GOST 30415-96

I N T E R S T A T E   S T A N D A R D

STEEL
Non-destructive testing control of mechanical properties and microstructure of steel products by magnetic method

Official Edition

INTERSTATE COUNCIL FOR STANDARDIZATION, METROLOGY AND CERTIFICATION

Minsk

Preface

1. DEVELOPED by the International Technical Committee ITC 145 «Methods of steel products testing of Russian State Standard».

INTRODUCED by the Russian State Committee for Standardization.

2. APPROVED by the Interstate Council for Standardization, Metrology and Certification. (Protocol No. 10, October 4, 1996)

For confirmation voted:

The Names of States	The Names of national organization on standardization
Republic of Azerbaijan	Azgosstandard
Republic of Armenia	Armgosstandard
Republic of Byelorussia	Byelstandard
Republic of Kazakshstan	Kazakshstandard
Republic of Moldova	Moldovstandard
Russian Federation	The State Standard of Russia
Republic Tadjikistan	The Center for Standardization, Metrology & Certification of Tadjikistan
Turkmenistan	Turkmen Main State Inspection
Ukraine	The State Standard of Ukraine

3. In accordance with the Resolution of the State Committee for Standardization, Metrology and Certification of Russian Federation, February 27, 1997, No.71, Interstate Standard GOST 30415-96 is put into operation as the State Standard of Russian Federation from January 1, 1998.

4. INTRODUCED FOR THE FIRST TIME

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The date of put into operation 1998-01-01

1 FIELD OF APPLICATION

This Standard is spread on rolled product, such as bars, flats, strips, profiled bars, sheets with non-magnetic coating, tubes, many-layer sheets and tapes of carbon, alloyed and electrical grades of steel and determines non-destructive magnetic method of control of mechanical and technological properties and microstructure.

The Standard can be spread upon other types of steel products according to the agreement of the manufacturer with the consumer.

Non-destructive method of control is applied equally with testing methods, established in standards on definition:

yield point elongation, yield strength, tensile strength elongation, reduction of area after fracture according to the GOST 1497 and GOST 10006;
uniform elongation to GOST 1497;
tensile strain-hardening exponents (n-values), plastic strain ratio *r*, to the GOST 11701;
true stress in a tension to the GOST 10006;"
hardness to the GOST 2999, GOST 9012, GOST 9013, GOST 22975, GOST 23273;
grain size in accordance with GOST 5639;
lamination and structural free cementite to the GOST 5640;
ability to the mechanical ageing to the GOST 7268;
an impact strength to the GOST 9454;
percent shear fracture to the GOST 10006;
ball punch deformation of metallic sheet material to the GOST 10510;
modulus of rupture in bending to the GOST 13813;
flattening to the GOST 8695;
angle of bend to the GOST 1419;
depth of decarbonized layer to the GOST 1763; compressive strength to the GOST 8817;
bend-over results to the GOST 3728.

Publishing is official.

2 NORMATIVE REFERENCES

The real Standard has got references on following Standards:

GOST 27.202-83 Reliability in technique. Technological systems. Methods of reliability evaluation product quality.

GOST 1497-84 Metals. Methods of tension test.

GOST 1763-68 Steel. Methods of determination for depth of decarbonized layer.

GOST 2999-75 Metals and alloys. Vickers hardness test by diamond pyramid.

GOST 3728-78 Tubes. Method of bend-over test.

GOST 5639-82 Steels and alloys. Methods for detection and determination of grain size.

GOST 5640-68 Steel. Metallographical method for determination of microstructure of sheets and bands.

GOST 7268-82 Steel. Methods of determination of ability to mechanical ageing by impact bend testing.

GOST 7564-73 Steel. General rules of samples, blanks and test pieces selection for mechanical and technological tests.

GOST 8695-75 Tubing. Flattening testing method.

GOST 8817-82 Metals. Upsetting test method.

GOST 9012-59 Metals. Method of Brinell hardness measurement.

