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SUPPLEMENTARY COMPARISON OF NATIONAL STANDARD FACILITIES IN THE FIELD OF MEASURING THE POLARIZATION AND SPECIFIC TOTAL POWER LOSS IN SOFT MAGNETIC MATERIALS

FINAL REPORT

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Introduction

At a meeting at the PTB in Braunschweig on the 5th and 6th of March 2014 between the representatives of UNIIM (Russia), PTB (Germany), CMI (Czech Republic), NPL (United Kingdom) the decision was made to carry out a supplementary comparison for the measurement of specific total power loss in soft magnetic materials. The measurements were done in compliance to IEC 60404 part 2 on a defined set of magnetic materials supplied by UNIIM and NPL. An additional participant is INRIM (Italy).

Two work items have been defined:

- First: the results of the measurements shall demonstrate the degree of equivalence between the laboratories.
- Second: the capability of the test equipment shall be compared.

CMC classification numbers:

12.3.1 Specific total power loss: Epstein, ring and single sheet sample

1. Participants

Table 1 – The list of participants of comparisons

№	NMI	Address	Abbreviation oft he NMI	Contact	E-Mail Telephone
1	Ural Scientific Research Institute of Metrology	620000, Russia, Yekaterinburg, Krasnoarmeyskaya Str, 4	UNIIM	Malygin Michael Aleksandrovich	E-mail: maligin@uniim.ru Tel/Fax: +7 343 355-38-92
2	Physikalisch-Technische Bundesanstalt	Bundesallee 100 38116 Braunschweig Germany	PTB	Martin Albrecht	E-mail: martin.albrecht@ptb.de +49 (0)531 5922250
3	Czech Metrology Institute	Czech Republic, V Botanice 4, Praha 5 15072	CMI	Josef Kupec Michal Ulvr	E-mail: jkupec@cmi.cz
4	Istituto Nazionale di Ricerca Metrologica	Strada delle Cacce 10135 Torino ITALY	INRIM	Carlo Appino	E-mail: c.appino@inrim.it Tel: +390113919841 Fax: +390113919834
5	National Physical Laboratory	Hampton Road, Teddington, Middlesex, TW11 0LW.	NPL	Michael Hall Steven Turner	E-mail: steven.turner@npl.co.uk

2. Organization of the comparisons

2.1 Organization of the comparisons

The Comparison is carried out by a circulation scheme. Standard samples were produced by UNIIM (Russia) by May 2014 and measured with ГЭТ 198-2011. After initial measurements at UNIIM one set of each sample and the single NPL ring core were sent to: 1. PTB, 2. CMI, 3. INRIM, 4. NPL, and after this returned to UNIIM for final measurements to establish the stability (except NPL ring core). After measurements the data were sent to UNIIM for evaluation of the comparison results.

2.2 The transfer standard

Four samples were used for comparisons:

2 Epstein samples (UNIIM);

1 ring sample for comparison (UNIIM); and

1 ring sample for the comparison of the electrical measurements (NPL).

For the transfer standards provided by UNIIM three sets of each sample were prepared. Two sets stay at UNIIM and one set is distributed around the participants for the measurements of the comparison. Two sets are kept in reserve in case of damage to samples being circulated.

The transfer standards are samples of grain oriented and non-oriented electrical steel:

- one sample (No 1) of non-oriented steel in the form of strips with the dimensions (30×280) mm for Epstein frame measurements with a weight of approximately 0.5 kg and thickness of approximately 0.35 mm. The quantity of the strips in the sample must be a multiple of 4;
- one sample (No 2) of grain oriented steel in the form of strips with the dimensions (30×280) mm for Epstein frame measurements with a weight of approximately 0.5 kg, and thickness of approximately 0.23 mm. The quantity of the strips in the sample must be a multiple of 4;
- one ring sample made by a method of stamping of rings from grain oriented steel with the primary and secondary winding placed on the core and fixed firmly in position.
- one ring sample made of non-oriented steel with known characteristic supplied by NPL.

Samples are packed in wooden boxes for their safety during transportation.

3. Description of the method of measurement

During the comparisons measurements are carried out using the measurement standards of National Metrological Institutes (NMI).

3.1 Epstein samples

3.1.1 Preparation of the transfer samples for measurements

The sample in the form of strips with sizes 30x280 mm should be loaded into the Epstein frame in accordance with figure 1. On each strip an index showing the position within the pack and an arrow specifying position of the strip in the solenoids of the Epstein frame. The strips 1.1 and 3.1 are placed in solenoids 1 and 3 of the Epstein frame first. The solenoids 1 and 3 of the Epstein frame are parallel. The strips 2.1 and 4.1 are placed in the solenoids 2 and 4 of the Epstein frame. This sequence is repeated until all strips are loaded into the frame.

