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SUPPLEMENTARY COMPARISONS

IN THE FIELD OF MEASUREMENTS OF MAGNETIC LOSS POWER IN ELECTRICAL STEEL AT THE FREQUENCY OF 50 HZ AND 60 HZ

REPORT B

Pilot lab: Laboratory of electromagnetism metrology (262), Laboratory of magnetic and acoustic quantity metrology (261)

NMI name and abbreviation
The Federal State Unitary Enterprise
"The Urals Research Institute for Metrology" (FGUP "UNIIM")

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1. Participants

The decision to carry out pilot comparisons in the field magnetic loss power measurement was taken at the meeting of the representatives of UNIIM (Ekaterinburg, Russia) and PTB (Germany) on 27 October 2010.

List of NMIs, participating in comparisons is given in table 1.

Table 1 – Participants

№	NMI	Mail address for delivery	NMI acronym	Contact person	E-mail, Telephone, Fax
1	The Urals Research Institute for Metrology	4, Krasnoarmeyskya Str., Ekaterinburg, 620000, Russia,	UNIIM	Yury I. Didik Mikhail A. Malygin	E-mail: lab262@uniim.ru Тел./Факс +7 343 350-23-13 E-mail: lab261@uniim.ru Тел./Факс +7 343 355-38-92
2	Physikalisch-Technische Bundesanstalt	Bundesallee 100 38116 Braunschweig Germany	PTB	Albrecht Martin	E-mail: martin.albrecht@ptb.de
3	Czech Metrology Institute	Czech Republic, Brno, Okruzni 31, Post Code 638 00	CMI	Josef Kupec	E-mail: jkupec@cmi.cz
4	Czech Metrology Institute	Czech Republic, Brno, Okruzni 31, Post Code 638 00	CMI	Michal Ulvr	E-mail: mulvr@cmi.cz

2 Organization of comparisons

2.1 The scheme of carrying out comparisons

Comparisons are carried out by circulation (round robin) scheme.

Principle of comparison: comparisons of the measurement standard of the power unit of magnetic losses are carried out using samples of magnetic losses, produced from isotropic and anisotropic electrical steel.

Schedule of comparisons: samples are produced in UNIIM (Russia) by February, 2011. The measurements of samples on the measurement standard of UNIIM (Russia) are made by l March, 2011.

Samples are delivered to Germany by UNIIM (Russia) in March, 2011.

After measurements, made on the measurement standard of PTB (Germany), samples in the form of Epstein strips and in the ring form are delivered to the Czech Metrology Institute (Czech Republic).

After the measurements, made on the measurement standard of the Czech Metrology Institute (Czech Republic), samples are returned to PTB (Germany) and remain there.

The results of measurement with indication of uncertainty and all its components are sent to the Pilot laboratory (UNIIM, Russia) for processing and preparation of the report.

The pilot laboratory sends the draft report on comparisons to the NMIs, participating in the comparisons by September, 2011.

2.2 Transfer standard

Transfer standards are samples of specific magnetic losses, produced from isotropic and anisotropic electrical steel:

- two samples in the form of strips with the size of 30×280 mm for Epstein frame of about 1 kg, the quantity of strips in the sample is divisible by 4;
- two samples of toroidal form, produced by the method of ring stamping with applied measuring and magnetizing windings;
- three samples in the form of sheet with the sizes 500×500 mm; on samples are put additional windings (W=10, d<0,15mm) in the central part of the sample.

Samples are packed into the wooden boxes providing their safety in the process of transportation.

3. Description of measurement procedure

3.1 In the course of comparisons measurements are made on samples with the use of NMI measurement standards of the following quantities:

- on samples in the form of Epstein strips specific magnetic losses at remagnetization frequency of 50 Hz and amplitudes of magnetic induction are measured from the lowest value, the measurement standards can provide, through 0,1 T steps, to the highest value, the measurement standards can provide. At the same values of amplitudes of magnetic induction the values of the amplitude of magnetic field strength are measured simultaneously;
- on samples of toroidal form specific magnetic losses at remagnetization frequency of 50 Hz, 60 Hz and amplitudes of magnetic induction are measured from the lowest value, the measurement standards can provide, through 0,1 T steps, to the highest value, the measurement standards can provide. At the same values of amplitudes of magnetic induction the values of the amplitude of magnetic field strength are measured simultaneously;
- on samples in the form of sheet magnetic losses at a frequency of 50 Hz and magnetic flux density values of 1.5 and 1.7 T.

All values should be stored. The comparisons will be carried out at the magnetic field strength H=800 A/m at the magnetic induction values of 1,0 T and 1,5 T for samples of isotropic electrical steel and 1,5 T and 1,7 T for samples of anisotropic electrical steel.

3.2 Preparation of the sample in the form of Epstein strips to measurements

The sample in the form of strips with the size 30×280 mm is placed in the magnetizing device - Epstein frame (EF), according to marking. The package number (1,2,3,4), the index, designating the serial number of a strip in the package (1,2,3, …), and the arrow, indicating the position of a strip in the coils of EF (see fig. 1) are indicated on each strip. The strips 1.1 and 3.1 are placed in the coils 1 and 3 of EF first. The coils 1 and 3 of EF are parallel. The strips 2.1 and 4.1 are placed in the coils 2 and 4 of EF. Then strips 1.2 and 3.2; 2.2 and 4.2 are placed in corresponding coils and so on.

The sample is demagnetized by a variable magnetic field with the frequency of 50 Hz and with decreasing amplitude. For this purpose the amplitude of magnetic induction in the sample is established not less, than 1,8 T for anisotropic steel and not less than 1,6 T for isotropic steel, then the amplitude of magnetic induction is smoothly reduced to the value below or equal to the start value of the measurement. The time of demagnetization should be not less than 40 s.

The demagnetization should precede each series of measurements of specific magnetic loss (L_{sp}), with the amplitude of magnetic induction beginning at the lowest preset value.

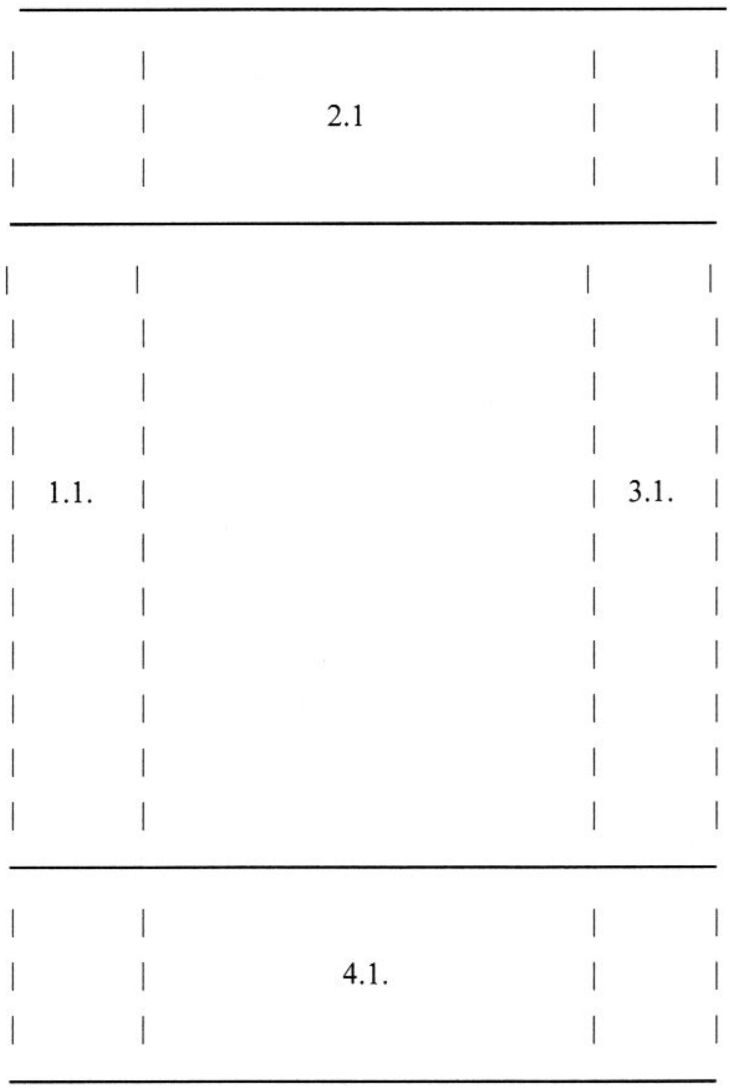

Fig.1 Method of packing strips in EF

3.3 Carrying out measurements of the samples in the form of Epstein strips

According to the operation manual on the use of standard measurement equipment, intended for comparison, the quantities are measured, as stated in p. 3.1.