GOST 9013-59 Metals. Method of measuring Rockwell hardness.

GOST 9454-78 Metals. Method for testing the impact strength at low, room and high temperature.

GOST 10006-80 Metals. Tubes. Tensile test methods.

GOST 10510-80 Metals. Method of testing on squeezing of sheets and tapes according to Ericksen.

GOST 11701-84 Metals. Erikson test method of sheets and strip extrusion.

GOST 13813-68 Metals. Method of testing sheets and strips for bending.

GOST 14019-80 Metals and alloys. Bend test methods.

GOST 15467-79 Product quality control. Basic concepts. Terms and definitions.

GOST 15895-77 Statistic methods of product-quality controls. Terms and definitions.

GOST 16504-81 The state system of quality inspection. Product test. General terms and definitions.

GOST 18321-73 Statistical quality control. Stem-by-item random sampling method.

GOST 20736-75 Statistic reception control on quality sign. Sampling. Inspection by variables. Control plans.

GOST 22975-78 Metals and alloys. Rockwell test under low loading (using Super-Rockwell test).

GOST 23273-78 Metals and alloys. Measurement of hardness with method of striker recoil.

GOST 27772-88 Rolled products for structural steel constructions. General specifications.

3 GENERAL REQUIREMENTS

3.1. Non-destructive magnetic method of control is applied in the presence of the stable pair or multiple probabilistic correlation between of qualitative characteristics and magnetic characteristics of steel product.

All probabilistic estimations used in the present Standard are applied with probability not less than 0.95.

When continuous on-line or sampling non-destructive magnetic method of control is used, this acceptable probability guarantee of standard norms must be provided in each lot.

3.2. Correlation dependence between magnetic characteristics and qualitative characteristics is defined at each enterprises on the base of informative data file for each grade or groups of grades of steel, which differ only by the content of carbon.

Assumed the group of different grades of steel and one type profile of rolling if calculated equation of regression has got significant coefficient of correlation.

If it is necessary, the control is carried out taking into consideration structure-sensible characteristics, chemical composition of metal and technological parameters.

3.3. Terms, basic notions and designations are acceptable in accordance with GOST 16504, GOST 15895, GOST 15467, GOST 18321, GOST 20736.

4 MEASURING INSTRUMENT

4.1. For non-destructive testing according to the real Standard the instruments are used measuring one or some structure-sensible characteristics with measurement error not more than 5% in the working diapason of measuring.

4.2. Other ferromagnetic solids and electromagnetic fields, characteristics of which do not conform to the requirements and conditions of operation of instruments must not influence on the results of measuring of magnetic characteristic of metal products.

5 TECHNICAL REGULATION OF PREPARATION TO THE TESTING

5.1. Selection of samples for carrying out of tests is acceptable according to GOST 7564.

5.2. Quantity of samples, subjected to non-destructive tests must be agreed in specifications on metal products.

5.3. Quantity of measuring of magnetic parameters and direction of setting of two-poles sensing elements in testing fields of samples must be agreed in normative technical documents on carrying out of non-destructive tests.

5.4. When non-destructive test of qualitative characteristics, estimated as "yes or no" is used, possible limit of measuring magnetic characteristic is established to guarantee fixed norms with acceptable in the Standard probability.
5.5. Precise qualitative characteristics of metal product may be used, if they except destructive testing errors.
5.6. Lower limit of confidence interval of coefficient of correlation according to absolute variable must be higher its critical value if significance level $\alpha = 0.05$.

