

QUANTIFICATION OF COTTON FIBER QUALITY

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Abstract

There exist plenty of standards and HVI techniques for characterization of cotton fibers. It is known that there are some differences in the principles of measurements and the results of AFIS and HVI spectrum apparatuses. Differences exist between measurements of fiber strengths based on the bundles concept or single fiber concept as well. Despite these differences, it is possible to specify basic cotton fiber properties having a potential influence on the cotton quality. The main problem with utilization of these properties for quality characterization is the multivariate character of information, various units and lack of transformation to the utility scale. According to the general definition, quality is characterized by several properties expressing the ability of a product to fulfill functions it was designed for. The degree of quality (complex criterion) is often expressed as utility value U . The method for complex evaluation of cotton fiber performance based on this idea is presented. The results of HVI measurements are used as input data. The program QCOTTON written in MATLAB is briefly mentioned. The application of complex criterion is demonstrated on the simulation based examples and real data.

Introduction

Quality is very frequently used in industry as synonym for good product, technologies etc. Strictly speaking, this word is frequently misused or misinterpreted. In some cases word "quality" is used for the expression of maintainability, reliability or economy of production. Especially in the textile branch, it is necessary to define quality very precisely because textile products (e.g. weaves) can be used for a lot of various applications (ranged from clothing to wipes). One general definition of quality is: "Quality express ability to fulfill needs of applicability". Therefore before speaking about quality it is necessary to specify the potential target application of textiles.

The quality of the textile fibers is dependent on the aims of evaluation:

- Fiber producers: quality means the achievement of required technological parameters (geometrical evenness, fineness, shrinkage, mechanical and physical parameters etc.).
- Textiles producers: quality means the ability to fulfill requirements of technologic operations and process ability (friction, surface properties, cohesion, selected mechanical and physical properties, and evenness).
- Consumers: fiber quality is hidden in the properties and comfort of fabrics (hand, wearing pleasance, thermal comfort, transport properties etc.).

Natural fibers

Controlled changes of properties are very difficult (selection, breeding, gene manipulation) and therefore the quality is oriented to the process ability, yarns characteristics (especially strength) and mixing potency.

Chemical and synthetic fibers

By variation of fiber geometry (fineness, cross section profile, texturing) and spinning conditions (rate of production, drawing degree, temperature, forming conditions) it is possible to markedly change majority of properties. The chemical modification is another way to change of properties. The general definition of quality according to the aim of utilization can be here used for ranking and classification.

According to the general definition, quality is characterized by several properties expressing the ability of a product to fulfill functions it was designed for. The degree of quality (complex criterion) is often expressed as utility value U (Militky (1980)). Evidently, general quality of textiles is characterized by many of various utility properties R_i ($i=1, \dots, m$). These are such properties that make it possible for the product to fulfill its function. Utility value $U \in \langle 0, 1 \rangle$ aggregates then in some certain way partial quality properties (Arrow (1971), Cerny (1980)).

The purpose of the paper is to describe the complex evaluation of cotton fiber quality based on this idea. The results of HVI measurements are used as input information. The application of complex criterion is demonstrated on the simulation-based and practical examples.

Cotton Fiber Quality

In 1907 an international group of cotton industry representatives recommended the establishment of uniform cotton standards to “eliminate price differences between markets and make the farmers more cognizant of the value of the value of their products”. In response to requirements of standardization, the cotton grade standards and cotton classification systems were elaborated and authorized by US Dept. of Agriculture.

The cotton classification is now system of standardized procedures for measuring of raw cotton properties (physical attributes) that affect quality of processing (spinning mainly) and quality of products (yarns). The classification system of US cottons is described on the net (<http://www.cottonic.com/CottonClassification>).

There exists plenty of standard and HVI techniques for characterization of cotton fibers. It is known that there are some differences in the principles of measurements and the results of AFIS and HVI spectrum apparatus. Differences exist between measurements of fiber strengths based on the bundles concept or single fiber concept as well (Militký (2004)). Despite these differences it is possible to specify basic cotton fiber properties having a potential influence on the cotton yarn strength (Rasked (2002)):

Fiber length (expressed as upper half mean *UHM* [mm]),
 fiber length uniformity (expressed as uniformity index *UI* [%]),
 fiber strength (as bundle strength *STR* [cN/tex]),
 fiber elongation ant break (*EL* [%])
 fiber fineness and maturity (expressed by micronaire reading (*MIC* [-]),
 short fiber content (*SF* [%]),
 trash content *TR* [%].

