Structure and Elongation of fine Ladies' Hosiery

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Abstract. On a sock-knitting machine with diameter of cylindrical needle bed 100 mm (4" e) that knitted with 400 needles, samples of fine women’s hosiery were made from four PA filament yarns in counts 20 dtex f 20, 30 dtex f 34, 40 dtex f 40 and 60 dtex f 60. Each type of yarns was used to make hosiery samples with four loop sinking depths of unit values in a computer program 400, 550, 700 and 850. For all the samples, parameters of yarn structure were analyzed and elongation properties of knitted fabric were measured. During the elongation of knitted fabric, areas of knitted fabric elasticity, beginning of permanent deformation and elongation at break were measured. Elongation of knitted fabric in the wale direction, i.e. transverse hosiery elongation and elongation of knitted fabric in the course direction, or longitudinal direction of hosiery were measured. Yarn fineness and loop sinking depth significantly influence the elongation properties of hosiery.

1. Introduction

Fine ladies’ hosiery is made on specially designed sock-knitting machines. Those are cylindrical machines of small-diameter needle bed, most commonly 90 to 125 mm (3 ½ to 5 e). Hosiery is basically intended for adult women and is often made on automatic machines with cylinder diameter of 100 mm (4 e), that use 400 needles, i.e. have the gauges E32, cf. Table 1. On such an automatic machine, a sock is knitted in 120 to 300 s, depending on the constructional shape of a sock and a series of technological parameters. After the knitting process, the sock needs to be finished in the sewing department. In case of pantyhose, two legs are joined, without or with different inlays. The sewing process is followed by the refinement process, including sock dyeing and ironing [1-3].

Table 1. Relation between cylinder diameter, machine gauge and number of needles in one-cylinder automatic sock-knitting machines designed for making fine ladies' hosiery [4]

| Machine gauge, E | Number of needles in a machine |
|------------------|-------------------------------|
|                  | Cylinder diameter, (approximate) |
|                  | mm → 90 | 95 | 100 | 110 | 115 | 125 |
| in → 3 ½        | 3 ¾     | 4 ½ | 4 ½ | 4 ½ | 5   |
| 24               | 260/264 | 284 | 304 |     | 376 |
| 26               | 280     | 328 |     |     |     |
| 28               | 306     | 330 | 340 | 376 | 396 | 440 |
| 30               | 330     | 354 | 376 | 400 | 424 | 472 |
| 32               | 352     | 376 | 400/402 | 432 | 452 | 500 |
| 34               | 370     | 400 | 422 |     | 480 |
| 36               |         | 424 |     |     |     |
| 38               |         | 448 |     |     | 512 |
Fine women’s hosiery is usually made using three types of thread [5-7]:
1. polyamide (PA) filament threads,
2. polyester (PES) filament threads,
3. elastane threads.

The given thread types are used in various combinations depending on the purpose of hosiery. In the production of simpler and cheaper hosiery, only one thread composition is used, usually only PA filament threads, rarely PES threads, Figure 1. Apart from PA filament thread, different elastane threads (e.g. Lycra) are used due to hosiery’s comfortable fit on the leg and wearing comfort. Elastane thread can be knitted into each row next to the PA filament thread, or knitted only into certain rows or separate sections of hosiery. When designing structure and tensile properties of hosiery at its particular sections, a designer will use the elongation properties of PA and elastane yarns and incorporate them to an extent into certain parts of hosiery. The share of elastane thread significantly determines hosiery’s elongation properties, i.e. its compressibility on the leg, and thereby its wearing comfort.

![Figure 1](image_url)

**Figure 1.** Basic structure of simple fine women’s PA hosiery; a) plain is the base structure of ladies’ hosiery, b) position of PA filament thread in the basic structure of hosiery – a stretched structure and c) position of threads in shrunk hosiery.

One of hosiery’s roles is to protect the leg from external influences, primarily cold and wind. Therefore, the structure of filament yarns for hosiery production is different than the structure of filament yarns for the production of clothes: T-shirt, shirts, dresses, skirts, pants, etc.

