambda y - {}^{F.y}/_{P} + {}^{M_A}/_{P} = 0 \tag{7}$$

By introducing $X(\ell) = 0$, we can write:

$${}^{F}/_{P\lambda} \sin\lambda\ell - {}^{M_A}/_{P} \cos\lambda\ell - {}^{F.y}/_{P} + {}^{M_A}/_{P} = 0 \tag{8}$$

When we apply $X^{\backslash}(\ell) = 0$, we can say:

$${}^{F}/_{P} \cos\lambda\ell + {}^{M_A.\lambda}/_{P} \sin\lambda\ell + {}^{F}/_{P} = 0 \tag{9}$$

From formulas (8 & 9) for a nontrivial solution of F & M_A , we must obtain (fundamental critical load formula):

$$\lambda\ell \sin\lambda\ell + 2\cos\lambda\ell - 2 = 0 \tag{10}$$

By introducing the trigonometrical identity $\sin\lambda\ell = 2\sin\lambda\ell/2\ \cos\lambda\ell/2$ and $\cos\lambda\ell = 1 - 2\sin^2\lambda\ell/2$, then equation (10) can be written as:

$$\sin\frac{\lambda\ell}{2}\left[\frac{\lambda\ell}{2} - \sin\frac{\lambda}{2}\right] = 0 \tag{11}$$

The last formula (11) can be satisfied if either the first term $\sin\frac{\lambda\ell}{2}$ or the items in the parenthesis disappear. If the first term disappears, the solution is $\lambda\ell = 2\pi.n$ where $n = 1, 2, 3,$ ....from which the critical axial compressive force P_{cr} is obtained by substituting $n = 1$, this means that:

$$P_{cr} = \frac{\pi^2}{\left({}^{1}/_{2}\right)^2} * \frac{EI^{\backslash}}{\ell^2} = \eta^{\backslash}\frac{EI}{\ell^2} \tag{12}$$

where: $\lambda = \frac{1}{2}$, $\eta^{\backslash} = 4\pi^2$ and $P_{cr} = P_e$ (Euler load).

For the sewing needle (symmetrical) of an industrial sewing machine, the value $\frac{EI^{\backslash}}{\ell^2} = 42$ N [8]. The critical load is:

$$P_{cr} = 1658\ N \tag{13}$$

If the terms in the parenthesis vanish, then the lowest value that gives satisfaction equation $\frac{\lambda\ell}{2}\cos\frac{\lambda\ell}{2} = 0$ or $\tan\frac{\lambda\ell}{2} = \frac{\lambda\ell}{2}$ is $\lambda\ell = 8.987$ from that; the critical axial compressive force P_{cr} (for unsymmetrical) is:

$$P_{cr} = \frac{80.766}{(1)^2} * \frac{EI^{\backslash}}{\ell^2} \tag{14}$$

For the industrial sewing needle $(EI^{\backslash}/\ell^2) = 42\ N$, then:

$$P_{cr} = 3392\ N \tag{15}$$

i.e. for the sewing needle, the critical load when it completely fixed from both ends, specially lower end when it penetrates a heavy multilayer sewn fabrics, the axial critical compressive force P_{cr} is varying from 1658-3392 N.

The symmetric buckling load of the sewing needle is shown in Figure 3c in such more of buckling means that the lower end of the sewing needle just to get started few millimeters in the sewn multilayer fabrics. The continuity of the lower end of the sewing needle – downward motion - gives more resistance to penetration. Therefore the strength of lower end fixation is increased consequently, the buckling made of the needle is getting may be unsymmetrical as shown in Figure 3d. The change from buckling symmetrical mode to the unsymmetrical buckling made will be explained as follow:

This may be related to the strength of support rigidity or stiffness where it is weak we have low critical load i.e. less resistance to buckling, while when the support stiffness is great will lead to great resistance for buckling. Consequently the axial compressive critical load is folded, i.e. is relative high value. The values of equations 14 and 15 correspond to critical load of symmetric (Figure 3c) or unsymmetrical (Figure 3d) buckling modes of the sewing needle, consequently. The critical load of the symmetric buckling mode is lower than that of the unsymmetrical buckling mode.

