United Nations ECE/TRANS/WP.11/2016/4

Economic and Social Council

Distr.: General
19 July 2016
English
Original: Russian

Economic Commission for Europe

Inland Transport Committee

Working Party on the Transport of Perishable Foodstuffs

Seventy-second session
Geneva, 4-7 October 2016
Item 5 (b) of the provisional agenda
Proposals of amendments to ATP:
New proposals

Addition to Annex 1 of ATP of clarification in respect of the margin of error in the overall coefficient of heat transfer of special equipment and inclusion of its calculation in the ATP Handbook

Transmitted by the Russian Federation

Summary

Executive summary: In accordance with ATP, Annex 1, Appendix 2, sub-section 2.3.2, the overall coefficient of heat transfer (the K coefficient) of a body of special equipment must be determined with a maximum margin of error of ± 10% when using the method of internal cooling and ± 5% when using the method of internal heating. The wording leaves unclear specifically which margin of error for the K coefficient are addressed.

The ATP Handbook contains comments relating to this sub-section, which give a description of the possible margins of error that occur in determining the K coefficient and give general proposals to define such margins of error. However, the information is not sufficient to provide a justifiable and unambiguous practical definition of the margins.

Action to be taken: Clarify the wording of ATP Annex 1, Appendix 2, sub-section 2.3.2 relating to the margin of error for the K coefficient.

Replace the comments relating to sub-section 2.3.2 with a more complete version, including the method for calculating the margin of error for the K coefficient.

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	Introduce the corresponding changes to model test reports Nos. 2 A and 2 B.
Related documents:	None.

Introduction

1. At its seventieth session, WP.11 considered proposals from the United Kingdom on methods for defining the external surface area of van bodies without windows in the cargo compartment.

At the seventy-first session the Russian Federation presented an unofficial document expanding upon the methods proposed by the United Kingdom and addressing also the definition of the surface areas of railway wagon bodies.

During the discussion of the unofficial document, the specialists from the Russian Federation expressed the opinion that each proposed method (including for defining heat transfer areas of bodies of special equipment) should present an estimate of its margin of error, indicating inter alia the methods used for its calculation. This is related first and foremost to the need to ensure the level of accuracy required by ATP in the test procedure for determining the K coefficient. According to ATP Annex 1, Appendix 2, sub-section 2.3.2, the margin of error in the K coefficient must not exceed:

±10% when using the method of internal cooling; and

±5% when using the method of internal heating.

The specialists from the Russian Federation also noted that the test method set out in ATP does not contain any indication of how to calculate the margin of error when determining the K coefficient. The ATP Handbook contains comments relating to sub-section 2.3.2, but the information is insufficient for an unambiguous interpretation and for practical calculations of the margin of error. The comments in question need to be revamped and expanded with the corresponding methodology for the calculation of margins of error when determining K coefficients.

The Working Party, understanding the complexity of the question, expressed the desire to discuss the remarks made on this subject if the Russian Federation submitted the corresponding document at the seventy-second session.

2. In the light of the above, the Russian Federation has prepared, as an official document, proposals for the introduction into ATP and the ATP Handbook of the corresponding provisions.

The specialists of the Russian Federation propose:

To indicate in ATP Annex 1, Appendix 2, sub-section 2.3.2 the type of margin of error of the K coefficient;

In the ATP Handbook, to introduce into the test procedure a method to calculate the margin of error of the K coefficient;

To bring model test reports Nos. 2 A and 2 B into line with the proposed changes.

3. It was decided to introduce the calculation method for K coefficients into the ATP Handbook and not ATP itself, as the method in question takes into account only the basic and most significant factors that lead to errors during testing. No less important is the fact that, in calculating the margin of error of the K coefficient, approaches other than the mathematical methods proposed by the ATP Handbook may be used, in some

circumstances justifiably. Still, the proposed method can be successfully applied in the overwhelming majority of the tests that determine the K coefficient of special equipment.

Proposals

4. Reword ATP Annex 1, Appendix 2, sub-section 2.3.2, as follows:[1]

"2.3.2 Accuracy of measurements of the K coefficient

Testing stations shall be provided with the equipment and instruments necessary to ensure that the K coefficient is determined with a maximum relative margin of error from the result obtained of ± 10% when using the method of internal cooling and ± 5% when using the method of internal heating. In calculating the margin of error of the K coefficient using probability and mathematical statistics theory, the level of reliability must be at least 95%.

The reference data and the calculation of the margin of error for the K coefficient shall be set out in the test report for measuring the K coefficient of the body of the special equipment, drawn up in accordance with model test reports Nos. 2 A and 2 B."

5. Reword the comments in the ATP Handbook relating to ATP Annex 1, Appendix 2, sub-section 2.3.2, as follows:[2]

"*Comments to 2.3.2:*

1. Examples for the errors which are normally taken into account by the test stations are temperature, ~~power~~ heat output, which is generally dependent on the electrical power consumed by the electric heating units (for the method of internal heating) or cold production (for the method of internal cooling) and the surface area of the body.

~~*The method of calculating the error, which is usually applied, is the total admissible error ε:*~~

$$\cancel{\varepsilon = \sqrt{\left(\frac{\Delta S}{S}\right)^2 + \left(\frac{\Delta W}{W}\right)^2 + \left(2\cdot\frac{\Delta T}{T_e - T_i}\right)}}$$

~~*or the absolute error ε_m:*~~

$$\cancel{\varepsilon_m = \frac{\Delta S}{S} + \frac{\Delta W}{W} + 2\cdot\frac{\Delta T}{T_e - T_i}}$$

~~*where:*~~

~~*S is the mean surface area of the vehicle body (geometric mean of the internal and external surfaces);*~~

~~*W is the power dissipated inside the vehicle body in the steady state; T_e and T_i are in the respective external and internal temperatures of the vehicle body under test.*~~

The relative margin of error for determining the K coefficient, ε_K, can be obtained by the relationship between the absolute margin of error for determining the K coefficient, ΔK, and its calculated (average) value, $\overline{K}$. As it is generally very complicated to establish the value for ΔK, it is advisable to use probability and mathematical statistic theory methods, determining the value of the confidence interval (of the random error) for $\overline{K}$, $\Delta_{\overline{K}}$, with a confidence probability (reliability) greater than 95%. In this case:

[1] Hereinafter, additions to the text are underlined and deletions are marked in strikethrough.