The importance of these properties is generally dependent on the spinning technology. The relative weight *b* of above listed properties (as importance percentages divided by 100 and then standardized - sum of weights should be one) is given in the Table I.

TABLE I. Contribution of cotton properties to the yarn strength

Property/ weight	Rotor yarn	Ring yarn
<i>UI</i> [%]	0.20	0.22
<i>MIC</i> [-]	0.16	0.17
<i>UHM</i> [mm]	0.14	0.24
<i>STR</i> [g/tex]	0.28	0.22
<i>EL</i> [%]	0.09	0.06
<i>SF</i> [%]	0.06	0.06
<i>TR</i> [%]	0.07	0.03

The values in the Table I were derived from pie graphs presented in the work (Rasked (2002)). The main problem with utilization of above-mentioned properties for quality characterization is the multivariate character of information, various units and lack of transformation to the utility scale.

One of first attempts to create aggregated criterion of cotton yarn quality was *FQI* index expressed by relationship (Anonym (1983))

$$FQI = (\text{fiber strength} \cdot \text{length}) / \text{fineness} \quad (1)$$

In the book (Korickij (1983)) the so-called geometric properties index IG was introduced. This index is based on LVI measured properties

$$IG = 0.1 * L_m * UI * (1 - SF/100) * MAT * (FI)^{-0.5} \quad (2)$$

where L_m is cotton fiber weighted mean length, FI is fiber fineness and MAT is maturity. For HVI measured properties can be IG expressed as

$$IGa = \frac{UHM * UI * (100 - SF)}{10000 * \sqrt{MIC}} \quad (3)$$

or

$$IG = \frac{UHM * UI * (100 - SF) * MAT}{1000000 * \sqrt{FI}} \quad (4)$$

The relationship (3) is very rough because the micronaire is combination of fiber fineness and maturity. Index IG correlates with yarn mass unevenness by empiric relationship (Korickij (1983))

$$CV = \frac{100 * A_2}{I_g \sqrt{TP}} \quad (5)$$

where $A_2 = 11.7$ for long staple cottons and $A_2 = 14.7$ for medium staple cottons. TP is yarn fineness. Index IG correlates with yarn strength variation coefficient CVP by empiric relationship [4]

$$CV_p = \frac{100 * A_3}{I_g * \sqrt[4]{TP}} \quad (6)$$

where $A_3 = 3.85$ for long staple cottons and $A_3 = 4$ for medium staple cottons.

Cotton yield during spinning is expressed by relationship

$$B = 95.4 - 2.9 * TR \quad (7)$$

Complex quality index IK expressing the spinning ability of cottons is then defined as combination of IG and B with including of cotton fibers price C .

$$I_K = A_4 * B * I_g^4 / C \quad (8)$$

where $A_4 = 0.0108$ for long staple cottons and $A_4 = 0.0141$ for medium staple cottons. These relationships were derived from Russian cottons, LVI measurements and contain a lot of dimensional parameters. The main problem with the Korickij approach is dependence on the cotton property's units used for empiric function evaluation and no inclusion of individual fiber property's importance.

Our approach based on the utility function concept is more general and be easily modified for the future (the properties of cottons are in dependence on time progressively changed in positive sense due to breeding and genetic manipulation)

Utility Value Concept

Evaluation of quality based on a complex criterion is closely related to the well-known problem of complex evaluation of variants (Cerny (1980)). For complex evaluation of variants, the X matrix of the $(n \times m)$ order is available containing for individual V_1, \dots, V_n variants (X matrix rows) the values of selected R_1, \dots, R_m characteristics (X matrix columns).

The x_{ij} element of the matrix thus expresses the value of the j -th characteristic of R_j for the i -th variant of V_i . The aim is to sort individual variants in the order of their importance. In economics several different methods are used in this field and most of them are based on preferential relationships (Cerny (1980)). A special technique is the so called "useful effect method" or "base variant method". Base variant practically represents an ideal state where individual characteristics get optimum values.