The demagnetization of the sample and the subsequent measurements are made not less than three times for each sample.

3.4 Preparation of the sample in toroidal form to measurements

The sample is connected to the standard measurement equipment intended for comparison. The sample is degaussed by a variable magnetic field with the frequency of 50 Hz and with decreasing amplitude. For this purpose the amplitude of magnetic induction in the sample is established not less, than 1,8 T for anisotropic steel and not less than 1,6 T for isotropic steel, then the amplitude of magnetic induction is smoothly reduced to the value below or equal to the start value of the measurement. The time of demagnetization should be not less than 40 s.

The demagnetization should precede each series of measurements of L_{sp}, with the amplitude of magnetic induction beginning at the lowest preset value.

3.5 Measurement of the sample of toroidal form

According to the operation manual on the use of standard measurement equipment, intended for comparison, specific magnetic losses at the amplitudes of magnetic induction 1,0; 1,5 T for isotropic steel and 1,5; 1,7 T for anisotropic steel at the frequency of 50 Hz are measured. The measured values are accompanied by the full budget of uncertainty. Measurements of L_{sp} are made at each value of the amplitude of magnetic induction not less than three times and average arithmetic value is calculated.

4. Results of comparisons

4.1 Results of measurements of samples in the form of Epstein strips are presented in Tables 2, 3.

4.1.1 CRM 859-76 №32

$m=0,53382$ kg, $\gamma=7650$ kg/m^3, $S=0,62304$ cm^2, $f=50$ Hz

Calculation of reference value Xref, standard uncertainty of reference value u(Xref), additive correction Δ and its uncertainty u(Δ) was made by equations 1, 2, 4, 5 in section 5.1.

Table 2 – Results of measurement of sample №32

The value of magnetic induction Bmax, T	Specific magnetic losses, W/kg				
	UNIIM X1	CMI, CR X2	PTB, Germany X3	Reference value X ref	Additive correction, Δ
0,1	0,0045	0,0044	0,0045	0,00446	-0,000017
0,2	0,0156	0,0158	0,0157	0,01570	-0,000023
0,3	0,0328	0,0330	0,0338	0,03324	0,000026
0,4	0,0557	0,0563	0,0572	0,05641	0,000006
0,5	0,0840	0,0849	0,0854	0,08476	0,00039
0,6	0,1180	0,1189	0,1197	0,11885	0,000006
0,7	0,1577	0,1582	0,1595	0,15850	0,000045
0,8	0,2024	0,2037	0,2051	0,20375	-0,000005
0,9	0,2533	0,2550	0,2569	0,25508	0,000007
1,0	0,3110	0,3130	0,3151	0,31305	-0,000005
1,5	0,7180	0,7220	0,7282	0,72310	0,00015
1,6	0,8470	0,8500	0,8584	0,85205	0,000081
1,7	1,0290	1,0350	1,0431	1,03655	-0,000702

Standard uncertainty	Standard deviation
u(X1) = 0,40%	S_1=0,05%
u(X2) = 0,50%	S_2=0,10%
u(X3) = 0,40%	S_3=0,05%
u(Xref) = 0,25%	u(Δ)=0,033%

4.1.2 CRM 859-76 №33
m=0,51219 kg, γ=7650 kg/m^3, S=0,5978 cm^2, f=50 Hz

Table 3 – Results of measurement of sample №33

The value of magnetic induction Bmax, T	Specific magnetic losses, W/kg				
	UNIIM X1	CMI, CR X2	PTB, Germany X3	Reference value X ref	Additive correction, Δ
0,1	0,0052	0,0051	0,0052	0,005175	0,000018
0,2	0,0187	0,0184	0,0186	0,01859	0,000022
0,3	0,0393	0,0390	0,0392	0,03919	0,000037
0,4	0,0666	0,0660	0,0665	0,06638	0,000109
0,5	0,0997	0,0987	0,0997	0,09942	0,000217
0,6	0,1388	0,1377	0,1388	0,13850	0,000212
0,7	0,1823	0,1820	0,1840	0,18277	0,000243
0,8	0,2330	0,2330	0,2355	0,23391	0,000151
0,9	0,2907	0,2910	0,2939	0,29194	0,000176
1,0	0,3558	0,3560	0,3597	0,35728	0,000239
1,1	0,4278	0,4280	0,4329	0,42972	0,000297
1,2	0,5066	0,5080	0,5140	0,50970	0,000475
1,3	0,5946	0,5980	0,6037	0,59882	0,000084
1,4	0,6930	0,6960	0,7042	0,69791	0,000253
1,5	0,8068	0,8100	0,8192	0,81250	0,000082
1,6	0,9448	0,9510	0,9618	0,95274	0,000222
1,7	1,1460	1,1500	1,1598	1,15280	-0,000332

Standard uncertainty
u(X1) = 0,40%
u(X2) = 0,50%
u(X3) = 0,40%
u(Xref) = 0,25%

Standard deviation
S_1=0,05%
S_2=0,10%
S_3=0,05%
u(Δ)=0,033%

4.2 Results of measurement of samples of toroidal form are presented in Tables 4-7.

4.2.1 CRM 3134-85 №17
m=0.22575 kg, γ=7650 kg/m^3, lcp=0,1791 m, S=1,648 cm^2

Table 4 – Results of measuring sample №17 at the frequency f=50 Hz

The value of magnetic induction Bmax, T	Specific magnetic losses, W/kg		
	UNIIM X1	CMI, CR X2	Reference value X ref
0,1	0,0084	0,0082	0,00831
0,2	0,0288	0,0285	0,02867
0,3	0,0592	0,0594	0,05925
0,4	0,0994	0,0997	0,09953
0,5	0,1486	0,1487	0,14864
0,6	0,2071	0,2069	0,20705
0,7	0,2748	0,2755	0,27510
0,8	0,3507	0,3525	0,35138
0,9	0,4364	0,4391	0,43744
1,0	0,5322	0,5334	0,53266
1,1	0,6363	0,6393	0,63750
1,2	0,7540	0,7592	0,75603
1,3	0,8886	0,8948	0,89100
1,4	1,0398	1,0528	1,04487
1,5	1,2512	1,2483	1,25007

Standard deviation
S_1=0,05%
S_2=0,10%
u(Δ)=0,063%

Standard uncertainty
u(Xref) = 0,31%
u(X1) = 0,4%
u(X2) = 0,5%

Table 5 – Results of measurement of sample №17 at the frequency f=60 Hz

The value of magnetic induction Bmax, T	Specific magnetic losses, W/kg		
	UNIIM X1	CMI, CR X2	Reference value X ref
0,1	0,0108	0,0105	0,01065
0,2	0,0374	0,0367	0,03710
0,3	0,0779	0,0764	0,07729
0,4	0,1300	0,1283	0,12931
0,5	0,1938	0,1915	0,19287
0,6	0,2703	0,2682	0,26945
0,7	0,3576	0,3568	0,35726
0,8	0,4582	0,457	0,45773
0,9	0,5709	0,5685	0,56993
1,0	0,6958	0,6951	0,69553
1,1	0,8342	0,8333	0,83385
1,2	0,9907	0,9883	0,98976
1,3	1,1645	1,1631	1,16395
1,4	1,3640	1,3664	1,36494
1,5	1,6080	1,6128	1,60987

Standard deviation
S_1=0,05%
S_2=0,10%
u(Δ)=0,063%

Standard uncertainty
u(Xref) = 0,31%
u(X1) = 0,4%
u(X2) = 0,5%

4.2.2 CRM 3134-85 №18

m=0.23928 kg, γ=7650 kg/m³, lcp=0,18064 m, S=1,732 cm²

Table 6 – Results of measurement of sample №18 at the frequency f=50 Hz

The value of magnetic induction Bmax, T	Specific magnetic losses, W/kg				
	UNIIM X1	CMI, CR X2	PTB, Germany X3	Reference value X ref	Additive correction, Δ
0,1	0,0069	0,0068	0,006301	0,00663	-0,000036
0,2	0,0231	0,023	0,022651	0,02292	-0,000029
0,3	0,0477	0,0472	0,047573	0,04753	-0,000049
0,4	0,0801	0,0794	0,08038	0,080105	-0,000011
0,5	0,1197	0,1188	0,12074	0,11988	0,000015
0,6	0,1671	0,1656	0,16854	0,16726	0,000201
0,7	0,2212	0,2196	0,22383	0,22182	0,000168
0,8	0,2835	0,2818	0,28679	0,28432	0,000268
0,9	0,3530	0,351	0,35768	0,35431	0,000328
1,0	0,4313	0,4286	0,43677	0,43320	-0,000018
1,1	0,5180	0,5158	0,5244	0,51988	0,000448
1,2	0,6151	0,6127	0,6212	0,61682	-0,000401
1,3	0,7236	0,7227	0,7285	0,72554	0,000240
1,4	0,8507	0,8501	0,8493	0,85001	0,000004
1,5	1,0038	1,0051	0,9913	0,99936	-0,000025