Filament yarns for hosiery production are made of several fibers. Fineness and number of fibers determine the fineness of filament yarn. Number of twists determines the structure of filament yarn. Greater number of threads in filament yarn brings greater wearing comfort of hosiery. Yarn with a larger number of fibers produces more difficulties and hold-ups in the knitting process causing a significantly higher amount of errors, losses and production waste. It is necessary to find an optimal number of fibers that will make-up a filament yarn according to the product’s purpose. On the market, there are various counts of filament yarns with different number of fibers. Filament yarns from 10 to 33 dtex, most commonly 13, 17, 22 and 33 dtex are usually used to make fine women’s hosiery. These yarns may contain 5 to 37 fibers which usually have a circular cross-section and counts in 2.5 to 3.5 dtex. Somewhat coarser hosiery is made of 20 to 60 dtex yarns, most commonly 20, 33, 40 and 60 dtex with microfibers from 0.8 to 1 dtex [8,9].

There are a few methods of making filament yarns for hosiery production. Classic filament yarns are made with very few twists, usually up to 50 twists/m, or without twists, i.e. fibers are not twisted during yarn construction. In this case, yarn in the knitted fabric is not compact but spread out on the surface it covers. In that way, fibers have a bigger surface of fit on the leg and produce a higher surface friction coefficient and greater wearing comfort. Only much finer fibers are used in the construction of the other yarn shape, often 1.5 to 2.5 dtex, of which there are more in a single yarn. Use of microfibers results in high-quality hosiery. In order to prevent fibers from causing problems...
during knitting, yarns are ostensibly stuck together at every 10, 15, 20 or 25 mm and thus knitted into loop wales. Elongation at break of PA filament yarns for hosiery production is 20 to 35 %, and that of elastane yarns is 200 to 900 %. With such yarns, it is possible to accomplish different extensibility and compressibility of hosiery on the leg. In the production of classic cotton short socks, cotton yarns of elongation at break around 5 % are used, cf. Figure 2.

![Figure 2. Yarn elongation properties in hosiery production: a) cotton yarns used in the production of short socks, b) PA filament yarns for the production of fine ladies' hosiery and c) elastane yarns](image)

When designing fine ladies’ hosiery a constructor or designer must be familiar with measures of the leg for which the hosiery is intended and fit the measures to the sizes found in the standard. In order to make a functional product, a designer should also be familiar with structures, and primarily elongation properties of yarns they want to use to make fine hosiery. Fibers that build the yarn can be smooth or textured, i.e. slightly wavy. Some yarn structures are used to make hosiery for particular purposes.

Structure and elongation properties of yarns are key parameters in hosiery design. Yarn properties should be consolidated with constructional properties of a machine in order to make hosiery of a particular size and wearing comfort. In different interlacements, a single sock-knitting machine can be used to knit with filament yarns of certain yarn count, structure and elongation properties. When making hosiery using a single count of filament yarn, it is necessary to obtain certain widths of a knit on different hosiery sections that will envelop the leg comfortably. Apart from different widths in one sock, it is necessary to obtain a certain hosiery elongation. This is usually realized by the application a certain interlacement and regulation of loop sinking depth on the machine. Therefore, yarn count and elongation properties of filament yarn, as well as the type of interlacement and loop sinking depth are the main parameters that determine elongation properties of hosiery being used. That is why the experimental part of this paper investigates the influence of yarn count and loop sinking depth on elongation properties of fine women’s hosiery.

2. Experimental work

The aim of this research is to get information about the extent of influence of count of PA filament yarn and loop sinking depth on the structure and elongation properties of fine women’s hosiery. A machine used in everyday production was used to make sample hosiery. Simpler forms of fine women’s hosiery available on the market are made in plain structure, cf. Figure 1a. This interlacement was used to conduct this experiment. Hosiery is produced from filament PA yarns of different counts and structures. Four different kinds of PA yarn counts and four loop sinking depths were used in this experiment.

3. Properties of the machine for the production of samples

For this research, an automatic sock-knitting machine with diameter of cylindrical needle bed 4e” that knitted with 400 needles on four knitting systems was used, Table 2. The distance between the centers of two neighbouring needles is 0.80 mm. Needle body thickness is 0.33 mm, and the hook for picking up threads 0.26 mm. In this construction of automatic machine, needle hook thickness is 2 to 5 times bigger than the conditional knitting-yarn thickness, i.e. such automatic machines are recommended for producing fine women's hosiery with threads of conditional thickness 0.05 to 0.1 mm, i.e. yarn count.
in 13 to 72 dtex. A single type of yarn and different loop sinking depths are used to make fine women’s hosiery. In this case, sampling hosiery and measuring their elongation is difficult, because two or three different yarn densities obtained at particular loop sinking depths are mixed on a small surface of the knitted fabric. Therefore, the hosiery samples used in this research were made at a single loop sinking depth. Samples of tubular knits and socks are 40 to 80 cm long and suitable for various analyses.

