Supplementary bilateral comparison for the primary standard of the voltage harmonic coefficient COOMET 709/RU-a/16 (COOMET.EM-S24)

Sergey V. Bezdenezhnykh[1], Oleg V. Kaminsky[2], Kseniia A. Stal'nova[3], Alexander V. Galygo[4], Nadezhda A. Gerasimiva[5]

[1, 2, 3] Federal State Unitary Enterprise "All-Russian Research Institute of Physical Technical and Radio Technical Measurements" (VNIIFTRI), Mendeleevo, Moscow Region, Russia
[1]bsv@vniiftri.ru, [2]kaminsky@vniiftri.ru, [3]stalnova@vniiftri.ru
[4, 5] Belarusian State Institute of Metrology (BelGIM), Minsk, Republic of Belarus,
[4]galygo@belgim.by, [5]gerasimova@belgim.by

Abstract

This supplementary bilateral comparison of primary standards of the voltage harmonic coefficient was conducted on the initiative of the National Metrology Institutes (NMIs) VNIIFTRI (Russia) and BelGIM (Republic of Belarus). Its description and measurement results are presented below.

Index Terms – Comparisons, standard uncertainty, measurement, field of the voltage harmonic distortion measurements, voltage harmonic coefficient.

This supplementary bilateral comparison of the voltage harmonic coefficient was carried out under COOMET project 709/RU-a/16 (COOMET.EM-S24). The comparison involved the Russian State primary standard of the voltage harmonic coefficient GET 188-2010 (VNIIFTRI) and the national standard of the voltage harmonic coefficient of Republic of Belarus NET (BelGIM). GET 188-2010 is traceable to primary special standard of electrical voltage unit (volt) in the frequency range of (10 - $3\cdot10^7$) Hz, GET 89-2008 and primary standard of time, frequency and national time scale units, GET 1-2018. NET is traceable to the national standard of AC voltage unit in the frequency range of 10 Hz – 2 GHz NS RB 5-01.

Comparisons were carried out at the following frequencies of the voltage harmonic coefficient: 10; 20; 200 Hz, 1; 20; 100 and 200 kHz. The voltage of the voltage harmonic coefficient at all frequencies was 1 V. A calibrator-distortion meter CK6-20 (manufacturer "ZET", Zelenograd) was used as a traveling standard. The values of the voltage harmonic coefficient produced by the national standards were measured by means of the traveling standard: 0,003; 0,01; 0,03; 0,1; 0,3; 1; 3; 10; 30 and 100 %, at each frequency: 0,01; 0,02; 0,2; 1; 20; 100 and 200 kHz at the fundamental voltage harmonic voltage value of 1 V. For each reproducible value of the voltage harmonic coefficient at each of the shown frequencies of the fundamental voltage harmonic, the arithmetic mean and standard deviation were calculated for 10 measurements. The purpose of the comparisons was to confirm confidence in the measurement results and calibration certificates issued by the NMIs in the field of voltage harmonic distortion measurements, and to confirm the calibration and measurement capabilities (CMCs) in this area. Measurements were carried out from July to September 2018. VNIIFTRI acted as a pilot laboratory.

The measurements of voltage harmonics coefficients, produced by the primary standards, by means of the traveling standard were carried out in the following order: first voltage harmonics coefficients on GET 188-2010 were measured, then they were measured on NET and finally again on GET 188-2010. The measurement results in these two series were tested for consistency. The differences Kg_{TS1}-Kg_{TS2} (Kg_{TS1} and Kg_{TS2} are the results of measurements by the traveling standard on GET 188-2010 and NET, respectively) were within the confidence interval $\pm t\cdot RMS_{12}$ with a confidence probability of 0.95 (RMS_{12} is the standard deviation of the measurement results in a combined series of measurements on GET 188-2010 and NET, t - Student's coefficient). In accordance with Fisher's criterion (P=0.95), the measurement results in the two series are equally scattered. Since the series are homogeneous (equally scattered with an insignificant difference in the arithmetic means), the traveling standard measurement results included in them were considered and processed as a single array. Thus, the GET 188-2010 results are the average values of the before and after measurements. The GET 188-2010 results include the stability of the travelling standard.