Standard uncertainty
u(X1) = 0,30%
u(X2) = 0,50%
u(X3) = 0,30%
u(Xref) = 0,20%

Standard deviation
S_1=0,05%
S_2=0,10%
S_3=0,05%
u(Δ)=0,033%

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Table 7 – Results of measurement of sample №18 at the frequency f=60 Hz

The value of magnetic induction Bmax, T	Specific magnetic losses, W/kg				
	UNIIM X1	CMI, CR X2	PTB, Germany X3	Reference value X ref	Additive correction, Δ
0,1	0,0089	0,0088	0,0089	0,00888	0,000019
0,2	0,0304	0,0302	0,0305	0,03041	0,000022
0,3	0,0630	0,0624	0,0632	0,06296	0,000048
0,4	0,1058	0,1049	0,1060	0,10571	0,000021
0,5	0,1584	0,1573	0,1585	0,15828	0,000018
0,6	0,2205	0,2191	0,2206	0,22029	0,000121
0,7	0,2924	0,2906	0,2922	0,29193	0,000107
0,8	0,3737	0,3718	0,3736	0,37324	-0,000011
0,9	0,4661	0,4630	0,4654	0,46517	0,000188
1,0	0,5686	0,5656	0,5681	0,56793	0,000018
1,1	0,6831	0,6799	0,6829	0,68250	0,000025
1,2	0,8109	0,8073	0,8113	0,81052	-0,000102
1,3	0,9547	0,9522	0,9564	0,95510	0,000083
1,4	1,1213	1,1184	1,1241	1,12206	0,000148
1,5	1,3230	1,3198	1,3263	1,32391	0,000065

Standard uncertainty	Standard deviation
u(X1) = 0,30%	S_1=0,05%
u(X2) = 0,50%	S_2=0,10%
u(X3) = 0,30%	S_3=0,05%
u(Xref) = 0,20%	u(Δ)=0,033%

4.3 Results of measurement of sheet samples are presented as additional in Tables 8, 9, 10.

Table 8 – Results of measurement of sample №21 (the anisotropic sheet sample) at the frequency f=50 Hz

Sample's number	21			
The organisation	FGUP «UNIIM»		PTB	
Mode	Current			
l'_{ef}, mm	462	470		
The measured parametre	$P_{1,5}$, Wt/kg	$P_{1,7}$, Wt/kg	$P_{1,5}$, Wt/kg	$P_{1,7}$, Wt/kg
Results of measurements	0,8248	1,213	0,8203	1,1845
	0,8256	1,207	0,8209	1,1858
	0,8259	1,211	0,8188	1,1843
	0,8251	1,202	0,8188	1,184
	0,8253	1,209	0,819	1,1842
	0,8255	1,207		
Average	0,8254	1,2083	0,8196	1,1846

Table 9 – Results of measurement of sample №22 (the anisotropic sheet sample) at the frequency f=50 Hz

Sample's number	22			
The organisation	FGUP «UNIIM»		PTB	
Mode	Current			
l_{ef}, mm	462	470		
The measured parametre	$P_{1,5}$, Wt/kg	$P_{1,7}$, Wt/kg	$P_{1,5}$, Wt/kg	$P_{1,7}$, Wt/kg
Results of measurements	0,7618	1,103	0,7604	1,1088
	0,7614	1,098	0,7605	1,1094
	0,7614	1,098	0,7602	1,1093
	0,7616	1,103	0,7602	1,1102
	0,7615	1,101	0,7602	1,1094
	0,7617	1,102		
Average	0,7616	1,101	0,7603	1,1094

Table 10 – Results of measurement of sample №24 (the anisotropic sheet sample) at the frequency f=50 Hz

Sample's number	24			
The organisation	FGUP «UNIIM»		PTB	
Mode	Current			
l_{ef}, mm	462	470		
The measured parametre	$P_{1,5}$, Wt/kg	$P_{1,7}$, Wt/kg	$P_{1,5}$, Wt/kg	$P_{1,7}$, Wt/kg
Results of measurements	0,9335	1,313	0,9262	1,3034
	0,9332	1,303	0,9273	1,3044
	0,9332	1,311	0,9275	1,3053
	0,9329	1,312	0,926	1,3034
	0,9332	1,306	0,9233	1,3008
	0,9333	1,314		
Average	0,9332	1,3098	0,9261	1,3035

5 Processing of results

5.1 Processing of the sample measurement results was conducted in compliance with Guidelines for data evaluation of COOMET key comparisons (COOMET R/GM/14:2006).

On its basis the following characteristics were calculated:

- reference value of specific magnetic losses X_{ref}, W/kg by the formula:

$$X_{ref} = \frac{\sum_{i=1}^{N} \frac{X_i}{u^2(X_i)}}{\sum_{i=1}^{N} \frac{1}{u^2(X_i)}} \quad (1)$$

N is the number of participants;
X_i is the sample measurement results at the preset value of magnetic induction;
$u(X_i)$ is standard uncertainty.

- standard uncertainty of the reference value of specific magnetic losses $u(X_{ref})$ by the formula:

$$u^2(x_{ref}) = \frac{1}{\sum_{1}^{N} \frac{1}{u^2(x_i)}} \quad (2)$$

- expanded uncertainty of the reference value of specific magnetic losses $u_p(Xref)$ by the formula:

$$u_p(X_{ref}) = 2 \cdot \sqrt{u^2(X_{ref})} \quad (3)$$

- the additive correction is a weighted mean of correction estimates based on results of every linking NMI by the formulas:

$$\Delta = \frac{\sum_{1}^{3} \frac{(x_i - x_{ref})}{S_i^2}}{\sum_{1}^{3} S_i^{-2}} \quad (4)$$

$$u^2(\Delta) = \frac{2}{\sum_{i=1}^{3} S_i^{-2}}, \quad (5)$$

where S_i - standard deviation of the results of i-th linking NMI that obtained in conditions of intermediate precision

- transformed results of comparisons by the formula:

$$x_i' = x_i + \Delta \quad (6)$$

- uncertainty of transformed results of comparisons by the formula:

$$u^2(x_i') = u^2(x_i) + u^2(\Delta) \quad (7)$$

- degree of equivalence of the i-th NMI is estimated by formula:

$$d_i = x_i + \Delta - x_{ref} \quad (8)$$

with associated standard uncertainty

$$u^2(d_i) = u^2(x_i) + u^2(x_{ref}) + u^2(\Delta)\left\{1 - u^2\left(x_{ref}\right) \times \sum_{1}^{3} u^{-2}\left(x_i^*\right)\right\}, \quad (9)$$

where $u^2(x_i^*)$ – standard uncertainty of result of the linking NMI (FGUP “UNIIM”).

5.2 The declared uncertainties are judged as confirmed if the following equation is satisfied

$$|d_i| < 2u(d_i) \tag{10}$$

Fulfillment of equation (10) is confirmation of measurement capabilities of the NMI.

6 Calculation of the degree of equivalence of measurement standards

Calculation of the degree of equivalence of measurement standards for measuring of magnetic losses on measurement standards of comparisons participants was carried out for two samples in the form of Epstein strips (№32, №33) and for one sample of toroidal form (№18).

6.1 Samples in the form of Epstein strips and samples of toroidal form.

The results of calculations of the degree of equivalence of measurement standards for measuring of magnetic losses on CRM 859-76 №32 are presented in Table 11, on CRM 859-76 №33 are presented in Table 12, on CRM 3134-85 №18 are presented in Tables 13 (f=50 Hz), 14 (f=60 Hz).

