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NEP SIZE DISTRIBUTION IN COTTON DURING PROCESSING

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Abstract

This paper is a part of a larger research project aimed at the prediction of cotton yarn quality with respect to the number of neps per 1000 m on the basis of metrological characteristics of raw material. The sources of neps in cotton yarn are neps and trash present in the raw material used for production. However, not all neps and trash present in cotton appear in the yarn and are registered by Uster Tester as yarn faults. During the technological process in the spinning mill the number of neps and trash changes. Thus, the number of neps in semi-products for yarn manufacturing that is in the roving feeding the ring spinning frame and in the sliver feeding the rotor spinning frame, is very different from the number of neps in the raw material. But not all of them are the reason of yarn faults. Neps and trash particles of appropriate small sizes are not visible on the yarn surface and in the same way they are not registered by the measurement device as yarn neps. Only these neps and trashes contained in the fiber stream are registered as yarn neps, which size is bigger than the given critical value. Therefore, prediction of the cotton yarn quality, in the aspect of nep content, requires not only information about the number of neps and trash in the sliver or roving, as the direct material for yarn manufacturing, but also the knowledge about the mean size and distribution of size of these particles in the processed cotton. The author carried out an investigation of nep size distribution in semi-products for cotton yarn manufacturing. Moreover, for predictive purposes, it is desirable to understand the shape of the distribution of the nep size. In order to determine this distribution, the author tried to fit the observed distribution of nep size in the cotton roving, made by the carded spinning system, to a theoretical distribution by comparing the frequencies observed in the experimental data to the expected frequencies of the theoretical distribution.

1. Introduction

Neppiness is one of the most important quality parameters of cotton yarns. It influences the appearance of a yarn as well as woven and knitted fabrics produced from that yarn. The nep number per 1000 m of yarn depends on:

- the nep content in raw material used for the yarn manufacture,
- the changes of cotton neppiness during the fiber processing.

Neppiness of cotton is characterized by mean nep number per gram, mean nep size as well as the nep size distribution. The mean nep number per gram of cotton raw material is different depending on the cotton origin, the way of ginning as well as on fiber properties, especially their maturity. Similarly the differentiation is also observed in the case of mean nep size.

The importance of nep number per gram of cotton for quality of manufactured yarn is unquestionable. This problem was considered by many researchers [Alan G. 1978, Frydrych I., Matusiak M. 1999, Goldtwait C. F., Wites R. L, Van Sales V. R., 1961, Hebert J. J., Boylston E. K., Thibodeaux D. P.,1988]. The role of the nep size and the nep size distribution results from the procedure of measurement of the nep number per 1000 m of yarn. For the nep number assessment in cotton yarn the Uster tester is commonly used. According to standardized procedure [Polish Standard PN - 76/P - 04804, 1976] the nep number in yarn is determined at a device adjustment of sensitivity: +200% - for the ring-spun yarn, and +280% - for OE yarn. It means that as neps in the yarn are registered only these neps and trash particles coming into yarn, size of which is big.

The nep size, beyond which it is identified and registered by the Uster tester as a yarn nep is called the critical nep size [Färber Ch. 1996]. Each yarn linear density corresponds to different critical nep sizes. Critical nep size values for the ring-spun and rotor yarns of different linear densities were determined experimentally [Peters G. 1993, Färber Ch. 1996]. Moreover, a theoretical relationship on the critical nep size in a function of yarn linear density allowing the calculation of the critical nep size for any linear density of rotor and ring-spun carded yarn was elaborated [Matusiak M. 2002, Frydrych I., Matusiak M. 2002].

2. The nep size and the nep size distribution in roving

As was mentioned above that the size of neps and distribution of nep size is very important from the point of view of visibility of neps in the yarn of a given linear density. Barella and Manich [Barella A., Manich A.M.] carried out the studies on the statistical distribution of the sizes of neps for two samples of cotton raw material. They stated that histograms furnished by the Uster AFIS-N device showing the distribution of nep sizes follow very closely to *double exponential distribution*. But during the fiber processing both mean nep size and the nep size distribution are changed significantly. Due to this fact the nep number and the nep size in semi – products, from which the yarn is formed directly, i.e., in the roving feeding the ring spinning frame or sliver feeding the rotor spinning frame differ significantly from the nep number and nep size in raw material used for production.