By means of o_j ($j = 1, \dots, m$) values for individual characteristics of a base variant, dimensionless standard quantities u_{ij} are calculated. If the increase of the R_j characteristic is accompanied by an increase of quality, the standard quantities are calculated according to the relationship

$$u_{ij} = \min\left(\frac{x_{ij}}{o_j}, 1\right) \quad (9)$$

In the opposite case, the dividend and the divisor are interchanged. As $U(R) = U(u)$ is an aggregating function, a suitable weighted average is used. Generally the question may arise whether a suitable aggregating function really exists (Arrow (1971)).

Modification of this approach for expressing textile quality is shown in previous work (Militký (1980)). The procedure for prediction of cotton fibers quality from the point of view of the yarn strength is described in the sequel.

Let us have K utility properties R_1, \dots, R_K (cotton fiber properties selected in the Table I). Based on the direct or indirect measurements, it is possible to obtain some quality characteristics x_1, \dots, x_K (mean value, variance, quantiles etc.). These characteristics represent utility properties. Functional transformation of quality characteristics (based often on the psycho physical laws) leads to partial utility functions

$$u_i = f(x_i, L, H) \quad (10)$$

where L is value of characteristic for just non-acceptable cotton ($u_i = 0.01$) and H is value of characteristic for just fully acceptable product ($u_i = 1$). Utility value U (quality index) is weighted average of u_i with weights b_i

$$U = \text{ave}(u_i, b_i) \quad (11)$$

Weight b_i corresponds to the importance of a given utility property (Dobrov (1977)) and is closely connected with the area of cotton application.

The weighted geometric mean used as the average has the following advantages:

- For zero value of u_i is also $U = 0$. This means that combinations of other utility properties cannot replace non-acceptable utility property.
- Geometric mean is for not constant u_i always lower than arithmetic mean. This reflects evaluation based on the concept that the values of utility properties close to unsatisfactory cottons are more important for expressing the quality than those close to optimum cotton.

Basic steps of utility function computation are:

- Selection of characteristics x_i corresponding to utility properties R_i ,
- Determination of preferential functions $u(x_i)$ expressing "partial quality" for chosen utility property,
- Assessment of the importance of individual utility properties via weights b_i ,
- Proper aggregation, i.e., determination of the U function.

For the case of cotton fiber quality, the utility properties and weights are already selected (see. Table I). For aggregation, the weighted geometric mean can be used and therefore the preferential functions $u(x_i)$ have to be proposed only. The partial utility function is in fact psychophysical variable expressing the sensation of quality induced by (measured) characteristics of the cotton property.

The computation of preferential functions is dependent on the measurement scale and property type.

Ordinal characteristics

In this type of scale, classification has been introduced, but differences are not quantified. Grades are awarded by the comparison with etalons. Usually the higher is the grade; the higher is the partial quality.

Cardinal characteristics

These are usually expressed in physical units. There are two types of cardinal characteristics.

One-side bounded characteristics are those where after the H_j value has been exceeded, the utility does not change any more (fiber strength, length, etc.). After standardization, the partial utility function is computed e.g. by using the Harrington preference function.

Two-sides bounded characteristics are those where on both sides from "the optimum" the partial utility decreases. (e.g. fiber micronaire).

The nonlinear transformation to preference functions for cardinal utility values is given in previous work (Militký (1980)). For expressing quality of cotton fibers it is sufficient to replace standardization and nonlinear transformation to the partial utility function by the piecewise linear transformation.

For one side bounded properties, quality is monotone increasing or decreasing function of quality characteristic x and therefore the piecewise linear transformation has form shown on the Fig. 1

For the case of LB (lower is better) properties were limits selected according to the known ranges published e.g. in (Rasked (2002))

Thrash content TR [%]	$L = 6$	$H = 2$
Short fibre content SF [%]	$L = 18$	$H = 6$

For the case UB (upper is better) properties were limits selected according to the known ranges published e.g. in (Rasked (2002))

Strength HVI STR [g/tex]	$L = 23$	$H = 31$
Length UHM [mm]	$L = 25$	$H = 32$
Uniformity index UI [%]	$L = 77$	$H = 85$
Elongation EL [%]	$L = 5$	$H = 7.7$