Table 2. Properties of the machine used for the production of fine women’s hosiery samples

| Machine gauge, E | Cylinder diameter, mm | Number of knitting systems, S | Number of needles, N_i | Cylinder operating speed, min⁻¹ |
|-----------------|-----------------------|-------------------------------|------------------------|-------------------------------|
| 32              | 100                   | 4                             | 400                    | 250 do 700                    |

4. Properties of PA filament yarns for the production of samples

PA filament yarns of four different types of fineness were used. Every yarn has its properties, Table 3. The finest yarn has 20 dtex, and the coarsest 60 dtex. Yarn in 20 dtex is made with 20 fibrils and yarn in 60 dtex with 60 fibrils. Predominant fineness of fibrils is 1 dtex. Yarn elongation properties are presented in Figure 3 and Table 4. In diagrams showing yarn elongation properties it can be seen that yarns are uneven and that some fibrils are broken. Yarns in 40 dtex f 40 have the smallest elongation at break of 21.4±0.4 %, while yarns in 20 dtex f 20 have 25.9 ± 0.4 %. Breaking loads are within limits 3.8 to 5.0 cN/dtex. The given properties of yarns are the basic parameters used in theoretical research of relation between yarn elongation properties and hosiery united in an interlacement.

Table 3. Properties of PA fibrils and yarns for the production of samples

| Yarn count | Approximate fibril diameter, mm | Approximate total surface of fibril cross-section, mm² | Sample label |
|------------|--------------------------------|-----------------------------------------------------|--------------|
| 20 dtex f 20 | 0.012                         | 0.00226                                             | 1 X C 1 X Z 1 X P 1 X O |
| 33 dtex f 34 | 0.011                         | 0.00322                                             | 2 X C 2 X Z 2 X P 2 X O |
| 40 dtex f 40 | 0.012                         | 0.00452                                             | 3 X C 3 X Z 3 X P 3 X O |
| 60 dtex f 60 | 0.012                         | 0.00678                                             | 4 X C 4 X Z 4 X P 4 X O |

Figure 3. Diagrams of elongation properties of polyamide filament yarns for the production of samples: a) 20 dtex f 20, b) 33 dtex f 34, c) 40 dtex f 40 and d) 60 dtex f 60

Four knit samples at different loop sinking depths were made using each yarn. The machine works in CAD/CAM system whose smallest loop sinking depth is 400 and biggest 850 units. Samples made at the smallest loop sinking depth are labelled with C, and those at the biggest with O, Table 3.
5. Results of measuring parameters of knit structure in fine women's hosiery

Samples of fine women's hosiery were knitted using four PA filament yarns in counts 20, 33, 40, and 60 dtex, Table 5. Each yarn was used to make four basic samples. Each sample was made with a different loop sinking depth of 400, 550, 700 and 850 units (orientationally nondimensional number in a computer programme) [10]. Therefore, four groups of samples in four yarn counts were produced, or the total of 16 basic samples. Each sample was used to make ten pieces of hosiery, i.e. the total amount of hosiery knitted was 160 pieces, which were all torn during the analysis of the knit and measurement of yarn elongation properties.