6 WORKING PROCEDURE OF THE CONTROL

6.1. Statistical characteristics are subjected to obligatory definition on each data file, structure of which is given in enclosure A.
6.2. Meanings of acceptance numbers are calculated by means of formulas:

$C_{bi} = X_{oi} + t \cdot S_{res\,i}$ for characteristics, limited from below,

$C_{ai} = X^{o}_{i} + t \cdot S_{res\,i}$ for characteristics, limited from above,

where X_{oi} is the acceptance number for characteristics, given by the Specification limited from below,
X^{o}_{i} is the acceptance number for characteristics, given by the Specification limited from above ,
$S_{res\,i}$ is the residual standard deviation of i-qualitative characteristic, determined by the formula:

$$S_{res.1} = \sqrt{\sum_{i=1}^{N} \frac{(X_i' - X_i)^2}{(N-1)}} \quad \text{or} \quad S_{res.1} = S_i \sqrt{1 - R^2} ,$$

where X'_{i}, X_i are qualitative characteristics determined under destructive and non-destructive testing;
N is sampling size;
S_i is the standard deviation of i-qualitative characteristic;
R is the coefficient of correlation;
t is the value of Student test for the accepted confidence probability.

If the meaning of results of non-destructive testing come out of limit, limited by acceptance numbers, such lot is subjected to testing by means of arbitration methods.

6.3. Level of qualitative characteristic X_i in the lot corresponds to the requirements of Specifications, if following conditions are carried out on each characteristic:

$X_i \geq C_{bi}$ for characteristics limited from below;
$X_i \leq C_{ai}$ for characteristics limited from above;
$C_{bi} \leq X_i \leq C_{ai}$ for characteristics limited from below and above.

Controlled metal products satisfied to the conditions mentioned above are not subjected to the direct testing, but calculated meanings of qualitative characteristics are put in the test report.
6.4. Metal products, which are not satisfied to 6.3. ought to be tested according to corresponding State Standards GOST 1497, GOST 1763, GOST 2999, GOST 3728, GOST 5639, GOST 5640, GOST 7268, GOST 8695, GOST 8817,GOST 9012, GOST 9013, GOST 9454, GOST 10006, GOST 10510, GOST 13813, GOST 14019, GOST 22975, GOST 23273.
6.5. To estimate compliance of the results of qualitative characteristics definition by destructive and non-destructive methods the enterprise-manufacturer must subject to parallel testing by mentioned methods not less than 10% controlled lots of metal during the control period.
6.6. Tubes and wire made of half-finished products, delivered with estimation qualitative characteristics are subjected to parallel testing mentioned in the volume necessary for formation of representative sample during the control period.

7 TREATMENT OF RESULTS

7.1 For providing unique method and obtaining comparable results non-destructive magnetic control of mechanical properties of rolled product and tubes one must follow procedure of taking solution to build mathematical models of mechanical properties. Description of technology of automatic building of mathematical models is given in Enclosure B.
7.2. It is assumed carrying out calculation of pair and multiple correlation dependence and constructing equations of regression by method of restoration of correlation dependence according to data uncoordinated measuring that is measuring obtained on the samples separately taken, but belonging to given population according to the method mentioned in Enclosure B.
7.3. The estimation of compliance of the results of qualitative characteristics determination by non-destructive and destructive methods is carried out with the help of control chart by analytical or graphic methods.

It is assumed to unit the results of parallel control of mechanical properties of the group of thickness of rolled product and grades of steel in control chart.

7.4. Quantity of deflection coming out of the tolerance limits must not be more than 5% during the period of control. If the results of testing do not meet requirements, control of the lots is carried out in accordance with the requirements of State Standards and Specifications on metal products.
7.5. The estimations of qualitative characteristics is satisfactory if displacement of the centre of distribution concerning to the central line is not more than ±0.5 S_{res}. If the displacement is more than ±0.5 S_{res} the correction of equation of regression conclusion about necessity of the given correction is submitted on the base of the treatment of sample of the size not less than 50 lots.
7.6. The number of normative Specification, grade of steel, thickness, cross-section of the tested product, number of heat and lot, meaning of magnetic and qualitative characteristic is entered in the test report, on which the product is provided.
7.7. Mechanical properties in units of measure, established by the Specification on the product, are pointed out in the test report on the product, which is controlled according to the given Standard.
7.8. In the case of continuous or by sampling on-line non-destructive control in technological production line in the proceedings of testing level of properties of lots is pointed out, guaranteed by Specifications on the product with given in the Standard confidential probability.