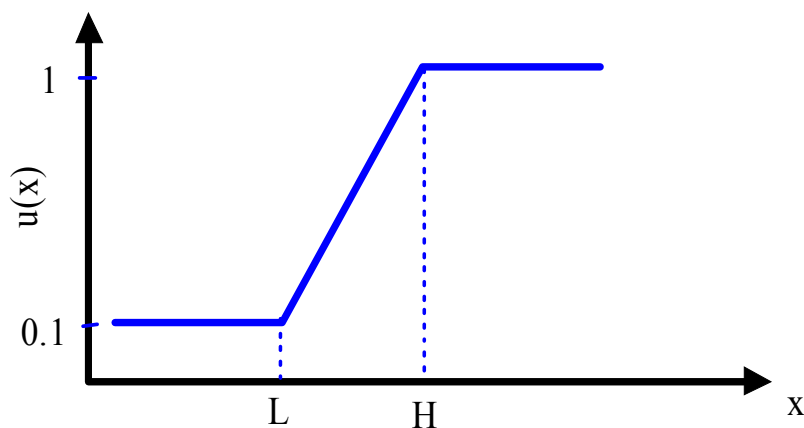


Fig. 1 Transformation for one side bounded cotton properties (L is lower limit and H is upper limit)

For two side bounded properties, quality is monotone decreasing function of property value x on both sides from optimal (constant) region and therefore has the piecewise linear transformation form shown on the Fig. 2

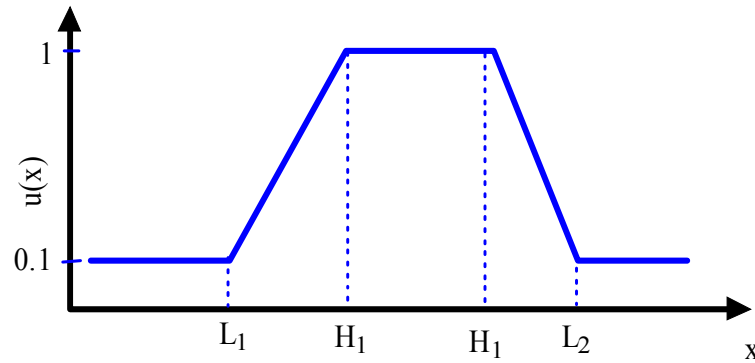


Fig. 2 Transformation for two side bounded cotton properties (L_1, L_2 are lower limits and H_1, H_2 are upper limits)

For this case limits were selected according to the known ranges published e.g. in (Rasked (2002))

$$\text{Micronaire } MIC [-] \quad L1 = 3.4, H1 = 3.7 \quad L2 = 5, H2 = 4.2$$

The weighted geometrical average U characterizing cotton fibers quality is then simply calculated by the relationship

$$U = \exp\left(\sum_{j=1}^m b_j \ln(u_j)\right) \quad (12)$$

When forming the aggregating function U from experimentally determined values of individual utility properties, the statistical character of the x_j quantities should be considered and the corresponding variance $D(U)$ should be also determined.