These studies of size distribution of neps in roving were taken into consideration. The neps in the roving are characterized by different sizes. In Figure 1, examples of the microscopic pictures of neps taken from the cotton roving made by the carded spinning system are presented.

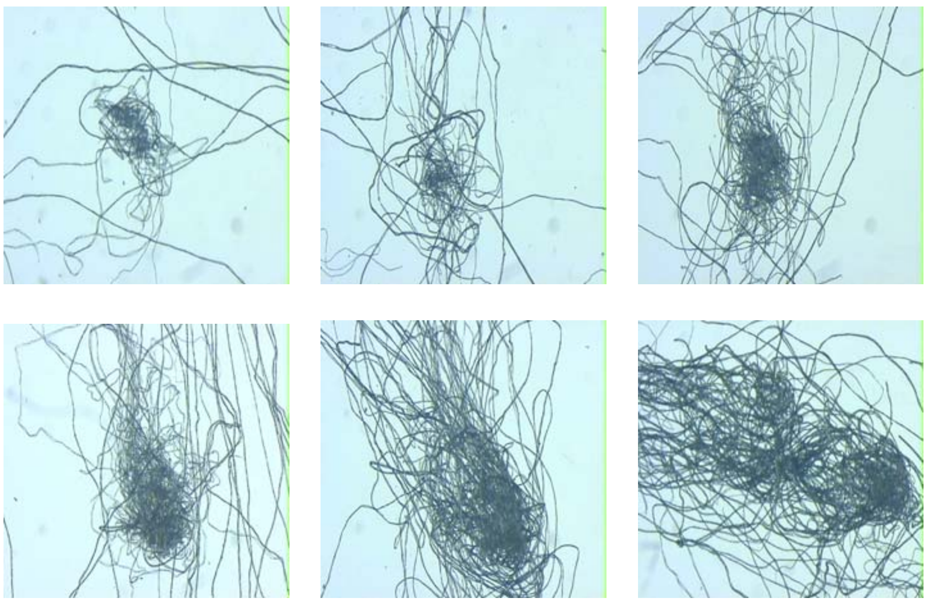

Fig. 1. Microscopic pictures of neps in cotton roving

For the research purpose 8 different cotton blends were processed by the carded spinning system. Prepared raw material blends contained the medium staple cotton lots originated from the Central Asia. From these cotton blends the roving samples were produced. Each roving sample was measured by means of the AFIS system in order to assess the parameters characterizing its neppiness. The obtained results are presented in Table 1.

Table 1. Results of measurement of neppiness of roving by means of the AFIS system

No.	Sample of roving	Nep number per gram [Nep Cnt/g]	Mean nep size [μm]
1.	N 50 w 234	110	668
2.	N 30 w 24	149	709
3.	N 20 w 226	134	701
4.	N 20 w 441	125	707
5.	N Z 4	75	679
6.	N Z 3	157	718
7.	N Z 2	146	681
8.	N Z 1	272	704

It was stated that the produced roving samples differ between each other in the frame of mean nep number per gram as well as of the mean nep size. The nep content in rovings is ranged from 75 neps/gram to 272 neps /g; whereas the mean nep size is in the interval from 668 µm to 718 µm. The stated differences result mainly from the differences in neppiness of raw materials used for production.

The AFIS measurement provides also the histograms illustrating the nep size frequency distribution. An example of obtained histogram is shown in Figure 2.

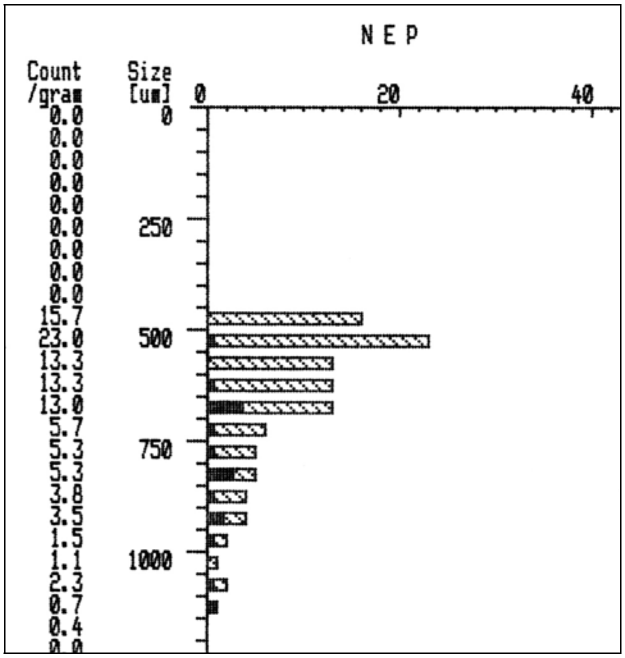

Fig. 2. The frequency distribution of size of neps in roving according to the AFIS measurement