APPENDIX A
(compulsory)

LIST OF CHARACTERISTICS TO BE COMPULSORY DETERMINED DURING NON-DESTRUCTIVE EVALUATION OF MECHANICAL PROPERTIES BY MAGNETIC METHOD

Table A.1

Designation	Definition	Normative document	Solving tasks
1	2	3	4
X	Sampling of observation matrix	GOST 15895	Data collection
$X_1, X_2 \dots X_k$	Indexes, *k* - index number in sampling	GOST 15895	Representation of sampling
N_r	Volume of sampling, *N* is the number of observation of each index	GOST 20736	Sufficiency of sampling volume
X	Average value	GOST 27.202	Evaluation of the main statistical characteristics
S_x	Root-mean-square deviation	GOST 27.202	Evaluation of the main statistical characteristics
I_{1x}, I_{2x}	Confidence interval of average value	GOST 27.202	Variation limits determination
$t_{ñð}$	Student′s statistics for checking the hypothesis of the average values equality	GOST 27.202	Data uniformity and technology stability checking.
$F_{ý}$	Fischer′s statistics for checking the hypothesis of dispersions equality	GOST 27.202	Merging of samplings. Data uniformity and technology stability checking. Merging of samplings.

1	2	3	4
$R_{x1, x2}$	Correlation coefficient for estimation of linear connection between indexes	GOST 27.202	Estimation of linear correlation level. Hypothesis of dependence checking
t_z	Student′s statistics for checking the significance of correlation coefficient	GOST 27.202	Hypothesis of correlation significance checking
$S_{îñò}$	Residual standard root-mean-square deviation of regression errors	GOST 15895	Estimation of confidential borders of regression equation
R_{yx}	Plural correlation coefficient between the target-oriented index and the plurality of depending indexes (This characteristic is defined when multiple factor testing is needed)	GOST 27.202	Estimation of plural linear dependence level
$C_{Í}$	The acceptable value of quality index, limited from below	GOST 27.772	Products certifications
$C_{Â}$	The acceptable value of quality index, limited from above	GOST 27.772	Products certifications

APPENDIX B

(reference)

COMPUTER AUTOMATIC DESIGN OF MATHEMATICAL MODELS

B1. Preparation on carriers and output data control

In process of preparation the initial information on computer carriers, technological checking is carried out, consisting of checking every number for wrong symbol. Data preparation errors are detected by printing the information and analysis of calculated tables of the main statistical characteristics, containing indexes of mechanical properties, chemical composition of steel, magnetic properties and other parameters.

After data correction the statistical characteristics are recalculated. Then begins the operational array forming and data analysis by means of sampling mathematical methods.

B2. Operational array arrangement. Testing results analysis.

Among many parameters of initial information a group of factors (operational array), containing all the influencing variables and index of mechanical properties is conditionally formed.

Values of quality indexes, that do not carry information in the context of solved task, and corresponding to them values of independent non-influencing variables are eliminated from the sampling. In this case the statistical characteristics should be recalculated.

Elimination of sharply distinguished values is made after the qualitative and quantitative analysis of the sampling. In the case of great number of observations the “three sigma rule” is used, when the value X is eliminated of its deviation from X exists $3S$, where S is root-mean-square value of quality index.

According with more exact criterion of values anomaly regulated sampling of observation results is considered

$$X_1 \leq X_2 \leq ,..., \leq X_n ,\qquad (B.1)$$

where n is the observation number in every index.

For estimation of X_1 and X_n belonging to the given totality and decision on elimination or retaining X_n (X_1) in the sampling, the following ratios, should be calculated:

$$U_n = \frac{X_n - \overline{X}}{S} \quad \text{and} \quad U_1 = \frac{\overline{X} - X_1}{S} \quad , \qquad (B.2)$$

The obtained results should be compared with Smirnov′s criterion value β calculated for critical values and probability P to be found from expressions

$$\alpha = P\,(U_n \geq \beta) \quad \text{and} \quad \alpha = P\,(U_1 \geq \beta),\qquad (B.3)$$

for the given volume of n and regression level $\alpha = 0.05$.