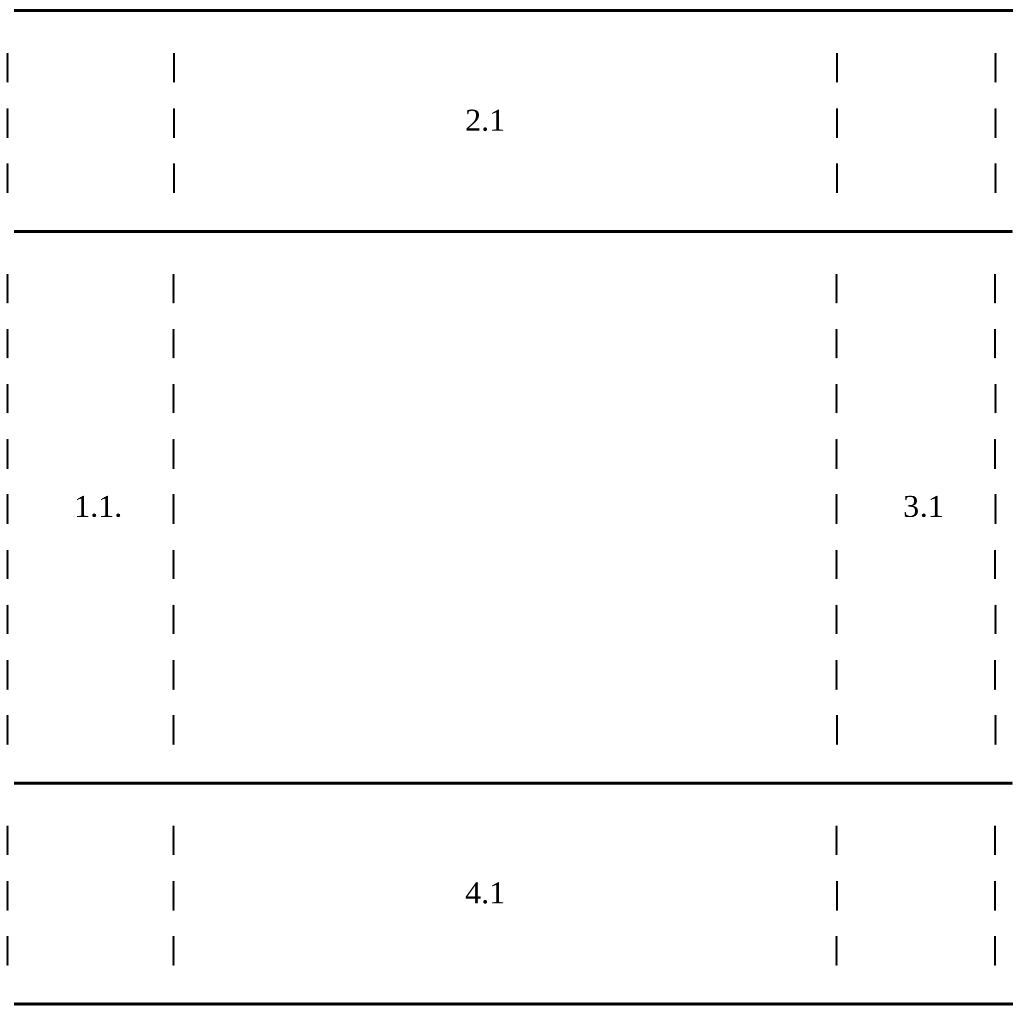

Figure 1 – Method of loading strips in the Epstein frame.

When loading the non-oriented steel, strips cut with the rolling direction should be loaded into two parallel solenoids with the strips cut against the rolling direction loaded into the other two solenoids.

The sample is demagnetized by a variable magnetic field with a frequency of 50 Hz and with decreasing amplitude starting from a peak polarization larger than that used for measurements to a value as close as possible to zero. This should be not less than 1.8 T for an grain-oriented steel and not less than 1.6 T for an non-oriented steel. The time taken for the demagnetization should be not less than 40 s.

This demagnetization should be performed before each series of measurements.

3.1.2 Measurements of the Epstein samples

Each participant performs the following measurements using their standard equipment and measurement procedure:

The specific total loss and specific apparent power are measured stepwise from the lowest to the highest peak polarization value given below. At these values of peak magnetic polarization the values of the peak magnetic field strength are measured simultaneously (preferably).

Parameters for Epstein sample No 1 (non-oriented):

Frequency 50 Hz, 60 Hz

Magnetizing curve $J_{max} = F(H_{max})$

H_{max} = 100, 200, 500, 1000, 2500, A/m.

Specific loss $P = F(J_{max})$

at J_{max} = 1.0; 1.1; 1.3; 1.5; 1.6 T.

Parameters for Epstein sample No 2 (grain oriented):

Frequency 50 Hz, 60 Hz

Magnetizing curve $J_{max} = F(H_{max})$

at H_{max} = 30, 100, 500, 1000, 1500 A/m.

Specific loss $P = F(J_{max})$

at J_{max} = 1.0; 1.3; 1.5; 1.7; 1.8 T.

3.2 Ring samples

3.2.1 Preparation of the ring samples

The sample is connected to the measurement setup used for this comparison. The sample is demagnetized by a variable magnetic field with frequency 50 Hz and with decreasing amplitude starting from a peak polarization larger than that used for measurements to a value as close as possible to zero. This should be not less than 1.8 T for grain-oriented steel and not less than 1.6 T for non-oriented steel. The time taken for the demagnetization should be not less than 40 s.

This demagnetization should be performed before each series of measurements.

3.2.2 Measurements of the ring samples

On the ring samples the specific total power loss and specific apparent power are measured stepwise from the lowest to the highest value given below. At the same values of the peak total magnetic flux density, B, the values of the peak magnetic field strength are measured simultaneously (preferably).

Parameter sets for the measurements on the grain oriented ring:

1. Frequency 50 Hz, 60 Hz
   Magnetizing curve $J_{max} = F(H_{max})$
   at H_{max} = 30, 100, 500, 1000, 1500 A/m.
   Specific loss $P = F(J_{max})$
   at J_{max} = 1.0; 1.3; 1.5; 1.7; 1.8 T
2. Frequency 400 Hz,
   Magnetizing curve $J_{max} = F(H_{max})$
   at H_{max} = 30, 100, 500, 1000, 1300 A/m.
   Specific loss $P = F(J_{max})$
   at J_{max} = 1.0; 1.3; 1.5; (1.6; 1.7) T
3. Frequency 1000 Hz if possible,
   Magnetizing curve $J_{max} = F(H_{max})$
   at H_{max} = 30, 100, 300, 500 A/m.
   Specific loss $P = F(J_{max})$
   at J_{max} = 0.5; 0.7; 1.0 T

Parameters for the NPL ring core manufactured from non-oriented Transil grade steel:

Frequency 50 Hz, 60 Hz
Magnetizing curve $J_{max} = F(H_{max})$
H_{max} = 100, 200, 500, 1000 A/m.
Specific loss $P = F(J_{max})$
at J_{max} = 1.0; 1.1, 1.3; 1.5; 1.6 T.

4. The results of comparisons

4.1 The results of measurements and a standard uncertainty of measurement results (%) of the sample from non-oriented electrical steel №1 with the following characteristics:

total weight – 0.5480 kg

effective mass – 0.4599 kg

sample length – 0.280 m

cross sectional area – $6.396 \cdot 10^{-5}$ m^2

density – 7650 kg/m^3

with Epstein tester are shown in Table 1.

4.2 The results of measurements and a standard uncertainty of measurement results (%) of the sample from grain-oriented magnetic steel №2 with the following characteristics:

total weight – 0.5082 kg

effective mass – 0.4265 kg

sample length – 0.280 m

cross sectional area – $5.931 \cdot 10^{-5}$ m^2

density – 7650 kg/m^3

with Epstein tester are shown in Table 2.

4.3 The results of measurements and a standard uncertainty of measurement results (%) of the ring sample from grain-oriented magnetic steel №18 with the following characteristics:

total weight – 0.2393 kg

length of magnetic path – 0.18064 m

cross sectional area – $1.732 \cdot 10^{-4}$ m^2

density – 7650 kg/m^3

are shown in Table 3.