[2] For technical reasons, the added formulae are not underlined.

$$\varepsilon_K = \frac{\Delta K}{\bar{K}} \cdot 100 \cong \frac{\Delta_{\bar{K}}}{\bar{K}} \cdot 100$$

$$\Delta_{\bar{K}} = \sqrt{\left(\frac{\Delta_{\bar{W}}}{\bar{S} \cdot (\bar{T_e} - \bar{T_\iota})}\right)^2 + \left(\frac{\bar{W} \cdot \Delta_{\bar{T_\iota}}}{\bar{S} \cdot (\bar{T_e} - \bar{T_\iota})^2}\right)^2 + \left(\frac{\bar{W} \cdot \Delta_{\bar{T_e}}}{\bar{S} \cdot (\bar{T_e} - \bar{T_\iota})^2}\right)^2 + \left(\frac{\bar{W} \cdot \Delta_{\bar{S}}}{\bar{S}^2 \cdot (\bar{T_e} - \bar{T_\iota})}\right)^2}$$

where:

<u>$\bar{W}$, $\bar{T_e}$, $\bar{T_\iota}$, $\bar{S}$ — are sample mean values respectively for the heat output (or cold production), in W; the external and internal temperatures of the body, in °C; and the area of the average surface of the body, in m^2;</u>

<u>$\Delta_{\bar{W}}$, $\Delta_{\bar{T_\iota}}$, $\Delta_{\bar{T_e}}$, $\Delta_{\bar{S}}$ — are the confidence intervals (random errors) respectively for the heat output (or cold production), in W; the external and internal tempertaures of the body, in °C; and the area of the average surface of the body, in m^2.</u>

$$\bar{W} = \frac{\sum_{k=1}^{n} W_k}{n}$$

$$W_k = \eta_k \cdot Q_k$$

$$\Delta_{\bar{W}} = \sqrt{\left(t_{\alpha,n} \cdot \sqrt{\frac{\sum_{k=1}^{n}(\bar{W} - W_k)^2}{n \cdot (n-1)}}\right)^2 + \left(\alpha \cdot \Delta_Q\right)^2}$$

$$\bar{T_\iota} = \frac{\sum_{k=1}^{n} \sum_{i=1}^{l} T_{i_{i,k}}}{n \cdot l}$$

$$\Delta_{\bar{T_\iota}} = \sqrt{\left(t_{\alpha,(n \cdot l)} \cdot \sqrt{\frac{\sum_{k=1}^{n} \sum_{i=1}^{l} \left(\bar{T_\iota} - T_{i_{i,k}}\right)^2}{(n \cdot l) \cdot (n \cdot l - 1)}}\right)^2 + \left(\alpha \cdot \Delta_{T_i}\right)^2}$$

$$\bar{T_e} = \frac{\sum_{k=1}^{n} \sum_{j=1}^{m} T_{e_{j,k}}}{n \cdot m}$$

$$\Delta_{\bar{T_e}} = \sqrt{\left(t_{\alpha,(n \cdot m)} \cdot \sqrt{\frac{\sum_{k=1}^{n} \sum_{j=1}^{m} \left(\bar{T_e} - T_{e_{j,k}}\right)^2}{(n \cdot m) \cdot (n \cdot m - 1)}}\right)^2 + \left(\alpha \cdot \Delta_{T_e}\right)^2}$$

$$\Delta_{\bar{S}} = \sqrt{\frac{\left(\bar{S_i} \cdot \Delta_{\bar{S_e}}\right)^2 + \left(\bar{S_e} \cdot \Delta_{\bar{S_i}}\right)^2}{4 \cdot \bar{S_e} \cdot \bar{S_i}}}$$

where:

<u>Q_k, W_k — are the measured values respectively of the electical power consumed from the grid and the heat output (or cold production), when measuring the kth measurement (overall, for the calculation period, at the end of the steady state period, n measurements taken), in W;</u>

<u>η_k — is the coefficient of efficiency of electrical heating devices, taking into account losses in wiring (for the method of internal heating) or of heat exchangers (for the method of internal cooling), when measuring the th measurement, expressed as a fraction;</u>

$T_{i\,i,k}$, $T_{e\,j,k}$ — are the temperatures measured at the kth measurement, respectively using the i-instrument inside the body of the special equipment under test (in all, with one measurement, simultaneously taken by l uniformly precise thermometers) and by instrument j on the outside of the body of the special equipment under test (in all, with one measurement, simultaneously taken by m uniformly precise thermometers), in °C;

Δ_{T_i}, Δ_{T_e}, Δ_Q — are the instrument margins of error for the measurement of temperatures respectively inside and outside the body of the special equipment under test, in K, and the electrical power consumed from the grid, in W;

$t_{\alpha,n}$, $t_{\alpha,(n\cdot l)}$, $t_{\alpha,(n\cdot m)}$— are the values of the Student's t-coefficient for a given confidence level α (α ⩾0.95) and the corresponding quantity of measurements taken of physical magnitudes;

$\overline{S_i}$, $\overline{S_e}$, — are the sample mean areas respectively of the inner and outer surfaces of the body of the special equipment under test (disregarding corrugation), in m^2;

$\Delta_{\overline{S_i}}$, $\Delta_{\overline{S_e}}$ — are the confidence intervals (random errors) of the area of the body surface respectively of the inner and outer surfaces of the special equipment under test, in m^2.

Using the method of internal heating, η_k can be calculated based on the assumption that the electrical power in the electric heating units is transformed into heat with practically no loss. In such a case the only loss will be in the wiring, calculated as follows:

$$\eta_k = 1 - \frac{2 \cdot Q_k \cdot L_{line} \cdot \rho}{U^2 \cdot s}$$

where:

Q_k — is the value of the electric power consumed from the grid measured at the th measurement, in W;

L_{line} — is the length of the power cable from the meter to the location of the corresponding device, in m;

ρ — is the resistivity of the wire in the power cable, in ohm·mm^2/m;

U — is the rated electric tension in the grid, in V;

s — is the cross-sectional area of the wire in the power cable, in mm^2.

When using the method of internal cooling, the calculation of η_k must take into account the specific means of cooling employed and the equipment used.

Instrument margins of error may be indicated by the manufacturer of the measurement equipment as absolute values, in which case they shall be used directly in the calculation formulae or as an accuracy class. In the latter case, the margin of error may be standardized in relation to the result of the measurement:

$$\Delta_x = \frac{\delta}{100} \cdot x$$

or may be expressed thus:

$$\Delta_x = \frac{\delta}{100} \cdot X$$

where:

δ — is the value of the accuracy class indicated by the manufacturer of the measurement instrument, in %;

x — is the value of the measured physical phenomenon. If it is determined in a series of measurements as an average of the results, it is advisable to use the maximum value in the series of measurements for the calculated value of x;

X — is the maximum admissible value for the measured physical phenomenon x in a given operating range of the measurement instrument.