Given the uncertainty of the measurements results presented by participants of comparisons, the formula (9) is:

- for sample in the form of Epstein strips:

$$u^2(d_i) = u^2(x_i) + u^2(x_{ref}) + u^2(\Delta)\,(1\text{-}0{,}95) \tag{11}$$

- for sample in the form of Epstein strips:

$$u^2(d_i) = u^2(x_i) + u^2(x_{ref}) + u^2(\Delta)\,(1\text{-}1{,}007) \tag{12}$$

Table 11 – Calculation of the degree of equivalence of measurement standards for measuring of magnetic losses on CRM 859-76 №32

Reference value X_{ref}, W/kg	UNIIM, Russia				CMI, CR				PTB, Germany			
	Transformed value x_i, W/kg	$\lvert d_i \rvert \cdot 10^4$, W/kg	$u^2 \lvert d_i \rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i \rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i \rvert \cdot 10^4$, W/kg	$u^2 \lvert d_i \rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i \rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i \rvert \cdot 10^4$, W/kg	$u^2 \lvert d_i \rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i \rvert}{u(d_i)}$
0,00446	0,00448	0,23	0,0445	1,10	0,00438	0,80	0,0601	3,27	0,00448	0,23	0,0446	1,10
0,01570	0,01558	1,20	0,7636	1,37	0,01578	0,77	0,7778	0,87	0,01568	0,23	0,7638	0,26
0,08476	0,08439	3,70	25,881	0,73	0,08529	5,30	32,655	0,93	0,08579	10,3	26,269	2,00
0,11885	0,11801	8,40	31,342	1,50	0,11891	0,56	40,119	0,09	0,11971	8,56	31,694	1,52
0,15850	0,15775	7,55	55,497	1,01	0,15824	2,60	78,297	0,29	0,15954	10,40	55,856	1,39
0,20375	0,20235	14,00	91,462	1,46	0,20369	0,55	129,68	0,05	0,20509	13,45	91,508	1,41
0,25508	0,25331	17,73	143,30	1,48	0,25501	0,73	203,24	0,05	0,25691	18,27	144,26	1,52
0,31305	0,31099	20,55	216,00	1,40	0,31299	0,55	306,17	0,03	0,31509	20,45	216,85	1,39
0,72310	0,71815	49,49	1152,36	1,46	0,72215	9,50	1631,11	0,24	0,72835	52,51	1202,45	1,51
0,85205	0,84708	49,69	1601,54	1,24	0,85001	20,40	2259,94	0,43	0,85213	0,81	1686,24	0,02
1,03655	1,02830	82,52	2363,00	1,70	1,03430	22,50	3346,29	0,39	1,04240	58,48	2410,22	1,19

Table 12 – Calculation of the degree of equivalence of measurement standards for measuring of magnetic losses on CRM 859-76 №33

Reference value X_{ref}, W/kg	UNIIM, Russia				CMI, CR				PTB, Germany			
	Transformed value x_i, W/kg	$\lvert d_i\rvert \cdot 10^4$, W/kg	$u^2\lvert d_i\rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i\rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i\rvert \cdot 10^4$, W/kg	$u^2\lvert d_i\rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i\rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i\rvert \cdot 10^4$, W/kg	$u^2\lvert d_i\rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i\rvert}{u(d_i)}$
0,01859	0,018722	1,32	0,7832	1,49	0,018422	1,68	1,0784	1,62	0,018622	0,32	0,7666	0,37
0,03919	0,039337	1,47	3,435	0,79	0,03937	1,53	4,833	0,70	0,039237	0,47	3,422	0,25
0,06638	0,066709	3,29	9,852	1,05	0,066109	2,71	13,646	0,73	0,066609	2,29	9,831	0,73
0,09942	0,099917	4,97	22,084	1,06	0,098917	5,03	30,534	0,91	0,099917	4,97	22,084	1,06
0,13850	0,139012	5,12	42,810	0,78	0,137912	5,88	59,389	0,76	0,139012	5,12	42,810	0,78
0,18277	0,182543	2,27	74,049	0,26	0,182243	5,27	103,69	0,52	0,184243	14,73	75,045	1,70
0,23391	0,233151	7,59	121,06	0,69	0,233151	7,59	169,92	0,58	0,235651	17,41	122,93	1,57
0,29194	0,290876	10,61	188,49	0,77	0,291176	7,64	264,98	0,47	0,294076	21,36	191,48	1,54
0,35728	0,356039	12,41	282,33	0,74	0,356239	10,41	396,62	0,52	0,359935	26,59	286,80	1,57
0,42972	0,428097	16,23	408,23	0,80	0,428297	14,23	573,46	0,59	0,433197	34,77	415,26	1,71
0,50970	0,507075	26,25	573,01	1,10	0,508475	12,25	807,54	0,43	0,514475	47,75	585,10	1,97
0,59882	0,594684	41,36	789,78	1,47	0,598084	7,36	1118,1	0,22	0,603784	49,64	807,23	1,75
0,69791	0,693253	46,57	1072,9	1,42	0,696253	16,57	1515,5	0,42	0,704453	65,43	1097,9	1,97
0,81250	0,806882	56,18	1454,1	1,47	0,810082	24,18	2052,9	0,53	0,819282	67,82	1486,4	1,76
0,95274	0,945022	77,18	1995,6	1,73	0,951222	15,18	2828,3	0,28	0,962022	92,82	2156,2	1,99
1,15280	1,145668	71,32	2931,9	1,32	1,149668	31,32	4136,8	0,49	1,159468	66,68	2982,6	1,22

Table 13 – Calculation of the degree of equivalence of measurement standards for measuring of magnetic losses on CRM 3134-85 №18 (f=50 Hz)

Reference value X_{ref}, W/kg	UNIIM, Russia				CMI, CR				PTB, Germany			
	Transformed value x_i, W/kg	$\lvert d_i\rvert \cdot 10^4$, W/kg	$u^2\lvert d_i\rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i\rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i\rvert \cdot 10^4$, W/kg	$u^2\lvert d_i\rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i\rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i\rvert \cdot 10^4$, W/kg	$u^2\lvert d_i\rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i\rvert}{u(d_i)}$
0,00664	0,006864	2,24	0,0600	9,14	0,006764	1,24	0,1291	3,45	0,006265	3,75	0,0530	16,30
0,02292	0,02307	1,51	0,6831	1,83	0,02297	0,51	1,530	0,41	0,02265	2,69	0,6722	3,28
0,04753	0,04765	1,21	2,949	0,70	0,04715	3,80	6,465	1,49	0,04752	0,06	2,938	0,04
0,08005	0,08009	0,39	8,323	0,14	0,07939	6,61	18,32	1,54	0,08037	3,19	8,357	1,10
0,11988	0,11972	1,65	18,65	0,38	0,11882	10,65	41,05	1,66	0,12076	8,75	18,88	1,98
0,16726	0,16730	0,41	36,38	0,07	0,16580	14,59	82,25	1,61	0,16844	11,81	36,81	1,94
0,22182	0,22137	4,52	73,78	0,53	0,21977	20,50	140,46	1,73	0,22350	16,78	74,63	1,94
0,43320	0,43128	19,3	242,27	1,04	0,42858	46,20	534,07	1,99	0,43659	33,90	350,12	1,81
0,51988	0,51845	14,32	449,96	0,68	0,51625	36,32	774,32	1,30	0,52395	40,72	455,28	1,91
0,61682	0,61470	21,21	492,31	0,96	0,61230	45,21	1089,9	1,37	0,62080	39,79	497,99	1,71
0,72554	0,72384	17,00	682,30	0,65	0,72294	26,00	1517,4	0,67	0,72874	32,00	688,40	1,22
0,85001	0,85074	7,3	940,27	0,24	0,85010	0,94	2096,1	0,02	0,84930	7,06	938,23	0,23
0,99936	1,00378	44,15	1306,6	1,22	1,00507	57,15	2925,1	1,06	0,99132	70,36	1284,5	1,96

Table 14 – Calculation of the degree of equivalence of measurement standards for measuring of magnetic losses on CRM 3134-85 №18 (f=60 Hz)