If U_n $(U_1) \geq \beta$, the suspected in anomaly result is eliminated from the sampling, otherwise it remains in the sampling.

The mentioned criterion is valid for small samplings with volumes ≤ 50.

B.3 The research of distributive characteristics and reduction them to normal ones

The target-oriented index (quality index) of the formed group of factors is investigated for normal distribution.

The verification is carried out by criteria: Pearson’s X^2 for sampling volume exceeding 200, Kolmogorov’s for sampling volume exceeding 100, Mises-Smirnov’s for sampling volume exceeding 50.

If the distribution is not normal, it is needed to transfer the initial index X into other variable Y by means of functional data transform.

When the target-oriented index has normal distribution or is converted to it, the calculated index's statistical characteristics have known distributions. For these characteristics it is possible to find the confidence limits of measurements and than the estimations of further model become estimated from probability and statistical points of view. This makes possible to go on to the next stage of modelling within the described procedure.

If the distribution is not converted into normal one, the results of model estimation will not be reliable.

B.4 The volume of measurements estimation

If the volume of sampling on the target-oriented parameter is not less than one calculated by formulae given below, the next stage of statistical data processing can be carried out. Otherwise data collection for sampling replenishing should be done and the modelling process should by repeated for the additional sampling in accordance with the described procedure.

Let $\bar{Y}$ be the average value of observations within the simple random sampling and the probability

$$P(\left|\bar{Y} - Y\right| \geq d) \quad \alpha , \tag{B.4}$$

where d is selected maximum error value;

α is some little probability;

$\bar{Y}$ is averaged general value.

As approximation of minimum volume n of sampling totality is chosen the value

$$n = 1 + \left(\frac{tS}{d} \right)^2, \qquad \text{(B.5)}$$

where t is abscissa of the normal distribution curve that cuts area α on "the tails".

B.5 Analysis of twin dependencies

The linear correlation between indexes X and Y is find out by comparing the correlation coefficient R with correlation ratio η.

If the difference $\left(\eta^2 - R^2\right) \leq 0.1$ the assumption of linear correlation is confirmed.

If $\left(\eta^2 - R^2\right) > 0.1$ the importance of difference between η and R should be estimated.

To reveal the character of non-linear dependence, correlation fields and empirical regression lines are plotted and forms of connection between X and Y indexes are estimated. Then and analytical formula describing the empirical curve is choose. For example

$$Y = X^2, \quad Y = \sqrt{X}, \quad Y = 1/X, \quad Y = \ln X, \quad Y = e^x$$

All the choose dependencies must display the quality dependencies of the mechanical properties on the influencing indexes.

B.6. Model construction

The statistical method for determination correlation between dependent variable Y and the assembly of influencing indexes $\left(X_i\right)$ uses stepwise method of plural regression, which allows to include and to exclude independent variables X_i in their importance order.

Parameter estimation is carried out for linear and linearizing models like

$$Y = b_0 + \sum_{i=1}^{m} b_i X_i \tag{B.6}$$

where X_i are indexes of original plurality (X_i) or indexes, obtained from by algebraic manipulations;

b_0, b_i are regression coefficients, estimation of model parameters.

Criterion of stepwise regressions construction is based on decreasing of the residual sum of (B.6) equation squares in this procedure in regression is entered a variable having the greatest influence on this decreasing and is eliminated the one having the least influence.

Model construction procedure is continued until all the different $X \in (X_i)$, $i = \overline{1,m}$ will be exhausted. In this case the whole plurality of possible models is 2^m. Stepwise construction assumes the moving in directions, perspective from the point of view of reducing the residual sum of squares. The final model choice is determined by its statistical reliability in the whole and of statistical reliability of every obtained estimation of model parameters b_i.