2. *Under normal test conditions, ~~S~~ $\overline{S_\iota}$ and $\overline{S_e}$ can be measured with a high degree of accuracy. ~~to 1%. However, there are cases where it is impossible to measure with this precision.~~ Generally, the following method may be used to determine the margins of error of $\overline{S_\iota}$ and $\overline{S_e}$, which are used to determine the average surface area of the body, $\bar{S}$.*

If $\overline{S_\iota}$ and $\overline{S_e}$ are presented as functions of a series of repeated measurements, $\overline{p_\iota}$ and $\overline{p_e}$, (for example, the length, width and height measured at various places in the body of the special equipment):

$$\overline{S_\iota} = f_1\left(\overline{p_{\iota_1}}, \overline{p_{\iota_2}}, \ldots, \overline{p_{\iota_Y}}\right)$$

$$\overline{S_e} = f_2\left(\overline{p_{e_1}}, \overline{p_{e_2}}, \ldots, \overline{p_{e_Z}}\right)$$

then:

$$\Delta_{\overline{S_i}} = \sqrt{\sum_{y=1}^{Y}\left(\Delta_{\overline{p_{\iota_y}}} \cdot \frac{\partial f_1}{\partial \overline{p_{\iota_y}}}\right)^2}$$

$$\Delta_{\overline{S_e}} = \sqrt{\sum_{z=1}^{Z}\left(\Delta_{\overline{p_{e_z}}} \cdot \frac{\partial f_2}{\partial \overline{p_{e_z}}}\right)^2}$$

where:

$\frac{\partial f_1}{\partial p_{\iota_y}}, \frac{\partial f_2}{\partial p_{e_z}}$ *— are respectively the partial derivatives for the functions to calculate $\overline{S_\iota}$ and $\overline{S_e}$;*

$\Delta_{\overline{p_{\iota_y}}}, \Delta_{\overline{p_{e_z}}}$ *— are respectively the confidence intervals for the parameters $\overline{p_{\iota_y}}$ and u $\overline{p_{e_z}}$.*

$$\overline{p_{\iota_y}} = \frac{\sum_{v=1}^{V} p_{i_{y_v}}}{V}$$

$$\Delta_{\overline{p_{\iota_y}}} = \sqrt{\left(t_{\alpha,V} \cdot \sqrt{\frac{\sum_{v=1}^{V}\left(\overline{p_{\iota_y}} - p_{i_{y_v}}\right)^2}{V \cdot (V-1)}}\right)^2 + \left(\alpha \cdot \Delta_{p_{i_y}}\right)^2}$$

where:

V — is the quantity of measurements carried out to determine the average value of parameter p_{i_y};

$p_{i_{y_v}}$ — is the measured value of parameter p_{i_y} at the th measurement;

$t_{\alpha,V}$ — is the value of the Student's t-coefficient for a given confidence level α ($\alpha \geqslant 0.95$) and the corresponding quantity of measurements of parameter p_{i_y}, V;

$\Delta_{p_{i_y}}$ — is the instrument margin of error for the parameter p_{i_y};

$\overline{p_{e_z}}$ and $\Delta_{\overline{p_{e_z}}}$ are determined in the same way as $\overline{p_{i_y}}$ and $\Delta_{\overline{p_{i_y}}}$.

The values of parameters $\overline{p_{i_y}}$ and $\overline{p_{e_z}}$ can be taken as given (in the technical documentation of the special equipment). In this case:

$$\Delta_{\overline{p_{i_y}}} = \alpha \cdot d_{p_{i_y}}$$

$$\Delta_{\overline{p_{e_z}}} = \alpha \cdot d_{p_{e_z}}$$

where:

$d_{p_{i_y}}$,.$d_{p_{e_z}}$ — are the unit in the highest digit position of the parameter in question, divided by two;

~~*The error of W does not exceed 1 %, although certain test stations use equipment giving a greater error.*~~

~~*Temperature is measured with an absolute accuracy of 0.1 K. The measurement of a temperature difference $(T_e - T_i)$ of the order of 20 K therefore gives an error of twice 0.5 %, i.e. ±1%.*~~

~~*The total error is therefore $\varepsilon = \pm\sqrt{0.0003} = \pm 0.017\%$. The maximum admissible error is ε_m=3%.*~~

3. Other errors which have not been taken into consideration can have an effect on the exact value of the K coefficient. These errors are as follows:

(a) Latent errors due to admissible variations in the internal and external temperatures, which are a function of the thermal inertia of the walls of the equipment, the temperature and time;

(b) Errors due to the variation of air velocity at the boundary layer and its effect on the thermal resistance.

If the internal and external air velocities are of equal value, the possible error will be about 2.5% as between 1 to 2 m/s for a mean K coefficient of 0.40 W/m^2.K. For a K coefficient of 0.70 W/m^2.K, this error will be nearly 5%. If there are significant thermal bridges, the influence of the speed and direction of the air will be greater.

~~*4. Finally, because of the error in the estimation of the surface area of the body, an error which in practice is difficult to calculate when dealing with non standard equipment, (this estimation involving factors of a subjective nature), one could envisage the determination of the error in the measurement of the overall heat transfer per degree temperature difference:*~~

$$\cancel{\frac{W}{T_e - T_i} = K \cdot S}$$

6. In model test reports Nos. 2 A and 2 B, recast the line on the margin of error for the definition of the K coefficient, as follows:

"~~Maximum~~ With the test used, the relative error ~~of measurement~~ in determining the values obtained, reliability …%"

Sample calculations

7. Annex A to this official document contains a sample Mathcad calculation of the margin of error in determining the K coefficient of an insulated railway wagon tested in

2015 by the Food and Perishable Goods Transport Administration, an open joint-stock company of the Railway Computerization, Automation and Communication Scientific Research and Construction Planning Institute, in the Russian Federation.

Justification

8. The measurement's margin of error, or error, is the result's deviation from the actual value of the physical quantity being measured. The accuracy of measurement is the inverse of the margin of error.

9. A distinction is made in the presentation between:

Absolute margin of error, defined as the difference between the actual and measured values of the physical quantity in question;

Relative margin of error, the relationship between the absolute error and either the actual value or the result of the measurement;

Fractional margin of error, the relationship between the absolute error and some standard (for example, a maximum admissible value) for the physical quantity in question.

The relative and fractional margins of error are generally expressed as percentages.

10. In the current wording of ATP Annex 1, Appendix 2, sub-section 2.3.2, the presentation of the margin of error as a percentage suggests that the intention is either to address one of the various types of relative margin of error or the fractional error. Quantifiable expressions of the various constituent types of error too will differ.

Thus, the type of margin of error to be considered in determining the K coefficient should be clearly indicated in ATP Annex 1, Appendix 2, sub-section 2.3.2.

11. Upon further analysis it becomes clear that the fractional error or the relative error relating to the actual value of the K coefficient should not be used.

Indeed, while at first glance the maximum value of the K coefficient for a given category of tested special equipment could hypothetically serve as a standard value, the fractional margin of error is usually indicated for certain *designs* of measurement instruments. This kind of margin of error is thus determined by the design characteristics of the measurement instruments and not by the nature of the measurements or the measured quantities. The value of the K coefficient is not determined using direct measurements; it is instead calculated according to a known functional relationship. As a rule, all the physical quantities entering into this functional relationship are measured with instruments whose accuracy is indicated in absolute or relative values, not in fractional ones.

The relative margin of error calculated as the relationship between the absolute error and the actual value presupposes that the actual value of the K coefficient can be obtained. Taking into account the complexity involved in determining the K coefficient (which is done indirectly, using physical values measured by means of a series of direct, repeated, uniformly precise measurements), it is practically impossible to determine the actual value of the K coefficient.