Analyzing the results of the comparisons according to the χ^2 criterion showed that the data obtained in the comparisons can be acknowledged as consistent, which is the objective confirmation of the announced uncertainties. The results of the comparison will be used for confirmation of calibration and measurement capabilities in the area of voltage harmonic distortion measurements provided by BelGIM.

The metrological results of the comparisons were the differences between the values of the voltage harmonic coefficient, produced by the national primary standards, and the average values of the results measured by the traveling standard for the above sets of the fundamental voltage harmonic frequencies and voltage harmonic coefficients:

$$\Delta(f, Kg) = Kg_{NE} - Kg_{TS} \qquad (1)$$

Kg_{NE} - values of the voltage harmonic coefficient, produced by the national primary standards;
Kg_{TS} - average values of the results measured by the traveling standard.

The participants provided results with associated measurement uncertainties and uncertainty budget. Reference values of comparison results Δ_{ref} and uncertainties of reference values u_{ref} were calculated by formulas (2) and (3), respectively.

$$\Delta_{ref}(f, Kg) = \frac{\Delta_{GET}(f,\ Kg)/u_{GET}^2(f, Kg) + \Delta_{NET}(f, Kg)/u_{NET}^2(f, Kg)}{1/u_{GET}^2(f, Kg) + 1/u_{NET}^2(f, Kg)} \qquad (2)$$

$$u_{ref}(f, Kg) = \sqrt{\frac{1}{1/u_{GET}^2(f, Kg) + 1/u_{NET}^2(f, Kg)}} \qquad (3)$$

$\Delta_{GET}(f, Kg)$ – measurements results on the primary standard GET 188-2010.
$\Delta_{NET}(f, Kg)$ - measurement results on the primary standard NET.
$u_{GET}(f, Kg)$ and $u_{NET}(f, Kg)$ are the standard uncertainties of measurement results on GET 188-2010 and on NET, respectively.

The results of the comparison are presented in Figures 1-4. Here the red and blue points are the GET 188-2010 and NET results respectively and the green points indicate the reference value. Bars show standard uncertainty.