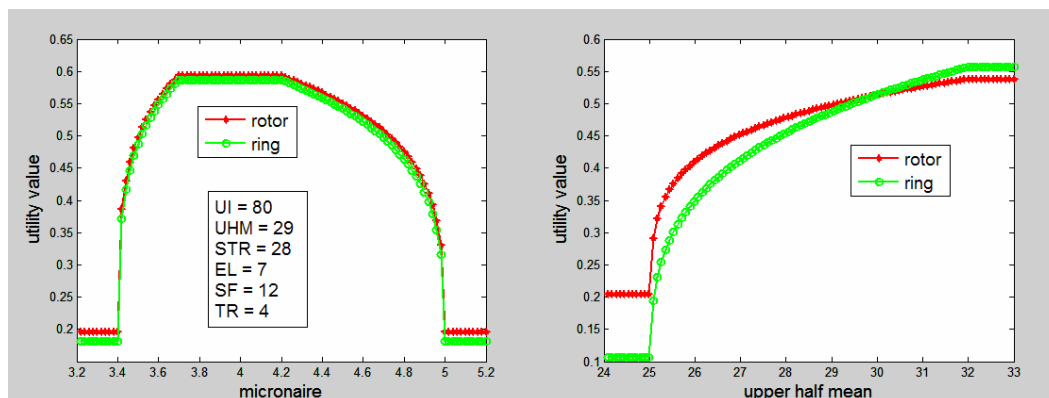
Program QCOTTON

Program *QCOTTON*, written in MATLAB, is based on the above-proposed procedure. The Bootstrap type technique described in (Meloun (1993)) has been applied for computation of the statistical characteristics of cotton fiber utility function. This technique is based on the assumption that for each utility property R_j the mean value x_j and variance s_j^2 are determined by standard treatment of the measured data. The procedure of the statistical characteristics of utility value U estimation is divided to the following parts:

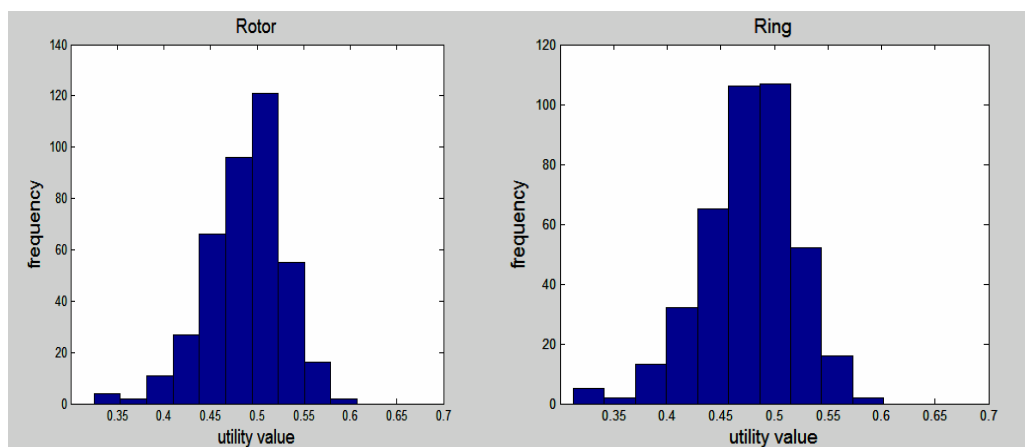
- I. Generation of $x_j^{(k)}$ ($j=1, \dots, m$) values having normal distribution with mean values x_j and variances s_j^2 . The pseudorandom number generator built in MATLAB is used.
- II. Calculation of the utility value $U^{(k)}$ using the relationship (12).
- III. The steps I and II are repeated for $k=1, \dots, n$ (usually $n=600$ is chosen).
- IV. Construction of a histogram from the values $U^{(k)}$ ($k=1, \dots, n$) and computation of the estimators of $E(U)$, $D(U)$.

Simulation Results

The influence of micronaire changes and upper half mean changes to the utility value of some ideal cotton fiber is shown on the fig. 3

Fig. 3 Influence of *MIC* and *UHM* on utility value

In accordance with the expectation, an increase of *UHM* leads to better quality expressed by *U* value. Micronaire's influence is more complex because the small values indicate immature cottons and high values are for too coarse cottons. The distribution of *U* for the idealized case when relative errors of measurement *CV* are 3 % for all properties are given on the Fig. 4.

Fig. 4 Distribution of *U* values for measurements with 3 %precision

There are visible differences between the *U* values for rotor and ring yarn weighting coefficients.

Complex criterion (weights rotor):

Mean	lower limit	upper limit
0.49	0.486	0.494

Complex criterion (weights ring):

Mean	lower limit	upper limit
0.479	0.475	0.484

The differences between both types of weights are not so high but the confidence intervals are not overlapped and conclusion is “this cotton is significantly better for rotor yarn production”.

Experimental

The 15 typical cotton varieties used in Czech Republic were selected (Militký (2004a)). Their basic properties are obtained from an HVI apparatus are graphically summarized on the figure 5.