For each measured roving the nep size is ranged from 475 µm to 1675 µm. Neps bigger than 1675 µm occurred sporadically. In all cases the most numerous class is the class representing neps of size 525 µm.

3. Analysis of the frequency distribution of nep size in the roving

Knowledge about the mean nep size and nep size distribution in roving is very important from the point of view of predicting the cotton yarn quality in the aspect of its neppiness. Knowing the nep size distribution in roving of known mean nep number per gram we can calculate the number of neps, which size is bigger than the critical one for a given linear density of produced yarn. In the same time we can predict the number of neps, which will be visible on the yarn surface and will be considered by Uster Tester as a yarn faults.

In the frame of this research work the fitting the observed distribution of nep size to a theoretical distribution was undertaken by comparing the frequencies observed in the measurement data to the expected frequencies of the theoretical distribution. For this purpose the statistical procedures of the STATISTICA software were used - *Process Analysis* module.

On the basis of the experimental data we analyzed fitting of the real nep size frequency distribution to the following theoretical distributions:

- *Exponential distribution*,
- *Normal distribution,*
- *Extreme value distributing,*
- *Gamma distribution,*
- *Log-normal distribution,*

- *Rayleigh distribution,*
- *Weibull distribution,*

According to the measurement results the statistical analysis was carried out at the assumption of the lower threshold value on the level of 475 μm. The results of the statistical analysis for the roving sample: "N 50 w 234" are presented in Table 3.

The *Maximum Likelihood Method* was used for estimation of the values of parameters for the theoretical distributions. STATISTICA fits distributions ordering the particular theoretical distributions according to the value of *d Kolmogorov - Smirnov* statistic. The lowest value of *d* statistic shows the best fitting; whereas the highest value – the worst.

Table 3. Results of the statistical analysis for roving N 50 w 234

Distribution	Assessment of parameters for all distributions				
	User parameter 1	Parameter 1	Parameter 2	d Kolmogorov-Smirnov	Probability level p
Exponential (threshold, scale)	474.9	194.57	-	0.142	$p < 0.01$
Extreme values (location, scale)	-	585.82	126.31	0.152	$p < 0.01$
Normal (location, scale)	-	669.50	222.02	0.199	$p < 0.01$
Weibull (threshold, scale, shape)	474.9	159.17	0.66	0.231	$p < 0.01$
Gamma (threshold, scale, shape)	474.9	385.17	0.50	0.244	$p < 0.01$
Log-normal (threshold, scale, shape)	474.9	4.01	2.69	0.323	$p < 0.01$
Rayleigh (threshold, scale)	474.9	208.69	-	0.364	$p < 0.01$

In almost all cases, the best fit occurred for the exponential distribution. The low values of the *d Kolmogorov - Smirnov* statistic were also stated for *extreme value distribution* and the *normal distribution*. In the case of both the *normal* and the *extreme value distributions* it was impossible to assume the lower threshold value. Due to this fact these theoretical distributions were not taken into the further considerations, because in the visible way they do not reflect the real distribution of nep size in the investigated roving samples.

The theoretical function describing the distribution of size of neps in roving made by carded spinning system can be expressed by the following equation:

$$y = \begin{cases} \lambda \cdot e^{-\lambda(x-d)} & \text{for } x \geq 474.9 \\ 0 & \text{for remaining } x \end{cases} \qquad (1)$$

where:
y - probability of occurrences of neps of size x in the total nep number in the roving,
λ - *exponential function parameter* (an alternative parameterization is *scale parameter* $b=1/\lambda$),
e - the base of the natural logarithm, called Euler's e (2.71...)
d - the threshold parameter.