Table 5. Parameters of knit structure in fine women’s hosiery produced

| T_l, dtex | h_k | m, g/m³ | S_p, mm | d_pl, mm | m_v, g/cm³ | D_h, l/cm | D_s, l/cm | C | D, l/cm² | ℓ, mm | L, mm/cm² |
|----------|-----|---------|---------|----------|------------|-----------|-----------|---|----------|-------|-----------|
| 20       | 400 | 38      | 118     | 0.28     | 0.146      | 17.0      | 45.9      | 0.59 | 779      | 2.16  | 1684      |
| 20       | 550 | 37      | 117     | 0.31     | 0.126      | 17.1      | 37.6      | 0.60 | 642      | 2.49  | 1598      |
| 20       | 700 | 35      | 122     | 0.33     | 0.112      | 16.4      | 33.4      | 0.77 | 548      | 2.80  | 1535      |
| 20       | 850 | 34      | 122     | 0.32     | 0.113      | 16.3      | 29.1      | 0.77 | 475      | 3.13  | 1486      |
| 33       | 400 | 55      | 111     | 0.32     | 0.184      | 18.1      | 40.3      | 0.46 | 730      | 2.19  | 1598      |
| 33       | 550 | 51      | 111     | 0.34     | 0.159      | 18.1      | 32.0      | 0.56 | 577      | 2.53  | 1460      |
| 33       | 700 | 50      | 124     | 0.37     | 0.141      | 16.1      | 30.7      | 0.67 | 494      | 2.86  | 1413      |
| 33       | 850 | 50      | 123     | 0.40     | 0.130      | 16.3      | 27.3      | 0.78 | 444      | 3.20  | 1422      |
| 40       | 400 | 58      | 118     | 0.32     | 0.191      | 17.0      | 38.3      | 0.44 | 651      | 2.17  | 1413      |
| 40       | 550 | 54      | 120     | 0.35     | 0.163      | 16.7      | 31.2      | 0.54 | 521      | 2.52  | 1312      |
| 40       | 700 | 50      | 128     | 0.37     | 0.143      | 15.6      | 27.1      | 0.76 | 422      | 2.81  | 1186      |
| 40       | 850 | 49      | 133     | 0.41     | 0.127      | 15.0      | 24.7      | 0.81 | 371      | 3.21  | 1191      |
| 60       | 400 | 99      | 116     | 0.38     | 0.276      | 17.2      | 43.3      | 0.34 | 744      | 2.15  | 1599      |
| 60       | 550 | 92      | 116     | 0.43     | 0.223      | 17.2      | 34.2      | 0.46 | 589      | 2.47  | 1455      |
| 60       | 700 | 83      | 119     | 0.45     | 0.193      | 16.8      | 28.1      | 0.58 | 471      | 2.82  | 1328      |
| 60       | 850 | 77      | 130     | 0.44     | 0.182      | 15.3      | 25.3      | 0.72 | 388      | 3.17  | 1229      |

Abbreviations: T_l – yarn count, dtex, h_k – loop sinking depth, dimensionless number, m – yarn mass per unit area, g/m², S_p – knit width, mm, d_pl – knit thickness, mm, m_v – knit volume mass, g/cm³, D_h – compactness of loops in the knit wale, l/cm, D_s – compactness of loops in the knit course, l/cm, C – coefficient of loop compactness, D – number of loops per basic unit of surface, l/cm², ℓ – thread consumption in a loop, mm, L – thread consumption per basic unit of surface, mm/cm²

Diameter of cylindrical needle bed of the automatic machine used to produce hosiery is 100 mm and its perimeter is around 315 mm. On a cylinder of this size, different lengths of hosiery were produced. The narrowest sock has the width of 111 mm x 2 (tubular shape) and it is produced by knitting yarns in 33 dtex and loop sinking depth of 400. In this sock, shrinkage of the knit in the wale
direction after removal from the machine and relaxation is 30 %. The widest sock is obtained by knitting with the coarsest yarn, i.e. yarn in count 60 dtex and loop sinking depth of 850, and it is 133 mm x 2. In this sock, knit shrinkage is around 15 %. Knit mass per unit area for hosiery is within the range of 34 and 99 g/m², and knit thickness in hosiery between 0.28 and 0.45 mm. Information about the knit given refers to one loop so as to demonstrate the fineness of the knit structure. Thread consumption for the formation of one loop ranges from 2.15 to 3.21 mm where the knit has 371 to 779 l/cm², or 1186 to 1648 mm of yarn is woven into one cm² of the knit. These knits are currently considered to be among finest knits in the world. An operating analyst striving to analyze parameters of their structure must be very experienced in order to conduct a proper analysis.

6. Results of measuring hosiery elongation

When using hosiery, the most important is the extensibility or elongation when tensile force is applied in the wale direction, or the so called transverse elongation, Fig. 4 and Table 6. It is significant when a sock is being put on a leg. Hosiery elongation in the course direction or the so called elongation along the sock is equally important, Table 7. It is primarily related to the height of a person wearing hosiery, as well as hosiery size. However, an important factor during long-term wear is the orbicular elongation of a sock which is flatly pressing the leg, and represents an important parameter in the evaluation of hosiery's wearing comfort. Orbicular elongation of a sock is the basis for determining its compressibility. This parameter is significant for the use of numerous hosiery types, e.g. socks for special uses: for soldiers and athletes (football, handball and volleyball players, skiers, etc.), for therapeutic purposes (injured patients who are often in a comatose condition), medical applications (prevention or protection of varicose veins) [11,12].