4.4 The results of measurements and a standard uncertainty of measurement results (%) of the ring sample from non-oriented magnetic steel T1002 with the following characteristics:

total weight – 0.5075 kg

length of magnetic path – 0.44061 m

cross sectional area – $1.503 \cdot 10^{-4}$ m^2

density – 7650 kg/m^3

are shown in Table 4

5 Processing of results

Processing of measurement results obtained from the comparisons carried out with the use of the Guidelines for data evaluation of COOMET supplementary comparisons (COOMET R/GM/19:2008) and the Guidelines for data evaluation of COOMET key comparisons (COOMET R/GM/14:2006).

In processing the experimental data following characteristics were calculated:

- supplementary comparisons reference value X_{ref} by the formula:

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

where X_i – results of the supplementary comparisons of the i-th participant of the comparisons;

$u(X_i)$ – declared standard uncertainty of the i-th participant of the comparisons, %;

N – the number of the participants of comparisons;

- standard uncertainty of the reference value of the supplementary comparisons $u(X_{ref})$, % by the formula:

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

- degree of equivalence of the i-th participant of the comparisons by the formulas 3, 4 and 5:

$$d_i = X_i - X_{ref} \quad (3)$$

$$u^2(d_i) = u^2(X_i) + u^2(X_{ref}) \quad (4)$$

$$E_n = \frac{|d_i|}{2\,u(d_i)}, \quad (5)$$

where d_i – degree of equivalence;

$u(d_i)$ – standard uncertainty of the degree of equivalence.

The declared uncertainties are judged as confirmed if equation $E_{Hi} < 2$ is satisfied, that is a confirmation of the relevant rows from CMC.

The results of calculations by the formulas 1 and 2 are shown in Tables 2-5.

The results of calculations by the formulas 3-5 are shown in Tables 6-9.

6 Evaluation of the comparisons results

After the evaluation of the data in agreement with the rules of EURAMET the agreement of the comparison seems to be good. The data of NMIs participating in the comparisons can be judged as concerted that is an objective confirmation of the declared uncertainties.

There is one exception for all participants for the measurement on a grain-oriented ring sample at high frequencies. The results show clearly that the measurement equipment used for this kind of samples is not suited to get consistent results. Thus, there is further work necessary to get equipment suited for higher frequencies. Until this is done, the uncertainties of all participants for these values have to be increased significantly!

Table 2. The results of measurements and a standard uncertainty of measurement results of the sample № 1

Parameter	CMI, Czech Republic		PTB, Germany		INRIM, Italy		NPL, United Kingdom		UNIIM, Russia		$\bar{X}_{ref}$	$u^2(\bar{X}_{ref})$	$u_{\bar{X}_{ref}}$
	X	u_x	X	u_x	X	u_x	X	u_x	X	u_x			
$P_{1,0/50}$ (W/kg)			0,9481	0,0019	0,959	0,0051	0,942	0,0031	0,9479	0,0049	0,9476	0,000002	0,0015
$P_{1,1/50}$ (W/kg)	1,1206	0,0056	1,1306	0,0023	1,141	0,0066	1,126	0,0037	1,1336	0,0068	1,1305	0,000003	0,0018
$P_{1,3/50}$ (W/kg)			1,6116	0,0039	1,621	0,0101	1,607	0,0052	1,6098	0,0068	1,6107	0,000007	0,0027
$P_{1,5/50}$ (W/kg)			2,3036	0,0056	2,3	0,0189	2,288	0,0086	2,2998	0,0083	2,2992	0,000016	0,0040
$P_{1,0/60}$ (W/kg)			1,1969	0,0024	1,213	0,0058	1,189	0,0039	1,193	0,0060	1,1964	0,000003	0,0018
$P_{1,1/60}$ (W/kg)			1,4272	0,0029	1,44	0,0079	1,422	0,0046	1,4254	0,0071	1,4268	0,000005	0,0022
$P_{1,3/60}$ (W/kg)			2,0319	0,0049	2,05	0,0119	2,026	0,0066	2,0295	0,0073	2,0313	0,000011	0,0033
$P_{1,5/60}$ (W/kg)			2,9043	0,0069	2,917	0,0239	2,886	0,0108	2,9025	0,0110	2,9005	0,000025	0,0050
$J_{100/50}$ (T)			0,9943	0,0014	0,988	0,0029	1,001	0,0026	1,0006	0,0060	0,9948	0,000001	0,0011
$J_{200/50}$ (T)			1,2352	0,0015	1,232	0,0036	1,237	0,0028	1,2355	0,0057	1,2352	0,000001	0,0012
$J_{500/50}$ (T)	1,3667	0,0068	1,3719	0,0016	1,3696	0,0037	1,373	0,0031	1,3713	0,0052	1,3718	0,000002	0,0013
$J_{1000/50}$ (T)	1,435	0,0072	1,4395	0,0017	1,4369	0,0037	1,44	0,0032	1,4395	0,0046	1,4393	0,000002	0,0013
$J_{2500/50}$ (T)	1,5327	0,0077	1,5352	0,0018	1,5353	0,0040	1,537	0,0035	1,5359	0,0046	1,5356	0,000002	0,0014
$J_{100/60}$ (T)			0,9934	0,0014	0,9831	0,0029	0,999	0,0026	1,0006	0,0060	0,9931	0,000001	0,0011
$J_{200/60}$ (T)			1,236	0,0015	1,2286	0,0036	1,237	0,0028	1,2355	0,0057	1,2353	0,000001	0,0012
$J_{500/60}$ (T)	1,3683	0,0068	1,373	0,0016	1,3708	0,0037	1,373	0,0031	1,3713	0,0052	1,3726	0,000002	0,0013
$J_{1000/60}$ (T)	1,4378	0,0072	1,4407	0,0017	1,4381	0,0037	1,441	0,0032	1,4395	0,0046	1,4403	0,000002	0,0013
$J_{2500/60}$ (T)	1,5351	0,0077	1,5366	0,0018	1,5364	0,0040	1,536	0,0035	1,5359	0,0046	1,5364	0,000002	0,0014

Table 3. The results of measurements and a standard uncertainty of measurement results of the sample № 2