In Figure 3 the histogram of nep size distribution in the roving N 50 w 234 with the fitted exponential function is presented. In order to assess the goodness of fit we used the *probability-probability* plot (Fig.4). The observed cumulative distribution function is plotted against the theoretical cumulative distribution function. In *probability-probability* plot the values of the respective variable are first sorted into ascending order. The *i*'th observation is plotted against one axis as *i/n* (i.e., the observed *cumulative distribution function*), and against the other axis as $F(x_{(i)})$, where $F(x_{(i)})$ stands for the value of the *theoretical cumulative distribution function* for the respective observation $x_{(i)}$. If the *theoretical cumulative distribution* approximates the observed distribution well, then all points in this plot should fall onto the diagonal line. In the plot the *confidence interval* is also presented. The *probability-probability* plot confirms a good quality of fitting the experimental data to the *exponential distribution.*

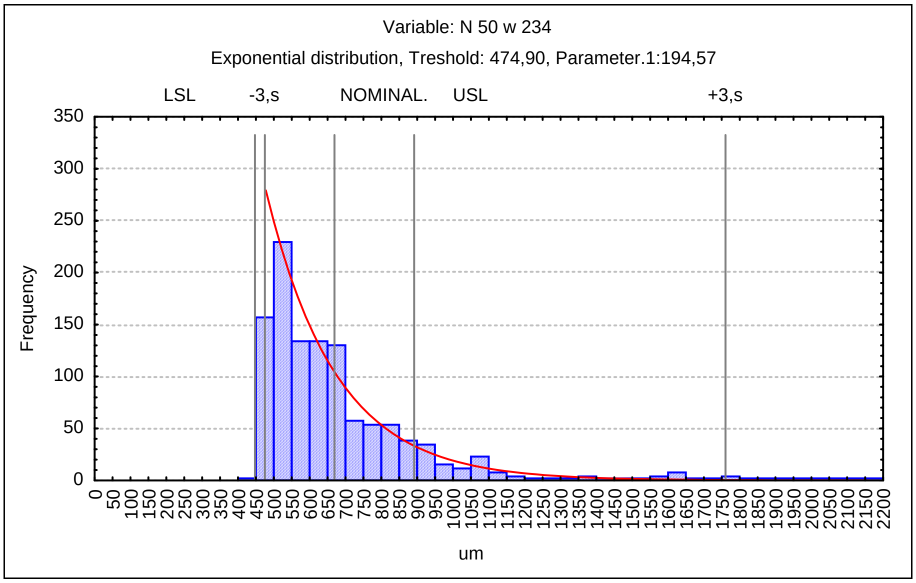

Figure 3. Histogram of nep size distribution in the roving N 50 w 234 with the fitted *exponential function*

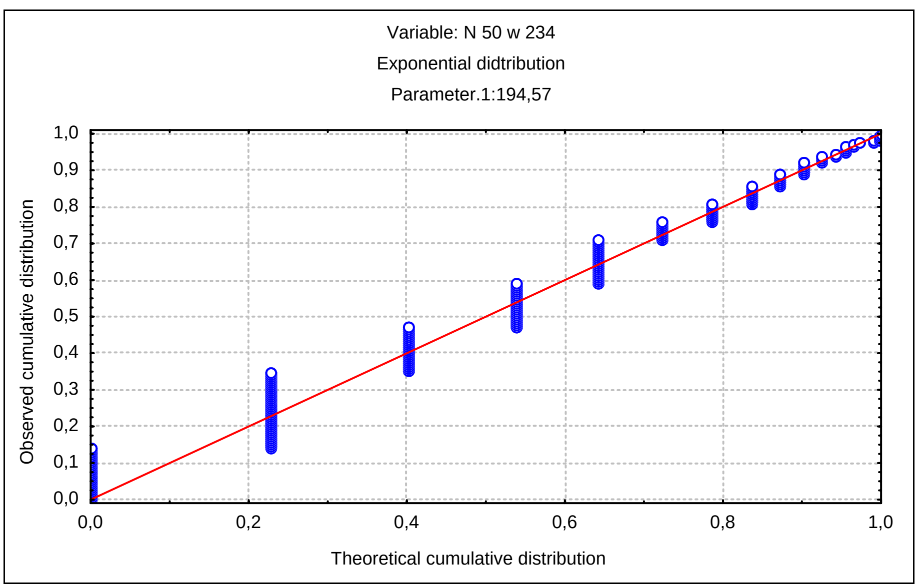

Figure 4. The *probability-probability* plot for variable N 50 w 234. *Exponential distribution*