At each *l* - step of regressive model construction are calculated its characteristics:

$S_{ocm_l} = \sqrt{\frac{n-1}{n-l} \cdot \frac{SS - SS_{sum}}{n-l-1}}$ is standard error of model estimation with taking into account the degrees of freedom;

$R_l = \sqrt{1 - \left(1 - \frac{n-1}{l} \cdot \frac{SS_{sum}}{SS}\right)^2 \cdot \frac{n-1}{n-l}}$ is coefficient of plural correlation, corrected to freedom degrees;

$F = \frac{n-l-1}{l} \cdot \frac{SS_{sum}}{SS - SS_{sum}}$ is reliability coefficient of plural correlation coefficient (Fischer's statistics);

$t_i = \frac{b_i}{S_{b_i}}$ is reliability coefficient of regression coefficients (Student's statistics),

where: SS is sum of squares of dependent variable deviation from its mean value;

SS_{sum} is the stored sum of squares, explained by plural regression;

n is number of observations for each variable

l is number of variables in regression equation in given step;

b_i is regression coefficient;

S_{b_i} are standard regression coefficient errors, calculated as elements of matrix, inverse to the correlative one.

According to the method of least squares the estimation of b_i parameters in regressive model at each step are choose so that they should minimize the difference between scattering of experimental data and the values predicted by the model.

When estimating the model quality the t_i values of reliability indexes of regression coefficients

are compared with the limit value of Student's statistics $t_{q,\ v}$ (q is assumed level of importance, v is the number of freedom degrees). The reliability coefficient F of plural correlation is compared with table of Fischer's statistics F_{q,v_1,v_2} (q is the assumed level of importance, $v_1 = l$, $v = n - l - 1$ are corresponding freedom degrees values).

If $t_i \geq t_{q,V}$, the value of ith regression coefficient is supposed to be reliable. When $F \geq F_{q,v_1,v_2}$ the value of plural regression coefficient is supposed to be unreliable.

First it is necessary to obtain models with reliable estimations of regression coefficients and coefficients of plural correlation, minimum approximation error and standard error of model estimation.

If must be choose such model, that gives reliable estimations t_i of regression coefficients b_i, reliable estimation F of plural correlation coefficient, minimal standard error of model estimation, sufficiently high plural correlation coefficient R as an index of determinative connection of variable Y with independent variables X, and contains variables X acceptable in context of problem to be solved.

APPENDIX C

(informative)

METHOD OF REGRESSIVE DEPENDENCIES RECONSTRUCTION FOR GIVEN EXPERIMENTAL DATA

For reconstruction of quantitative correspondence between mechanical characteristics values of rolled products and measured physical parameters in the case, when the sampling are made not in the proper way and include different number of measurements, a method of finding the coefficients of calibration equation based on reconstruction correlative dependencies is proposed. The reconstruction method is based on properties stability of tested objects afforded by used technology and normal low of joint distribution of measured values.

During dependence reconstruction different problem statements are reduced to mathematical problem of average risk using experimental data.

Indexes *Y* and *X* are supposed to be connected with regressive dependence, if each value of *x* for *X* index is assigned with a value *y* obtained by random test of index *Y* in accordance with a conventional probability density *P(y/x). I*n other words to each *X* is assigned the *S(y/x)* low in accordance with which choice of *y* is released in random test.

The complete knowing of the regressive dependence requires the reconstruction of conventional probability density *P(y/x)*, but practically in measured results processing problems it is necessary to know only one of its characteristics − the function of conventional expected value

$$y(x) = \int y \cdot P(y/x)\, dy, \qquad \text{(C.1)}$$

which is called regression.

The problem of conventional expected value reconstruction in this case is formulated as the problem of regression reconstruction, which is one of the main problem of applied statistics.

The problem statement consists in the following.

Measured values *x* randomly and independently appear during the test. In this medium operates *S(x/y)* converter, which to each x assigns *y* value, obtained as a result of random test realization in accordance which *P(y/x)* low.