Based on the above, it was proposed to specify in ATP, Annex 1, Appendix 2, sub-section 2.3.2, that when the K coefficient is determined, the relative margin of error *calculated in relation to the obtained results* should not exceed the values indicated in the text.

12. The value of the K coefficient is not measured directly, but is calculated on the basis of other physical parameters (heat output or cold production, *W*; the external temperature,

T_e, and internal temperature, T_i, of the special equipment's body; the average surface area of the body, *S*); it is related to them according to the following functional relationship:

For the method of internal heating:

$$K = \frac{W}{S \cdot (T_i - T_e)}$$

For the method of internal cooling:

$$K = \frac{W}{S \cdot (T_e - T_i)}$$

As the value of the K coefficient is determined indirectly, its margin of error is calculated as an aggregate of the separate derivative parameters of the corresponding functions for the margins of error in measuring such parameters:

$$\Delta_K = \sqrt{\left(\Delta_W \cdot \frac{\partial K}{\partial W}\right)^2 + \left(\Delta_S \cdot \frac{\partial K}{\partial S}\right)^2 + \left(\Delta_{T_i} \cdot \frac{\partial K}{\partial T_i}\right)^2 + \left(\Delta_{T_e} \cdot \frac{\partial K}{\partial T_e}\right)^2}$$

The amended comment to ATP Annex 1, Appendix 2, sub-section 2.3.2 includes the corresponding wording for the above formula, after a series of analyses.

13. The number of factors influencing the measurement accuracy of the physical parameters that enter into the functional relationship determining the K coefficient is quite large and any classification of margins of error for their measurement thus must be conditional.

In the proposed method for calculating the margin of error of the K coefficient, there is no analysis or accounting for systematic errors. It is considered that systematic errors or their causes can be identified and that the persons carrying out the measurements are sufficiently competent to remove them.

Similarly, gross errors or flaws may be relatively easily detected and excluded from the calculations in determining K coefficient values.

The proposed method for calculating the margin of error in determining the K coefficient in fact amounts to taking into consideration random errors that change in value or sign from one time to the next when the measurements are taken in identical ways and identical circumstances.

In the measurement of the physical parameters used to determine the K coefficient, we should consider that the random error of such measurements is the aggregate of the random error of direct single measurements, Δ_{SING}, and the random error of direct, repeated, uniform measurements, Δ_{REP}. To find the cumulative error resulting from the independent values, we use the law of combination of independent errors:

$$\Delta = \sqrt{\Delta_{SING}^2 + \Delta_{REP}^2}$$

14. In principle, it is impossible to predict a random error for a single measurement. Taking into account the fact that the values of the physical phenomena that are used to determine the K coefficient are obtained on the basis of averages of repeated (redundant), uniform measurements, to determine the margin of error of the result obtained (i.e., to assess the aggregate random error) it is advisable to make use of the known mathematical methods of probability and mathematical statistics theory. With a large enough sample of measurements, it is always possible to indicate the limits within which the true values will fall.

Any random error can be estimated with a certain level of confidence or reliability, and that level has to be determined. In this case, the requirement to determine the K coefficient with a *maximum* margin of error is inappropriate; instead, a certain level of *reliability* is required. As the K coefficient is a technical assessment of the insulation in special equipment, a reliability level of 95% has been deemed sufficient.

15. The random errors for repeated, uniform measurements are continuous and are characterized by a large number of random causes affecting each individual measurement in a distinct and unpredictable way. They may thus be random. In accordance with the central limit theorem, a random value established as an aggregate of several independent random processes is subject to the law of normal distribution. We may thus assume that the random errors for the repeated, uniform measurements of the physical parameters used to determine the K coefficient are subject to the law of normal distribution.

16. In light of the fact that the actual values of the K coefficient and of the physical parameters that determine it are unknown, the margin of error is calculated in relation to the average values of such parameters. In this case, to determine the limits of the confidence intervals of the (average) values found for the parameters in question, it is not normal distribution quantiles that should be used, but the corresponding Student’s t-coefficients that are taken for a specific confidence or reliability level and number of measurements performed.

Costs

17. There are no additional costs.

Feasibility

18. The proposed amendments to ATP will remove ambiguity about the instrument’s requirements for the accuracy of the K coefficient in special equipment testing. Clear recommendations for the calculation of K coefficient margins of error and the introduction of corresponding calculation methods in the ATP Handbook will reduce the possibility that special equipment will be erroneously classified by K coefficients and help to increase confidence among the ATP Contracting Parties.

Enforceability

19. No problems are foreseen for the application of the proposed improvements relating to the margin of error of the K coefficient for special equipment and its method of calculation.

Annex A

Sample calculation of the margin of error in determining the K coefficient of an insulated railway wagon tested in 2015 by the Food and Perishable Goods Transport Administration, an open joint-stock company of the Railway Computerization, Automation and Communication Scientific Research and Construction Planning Institute, in the Russian Federation (Mathcad printout)

1. Input data

Power consumed [QD] by electric heating units (without fans), in W; internal temperature of the body [TiD] and external temperature of the body [TeD], in °C:

$$QD := \begin{pmatrix} 1852.7 \\ 1829.7 \\ 1850.6 \\ 1835.9 \\ 1856.9 \\ 1840.0 \\ 1854.8 \\ 1829.7 \\ 1838.0 \\ 1856.9 \\ 1833.8 \\ 1850.6 \\ 1821.3 \\ 1836.0 \\ 1817.2 \\ 1842.2 \\ 1823.4 \\ 1817.2 \\ 1842.2 \\ 1810.9 \\ 1831.8 \\ 1798.4 \\ 1821.3 \\ 1802.5 \\ 1821.3 \\ 1794.2 \\ 1810.9 \\ 1785.8 \\ 1779.7 \\ 1798.3 \\ 1771.3 \\ 1802.4 \\ 1783.7 \\ 1813.0 \\ 1777.5 \\ 1785.8 \\ 1806.7 \\ 1777.5 \\ 1798.4 \\ 1771.2 \\ 1794.2 \\ 1781.6 \\ 1792.1 \\ 1813.0 \\ 1790.1 \\ 1810.9 \\ 1779.6 \\ 1796.2 \\ 1763.0 \end{pmatrix}$$