By comparison, Figure 5 shows the histogram of nep size in roving N 50 w 234 with fitted *Weibull distribution.*

On the basis of *d* parameter value we can state that the *Weibull distribution* reflects the real nep size distribution worse than the *exponential* one. It is also confirmed in *probability-probability* plot (Fig. 6.). In Figure 7, the differences between the observed frequencies and frequencies expected according to the exponential distribution at the scale parameter b = 194.57 are presented. For classes representing the neps, size of which is bigger than 750 μm the difference between observed and expected frequencies is in the range from –10 to +10 and in the most of cases is near to 0.The biggest differences occur for neps of size smaller than 750 μm but these neps as was told earlier are invisible for human eye and for the sensor of the measurement device and in the same time they are not the source of yarn faults.

In Figure 8, there are presented cumulative frequencies expected according to fitted exponential function in comparison to the observed cumulative frequencies. In the graph all points fall onto the diagonal lines, which confirms a good quality of fitting the experimental data to the *exponential distribution*. In analogous way the statistical analysis was carried out for the rest of roving samples. In all cases the best fitting was achieved at the *exponential distribution*.

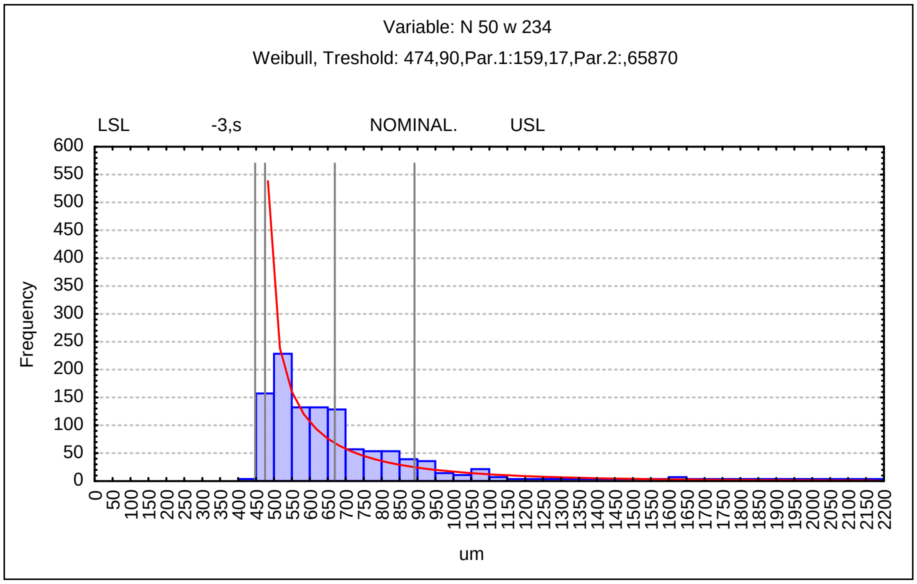

Figure 5. The histogram of nep size in roving N 50 w 234 with fitted *Weibull distribution*

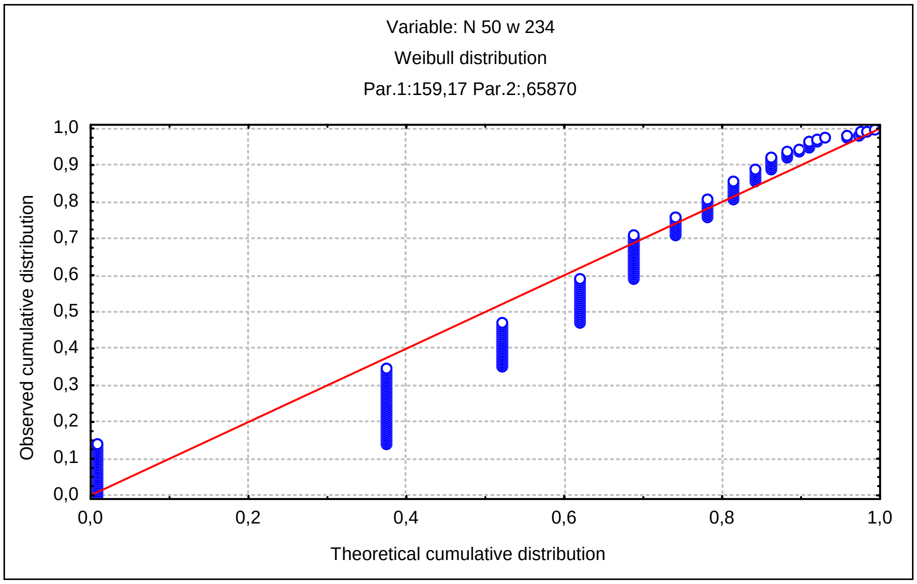

Figure 6. The *probability-probability* plot for variable N 50 w 234. *Weibull distribution*