In this research, hosiery elongation was measured in the wale direction and course direction. Samples were 50 mm wide and 150 mm long for all measurements while the distance between clamps on the testing machine was 100 mm. Figure 4 shows mean tear values of several main knit samples. Three important values related to hosiery elongation were read from the diagram [13]. First, the linear part of the diagram to the point T₁ represents an elastic area (εₑ) which in structures like this occupies around 53 % of total knit elongation, Figure 5. The other part of the diagram from the point T₁ to the point T₂ represents a boundary area or a part that connects the elastic area and the area of permanent deformation. Its share in this kind of structure is around 14 %. The third part of the diagram stretches from the point T₂ to the point of break and represents permanent or plastic deformation (εₚ). This part makes up around 33 % of total elongation. During elongation and in the moment of knit tearing, the testing machine records the length of elongation at break (εₚ), which is usually not controversial. However, simple and accurate determination of the area of elasticity, i.e. point T₁ and the beginning of permanent deformation, i.e. point T₂ is not always easy. In different knit structures including fine
women's hosiery, this area, i.e. the boundary area of elasticity and the area where permanent deformation begins, has not been investigated enough. Table 6 and Table 7 provide the values that were estimated for the given points.

**Figure 5.** Hosiery elongation; a) basic force/elongation diagram for fine women's hosiery and b) increased structure of the elongated knit with visible positions of some poorly spun fibers in filament yarn.

| Yarn count | Loop sinking depth | $\varepsilon_{ep}$, % | $\Delta\varepsilon_{ep}$, % | $\varepsilon_{pp}$, % | $\Delta\varepsilon_{pp}$, % | $\Delta\varepsilon_{pp} - \Delta\varepsilon_{ep}$, % | $\varepsilon_{tp}$, % | $\Delta\varepsilon_{tp} - \Delta\varepsilon_{pp}$, % |
|------------|-------------------|-----------------------|----------------------|-----------------------|----------------------|------------------------|-----------------------|------------------------|
| 20         | 400               | 90                    | 40                   | 150                   | 66                   | 26                     | 227                   | 34                     |
| 20         | 550               | 180                   | 60                   | 220                   | 73                   | 13                     | 302                   | 27                     |
| 20         | 700               | 260                   | 67                   | 290                   | 75                   | 8                      | 389                   | 25                     |
| 20         | 850               | 250                   | 68                   | 270                   | 74                   | 5                      | 366                   | 26                     |
| 33         | 400               | 140                   | 56                   | 160                   | 64                   | 8                      | 249                   | 36                     |
| 33         | 550               | 190                   | 58                   | 220                   | 67                   | 9                      | 330                   | 33                     |
| 33         | 700               | 220                   | 64                   | 240                   | 70                   | 6                      | 343                   | 30                     |
| 33         | 850               | 200                   | 53                   | 260                   | 69                   | 16                     | 378                   | 31                     |
| 40         | 400               | 90                    | 45                   | 130                   | 65                   | 20                     | 200                   | 35                     |
| 40         | 550               | 120                   | 45                   | 170                   | 64                   | 19                     | 267                   | 36                     |
| 40         | 700               | 160                   | 52                   | 210                   | 68                   | 16                     | 310                   | 32                     |
| 40         | 850               | 200                   | 57                   | 240                   | 69                   | 11                     | 349                   | 31                     |
| 60         | 400               | 60                    | 30                   | 110                   | 55                   | 25                     | 200                   | 45                     |
| 60         | 550               | 120                   | 44                   | 160                   | 59                   | 15                     | 270                   | 41                     |
| 60         | 700               | 180                   | 53                   | 240                   | 70                   | 18                     | 342                   | 30                     |
| 60         | 850               | 180                   | 50                   | 250                   | 69                   | 19                     | 360                   | 31                     |

| 53±5       | 67±3              | 14±3                  | 33±2                  |