The needle will buckle in the symmetric mode, unless the mid length of the needle is traced against lateral movement, P_{cr} will follow formula (13) will have little significance to us. The elastic line of the symmetric buckling mode can be obtained by substituting *F*=0 (because of symmetry) and $\lambda = \frac{2\pi}{\ell}$ in equation (7), then:

$$X = \frac{M_A}{P}\left(1 - \cos\frac{2\pi y}{\ell}\right) \tag{16}$$

If we write $\lambda\ell$ as the effective length of the fixed – fixed sewing needle, the equivalent pinned – pinned sewing needle Euler theorem $\lambda\ell$ (Figure 3c) that will with stand the same critical load as fixed – fixed sewing needle that has length ℓ can be obtained by finding a solution for the following formula:

$$\frac{\pi^2 EI}{(\lambda\ell)^2} = \frac{4\pi^2 EI}{\ell^2} \tag{17}$$

That can give $\lambda\ell = \frac{1}{2}\ell\ \ i.e.\ \lambda = \frac{1}{2}$, i.e. the equivalent length of the Euler beam (pinned – pinned column) is half of the fixed – fixed column the inflection points of the fixed – fixed needle are at a distance of $\ell/2$ apart (Figure 3c). The factor λ is called effective length factor of the fixed – fixed sewing needle. To the verification that the inflection points are indeed (as is shown in Figure 3c), we will write the moment expression along the length of the sewing needle and set it equal to zero to calculate distance y that gives the location of the inflection point. By differentiating the formula (16) twice we can write the moment expression as:

$$M = -EI.X^{\backslash\backslash} - EI\ \frac{M_A}{P}.\frac{\pi^2}{\ell^2}.\cos\left(\frac{2\pi y}{\ell}\right) = 0 \tag{18}$$

then $\cos\left(\frac{2\pi y}{\ell}\right) = 0$ or $y = \frac{n\ell}{4}$, $n = 1, 2, 3, \ldots\ldots$

Using $n = 1$ & 3 give $y = {}^{\ell}/_{4}$ & ${}^{3\,\ell}/_{4}$.

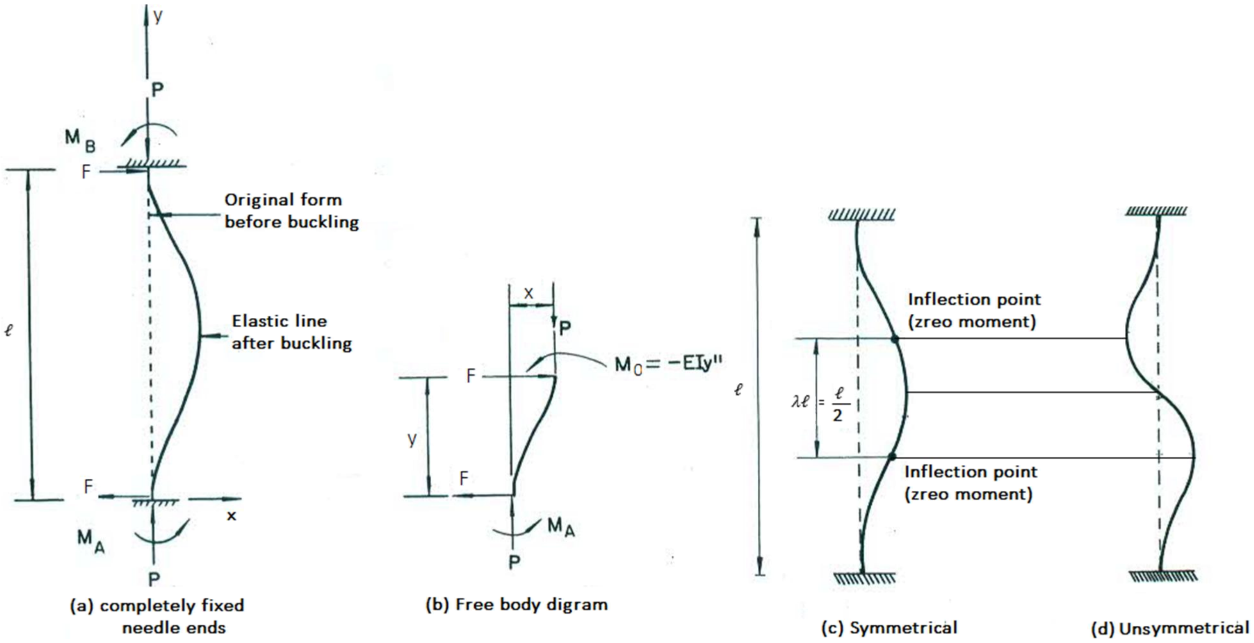

Figure 3 Fixed-fixed industrial sewing needle (a, b); symmetric and unsymmetrical buckling modes of a fixed-fixed industrial sewing needle (c, d)

Hence inflection points are located at $y = {}^{3\ell}/_4 - {}^{\ell}/_4 = {}^{\ell}/_2$ as shown in Figure 3c.