$$TiD := \begin{pmatrix}
33.8 & 33.7 & 33.6 & 33.2 & 34.0 & 34.1 & 32.8 & 33.0 & 33.2 & 33.2 & 32.4 & 33.6 \\
33.8 & 33.7 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.0 & 33.2 & 33.2 & 32.3 & 33.6 \\
33.8 & 33.7 & 33.6 & 33.1 & 34.1 & 34.1 & 32.8 & 33.1 & 33.2 & 33.3 & 32.3 & 33.7 \\
33.8 & 33.7 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.3 & 33.2 & 32.4 & 33.7 \\
33.9 & 33.7 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.4 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.2 & 32.9 & 33.1 & 33.4 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.6 & 33.2 & 34.1 & 34.2 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.2 & 32.9 & 33.2 & 33.3 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.2 & 32.9 & 33.2 & 33.4 & 33.4 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.2 & 32.9 & 33.1 & 33.3 & 33.3 & 32.4 & 33.8 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.2 & 32.9 & 33.1 & 33.4 & 33.3 & 32.4 & 33.8 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.2 & 32.8 & 33.2 & 33.4 & 33.4 & 32.4 & 33.8 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.1 & 34.2 & 32.8 & 33.1 & 33.3 & 33.4 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.2 & 32.9 & 33.2 & 33.4 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.1 & 34.2 & 33.0 & 33.2 & 33.4 & 33.4 & 32.3 & 33.8 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.2 & 34.2 & 32.9 & 33.1 & 33.3 & 33.4 & 32.4 & 33.7 \\
34.0 & 33.8 & 33.9 & 33.2 & 34.1 & 34.2 & 32.9 & 33.2 & 33.4 & 33.3 & 32.4 & 33.8 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.3 & 32.9 & 33.1 & 33.4 & 33.4 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.1 & 34.3 & 33.0 & 33.2 & 33.4 & 33.4 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.2 & 32.8 & 33.2 & 33.4 & 33.4 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.2 & 32.8 & 33.2 & 33.4 & 33.3 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.1 & 34.2 & 32.9 & 33.2 & 33.3 & 33.3 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.1 & 34.2 & 33.0 & 33.2 & 33.3 & 33.4 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.2 & 32.9 & 33.2 & 33.3 & 33.4 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.9 & 33.3 & 34.1 & 34.2 & 32.9 & 33.2 & 33.2 & 33.3 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.2 & 32.9 & 33.2 & 33.3 & 33.3 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.3 & 34.1 & 34.2 & 32.8 & 33.1 & 33.3 & 33.3 & 32.6 & 33.8 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.2 & 32.8 & 33.2 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.1 & 32.7 & 33.2 & 33.3 & 33.3 & 32.6 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.2 & 33.4 & 33.2 & 32.6 & 33.7 \\
33.8 & 33.8 & 33.9 & 33.2 & 34.1 & 34.1 & 32.9 & 33.2 & 33.3 & 33.2 & 32.6 & 33.7 \\
33.9 & 33.7 & 33.9 & 33.3 & 34.1 & 34.1 & 32.8 & 33.2 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.2 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.7 & 33.8 & 33.3 & 34.1 & 34.2 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.2 & 33.3 & 33.3 & 32.3 & 33.7 \\
33.9 & 33.8 & 33.8 & 33.2 & 34.1 & 34.1 & 32.9 & 33.2 & 33.3 & 33.2 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.2 & 33.3 & 33.3 & 32.4 & 33.7 \\
33.9 & 33.8 & 33.9 & 33.2 & 34.1 & 34.1 & 32.9 & 33.2 & 33.2 & 33.2 & 32.6 & 33.6 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.2 & 33.2 & 32.4 & 33.6 \\
33.8 & 33.7 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.2 & 33.3 & 32.3 & 33.6 \\
33.8 & 33.7 & 33.6 & 33.2 & 34.1 & 34.2 & 32.8 & 33.1 & 33.2 & 33.2 & 32.4 & 33.7 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.3 & 33.2 & 32.3 & 33.7 \\
33.9 & 33.7 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.8 & 33.6 & 33.2 & 34.1 & 34.1 & 32.9 & 33.1 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.8 & 33.3 & 34.1 & 34.1 & 32.8 & 33.2 & 33.3 & 33.2 & 32.4 & 33.7 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.8 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.3 & 33.3 & 32.4 & 33.6 \\
33.9 & 33.7 & 33.6 & 33.2 & 34.1 & 34.1 & 32.8 & 33.1 & 33.2 & 33.3 & 32.4 & 33.6
\end{pmatrix}$$