Parameter	CMI, Czech Republic		PTB, Germany		INRIM, Italy		NPL, United Kingdom		UNIIM, Russia		$\bar{X}_{ref}$	$u^2(\bar{X}_{ref})$	$u_{\bar{X}_{ref}}$
	X	u_x	X	u_x	X	u_x	X	u_x	X	u_x			
$P_{1,0/50}$ (W/kg)	0,3165	0,0016	0,3173	0,0007	0,3173	0,0014	0,3138	0,0010	0,3164	0,0016	0,3164	0,000000	0,0005
$P_{1,3/50}$ (W/kg)	0,52	0,0026	0,5232	0,0012	0,522	0,0023	0,517	0,0017	0,5222	0,0022	0,5213	0,000001	0,0008
$P_{1,5/50}$ (W/kg)	0,6985	0,0035	0,7041	0,0016	0,705	0,0031	0,697	0,0023	0,6996	0,0029	0,7015	0,000001	0,0011
$P_{1,7/50}$ (W/kg)	1,0073	0,0050	1,0154	0,0042	1,018	0,0052	1,008	0,0038	1,001	0,0036	1,0088	0,000004	0,0019
$P_{1,8/50}$ (W/kg)	1,3598	0,0068	1,3719	0,0087	1,374	0,0123	1,371	0,0064	1,3717	0,0049	1,3693	0,000009	0,0031
$P_{1,0/60}$ (W/kg)			0,4108	0,0009	0,403	0,0017	0,4051	0,0013	0,4041	0,0017	0,4076	0,000000	0,0006
$P_{1,3/60}$ (W/kg)			0,6795	0,0015	0,6697	0,0029	0,671	0,0022	0,6701	0,0028	0,6749	0,000001	0,0011
$P_{1,5/60}$ (W/kg)			0,9143	0,0021	0,9035	0,0039	0,905	0,0029	0,9055	0,0034	0,9092	0,000002	0,0014
$P_{1,7/60}$ (W/kg)	1,3036	0,0065	1,3054	0,0054	1,2925	0,0061	1,297	0,0049	1,2983	0,0047	1,2992	0,000006	0,0024
$P_{1,8/60}$ (W/kg)	1,7431	0,0087	1,745	0,0110	1,7453	0,0147	1,747	0,0081	1,7466	0,0063	1,7457	0,000015	0,0039
$J_{30/50}$ (T)	1,5066	0,0075	1,5027	0,0020	1,4951	0,0045			1,4999	0,0078	1,5016	0,000003	0,0017
$J_{100/50}$ (T)	1,7288	0,0086	1,7356	0,0021	1,736	0,0047	1,738	0,0039	1,7336	0,0062	1,7357	0,000003	0,0016
$J_{500/50}$ (T)	1,8449	0,0092	1,8449	0,0022	1,8456	0,0049	1,846	0,0042	1,8453	0,0044	1,8452	0,000003	0,0016
$J_{1000/50}$ (T)	1,8855	0,0094	1,8843	0,0022	1,8875	0,0050	1,885	0,0042	1,8839	0,0045	1,8847	0,000003	0,0017
$J_{1500/50}$ (T)	1,9095	0,0095	1,9071	0,0023	1,909	0,0051	1,908	0,0043	1,908	0,0046	1,9077	0,000003	0,0017
$J_{30/60}$ (T)	1,4799	0,0074	1,4909	0,0020	1,4937	0,0045			1,4929	0,0078	1,4908	0,000003	0,0017
$J_{100/60}$ (T)	1,7296	0,0086	1,7377	0,0021	1,736	0,0047	1,738	0,0039	1,7359	0,0062	1,7371	0,000003	0,0016
$J_{500/60}$ (T)	1,8452	0,0092	1,8468	0,0022	1,8477	0,0049	1,846	0,0042	1,8464	0,0044	1,8467	0,000003	0,0016
$J_{1000/60}$ (T)	1,8851	0,0094	1,8862	0,0022	1,8834	0,0050	1,885	0,0042	1,8856	0,0045	1,8856	0,000003	0,0017
$J_{1500/60}$ (T)	1,9085	0,0095	1,909	0,0023	1,9054	0,0050	1,908	0,0043	1,9081	0,0046	1,9083	0,000003	0,0017

Table 4. The results of measurements and a standard uncertainty of measurement results of the ring sample № 18