Reference value X_{ref}, W/kg	UNIIM, Russia				CMI, CR				PTB, Germany			
	Transformed value x_i, W/kg	$\lvert d_i \rvert \cdot 10^4$, W/kg	$u^2 \lvert d_i \rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i \rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i \rvert \cdot 10^4$, W/kg	$u^2 \lvert d_i \rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i \rvert}{u(d_i)}$	Transformed value x_i, W/kg	$\lvert d_i \rvert \cdot 10^4$, W/kg	$u^2 \lvert d_i \rvert \cdot 10^8$, $(W/kg)^2$	$\frac{\lvert d_i \rvert}{u(d_i)}$
0,00888	0,008919	0,39	0,1030	1,21	0,008819	0,61	0,2253	1,28	0,008919	0,39	0,1030	1,21
0,03041	0,030422	0,12	1,2014	0,11	0,03022	1,86	2,6498	1,14	0,030522	0,42	1,2068	0,38
0,06296	0,063048	0,88	5,1547	0,39	0,062448	5,12	11,317	1,52	0,063248	2,88	5,1774	1,27
0,10571	0,105821	1,11	14,543	0,29	0,104948	7,62	31,979	1,35	0,106048	3,38	14,581	0,89
0,15828	0,158418	1,38	32,605	0,24	0,157318	9,62	71,882	1,13	0,158518	2,38	32,634	0,42
0,22029	0,220621	3,31	63,171	0,42	0,219221	10,69	139,42	0,91	0,220721	4,31	63,211	0,54
0,29193	0,292507	5,77	111,04	0,55	0,290707	12,23	245,21	0,78	0,292307	3,77	111,01	0,36
0,37324	0,373689	4,49	181,98	0,33	0,371789	14,51	401,31	0,72	0,373589	3,49	181,34	0,26
0,46517	0,466288	11,18	282,07	0,67	0,463188	19,82	622,47	0,79	0,465588	4,18	281,48	0,25
0,56793	0,568618	6,88	420,00	0,34	0,565618	23,12	928,78	0,76	0,568118	1,88	419,42	0,09
0,68250	0,683125	6,25	606,29	0,25	0,679825	26,75	1301,9	0,74	0,682925	4,25	606,04	0,17
0,81052	0,810798	2,78	854,71	0,10	0,807198	33,22	1892,1	0,76	0,811028	5,08	855,20	0,17
0,95510	0,954783	3,17	1185,2	0,09	0,952283	28,17	2631,6	0,55	0,956483	13,83	1188,1	0,40
1,12206	1,121448	6,12	1635,2	0,15	1,118548	35,12	3630,6	0,58	1,124248	21,88	1640,8	0,54
1,32391	1,323065	8,45	2276,38	0,18	1,319865	40,45	5055,8	0,57	1,326365	24,55	2284,2	0,51

6.2 Sheet samples

Table 15 – Calculation of the degree of equivalence for samples №21 at the frequency f=50 Hz

The measured parametre	Sample № 21			
	P1,5, W/kg		P1,7, W/kg	
	UNIIM, X1	PTB, X2	UNIIM, X1	PTB, X2
Average Xi	0,8254	0,8196	1,2083	1,1846
Reference value Xref, W/kg	0,8217		1,1943	
Degree of equivalence di, W/kg	0,0037	-0,0021	0,014	-0,0097
$\frac{\lvert d_i \rvert}{u(d_i)}$	0,52	0,33	1,96	1,54

Table 16 – Calculation of the degree of equivalence for samples № 22 at the frequency f=50 Hz

The measured parametre	Sample № 22			
	P1,5, W/kg		P1,7, W/kg	
	UNIIM, X1	PTB, X2	UNIIM, X1	PTB, X2
Average Xi	0,7616	0,7603	1,1008	1,1094
Reference value Xref, W/kg	0,7608		1,1058	
Degree of equivalence di, W/kg	0,0008	-0,0005	-0,005	0,0036
$\frac{\lvert d_i \rvert}{u(d_i)}$	0,11	0,08	0,7	0,57

Table 17 – Calculation of the degree of equivalence for samples №24 at the frequency f=50 Hz

The measured parametre	Sample № 24			
	P1,5, W/kg		P1,7, W/kg	
	UNIIM, X1	PTB, X2	UNIIM, X1	PTB, X2
Average Xi	0,9332	0,9261	1,3098	1,3035
Reference value Xref, W/kg	0,9290		1,3061	
Degree of equivalence di, W/kg	0,0042	-0,0029	0,0037	-0,0026
$\frac{\lvert d_i \rvert}{u(d_i)}$	0,59	0,46	0,52	0,41

Standard uncertainty
u(X1) = 0,6%
u(X2) = 0,5%
$u^2(Xref) = (0,0015)^2$
$u^2(d1) = (0,0051)^2$
$u^2(d2) = (0,004)^2$

6.3 As examples the results of the measurements and calculations for CRM 3134-85 №18 (f=60 Hz) are shown in Figures 1-8.

In the figures, straight line indicates the reference value, square dots – transformed values and intervals $u(d_i)$ for transformed values obtained by comparisons participants.