$$TeD := \begin{pmatrix}
7.1 & 7.2 & 7.0 & 6.9 & 7.2 & 7.2 & 6.7 & 6.8 & 7.5 & 7.5 & 6.8 & 7.7 \\
7.1 & 7.2 & 6.9 & 6.8 & 7.2 & 7.2 & 6.8 & 6.8 & 7.5 & 7.5 & 6.9 & 7.7 \\
7.1 & 7.2 & 7.0 & 6.8 & 7.3 & 7.2 & 6.7 & 6.8 & 7.5 & 7.5 & 6.9 & 7.8 \\
7.1 & 7.1 & 7.0 & 6.9 & 7.2 & 7.2 & 6.7 & 6.7 & 7.5 & 7.4 & 6.9 & 7.7 \\
7.0 & 7.1 & 6.9 & 6.9 & 7.2 & 7.1 & 6.7 & 6.7 & 7.4 & 7.4 & 6.8 & 7.7 \\
7.1 & 7.1 & 6.9 & 6.9 & 7.2 & 7.1 & 6.7 & 6.8 & 7.4 & 7.5 & 6.8 & 7.8 \\
7.0 & 7.1 & 6.9 & 6.8 & 7.2 & 7.1 & 6.7 & 6.8 & 7.4 & 7.5 & 6.8 & 7.7 \\
7.0 & 7.1 & 6.9 & 6.8 & 7.2 & 7.1 & 6.7 & 6.7 & 7.5 & 7.4 & 6.9 & 7.7 \\
7.0 & 7.1 & 6.9 & 6.8 & 7.2 & 7.1 & 6.7 & 6.7 & 7.4 & 7.4 & 6.8 & 7.7 \\
7.1 & 7.1 & 6.9 & 6.8 & 7.2 & 7.2 & 6.7 & 6.7 & 7.5 & 7.5 & 6.8 & 7.7 \\
7.0 & 7.1 & 6.9 & 6.8 & 7.2 & 7.1 & 6.7 & 6.7 & 7.4 & 7.5 & 6.8 & 7.7 \\
7.1 & 7.1 & 6.7 & 6.6 & 7.2 & 7.1 & 6.7 & 6.8 & 7.4 & 7.5 & 6.6 & 7.8 \\
7.0 & 7.1 & 6.9 & 6.8 & 7.2 & 7.1 & 6.7 & 6.7 & 7.4 & 7.4 & 6.7 & 7.7 \\
7.0 & 7.1 & 6.7 & 6.6 & 7.2 & 7.0 & 6.5 & 6.6 & 7.3 & 7.4 & 6.6 & 7.7 \\
7.0 & 7.1 & 6.7 & 6.6 & 7.1 & 7.0 & 6.6 & 6.6 & 7.3 & 7.4 & 6.7 & 7.7 \\
6.9 & 7.0 & 6.7 & 6.6 & 7.1 & 7.0 & 6.6 & 6.7 & 7.4 & 7.4 & 6.7 & 7.7 \\
6.9 & 7.0 & 6.5 & 6.6 & 7.1 & 6.9 & 6.6 & 6.6 & 7.3 & 7.3 & 6.6 & 7.6 \\
6.9 & 7.0 & 6.6 & 6.6 & 7.0 & 6.9 & 6.5 & 6.5 & 7.2 & 7.3 & 6.6 & 7.6 \\
6.8 & 6.9 & 6.6 & 6.6 & 6.9 & 6.8 & 6.4 & 6.5 & 7.2 & 7.2 & 6.6 & 7.6 \\
6.8 & 6.9 & 6.5 & 6.6 & 6.9 & 6.8 & 6.4 & 6.5 & 7.2 & 7.3 & 6.5 & 7.5 \\
6.7 & 6.9 & 6.5 & 6.5 & 6.9 & 6.8 & 6.5 & 6.5 & 7.1 & 7.2 & 6.6 & 7.5 \\
6.7 & 6.8 & 6.4 & 6.5 & 6.8 & 6.8 & 6.5 & 6.5 & 7.1 & 7.2 & 6.4 & 7.5 \\
6.7 & 6.8 & 6.3 & 6.4 & 6.9 & 6.7 & 6.4 & 6.5 & 7.1 & 7.2 & 6.4 & 7.5 \\
6.7 & 6.8 & 6.3 & 6.4 & 6.8 & 6.7 & 6.4 & 6.4 & 7.1 & 7.2 & 6.4 & 7.4 \\
6.7 & 6.8 & 6.4 & 6.4 & 6.8 & 6.8 & 6.3 & 6.4 & 7.1 & 7.1 & 6.5 & 7.4 \\
6.7 & 6.8 & 6.3 & 6.4 & 6.8 & 6.7 & 6.4 & 6.4 & 7.0 & 7.1 & 6.4 & 7.4 \\
6.7 & 6.8 & 6.4 & 6.5 & 6.8 & 6.7 & 6.4 & 6.4 & 7.1 & 7.2 & 6.5 & 7.4 \\
6.7 & 6.8 & 6.3 & 6.4 & 6.8 & 6.7 & 6.4 & 6.4 & 7.1 & 7.1 & 6.4 & 7.5 \\
6.7 & 6.8 & 6.3 & 6.4 & 6.8 & 6.7 & 6.3 & 6.4 & 7.1 & 7.1 & 6.3 & 7.3 \\
6.6 & 6.7 & 6.3 & 6.4 & 6.7 & 6.7 & 6.4 & 6.4 & 7.0 & 7.1 & 6.4 & 7.4 \\
6.7 & 6.8 & 6.2 & 6.3 & 6.8 & 6.7 & 6.3 & 6.3 & 6.9 & 7.0 & 6.3 & 7.4 \\
6.6 & 6.7 & 6.2 & 6.3 & 6.7 & 6.6 & 6.3 & 6.4 & 7.0 & 7.1 & 6.3 & 7.3 \\
6.6 & 6.7 & 6.3 & 6.4 & 6.7 & 6.6 & 6.2 & 6.3 & 7.0 & 7.0 & 6.4 & 7.4 \\
6.8 & 6.8 & 6.3 & 6.4 & 6.9 & 6.8 & 6.4 & 6.4 & 7.1 & 7.1 & 6.4 & 7.4 \\
6.7 & 6.8 & 6.3 & 6.4 & 6.7 & 6.7 & 6.4 & 6.4 & 7.0 & 7.1 & 6.4 & 7.3 \\
6.8 & 6.8 & 6.3 & 6.3 & 6.8 & 6.8 & 6.4 & 6.4 & 7.0 & 7.1 & 6.4 & 7.4 \\
6.7 & 6.8 & 6.2 & 6.4 & 6.8 & 6.7 & 6.4 & 6.5 & 7.1 & 7.1 & 6.3 & 7.4 \\
6.8 & 6.8 & 6.3 & 6.4 & 6.9 & 6.7 & 6.4 & 6.4 & 7.1 & 7.1 & 6.4 & 7.5 \\
6.8 & 6.8 & 6.4 & 6.5 & 6.9 & 6.8 & 6.4 & 6.5 & 7.2 & 7.2 & 6.5 & 7.5 \\
6.9 & 6.9 & 6.3 & 6.4 & 6.9 & 6.9 & 6.4 & 6.5 & 7.2 & 7.2 & 6.4 & 7.5 \\
6.9 & 6.9 & 6.4 & 6.5 & 7.0 & 6.9 & 6.5 & 6.5 & 7.3 & 7.2 & 6.4 & 7.5 \\
6.9 & 7.0 & 6.5 & 6.5 & 7.0 & 6.9 & 6.5 & 6.5 & 7.2 & 7.2 & 6.5 & 7.6 \\
6.9 & 7.0 & 6.4 & 6.5 & 7.1 & 7.0 & 6.5 & 6.6 & 7.2 & 7.3 & 6.5 & 7.6 \\
6.9 & 7.0 & 6.4 & 6.5 & 7.0 & 7.0 & 6.5 & 6.5 & 7.3 & 7.3 & 6.5 & 7.6 \\
7.0 & 7.0 & 6.5 & 6.5 & 7.1 & 7.0 & 6.5 & 6.6 & 7.2 & 7.3 & 6.5 & 7.6 \\
7.0 & 7.0 & 6.4 & 6.5 & 7.1 & 7.0 & 6.5 & 6.5 & 7.2 & 7.3 & 6.5 & 7.7 \\
6.9 & 7.0 & 6.4 & 6.4 & 7.0 & 6.9 & 6.5 & 6.5 & 7.2 & 7.2 & 6.5 & 7.6 \\
7.0 & 7.0 & 6.4 & 6.5 & 7.0 & 7.0 & 6.5 & 6.5 & 7.2 & 7.3 & 6.5 & 7.6 \\
7.0 & 7.0 & 6.4 & 6.5 & 7.1 & 7.0 & 6.5 & 6.5 & 7.3 & 7.3 & 6.5 & 7.7
\end{pmatrix}$$

Confidence (reliability) of the K coefficient, as a fraction: $\boxed{\alpha := 0.95}$

Accuracy class of the electric power consumption meter, % of measured result: $\boxed{\delta\_Q := 1}$

Instrument margin of error for the electric power consumption measurement, in W: $\Delta\_Q := \frac{\delta\_Q}{100} \cdot \max(QD) = 18.6$

Instrument margin of error for the wagon body's internal temperature measurement, in K: $\boxed{\Delta\_Ti := 0.5}$

Instrument margin of error for the wagon body's external temperature measurement, in K: $\boxed{\Delta\_Te := 0.5}$

External dimensions of the wagon body:

Comment: The external dimensions of the wagon body are taken from the technical documentation. Their margin of error is taken from the unit in the highest digit position for this parameter, divided by two.

length, average value of the length and the assigned margin of error, in m:

$\boxed{LeD := 15.750}$ $mLe := mean(LeD) = 15.750$ $\boxed{\Delta\_Le := \frac{10^{-3}}{2} = 0.0005}$

width, average value of the width and the assigned margin of error, in m:

$\boxed{BeD := 2.790}$ $mBe := mean(BeD) = 2.790$ $\boxed{\Delta\_Be := \frac{10^{-3}}{2} = 0.0005}$

side wall height, its average value and the assigned margin of error, in m:

$\boxed{HeD := 2.915}$ $mHe := mean(HeD) = 2.915$ $\boxed{\Delta\_He := \frac{10^{-3}}{2} = 0.0005}$

central longitudinal axis height, its average value and the assigned margin of error, in m:

$\boxed{HHeD := 3.323}$ $mHHe := mean(HHeD) = 3.323$ $\boxed{\Delta\_HHe := \frac{10^{-3}}{2} = 0.0005}$

Internal dimensions of the wagon body (cargo compartment):

Comment: The internal dimensions of the wagon body are taken from the results of measurements (direct, repeated, uniform measurements) carried out at various places in the body. The instrumental margin of error is taken to be 0.005 m (half the smallest graduation of the measuring tape); additionally, for the length of the wagon body, the instrumental margin of error has been doubled, as the measurement was taken in two steps, by adding the values obtained.

instrumental margin of error of the measuring tape, in m: $\boxed{\Delta\_tape := \frac{10^{-2}}{2} = 0.005}$

length, average value of the length and instrumental margin of error, in m:

$\boxed{LiD := (15.395\ \ 15.405\ \ 15.400\ \ 15.400)}$ $mLi := mean(LiD) = 15.400$ $\boxed{\Delta\_Li := 2 \cdot \Delta\_tape = 0.010}$

width, average value of the width and the instrumental margin of error, in m:

$\boxed{BiD := (2.455\ \ 2.450\ \ 2.455\ \ 2.455)}$ $mBi := mean(BiD) = 2.454$ $\boxed{\Delta\_Bi := \Delta\_tape = 0.005}$

side wall height, its average value and the instrumental margin of error, in m:

$\boxed{HiD := (2.640\ \ 2.630\ \ 2.640\ \ 2.630)}$ $mHi := mean(HiD) = 2.635$ $\boxed{\Delta\_Hi := \Delta\_tape = 0.005}$

central longitudinal axis height, its average value and instrumental margin of error, m:

$\boxed{HHiD := (2.905\ \ 2.900)}$ $mHHi := mean(HHiD) = 2.902$ $\boxed{\Delta\_HHi := \Delta\_tape = 0.005}$

Calculation of heat output:

length of the power cable from the electric meter to the heater, in m: $\boxed{L\_line := 60}$

resistivity of the wire in the power cable, in ohm·mm^2/m: $\boxed{\rho := 0.0175}$

rated electrical tension in the grid, in V: $\boxed{U := 220}$

cross-sectional area of the wire in the power cable, in mm^2: $\boxed{s := 2.5}$

calculation of the heat output, W: $WD := \overrightarrow{\left[QD \cdot \left(1 - \frac{2 \cdot QD \cdot L\_line \cdot \rho}{U^2 \cdot s}\right)\right]} =$

1793.1
1771.6
1791.2
1777.4
1797.1
1781.2
1795.1
1771.6
1779.4
1797.1
1775.4
1791.2
...

2. Determining the average surface area of the wagon body and its confidence interval (random error)

Confidence interval for the measurement of the internal length of the wagon body:

confidence interval for direct, repeated, uniform measurements of the internal length of the body, in m:

$$\Delta\_mLi\_rep := qt\left[\frac{\alpha + 1}{2}, (cols(LiD) - 1)\right] \cdot \sqrt{\frac{\sum \overrightarrow{(mLi - LiD)^2}}{cols(LiD) \cdot (cols(LiD) - 1)}} = 0.006$$

confidence interval for direct, single measurements of the internal length of the body, in m:

$$\Delta\_mLi\_sing := \alpha \cdot \Delta\_Li = 0.010$$

aggregate confidence interval for the measurement of the internal length of the body, in m:

$$\Delta\_mLi := \sqrt{\Delta\_mLi\_rep^2 + \Delta\_mLi\_sing^2} = 0.012$$

Also, the width and side wall height and central longitudinal axis height of the wagon body, in m:

$$\Delta\_mBi\_rep := qt\left[\frac{\alpha + 1}{2}, (cols(BiD) - 1)\right] \cdot \sqrt{\frac{\sum \overrightarrow{(mBi - BiD)^2}}{cols(BiD) \cdot (cols(BiD) - 1)}} = 0.004$$

$$\Delta\_mBi\_sing := \alpha \cdot \Delta\_Bi = 0.005 \qquad \Delta\_mBi := \sqrt{\Delta\_mBi\_rep^2 + \Delta\_mBi\_sing^2} = 0.006$$

$$\Delta\_mHi\_rep := qt\left[\frac{\alpha + 1}{2}, (cols(HiD) - 1)\right] \cdot \sqrt{\frac{\sum \overrightarrow{(mHi - HiD)^2}}{cols(HiD) \cdot (cols(HiD) - 1)}} = 0.009$$

$$\Delta\_mHi\_sing := \alpha \cdot \Delta\_Hi = 0.005 \quad \Delta\_mHi := \sqrt{\Delta\_mHi\_rep^2 + \Delta\_mHi\_sing^2} = 0.010$$

$$\Delta\_mHHi\_rep = qt\left[\frac{\alpha+1}{2}, (cols(HHiD) - 1)\right] \cdot \sqrt{\frac{\sum \overrightarrow{(mHHi - HHiD)^2}}{cols(HHiD) \cdot (cols(HHiD) - 1)}} = 0.032$$

$$\Delta\_mHHi\_sing := \alpha \cdot \Delta\_HHi = 0.005 \quad \Delta\_mHHi := \sqrt{\Delta\_mHHi\_rep^2 + \Delta\_mHHi\_sing^2} = 0.032$$

The confidence interval for the external length and width and the side wall height and central longitudinal axis height of the wagon body:

$$\Delta\_mLe := \alpha \cdot \Delta\_Le = 0.0005 \quad \Delta\_mBe := \alpha \cdot \Delta\_Be = 0.0005 \quad \Delta\_mHe := \alpha \cdot \Delta\_He = 0.0005 \quad \Delta\_mHHe := \alpha \cdot \Delta\_HHe = 0.0005$$

Determining twice the average rounded length of the wagon roof and its confidence interval (random error):

Comment: Below is an approximation formula for calculating twice the rounded length of the wagon's roof, based on the assumption that its form is semielliptic. The maximum margin of error of this formula is ~0.3619%, for an ellipse eccentricity of ~0.979811 (axis correlation of ~1/5). Such a methodic margin of error is always positive.

$$x := \frac{\ln(2)}{\ln\left(\frac{\pi}{2}\right)}$$

Empirical parameter:

Function for calculating twice the rounded length of the wagon's roof:

$$fP(B, H, HH) := 4 \cdot \left[\left(\frac{B}{2}\right)^x + (HH - H)^x\right]^{\frac{1}{x}}$$