Parameter	CMI, Czech Republic		PTB, Germany		INRIM, Italy		NPL, United Kingdom		UNIIM, Russia		$\bar{X}_{ref}$	$u^2(\bar{X}_{ref})$	$u_{\bar{X}_{ref}}$
	X	u_x	X	u_x	X	u_x	X	u_x	X	u_x			
$P_{1,0/50}$ (W/kg)	0,426	0,0021	0,432	0,0029	0,430	0,0018	0,430	0,0024	0,4332	0,0033	0,4297	0,000001	0,0011
$P_{1,3/50}$ (W/kg)	0,716	0,0036	0,725	0,0048	0,723	0,0033	0,722	0,0040	0,7279	0,0045	0,7222	0,000003	0,0017
$P_{1,5/50}$ (W/kg)	1,000	0,0050	1,007	0,0071	1,006	0,0052	1,004	0,0065	1,0042	0,0058	1,0039	0,000007	0,0026
$P_{1,7/50}$ (W/kg)	1,471	0,0074	1,461	0,0121	1,469	0,0174	1,459	0,0190	1,4585	0,0076	1,4642	0,000020	0,0045
$P_{1,8/50}$ (W/kg)	1,837	0,0092	1,862	0,0158	1,863	0,0361	1,863	0,0242	1,8607	0,0119	1,8499	0,000039	0,0063
$P_{1,0/60}$ (W/kg)	0,565	0,0028	0,569	0,0038	0,568	0,0024	0,568	0,0031	0,5720	0,0037	0,5679	0,000002	0,0014
$P_{1,3/60}$ (W/kg)	0,949	0,0047	0,956	0,0065	0,954	0,0043	0,953	0,0052	0,9593	0,0061	0,9536	0,000005	0,0023
$P_{1,5/60}$ (W/kg)	1,317	0,0066	1,324	0,0092	1,323	0,0064	1,320	0,0086	1,3288	0,0077	1,3220	0,000011	0,0033
$P_{1,7/60}$ (W/kg)	1,898	0,0095	1,905	0,0149	1,918	0,0209	1,902	0,0247	1,9053	0,0099	1,9033	0,000034	0,0058
$P_{1,0/400}$ (W/kg)			11,447	0,0067	11,405	0,0490			11,4618	0,0504	11,4465	0,000044	0,0066
$P_{1,3/400}$ (W/kg)			20,070	0,0070	20,165	0,0887			20,1480	0,0927	20,0710	0,000048	0,0069
$P_{1,5/400}$ (W/kg)			28,960	0,0073	28,953	0,1306			28,7930	0,1324	28,9595	0,000052	0,0072
$P_{1,7/400}$ (W/kg)			42,580	0,0078	42,188	0,3059			42,3240	0,6095	42,5797	0,000060	0,0077
$P_{0,5/1000}$ (W/kg)	13,959	0,0977	14,138	0,0928	13,680	0,1176			14,1460	0,1301	14,0061	0,002840	0,0533
$J_{30/50}$ (T)	1,329	0,0066	1,333	0,0039	1,334	0,0069			1,3289	0,0032	1,3308	0,000005	0,0022
$J_{100/50}$ (T)	1,552	0,0078	1,557	0,0025	1,557	0,0042	1,558	0,0035	1,5550	0,0037	1,5565	0,000003	0,0016
$J_{500/50}$ (T)	1,680	0,0084	1,688	0,0030	1,687	0,0044	1,689	0,0038	1,6876	0,0041	1,6876	0,000003	0,0018
$J_{1000/50}$ (T)	1,755	0,0088	1,758	0,0029	1,759	0,0046	1,758	0,0040	1,7570	0,0042	1,7579	0,000003	0,0018
$J_{1500/50}$ (T)	1,802	0,0090	1,802	0,0030	1,803	0,0047	1,802	0,0041	1,8014	0,0043	1,8020	0,000004	0,0019
$J_{30/60}$ (T)	1,294	0,0065	1,294	0,0065	1,286	0,0067		0,0000	1,2938	0,0031	1,2929	0,000006	0,0024
$J_{100/60}$ (T)	1,552	0,0078	1,558	0,0026	1,558	0,0042	1,558	0,0035	1,5547	0,0037	1,5571	0,000003	0,0016
$J_{500/60}$ (T)	1,679	0,0084	1,690	0,0028	1,687	0,0044	1,688	0,0038	1,6889	0,0041	1,6882	0,000003	0,0017
$J_{1000/60}$ (T)	1,753	0,0088	1,759	0,0029	1,761	0,0046	1,758	0,0040	1,7584	0,0077	1,7590	0,000004	0,0020
$J_{1500/60}$ (T)	1,800	0,0090	1,803	0,0030	1,802	0,0047	1,801	0,0041	1,8031	0,0079	1,8022	0,000004	0,0020
$J_{30/400}$ (T)	0,307	0,0018	0,336	0,0027	0,317	0,0016			0,3149	0,0010	0,3156	0,000001	0,0007
$J_{100/400}$ (T)	1,269	0,0076	1,272	0,0052	1,270	0,0066			1,2716	0,0043	1,2710	0,000008	0,0028
$J_{500/400}$ (T)	1,673	0,0100	1,680	0,0027	1,682	0,0044			1,6803	0,0050	1,6802	0,000004	0,0020
$J_{30/1000}$ (T)	0,153	0,0009	0,159	0,0013	0,151	0,0008			0,1544	0,4600	0,1527	0,000000	0,0005

Table 5. The results of measurements and a standard uncertainty of measurement results of the ring sample T1002

Parameter	CMI, Czech Republic		PTB, Germany		INRIM, Italy		NPL, United Kingdom		UNIIM, Russia		$\bar{X}_{ref}$	$u^2(\bar{X}_{ref})$	$u_{\bar{X}_{ref}}$
	X	u_x	X	u_x	X	u_x	X	u_x	X	u_x			
$P_{1,0/50}$ (W/kg)			1,2001	0,0036	1,2113	0,0064	1,201	0,0039	1,2107	0,4116	1,2021	0,000006	0,0024
$P_{1,1/50}$ (W/kg)	1,4191	0,0071	1,4242	0,0043	1,44	0,0082	1,425	0,0046	1,4276	0,5425	1,4255	0,000007	0,0027
$P_{1,3/50}$ (W/kg)	1,9594	0,0098	1,9583	0,0061	1,9775	0,0119	1,96	0,0064	1,962	0,8240	1,9610	0,000014	0,0038
$P_{1,5/50}$ (W/kg)	2,752	0,0138	2,7576	0,0097	2,777	0,0200	2,759	0,0103	2,7551	0,6061	2,7588	0,000036	0,0060
$P_{1,6/50}$ (W/kg)	3,394	0,0170	3,391	0,0130	3,432	0,0510	3,391	0,0127	3,3931	2,1716	3,3926	0,000063	0,0079
$P_{1,0/60}$ (W/kg)	1,469	0,0073	1,4973	0,0045	1,5171	0,0074	1,5	0,0049	1,5035	0,5413	1,4969	0,000009	0,0030
$P_{1,1/60}$ (W/kg)			1,7773	0,0053	1,7997	0,0180	1,78	0,0058	1,7835	0,6777	1,7795	0,000015	0,0039
$P_{1,3/60}$ (W/kg)	2,432	0,0122	2,4432	0,0076	2,4714	0,0141	2,448	0,0080	2,4517	1,0787	2,4464	0,000026	0,0051
$P_{1,5/60}$ (W/kg)	3,394	0,0170	3,434	0,0120	3,474	0,0233	3,436	0,0129	3,4346	0,8930	3,4311	0,000067	0,0082
$P_{1,6/60}$ (W/kg)	4,177	0,0209	4,206	0,0170	4,2588	0,0596	4,216	0,0158	4,2034	1,1770	4,2048	0,000129	0,0114
$J_{100/50}$ (T)	0,9746	0,0049	0,9714	0,0018	0,967	0,0038			0,9696	0,2327	0,9710	0,000002	0,0015
$J_{200/50}$ (T)	1,2734	0,0064	1,273	0,0016	1,2728	0,0038	1,278	0,0029	1,2709	0,3050	1,2740	0,000002	0,0013
$J_{500/50}$ (T)	1,4557	0,0073	1,4565	0,0015	1,4543	0,0039	1,458	0,0033	1,4539	0,3489	1,4565	0,000002	0,0013
$J_{1000/50}$ (T)	1,5227	0,0076	1,5258	0,0016	1,523	0,0040	1,526	0,0034	1,5232	0,3960	1,5254	0,000002	0,0013
$J_{100/60}$ (T)	0,9687	0,0048	0,9704	0,0018	0,964	0,0038	0,979	0,0025	0,9614	0,4230	0,9718	0,000002	0,0013
$J_{200/60}$ (T)	1,2728	0,0064	1,2733	0,0016	1,2712	0,0038	1,277	0,0029	1,27	0,3048	1,2738	0,000002	0,0013
$J_{500/60}$ (T)	1,4538	0,0073	1,4575	0,0015	1,4532	0,0039	1,458	0,0033	1,4537	0,3489	1,4570	0,000002	0,0013
$J_{1000/60}$ (T)	1,5209	0,0076	1,5271	0,0016	1,5242	0,0040	1,527	0,0034	1,5216	0,3652	1,5266	0,000002	0,0013