Properties of *P(x)* medium and *P(y/x)* low are unknown, but it is known that there is a regression

$$y = y(x) \tag{C.2}$$

Having a pair of random independent samplings of different volume (in common case)

$$\left(X_i\right),\ i = \overline{1,m}\ ;\quad \left(Y_j\right),\ j = \overline{1,n} \tag{C.3}$$

it is required to reconstruct the regression, i.e. in function class *F(x,a)* to find a function $F(X,a^x)$, which is the nearest one to *y(x)* regression.

Here *m, n* are volumes of independent samplings under indexes *Y, X,* and *F* is designation of regression class functions, which differ by parameter values and belong to *a* set of values.

The problem of regression is reduced to the problem of minimization the functional

$$I(a) = \int \left(y - F(x,a)\right)^2 \cdot P(y/x) \cdot P(x)dx\,dy \tag{C.4}$$

on the set $F(x,a) \in L_p$ of integrated with square on measure *P(x)* functions in situation, when joint probability density *P(x,y) = P(x/y) P(x)* is unknown.

It can be shown, that if regression *y = y(x)* belongs to *F(X,a)* class, it minimize the *I(a)* functional. When regression does not belong to *F(x,a),* the minimum is obtained on the nearest to the regression *F(x,a)* function, i.e. in any case the solution will be optimal relative to given assumptions.

The proximity of functions is understandable in the sense of L_p metric (square standard)

$$d\left[f_1(x), f_2(x) = \sqrt{\int \left(f_1(x) - f_2(x)\right)^2 \cdot P(x)dx}\right] \tag{C.5}$$

The common form of formula (4) is

$$I(a) = \int Q(z,a)P(z)dr \qquad (C.6)$$

where: *I(a)* is average risk;

Q (z ,a) is function of losses in average risk minimization problem during regression reconstruction based on empirical data z_1, z_2...

The minimum value of (C.6) is obtained with confidence *P*, called the reconstruction reliability.

The practical problem solution affording the average risk of regression reconstruction minimization with given reliability on samplings of limited volume is in creation of an equation of selected 100(1 − α) - percent domain D_{yx} of joint *Y* and *X* values distribution

$$D_{yx} : D(\alpha ,u) = 0, \qquad (C.7)$$

where *u* is vector of parameters, which includes reference values of joint measurements *x, y* distribution, mean $\bar{y}$, $\bar{x}$ values, root-mean- square deviations S_y, S_x and twin correlation coefficient R_{xy}.

The equation is solved with respect to R_{yx} using selected reference values. In particular, 100(1−α) − percent confidence domain of joint hit of *y, x* values is determined by ellipse equation

$$\frac{\left(y-\bar{y}\right)^2}{S_y} - 2R_{yx}\left(y-\bar{y}\right)\cdot\left(x-\bar{x}\right) + \frac{\left(x-\bar{x}\right)^2}{S_x} = 1 - R_{yx} \qquad (C.8)$$

with extension, corresponding with fixed confident probability and volumes of samplings.

Setting statistical hypotheses of limited $Y = Y^0$ and $X = X^0$ values, we obtain solution of (C.8) equation with respect R_{yx}, that allows to find the calibration coefficient

$$b = \frac{S_y}{S_x} R_{xy} \qquad (C.9)$$

and offset

$$a = \overline{y} - b\overline{x} \qquad \text{(C.10)}$$

for reconstruction of the regression dependence

$$y = a + bx \qquad \text{(C.11)}$$

between the mechanical characteristic and the measured physical index.

As a rule, the equations of (C.11) type with respect to R_{yx} are non-linear ones. That is why it is expedient to use one of approximate techniques for solving with iteration at *i*-step

$$u(i+1) = u(i) + t(i)g(i) \qquad \text{(C.12)}$$

where *g(i)* is the unit vector in the gradient direction;

t(i) is the step value.