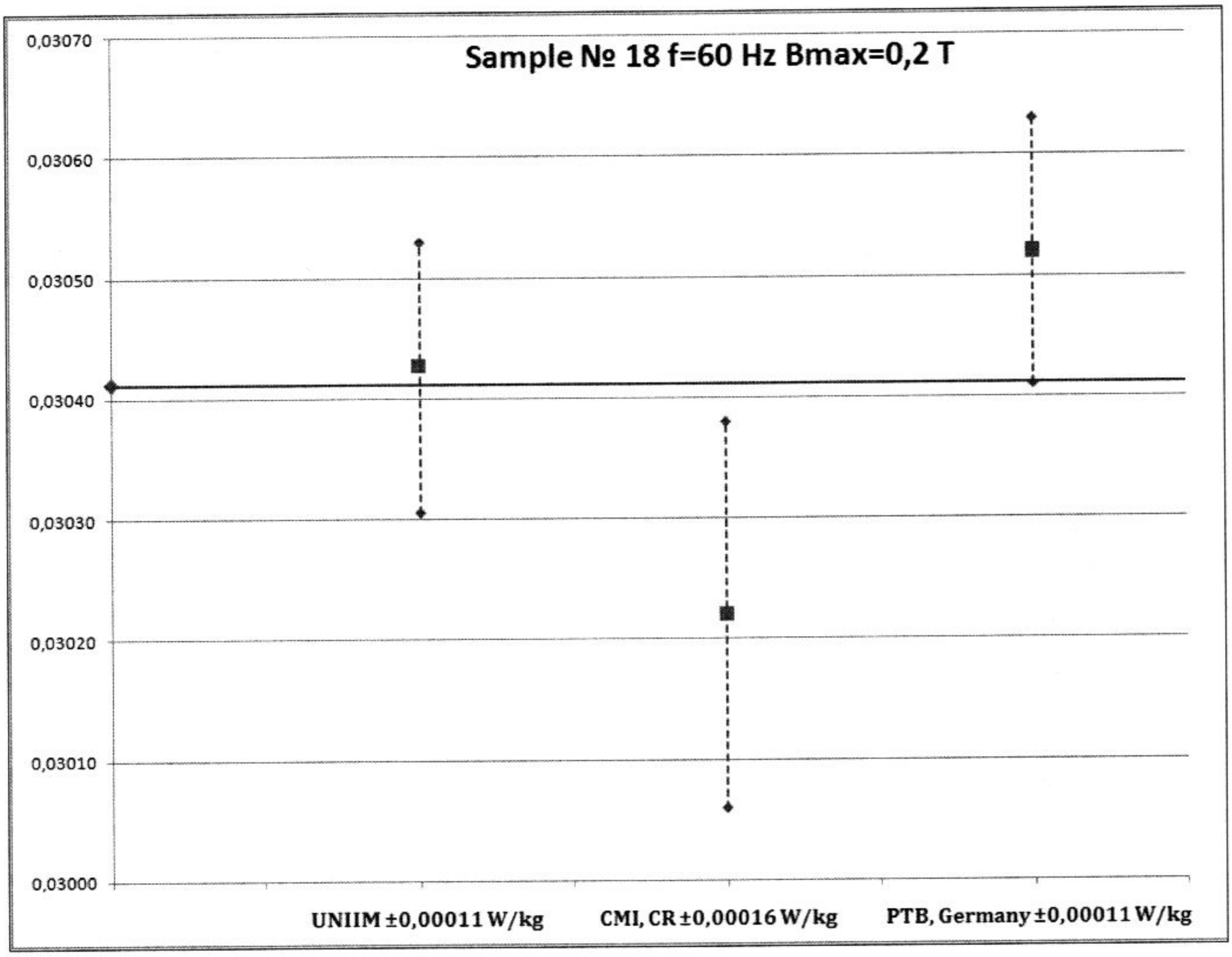

Figure 1

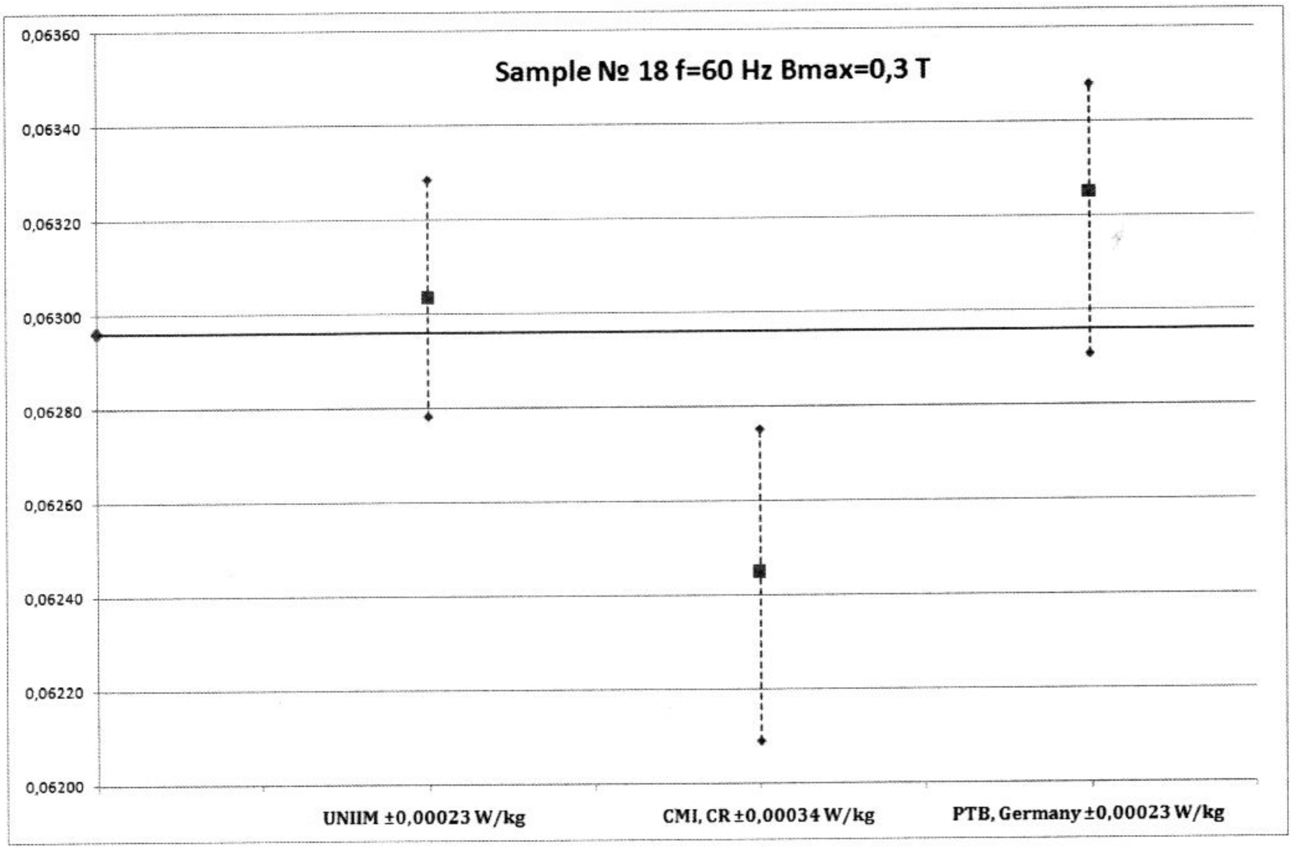

Figure 2

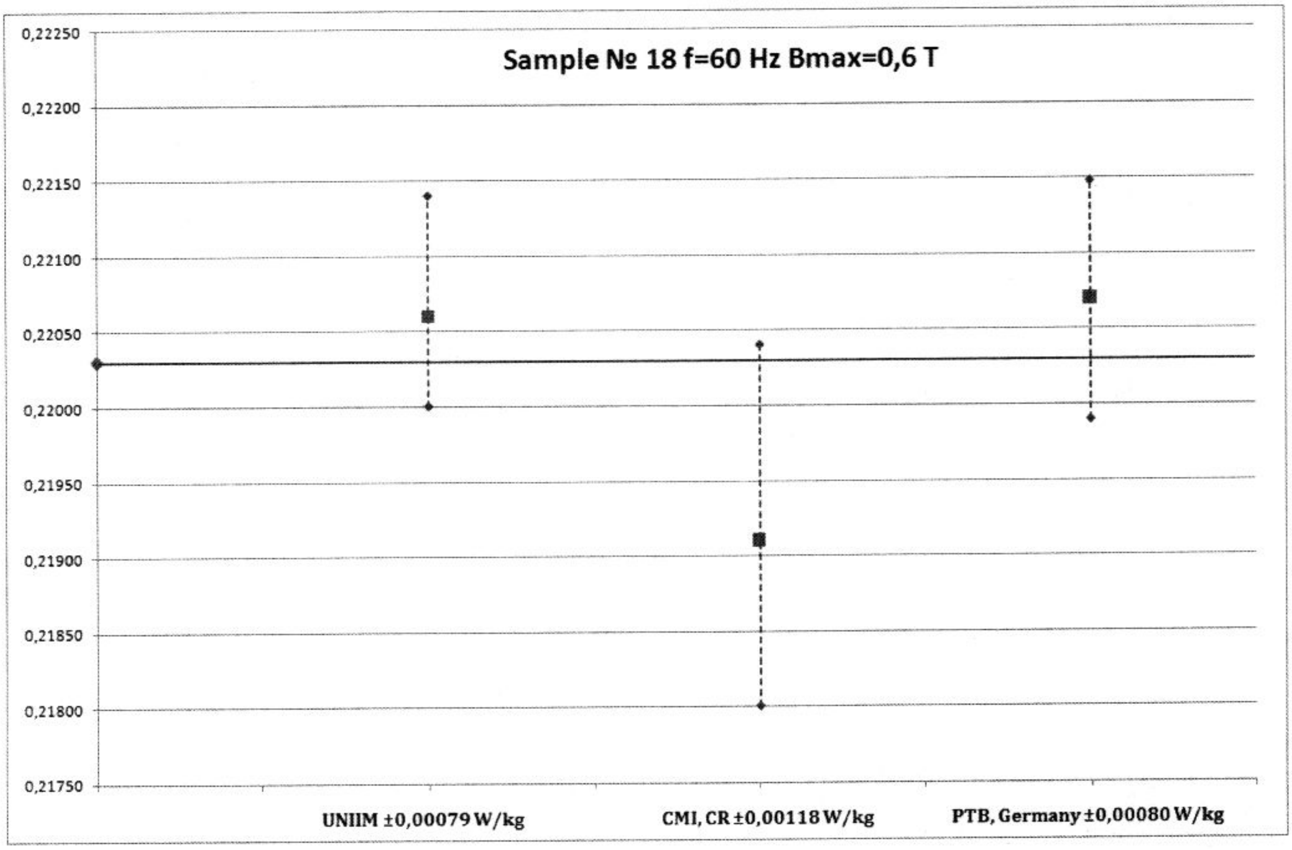

Figure 3

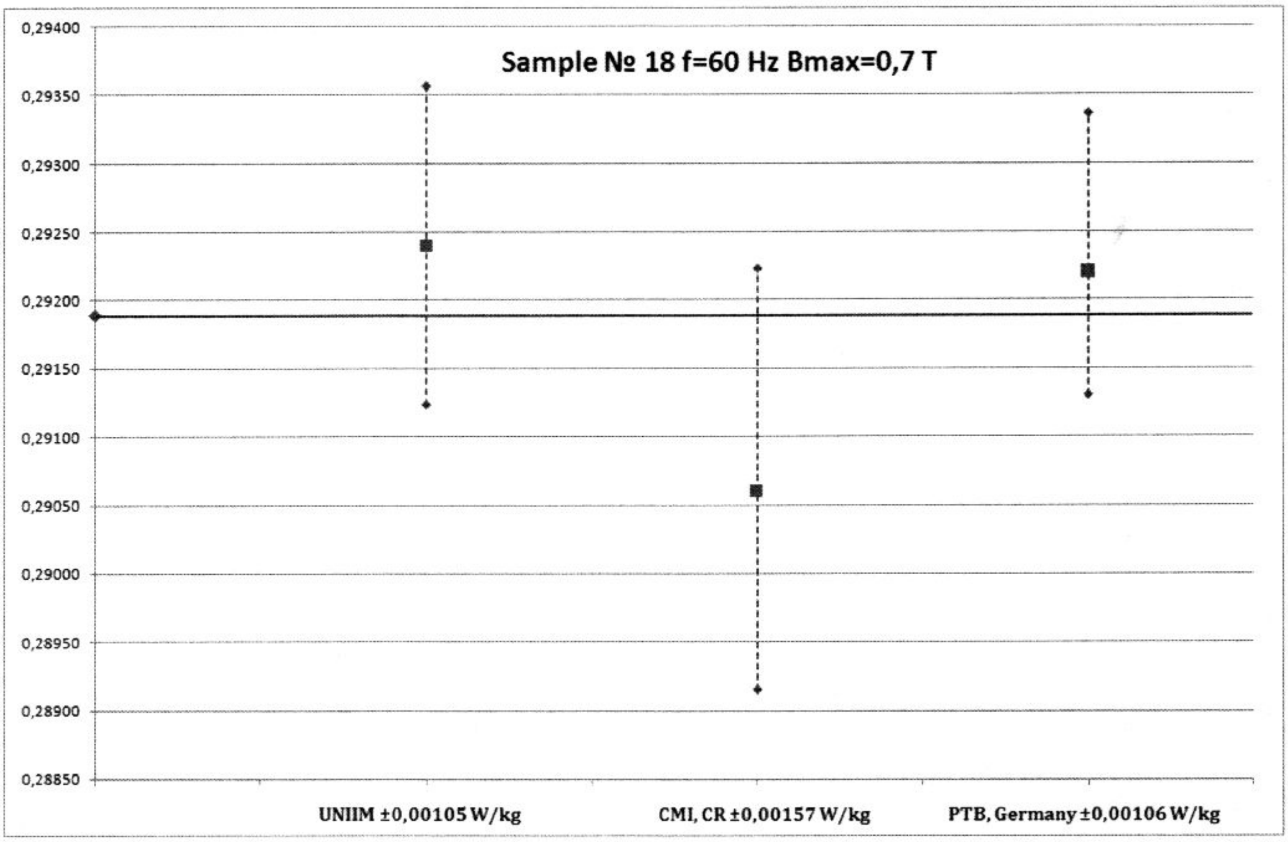

Figure 4

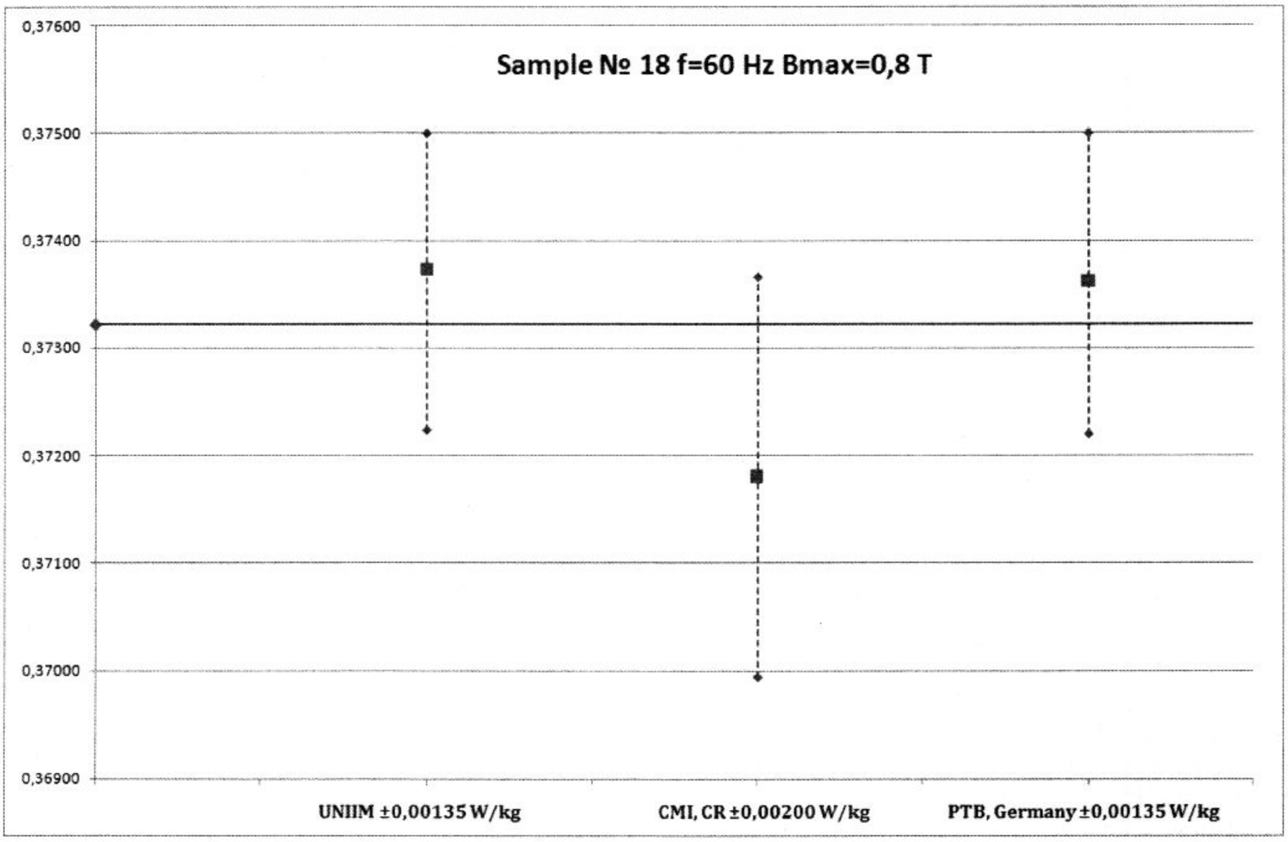

Figure 5

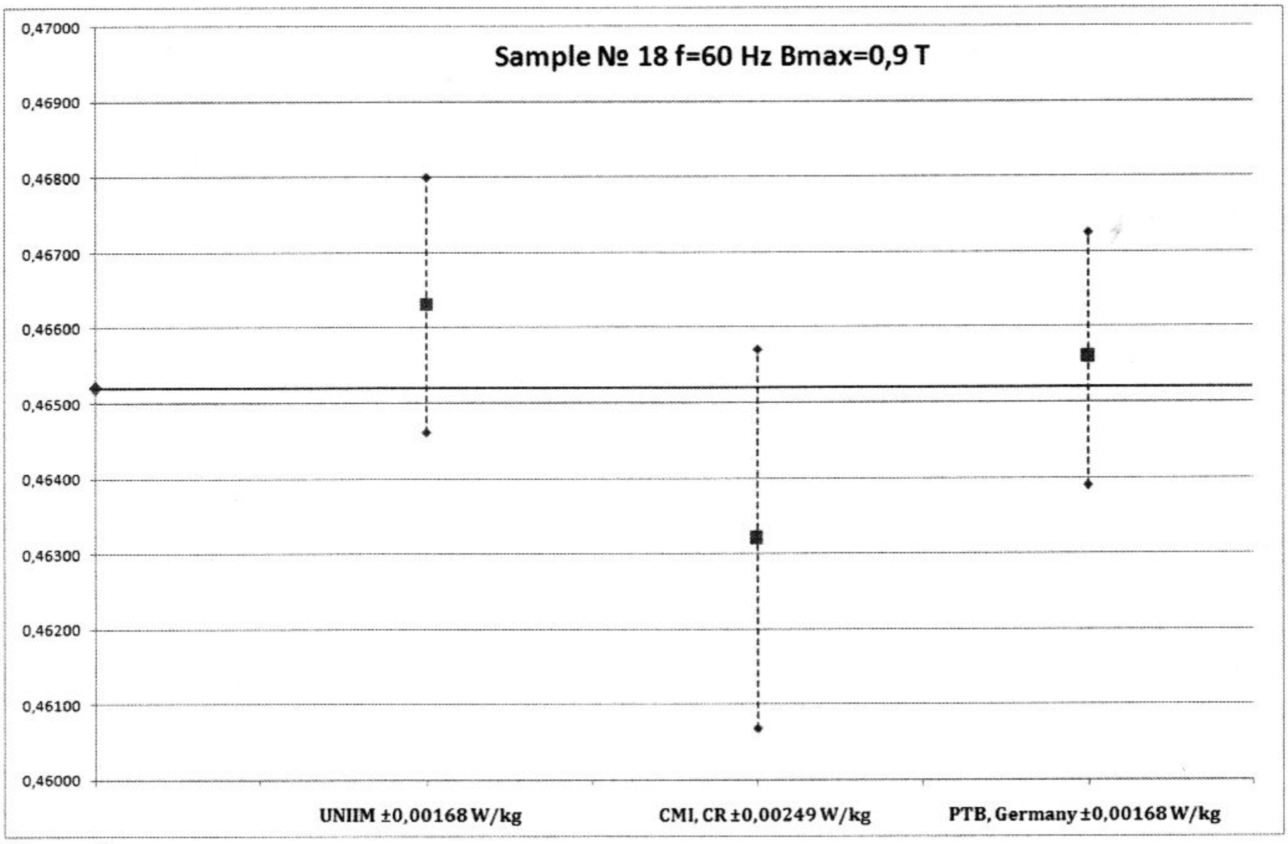

Figure 6

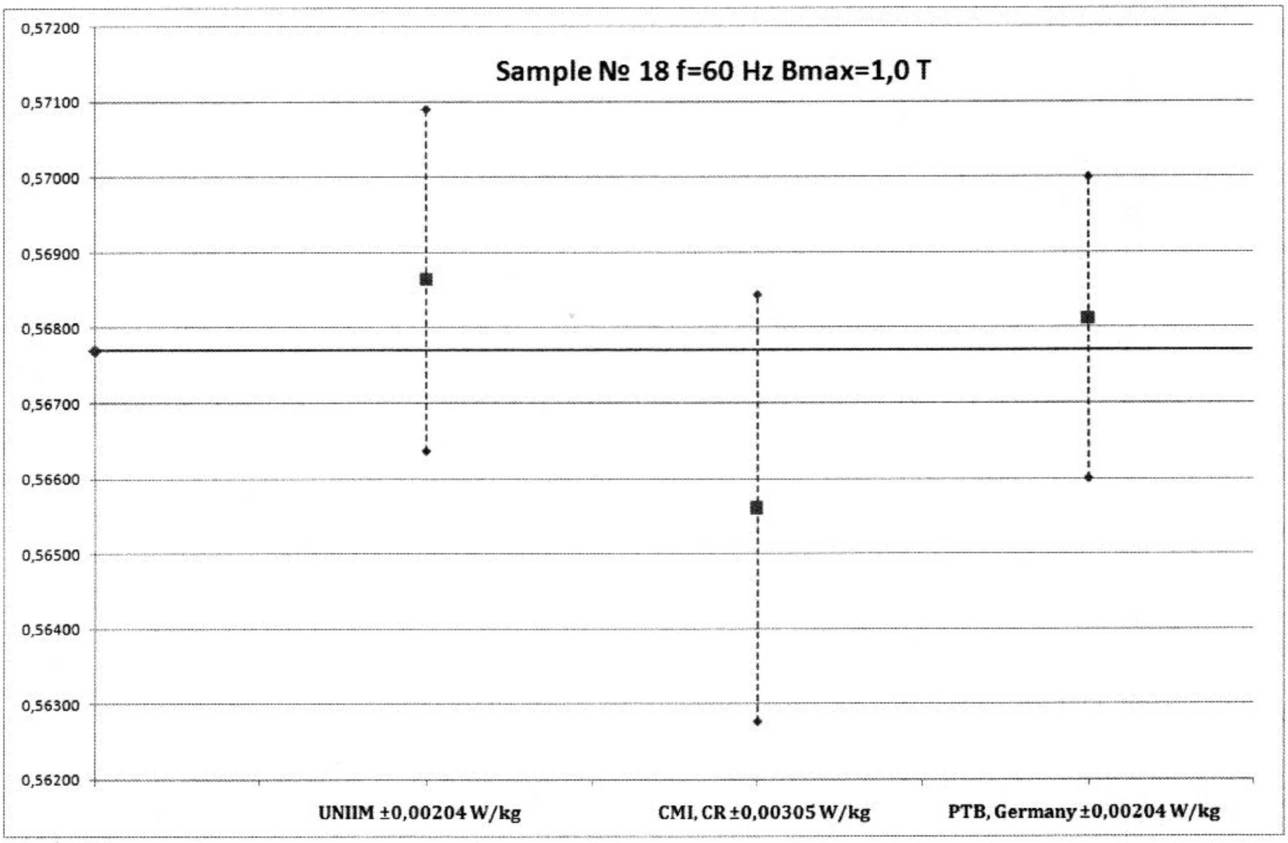

Figure 7

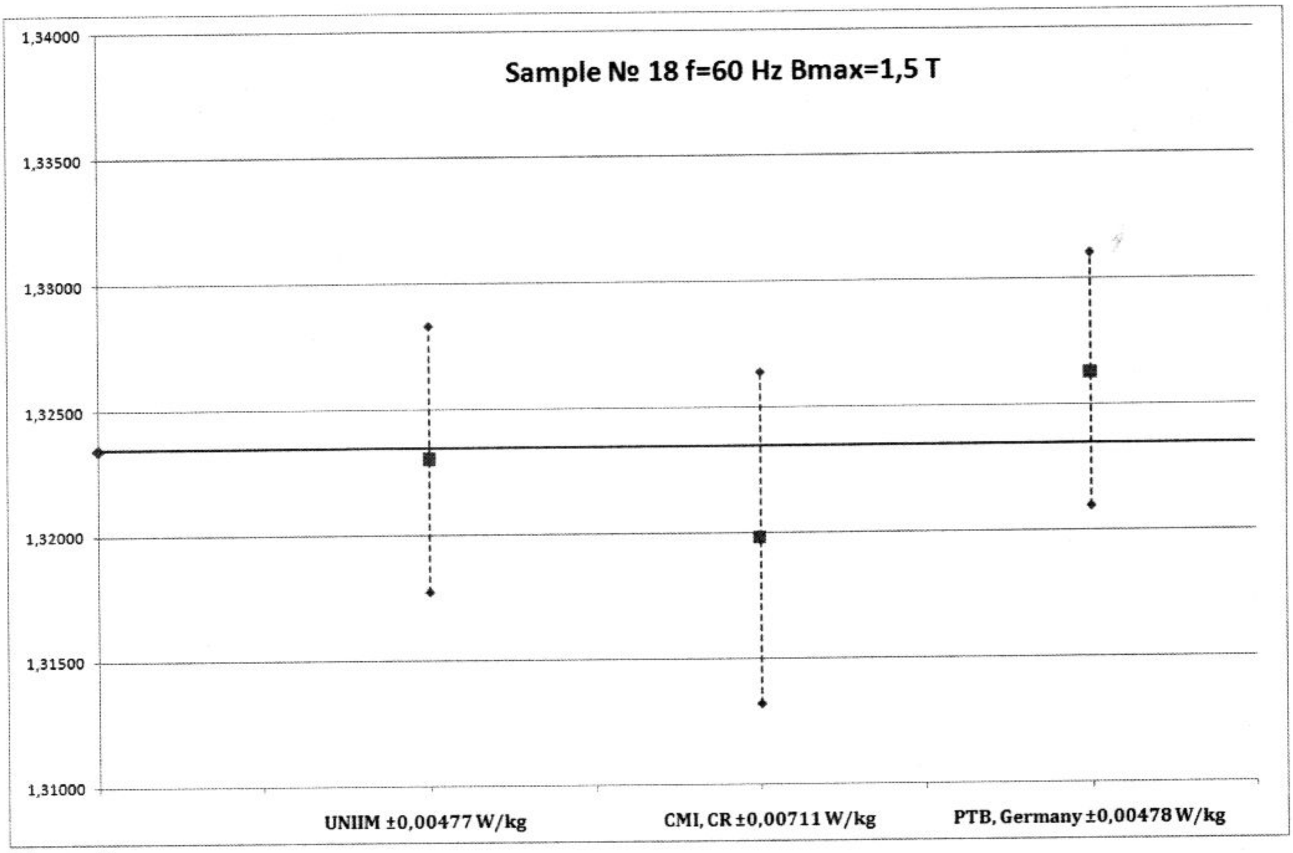

Figure 8

7 Conclusions

1. Fulfillment of equation (10) confirms agreement between comparisons data and estimated uncertainties of measurement results of magnetic losses declared by NMIs. The corresponding rows of measurements capabilities CMC can be judged as confirmed.

2. Results of the carried out comparisons (reported results of measuring the power of magnetic losses in electrical steel, accompanied by standard uncertainty) allow to draw a conclusion on equivalence of standards of power units of the magnetic losses belonging to UNIIM (Russia), PTB (Germany) and CMI (Republic Czechia). Due to a difference in the standards at the PTB the measurements were carried out measuring the polarization at UNIIM the induction was measured. For the same reason, the magnetic path lengths at the single sheet measurements are different. These differences did not affect the comparability seriously but are responsible for the major part of the differences in the result.

3. Deviation of results of the measurements received on sheet samples exceed deviations of results of the measurements received on samples of the toroidal form and samples in the form of Epstein strips. It is connected with a different design of sheet measuring. It is necessary to continue the work on studying influence of sheet devices design on the results of sheet sample measurements.

4. The results obtained in the course of these comparisons permit the conclusion to register the comparisons in the framework of COOMET as the pilot-key comparison.

8 References

COOMET R/GM/14:2006 Guidelines for data evaluation of COOMET key comparisons

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