Table 6. The results of calculation of the equivalence of measurement standards for CRM 2002-80 № 1

Parameter	CMI, Czech Republic			PTB, Germany			INRIM, Italy			NPL, United Kingdom			UNIIM, Russia		
	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n
$P_{1,0/50}$ (W/kg)				0,0005	0,0024	0,1064	0,0114	0,0053	1,0784	-0,0056	0,0034	0,8233	0,0003	0,0051	0,0302
$P_{1,1/50}$ (W/kg)	-0,0099	0,2500	1,9733	0,0001	0,0029	0,0228	0,0105	0,0069	0,7680	-0,0045	0,0041	0,5477	0,0031	0,0070	0,2227
$P_{1,3/50}$ (W/kg)				0,0009	0,0048	0,0900	0,0103	0,0104	0,4925	-0,0037	0,0059	0,3172	-0,0009	0,0073	0,0644
$P_{1,5/50}$ (W/kg)				0,0044	0,0069	0,3209	0,0008	0,0193	0,0210	-0,0112	0,0095	0,5913	0,0006	0,0092	0,0333
$P_{1,0/60}$ (W/kg)				0,0005	0,0030	0,0909	0,0166	0,0061	1,3639	-0,0074	0,0043	0,8599	-0,0034	0,0062	0,2687
$P_{1,1/60}$ (W/kg)				0,0004	0,0037	0,0508	0,0132	0,0082	0,8005	-0,0048	0,0051	0,4706	-0,0014	0,0075	0,0957
$P_{1,3/60}$ (W/kg)				0,0006	0,0059	0,0495	0,0187	0,0123	0,7568	-0,0053	0,0074	0,3603	-0,0018	0,0080	0,1130
$P_{1,5/60}$ (W/kg)				0,0038	0,0086	0,2207	0,0165	0,0244	0,3370	-0,0145	0,0119	0,6084	0,0020	0,0121	0,0814
$J_{100/50}$ (T)				-0,0005	0,0018	0,1374	-0,0068	0,0031	1,1047	0,0062	0,0028	1,0965	0,0058	0,0061	0,4756
$J_{200/50}$ (T)				0,0000	0,0019	0,0034	-0,0032	0,0038	0,4225	0,0018	0,0030	0,2988	0,0003	0,0058	0,0270
$J_{500/50}$ (T)	-0,0051	0,2500	1,0151	0,0001	0,0021	0,0302	-0,0022	0,0039	0,2778	0,0012	0,0033	0,1829	-0,0005	0,0054	0,0443
$J_{1000/50}$ (T)	-0,0043	0,2500	0,8505	0,0002	0,0022	0,0572	-0,0024	0,0040	0,2965	0,0007	0,0035	0,1066	0,0002	0,0048	0,0258
$J_{2500/50}$ (T)	-0,0029	0,2500	0,5754	-0,0004	0,0023	0,0825	-0,0003	0,0042	0,0327	0,0014	0,0037	0,1905	0,0003	0,0048	0,0335
$J_{100/60}$ (T)				0,0003	0,0018	0,0823	-0,0100	0,0031	1,6336	0,0059	0,0028	1,0427	0,0075	0,0061	0,6138
$J_{200/60}$ (T)				0,0007	0,0019	0,1773	-0,0067	0,0038	0,8941	0,0017	0,0030	0,2766	0,0002	0,0058	0,0152
$J_{500/60}$ (T)	-0,0043	0,2500	0,8667	0,0004	0,0020	0,0897	-0,0018	0,0039	0,2340	0,0004	0,0033	0,0548	-0,0013	0,0054	0,1242
$J_{1000/60}$ (T)	-0,0025	0,2500	0,5051	0,0004	0,0021	0,0878	-0,0022	0,0040	0,2806	0,0007	0,0035	0,0963	-0,0008	0,0048	0,0862
$J_{2500/60}$ (T)	-0,0013	0,2500	0,2619	0,0002	0,0023	0,0417	0,0000	0,0042	0,0011	-0,0004	0,0037	0,0549	-0,0005	0,0048	0,0529

Table 7. The results of calculation of the equivalence of measurement standards for CRM 10271-2013 № 2