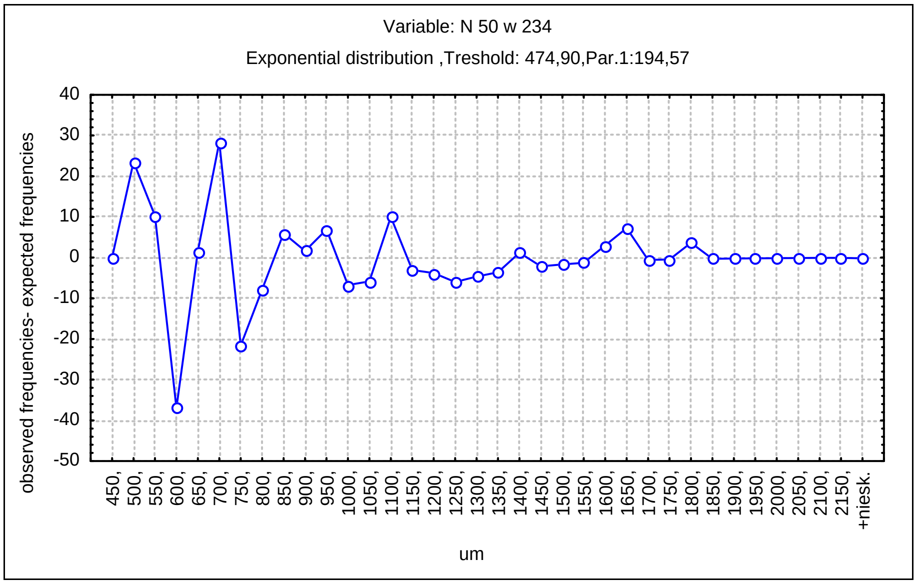

Figure7. The differences between the observed frequencies and frequencies expected according to the *exponential distribution* at parameter b = 194,57.

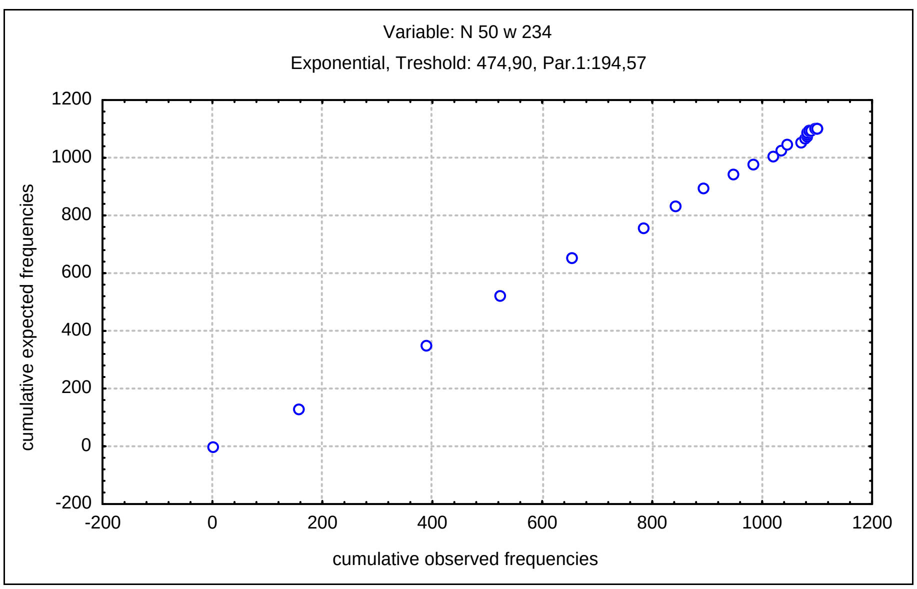

Figure 8. Cumulative percentage shares: observed and expected

On the basis of carried out analysis we can state that the distribution of sizes of neps in cotton roving made by the carded spinning system can by expressed by the *exponential function*. At the assumed value of the threshold parameter (d = 474.9) the values of the scale parameter b for all rovings were in the range from 194.57 to 243.60.
For the purpose of predicting the number of neps of a given size in roving made by the carded spinning system the mean value of scale parameter calculated on the basis of values of scale parameters obtained for all roving samples were taken as a scale parameter of the *theoretical exponential function*: b = 222.18.