Average values for twice the average rounded length of the wagon's roof on the exterior, Pe, and the interior, Pi, in m:

$$mPe := fP(mBe, mHe, mHHe) = 6.117$$

$$mPi := fP(mBi, mHi, mHHi) = 5.211$$

Confidence intervals for determining the rounded length of the wagon's roof on the exterior, Δ_mPe, and the interior, Δ_mPi, in m:

$$\Delta\_mPe := \sqrt{\left(\Delta\_mBe \cdot \frac{d}{dmBe} fP(mBe, mHe, mHHe)\right)^2 + \left(\Delta\_mHe \cdot \frac{d}{dmHe} fP(mBe, mHe, mHHe)\right)^2 \ldots + \left(\Delta\_mHHe \cdot \frac{d}{dmHHe} fP(mBe, mHe, mHHe)\right)^2} + \frac{0.3619}{100} \cdot mPe = 0.024$$

$$\Delta\_mPi := \sqrt{\left(\Delta\_mBi \cdot \frac{d}{dmBi} fP(mBi, mHi, mHHi)\right)^2 + \left(\Delta\_mHi \cdot \frac{d}{dmHi} fP(mBi, mHi, mHHi)\right)^2 \ldots + \left(\Delta\_mHHi \cdot \frac{d}{dmHHi} fP(mBi, mHi, mHHi)\right)^2} + \frac{0.3619}{100} \cdot mPi = 0.078$$

Determining the average surface area of the wagon body and its confidence interval (random error):

Function for calculating the wagon body surface:

$$fS'(L,B,H,HH,P) := L\cdot B + 2\cdot(L+B)\cdot H + L\cdot\frac{P}{2} + \pi\cdot\frac{B}{2}\cdot(HH - H)$$

Function for calculating the average wagon body surface:

$$fS(Le,Be,He,HHe,Pe,Li,Bi,Hi,HHi,Pi) := \sqrt{fS'(Le,Be,He,HHe,Pe)\cdot fS'(Li,Bi,Hi,HHi,Pi)}$$

Value of the average wagon body surface, in m^2:

$$mS := fS(mLe, mBe, mHe, mHHe, mPe, mLi, mBi, mHi, mHHi, mPi) = 186.953$$

Confidence interval (random error) for determining the average wagon body surface area, in m^2:

$$\Delta\_mS := \sqrt{\begin{aligned}&\left(\Delta\_mLe\cdot\frac{d}{dmLe}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mBe\cdot\frac{d}{dmBe}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mHe\cdot\frac{d}{dmHe}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mHHe\cdot\frac{d}{dmHHe}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mLi\cdot\frac{d}{dmLi}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mBi\cdot\frac{d}{dmBi}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mHi\cdot\frac{d}{dmHi}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mHHi\cdot\frac{d}{dmHHi}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mPe\cdot\frac{d}{dmPe}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2 \dots\\ &+\left(\Delta\_mPi\cdot\frac{d}{dmPi}fS(mLe,mBe,mHe,mHHe,mPe,mLi,mBi,mHi,mHHi,mPi)\right)^2\end{aligned}} = 0.397$$

3. Determining average heat output and its confidence interval

Average value of heat output, in W: $mW := mean(WD) = 1755.1$

Confidence interval (random error) for determining the average heat output:

confidence interval of direct, repeated, uniform measurements of the average heat output, in W:

$$\Delta\_mW\_rep = qt\left[\frac{\alpha+1}{2}, (rows(WD) - 1)\right]\cdot\sqrt{\frac{\sum\overrightarrow{(mW - WD)^2}}{rows(WD)\cdot(rows(WD) - 1)}} = 7.0$$

confidence interval of direct, single measurements of heat output, in W:

$$\Delta\_mW\_sing := \alpha\cdot\Delta\_Q = 17.6$$

aggregate confidence interval of the series of heat output measurements, W:

$$\Delta\_mW := \sqrt{\Delta\_mW\_rep^2 + \Delta\_mW\_sing^2} = 19.0$$

4. Determining average temperature inside the wagon body and its confidence interval

Average value of temperatures inside the wagon body, in °C: $mTi := mean(TiD) = 33.5$

Confidence interval (random error) for measuring the temperature inside the wagon body:

confidence interval of direct, repeated, uniform measurements of the temperature inside the wagon body, in K:

$$\Delta\_mTi\_rep := qt\left[\frac{\alpha+1}{2}, (rows(TiD)\cdot cols(TiD) - 1)\right]\cdot\sqrt{\frac{\sum \sum_{i=0}^{cols(TiD)-1}\left[\overrightarrow{(mTi - TiD)^2}\right]^{\langle i\rangle}}{(rows(TiD)\cdot cols(TiD))\cdot(rows(TiD)\cdot cols(TiD) - 1)}} = 0.04$$

confidence interval of direct, single measurements of temperature inside the wagon body, in K:

$$\Delta\_mTi\_sing := \alpha\cdot\Delta\_Ti = 0.5$$

aggregate confidence interval of the series of temperature measurements inside the wagon body, in K:

$$\Delta\_mTi := \sqrt{\Delta\_mTi\_rep^2 + \Delta\_mTi\_sing^2} = 0.5$$

5. Determining average temperature outside the wagon body and its confidence interval

Average value of temperatures outside the wagon body, in °C: $mTe := mean(TeD) = 6.9$

Confidence interval (random error) for measuring the temperature outside the wagon body:

confidence interval of direct, repeated, uniform measurements of the temperature outside the wagon body, in K:

$$\Delta\_mTe\_rep := qt\left[\frac{\alpha+1}{2}, (rows(TeD)\cdot cols(TeD) - 1)\right]\cdot\sqrt{\frac{\sum \sum_{j=0}^{cols(TeD)-1}\left[\overrightarrow{(mTe - TeD)^2}\right]^{\langle j\rangle}}{(rows(TeD)\cdot cols(TeD))\cdot(rows(TeD)\cdot cols(TeD) - 1)}} = 0.03$$

confidence interval of direct, single measurements of temperature outside the wagon body, in K: $\Delta\_mTe := \sqrt{\Delta\_mTe\_rep^2 + \Delta\_mTe\_sing^2} = 0.5$

6. Determining the average value of the K coefficient and its confidence interval

Function for calculating the value of the K coefficient: $fK(W, Ti, Te, S) := \frac{W}{S\cdot(Ti - Te)}$

Average value of the K coefficient, in W/(m^{2}K): $mK := fK(mW, mTi, mTe, mS) = 0.35$

Confidence interval (random error) in determining the K coefficient, in W/(m^{2}K):

$$\Delta\_mK := \sqrt{\left(\Delta\_mW \cdot \frac{d}{dmW} fK(mW, mTi, mTe, mS)\right)^2 + \left(\Delta\_mTi \cdot \frac{d}{dmTi} fK(mW, mTi, mTe, mS)\right)^2 \dots + \left(\Delta\_mTe \cdot \frac{d}{dmTe} fK(mW, mTi, mTe, mS)\right)^2 + \left(\Delta\_mS \cdot \frac{d}{dmS} fK(mW, mTi, mTe, mS)\right)^2} = 0.01$$

Value of the relative margin of error of the K coefficient, in %:

$$\varepsilon\_K := \frac{\Delta\_mK}{mK} \cdot 100 = 2.8$$