Parameter	CMI, Czech Republic			PTB, Germany			INRIM, Italy			NPL, United Kingdom			UNIIM, Russia		
	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n
$P_{1,0/50}$ (W/kg)	0,0001	0,0017	0,0369	0,0009	0,0008	0,5478	0,0009	0,0014	0,3188	-0,0026	0,0011	1,1440	0,0000	0,0017	0,0064
$P_{1,3/50}$ (W/kg)	-0,0013	0,0027	0,2309	0,0019	0,0014	0,6773	0,0007	0,0024	0,1534	-0,0043	0,0019	1,1454	0,0009	0,0023	0,2027
$P_{1,5/50}$ (W/kg)	-0,0030	0,0037	0,4156	0,0026	0,0019	0,6684	0,0035	0,0033	0,5232	-0,0045	0,0025	0,9061	-0,0019	0,0031	0,3095
$P_{1,7/50}$ (W/kg)	-0,0015	0,0054	0,1395	0,0066	0,0046	0,7154	0,0092	0,0055	0,8321	-0,0008	0,0043	0,0938	-0,0078	0,0041	0,9580
$P_{1,8/50}$ (W/kg)	-0,0095	0,0075	0,6373	0,0026	0,0092	0,1409	0,0047	0,0127	0,1854	0,0017	0,0071	0,1201	0,0024	0,0058	0,2065
$P_{1,0/60}$ (W/kg)				0,0032	0,0011	1,4913	-0,0046	0,0018	1,2431	-0,0025	0,0015	0,8509	-0,0035	0,0018	0,9621
$P_{1,3/60}$ (W/kg)				0,0046	0,0018	1,2577	-0,0052	0,0031	0,8455	-0,0039	0,0024	0,8021	-0,0048	0,0030	0,7962
$P_{1,5/60}$ (W/kg)				0,0051	0,0025	1,0128	-0,0057	0,0041	0,6832	-0,0042	0,0033	0,6356	-0,0037	0,0037	0,4906
$P_{1,7/60}$ (W/kg)	0,0044	0,0070	0,3155	0,0062	0,0059	0,5226	-0,0067	0,0065	0,5136	-0,0022	0,0055	0,2018	-0,0009	0,0053	0,0869
$P_{1,8/60}$ (W/kg)	-0,0026	0,0095	0,1368	-0,0007	0,0117	0,0304	-0,0004	0,0152	0,0134	0,0013	0,0090	0,0717	0,0009	0,0074	0,0603
$J_{30/50}$ (T)	0,0050	0,0077	0,3210	0,0011	0,0026	0,2010	-0,0065	0,0048	0,6799				-0,0017	0,0080	0,1087
$J_{100/50}$ (T)	-0,0069	0,0088	0,3915	-0,0001	0,0027	0,0164	0,0003	0,0050	0,0315	0,0023	0,0042	0,2730	-0,0021	0,0065	0,1618
$J_{500/50}$ (T)	-0,0003	0,0094	0,0164	-0,0003	0,0027	0,0559	0,0004	0,0052	0,0381	0,0008	0,0045	0,0888	0,0001	0,0047	0,0099
$J_{1000/50}$ (T)	0,0008	0,0096	0,0394	-0,0004	0,0028	0,0805	0,0028	0,0053	0,2614	0,0003	0,0046	0,0280	-0,0008	0,0048	0,0877
$J_{1500/50}$ (T)	0,0018	0,0097	0,0945	-0,0006	0,0029	0,0984	0,0013	0,0053	0,1249	0,0003	0,0046	0,0361	0,0003	0,0049	0,0341
$J_{30/60}$ (T)	-0,0109	0,0076	0,7183	0,0001	0,0026	0,0160	0,0029	0,0048	0,3003				0,0021	0,0080	0,1310
$J_{100/60}$ (T)	-0,0075	0,0088	0,4282	0,0006	0,0027	0,1060	-0,0011	0,0050	0,1144	0,0009	0,0042	0,1020	-0,0012	0,0065	0,0957
$J_{500/60}$ (T)	-0,0015	0,0094	0,0784	0,0001	0,0027	0,0237	0,0010	0,0052	0,0997	-0,0007	0,0045	0,0750	-0,0003	0,0047	0,0286
$J_{1000/60}$ (T)	-0,0005	0,0096	0,0255	0,0006	0,0028	0,1106	-0,0022	0,0053	0,2080	-0,0006	0,0046	0,0646	0,0000	0,0048	0,0012
$J_{1500/60}$ (T)	0,0002	0,0097	0,0109	0,0007	0,0029	0,1245	-0,0029	0,0053	0,2709	-0,0003	0,0046	0,0312	-0,0002	0,0049	0,0193

Table 8. The results of calculation of the equivalence of measurement standards for ring sample № 18

Parameter	CMI, Czech Republic			PTB, Germany			INRIM, Italy			NPL, United Kingdom			UNIIM, Russia		
	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n
$P_{1,0/50}$ (W/kg)	-0,0035	0,0024	0,7303	0,0020	0,0031	0,3327	0,0003	0,0021	0,0775	0,0005	0,0026	0,1023	0,0035	0,0035	0,5107
$P_{1,3/50}$ (W/kg)	-0,0062	0,0040	0,7765	0,0032	0,0051	0,3126	0,0008	0,0037	0,1099	-0,0002	0,0043	0,0215	0,0057	0,0048	0,5903
$P_{1,5/50}$ (W/kg)	-0,0035	0,0056	0,3110	0,0026	0,0075	0,1729	0,0021	0,0058	0,1798	0,0001	0,0070	0,0070	0,0003	0,0064	0,0234
$P_{1,7/50}$ (W/kg)	0,0063	0,0086	0,3674	-0,0032	0,0129	0,1224	0,0051	0,0180	0,1430	-0,0052	0,0195	0,1322	-0,0057	0,0088	0,3202
$P_{1,8/50}$ (W/kg)	-0,0134	0,0111	0,6006	0,0121	0,0170	0,3576	0,0134	0,0367	0,1832	0,0134	0,0250	0,2686	0,0108	0,0135	0,4027
$P_{1,0/60}$ (W/kg)	-0,0031	0,0031	0,5024	0,0007	0,0040	0,0811	0,0003	0,0028	0,0447	0,0001	0,0034	0,0074	0,0041	0,0039	0,5185
$P_{1,3/60}$ (W/kg)	-0,0046	0,0053	0,4376	0,0024	0,0069	0,1733	0,0004	0,0049	0,0385	-0,0006	0,0057	0,0544	0,0057	0,0066	0,4324
$P_{1,5/60}$ (W/kg)	-0,0052	0,0074	0,3512	0,0016	0,0097	0,0829	0,0005	0,0072	0,0356	-0,0020	0,0092	0,1078	0,0068	0,0084	0,4057
$P_{1,7/60}$ (W/kg)	-0,0053	0,0111	0,2382	0,0017	0,0160	0,0531	0,0144	0,0217	0,3319	-0,0013	0,0254	0,0256	0,0020	0,0115	0,0871
$P_{1,0/400}$ (W/kg)				0,0005	0,0094	0,0269	-0,0415	0,0495	0,4193				0,0153	0,0509	0,1505
$P_{1,3/400}$ (W/kg)				-0,0010	0,0098	0,0517	0,0940	0,0890	0,5280				0,0770	0,0929	0,4141
$P_{1,5/400}$ (W/kg)				0,0005	0,0102	0,0253	-0,0065	0,1308	0,0248				-0,1665	0,1326	0,6275
$P_{1,7/400}$ (W/kg)				0,0003	0,0110	0,0134	-0,3917	0,3060	0,6401				-0,2557	0,6095	0,2098
$P_{0,5/1000}$ (W/kg)	-0,0471	0,1113	0,2117	0,1319	0,1070	0,6160	-0,3261	0,1292	1,2625				0,1399	0,1406	0,4973
$J_{30/50}$ (T)	-0,0023	0,0070	0,1631	0,0026	0,0045	0,2938	0,0030	0,0073	0,2075				-0,0019	0,0039	0,2432
$J_{100/50}$ (T)	-0,0041	0,0079	0,2606	0,0002	0,0030	0,0283	0,0006	0,0045	0,0631	0,0015	0,0039	0,1903	-0,0015	0,0041	0,1885
$J_{500/50}$ (T)	-0,0072	0,0086	0,4184	0,0005	0,0035	0,0721	-0,0010	0,0047	0,1046	0,0014	0,0042	0,1673	0,0000	0,0044	0,0009
$J_{1000/50}$ (T)	-0,0026	0,0090	0,1438	0,0000	0,0034	0,0031	0,0015	0,0049	0,1544	0,0001	0,0044	0,0139	-0,0009	0,0046	0,0957
$J_{1500/50}$ (T)	0,0000	0,0092	0,0025	-0,0001	0,0035	0,0077	0,0008	0,0050	0,0837	-0,0001	0,0045	0,0061	-0,0006	0,0047	0,0588
$J_{30/60}$ (T)	0,0006	0,0069	0,0455	0,0015	0,0070	0,1096	-0,0066	0,0071	0,4624				0,0009	0,0039	0,1182
$J_{100/60}$ (T)	-0,0050	0,0079	0,3182	0,0010	0,0031	0,1556	0,0009	0,0045	0,0945	0,0009	0,0039	0,1103	-0,0024	0,0041	0,3004
$J_{500/60}$ (T)	-0,0095	0,0086	0,5565	0,0014	0,0033	0,2071	-0,0012	0,0047	0,1316	-0,0002	0,0042	0,0290	0,0007	0,0044	0,0744
$J_{1000/60}$ (T)	-0,0065	0,0090	0,3592	0,0003	0,0035	0,0501	0,0023	0,0050	0,2359	-0,0010	0,0044	0,1076	-0,0006	0,0080	0,0345
$J_{1500/60}$ (T)	-0,0019	0,0092	0,1013	0,0011	0,0036	0,1570	-0,0004	0,0051	0,0361	-0,0017	0,0045	0,1844	0,0009	0,0082	0,0569
$J_{30/400}$ (T)	-0,0083	0,0020	2,0893	0,0207	0,0028	3,6392	0,0011	0,0018	0,2994				-0,0007	0,0013	0,2854
$J_{100/400}$ (T)	-0,0023	0,0081	0,1403	0,0006	0,0059	0,0534	-0,0008	0,0072	0,0539				0,0006	0,0051	0,0612
$J_{500/400}$ (T)	-0,0075	0,0102	0,3643	-0,0002	0,0034	0,0239	0,0017	0,0048	0,1801				0,0001	0,0054	0,0127
$J_{30/1000}$ (T)	0,0004	0,0011	0,1878	0,0065	0,0014	2,2555	-0,0022	0,0010	1,1389				0,0017	0,4600	0,1880