**Abbreviations:** $\varepsilon_{e}$ – elongation or extensibility of the knit to the point $T_1$, elastic area, %; $\varepsilon_{p}$ – elongation or extensibility of the knit to the point $T_2$, to the beginning of the area of elasticity, %; $\varepsilon_{t}$ – elongation or extensibility of the knit to the moment of break, %; $\Delta\varepsilon_{e}$ - share of elastic area in relation to total elongation, %; $\Delta\varepsilon_{p}$ - share to the beginning of plastic area in relation to total elongation, %; $\Delta\varepsilon_{tp} - \Delta\varepsilon_{ep}$ - share between the points $T_1$ and $T_2$, %; $\Delta\varepsilon_{tp} - \Delta\varepsilon_{pp}$ - share between the point of break and $T_2$, %; index $p$ marks the wale direction – transversely, and in Table 7, longitudinal direction is marked by the index $u$. 
Table 7. Results of knit elongation in fine women's hosiery in the course direction – longitudinally

| Yarn count | Loop sinking depth | $\varepsilon_{cu}$, % | $\Delta\varepsilon_{cu}$, % | $\varepsilon_{pu}$, % | $\Delta\varepsilon_{pu}$, % | $\Delta\varepsilon_{pu} - \Delta\varepsilon_{cu}$, % | $\varepsilon_{tu}$, % | $\Delta\varepsilon_{cu} - \Delta\varepsilon_{pu}$, % |
|------------|------------------|------------------|------------------|------------------|------------------|---------------------------------|------------------|---------------------------------|
| 20         | 400              | 180              | 56               | 230              | 71               | 15                              | 323              | 29                              |
| 20         | 550              | 240              | 71               | 250              | 74               | 3                               | 338              | 26                              |
| 20         | 700              | 230              | 72               | 240              | 75               | 3                               | 319              | 25                              |
| 20         | 850              | 270              | 73               | 290              | 79               | 5                               | 369              | 21                              |
| 33         | 400              | 200              | 67               | 220              | 74               | 7                               | 298              | 26                              |
| 33         | 550              | 170              | 63               | 200              | 75               | 11                              | 268              | 25                              |
| 33         | 700              | 200              | 66               | 220              | 73               | 7                               | 302              | 27                              |
| 33         | 850              | 170              | 57               | 220              | 73               | 17                              | 300              | 27                              |
| 40         | 400              | 150              | 62               | 170              | 70               | 8                               | 243              | 30                              |
| 40         | 550              | 140              | 55               | 160              | 63               | 8                               | 255              | 37                              |
| 40         | 700              | 150              | 56               | 190              | 71               | 15                              | 266              | 29                              |
| 40         | 850              | 170              | 64               | 190              | 71               | 7                               | 267              | 29                              |
| 60         | 400              | 170              | 57               | 200              | 67               | 10                              | 300              | 33                              |
| 60         | 550              | 160              | 58               | 190              | 69               | 11                              | 277              | 31                              |
| 60         | 700              | 150              | 58               | 180              | 69               | 12                              | 260              | 31                              |
| 60         | 850              | 150              | 60               | 180              | 73               | 12                              | 248              | 27                              |
|            |                  | 62±3             | 72±2             | 9±1              |                  | 28±2                            |                  |                                  |

The main problem in measuring uniaxial tensile load of the knit is the very complex strain in the sample during tensile load. During elongation of a knit sample, the decrease of its width is uneven. At the point where it is fixed by grapples or clamps, the sample does not narrow. As the force and degree of elongation increase, the sample is becoming narrower and narrower in the middle. The point where the sample breaks is not always at the narrowest part. It often occurs at the point of contact with the grapple-clamp.

Peak loads or forces of breaking during strain are not important in the application of fine ladies’ hosiery. Instead, the significant information is related to hosiery's elasticity and compressibility on the leg. When they put on a sock, women usually apply the force up to 60 N to pull the sock to a certain part of the leg. When the sock is pulled on the leg, the knit of the sock is unevenly formed, similarly to elongation on a dynamometer. Elongation of particular sections of a sock is regularly checked in the technological process of hosiery production. In order to measure hosiery elongation, manufacturers have internal regulations in sewing departments and a tabular display of extensibility of a particular section of hosiery under the force of 45 N. Some hosiery manufacturers have an elaborate system for measuring hosiery elongation at various loads. Under certain conditions they use tensile forces from 35 to 60 N with the 5 N step. For example, that is the method of measuring the length of elongation of smooth hosiery made of PA filament yarns in count 13 dtex under the tensile force of 35 N. Hosiery made of yarn in count 17 dtex is loaded with the tensile force of 40 N, or the hosiery made of yarns in count 60 dtex with the tensile force of 55 N. The tensile forces and elongations given are in some factories prescribed and adjusted to yarn counts and structures, parts of hosiery, knit structures, for unfinished, as well as finished or completed hosiery.