The final version of the *exponential function* describing the nep size distribution in cotton roving is:

$$y = \begin{cases} \frac{1}{222.18} \cdot e^{-\left(\frac{x-474.9}{222.18}\right)} & \text{for } x \geq 474.9 \\ 0 & \text{for remaining } x \end{cases} \qquad (2)$$

where:
y - probability of occurrences of neps of size x in the total nep number in roving,
e - the base of the natural logarithm, called Euler's e (2.71...).
Derivative function of the above exponential function is:

$$F(x) = 1 - e^{-\frac{x-474.9}{222.18}} \qquad (3)$$

Probability that the random variable will take the value ≥ x is given by the *survival function*:

$$P(x) = 1 - F(x) = e^{-\frac{x-474.9}{222.18}} \qquad (4)$$

On the basis of the above equation (4) we can calculate the percentage of neps of size equal to or bigger than the critical size in the total nep number per gram of cotton roving, for which the total nep number in 1 gram is known. Figure 9 presents the comparison of the *survival function* given by eq. (4) and the real percentage distribution of nep size in investigated roving samples accumulated from the biggest size to the smallest one.

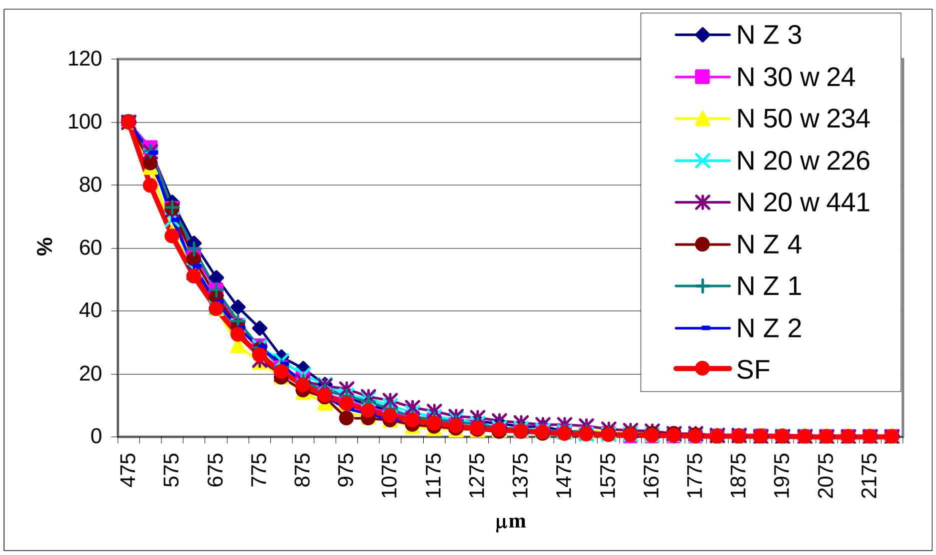

Figure 9. Comparison of the *survival function* of the *exponential distribution* and the real percentage distribution of nep size in investigated roving samples accumulated from the biggest size to the smallest one; *SF – survival function*

Summing up

On the basis of the carried out investigation it can be stated as follow:

- knowledge about the mean nep size and nep size distribution in the cotton roving is very important from the point of view of predicting the ring-spun yarn quality in the aspect of yarn neppiness,
- the nep size in roving made by carded spinning system is ranged from 475 μm to 1675 μm,
- the distribution of size of neps in carded roving can be expressed by the *exponential distribution* at the *threshold parameter d* = 474.5 and *scale parameter b* = 222.18,
- the statistical analysis confirmed the good quality of fitting the real nep size distribution to the *exponential distribution,*
- the number of neps of size equal to or bigger than the critical size in 1 gram of cotton roving of known the total nep number can be calculated according to the *survival function* of the *exponential distribution*.

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