Table 9. The results of calculation of the equivalence of measurement standards for ring sample T1002

Parameter	CMI, Czech Republic			PTB, Germany			INRIM, Italy			NPL, United Kingdom			UNIIM, Russia		
	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n	d_i	$u(d_i)$	E_n
$P_{1,0/50}$ (W/kg)				-0,0020	0,0044	0,2305	0,0092	0,0068	0,6748	-0,0011	0,0046	0,1201	0,0086	0,4116	0,0104
$P_{1,1/50}$ (W/kg)	-0,0064	0,0076	0,4185	-0,0013	0,0051	0,1238	0,0145	0,0086	0,8409	-0,0005	0,0054	0,0428	0,0021	0,5425	0,0020
$P_{1,3/50}$ (W/kg)	-0,0016	0,0105	0,0783	-0,0027	0,0072	0,1911	0,0165	0,0125	0,6603	-0,0010	0,0074	0,0704	0,0010	0,8240	0,0006
$P_{1,5/50}$ (W/kg)	-0,0068	0,0150	0,2250	-0,0012	0,0114	0,0506	0,0182	0,0209	0,4370	0,0002	0,0120	0,0103	-0,0037	0,6062	0,0030
$P_{1,6/50}$ (W/kg)	0,0014	0,0187	0,0363	-0,0016	0,0152	0,0539	0,0394	0,0516	0,3816	-0,0016	0,0150	0,0548	0,0005	2,1716	0,0001
$P_{1,0/60}$ (W/kg)	-0,0279	0,0079	1,7602	0,0004	0,0054	0,0325	0,0202	0,0080	1,2672	0,0031	0,0057	0,2662	0,0066	0,5413	0,0061
$P_{1,1/60}$ (W/kg)				-0,0022	0,0066	0,1659	0,0202	0,0184	0,5489	0,0005	0,0070	0,0370	0,0040	0,6777	0,0030
$P_{1,3/60}$ (W/kg)	-0,0144	0,0132	0,5444	-0,0032	0,0092	0,1728	0,0250	0,0150	0,8351	0,0016	0,0095	0,0864	0,0053	1,0788	0,0025
$P_{1,5/60}$ (W/kg)	-0,0371	0,0189	0,9841	0,0029	0,0145	0,0997	0,0429	0,0247	0,8690	0,0049	0,0153	0,1602	0,0035	0,8930	0,0020
$P_{1,6/60}$ (W/kg)	-0,0278	0,0238	0,5855	0,0012	0,0204	0,0283	0,0540	0,0607	0,4445	0,0112	0,0195	0,2866	-0,0014	1,1770	0,0006
$J_{100/50}$ (T)	0,0036	0,0051	0,3519	0,0004	0,0024	0,0838	-0,0040	0,0041	0,4859				-0,0014	0,2327	0,0030
$J_{200/50}$ (T)	-0,0006	0,0065	0,0456	-0,0010	0,0021	0,2413	-0,0012	0,0040	0,1502	0,0040	0,0031	0,6363	-0,0031	0,3050	0,0051
$J_{500/50}$ (T)	-0,0008	0,0074	0,0516	0,0000	0,0020	0,0097	-0,0022	0,0041	0,2664	0,0015	0,0035	0,2187	-0,0026	0,3489	0,0037
$J_{1000/50}$ (T)	-0,0027	0,0077	0,1755	0,0004	0,0021	0,0927	-0,0024	0,0042	0,2885	0,0006	0,0037	0,0797	-0,0022	0,3960	0,0028
$J_{100/60}$ (T)	-0,0031	0,0050	0,3107	-0,0014	0,0022	0,3174	-0,0078	0,0040	0,9701	0,0072	0,0029	1,2518	-0,0104	0,4230	0,0123
$J_{200/60}$ (T)	-0,0010	0,0065	0,0749	-0,0005	0,0021	0,1151	-0,0026	0,0040	0,3246	0,0032	0,0031	0,5126	-0,0038	0,3048	0,0062
$J_{500/60}$ (T)	-0,0032	0,0074	0,2166	0,0005	0,0020	0,1281	-0,0038	0,0041	0,4683	0,0010	0,0035	0,1426	-0,0033	0,3489	0,0047
$J_{1000/60}$ (T)	-0,0057	0,0077	0,3664	0,0005	0,0021	0,1295	-0,0024	0,0042	0,2818	0,0004	0,0037	0,0599	-0,0050	0,3652	0,0068