This paper gives the results of measuring structure parameters and elongation properties of knits after the knitting process. The knit is unfinished. In the process of production such knits are finished, i.e. they are subjected to chemical processes. After finishing, knitted fabrics change their properties, often around 3 %, and even up to 10 % for some of their properties. Therefore, pieces of
hosiery that can be found on the market have somewhat different properties than the one discussed above.

7. Properties of completed hosiery
From the above mentioned it can be concluded that parameter values of knit structure in fine women's hosiery have a direct impact on hosiery elongation properties and thereby hosiery's functionality as well. Wearing comfort of hosiery is primarily reflected in the fit of a sock on the leg and its pressure on the leg.

Mass of material knitted in hosiery is often the main parameter for calculating hosiery production costs. A bigger mass knitted in hosiery will increase its selling price. Therefore it is very important to consolidate several parameters when designing hosiery in order to make good quality hosiery which will sell on the market at affordable prices. Bigger hosiery sizes require a bigger mass of knitted yarn making such hosiery more expensive on the market, cf. Table 8. For sock functionality it is necessary to consolidate fineness of yarn used for knitting, its elongation properties and the amount knitted into a certain size.

Table 8. Mass of fine ladies’ pantyhose made in certain sizes and PA multifilament yarns of different fineness

| Size → | 1 (36-38) | 2 (38-40) | 3 (40-44) | 4 (44-46) | 5 (46-48) | 6 (52-54) | 7 (56-58) |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| XS     | 15.82     | 16.72     | 17.95     | 19.51     | 23.54     | 24.95     | 26.97     |
| S      | 22.83     | 24.06     | 24.72     | 26.19     | 31.29     | 32.69     | 34.82     |
| M      | 24.82     | 26.32     | 29.56     | 31.50     | 33.39     | 38.32     | 42.51     |
| L      | 43.10     | 45.02     | 49.39     | 54.68     | 59.84     | 61.27     | 66.48     |

8. Conclusion
Samples of fine ladies' hosiery were made using one automatic sock-knitting machine with four different loop sinking depths with the aim of determining elongation properties of hosiery. After the analysis of samples, the main conclusions are the following.

1. Increase of yarn count for hosiery production leads to the increase of mass per unit area of knitted fabric in hosiery (or hosiery mass) which is 38 to 99 g/m². Hosiery samples of mass per unit area of 34 to 38 g/m² were made of yarn in counts 20 dtex f 20 and samples of mass per unit area of 77 to 99 g/m² were made of yarn in counts 60 dtex f 60. This is important information because the price of hosiery depends on the amount of material used in its production.

2. Yarn count and loop sinking depth significantly affect the width of tubular hosiery shape which is 111 mm x 2 to 133 mm x 2.

3. Loop sinking depth has a significant influence on the parameters of yarn structure, primarily thread consumption per loop, which is at least 2.15 mm at the loop sinking depth of 400, and 3.21 mm at most at the loop sinking depth of 850.

4. Elongation properties of samples of fine women's hosiery produced depend on fineness of multifilament yarn they are made of, and primarily its elongation at break and the loop sinking depth at which hosiery is made. Elongation of the knit in the wale direction, or transverse elongation and elongation in the course direction, or elongation along hosiery were measured. During hosiery elongation three elongation areas were determined: elastic area, area of permanent deformation and boundary area connecting elastic and plastic area.
5. Elasticity of hosiery in the wale direction or transverse elasticity of hosiery is 60 to 260 % and depends on the yarn count and loop sinking depth at which the hosiery was made. Plastic area begins at hosiery elongation from 110 to 290 %. These two areas are significant during the use of hosiery. Elongation at break in the wale direction is very high and is 200 to 389 %. Elongation of hosiery in the course direction or elongation along hosiery does not have the same distribution as the elongation in the wale direction. Elasticity of hosiery in the course direction is 140 to 270 %. It slowly decreases with the increase of filament yarn count and is not so prominently dependent on loop sinking depth. Hosiery elongation in the course direction to the beginning of permanent deformation is 160 to 290 %, and elongation at break in the course direction 243 to 369 %. These are huge elongations that need to be adjusted in the construction of every sock.

The basic prerequisite in designing high-quality fine ladies' hosiery is to be familiar with elongation properties of yarns and structures of the knitted fabric in fine ladies' hosiery. Fineness and structure of filament PA yarn and loop sinking depth significantly influence the elongation properties of fine ladies' hosiery.

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