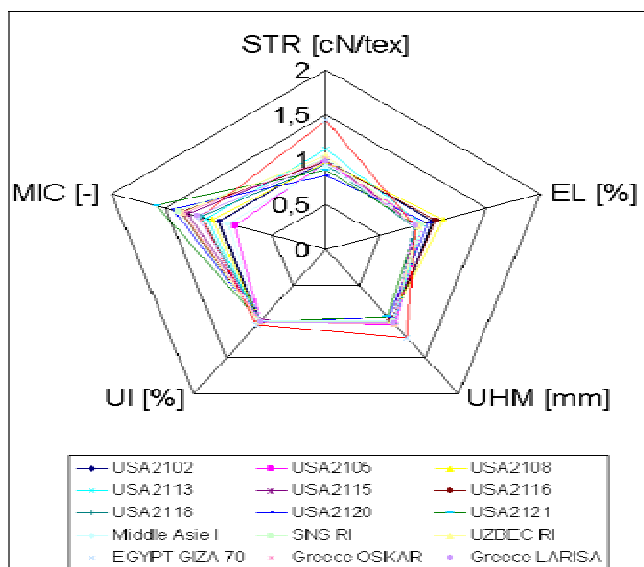


Fig. 5 Cotton varieties properties from HVI

From the point of view of mechanical properties and geometry, the most extreme is the cotton GIZA 70. This fiber has highest strength STR.

Results and Discussion

The correlation matrix between basic HVI parameters is given in the table II.

Table II. Correlation matrix between HVI parameters

Variable	STR	EL	UHM	MIC
STR	1	-0.25851	0.925335	-0.16529
EL	-0.25851	1	-0.39094	-0.18283
UHM	0.925335	-0.39094	1	-0.30175
MIC	-0.16529	-0.18283	-0.30175	1

The strength STR correlates strongly with length of fiber expressed by UHM. The other parameters are not significant. The relationship between UHM and HVI cotton strength (STR) are shown on the fig. 6.

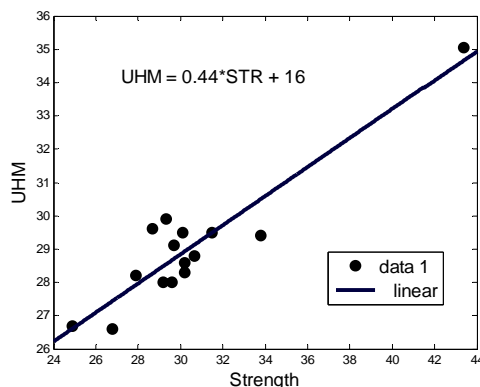


Fig. 6 Relationship between UHM and HVI cotton strength

The utility value for all cotton varieties are given on the fig. 7. Because the short fiber content and trash content were not measured, their corresponding optimal values are used ($TR = 2, SF = 6$)

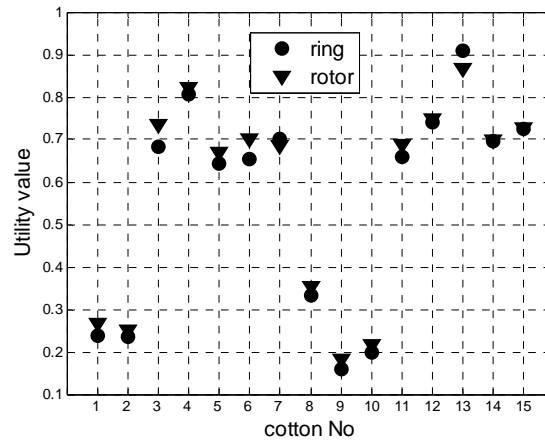


Fig. 7 Computed cotton quality indexes (utility values)

It is visible that according to the quality indexes, cotton varieties are separated into two groups. In the low value of U are cottons with very low strength (No. 8, 9) or very low maturity (No. 1, 2, 10). The greatest U value is for USA 2121 (No. 13) variety. The differences between ring and rotor yarn quality are not very high.

Conclusion

The described procedure for evaluation of cotton quality (utility value) can be very simply modified for other selected properties or other set of weights. This is important for future cotton varieties. Based on preliminary results it will be probably necessary to solve problems with some cotton varieties having small micronaire due to fineness and relatively high strength. For these cases will be necessary to add restriction to the L_I and H_I .

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