Generally, for a centrally and fixed – fixed sewing needle, the equivalent (effective) λ can be evaluated directly by the formula:

$$\lambda = \sqrt{\frac{P_e}{P_{cr}}} \tag{19}$$

where: P_{cr} – critical axial compressive force of sewing needle i.e. resisting force during needle penetration in the sewn fabric; P_e – Euler force of the pinned – pinned (minimum value of P_{cr}) sewing needle that have the same length factor similar to that of equations (17 & 19) can be easily derived from the definition of length factor λ as in equation (17).

By application of sewing needle database [8] for equations (12 & 14) we can have $P_{cr} = P_e = \pi^2 \frac{EI}{\ell^2}$ and for fixed – fixed ends column (needle) with symmetrical buckling curve $P_{cr} = 39.9484 \times \frac{EI}{\ell^2}$.

3 CONCLUSIONS & FUTURE VISIONS

From the previous results and discussions the following conclusions & future visions can be drawn out:

1. The industrial sewing needle when just to get starting of penetration in the layers of heavy multilayer sewn fabrics, several cases of ends constrain will be built:

   Case A: The lower end of the sewing needle will be surrounded by textile materials pressing everywhere to accumulate internal pressures. This will grip the needle lower end to make it fixed or completely partially supported:

   a) The needle elastics buckling line is symmetric i.e. has a two symmetric inflection points where bending moments around them is zero. The distance y between them is ${}^{\ell}/_2$ and between each point and needle supports is $y = {}^{\ell}/_4$ (this is for 3rd phase of penetration).

   b) The critical load (fundamental) in general is $P_{cr} = \eta^{\backslash} \frac{EI}{\ell^2}$

      where: P_{cr} - fundamental critical load, $\eta^{\backslash}$ - elastic stability factor, $\left(\frac{\pi}{\lambda}\right)^2$, EI - needle bending stiffness and ℓ - needle length

      then $P_{cr} = 4\pi^2 \times 42 = 1658\ N$, when $\eta^{\backslash} = 4\pi^2$, $\lambda = \frac{1}{2}$ & $\frac{EI}{\ell^2} = 42\ N$.

   Case B: When the lower end of the sewing needle of the industrial sewing machine – travels downward is increased, consequently:

   a) The buckling elastic line of the sewing needle became unsymmetrical.

   b) The anti-symmetric critical load is $P_{cr} = \frac{8\ 07\ 6\ 6}{(1)^2} \cdot \frac{EI}{\ell^2} = 81 * 42 = 3392\ \ N$

2. The equivalent length factor is $\lambda = \sqrt{\frac{\mathrm{P_e}}{\mathrm{P_{cr.}}}} = 0.3496\ \cong 0.30$

3. Always for the sewing needle under buckling load $\eta^{\backslash} = \frac{\pi^2}{\lambda^2}$, $P_{cr} = \eta^{\backslash} \frac{EI}{\ell^2}$, for traditional sewing needle $\frac{EI}{\ell^2} = 42\ \ N$, λ equivalent length factor.

4. The 3rd phase of the sewing needle interaction with the sewn multilayer fabric is fixed – fixed ends with different shapes of buckling elastic line.
5. Future vision means intensive experimental to verify the theoretical approaches. In addition, the theoretical study must consist of the sewing industrial needle with its variable cross-sections (CSA). In the running study we considered the sewing needle is with constant cross-section (CSA).
6. The data base of the applied needle for calculation is a commercial and industrial type with two – stepped sections, $\ell = 60\, mm$, $\bar{\varphi} = 1.965\, mm$ (constant cross-section), $I = 7.3185\,(E - 13)\, m^4$.
7. The equation of the buckled elastic line of the fixed – fixed ends needle (symmetrical) $X = \frac{M_A}{3390}\left(1 - cos\,\frac{2\pi y}{\ell}\right)$.

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