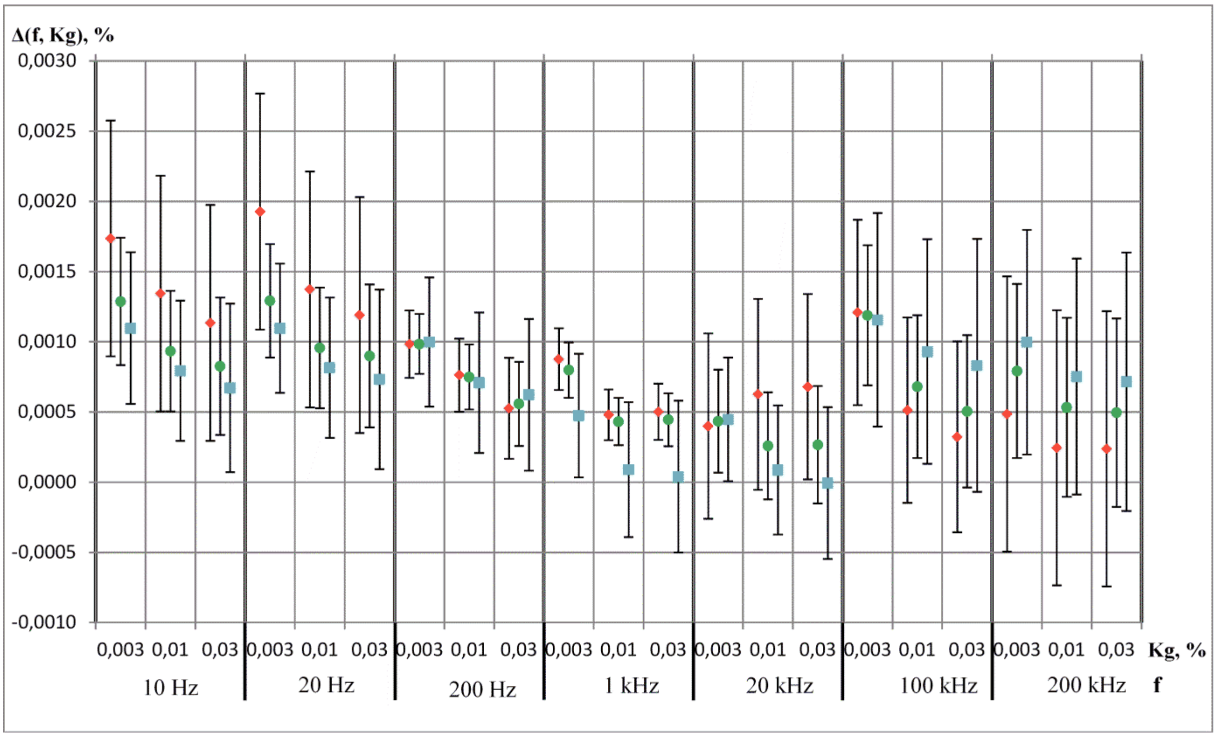

Figure 1 - Comparison data on the measured values of the voltage harmonic coefficient from 0,003 % to 0,03 %.

◆ – GET 188-2010 (VNIIFTRI); ■ – NET (BelGIM); ● – Reference values.

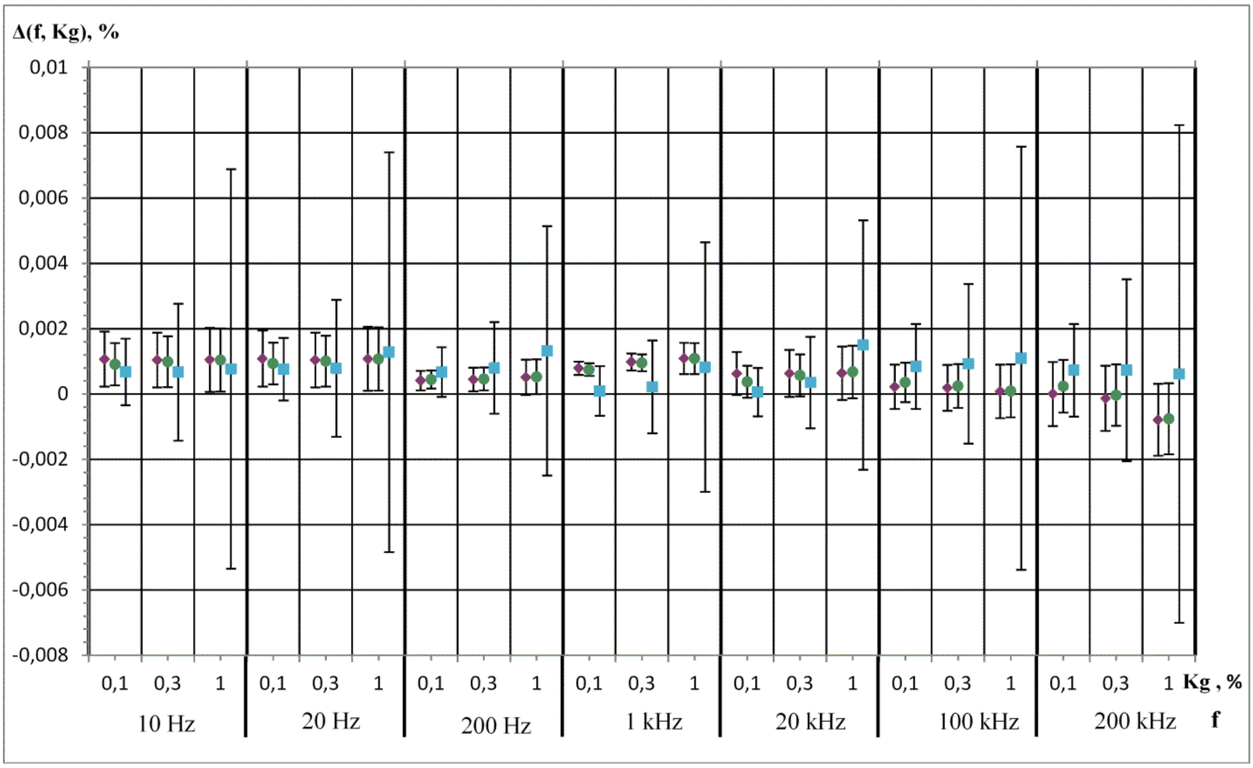

Figure 2 - Comparison data on the measured values of the voltage harmonic coefficient from 0,1 % to 1 %

◆ – GET 188-2010 (VNIIFTRI); ■ – NET (BelGIM); ● – Reference values.

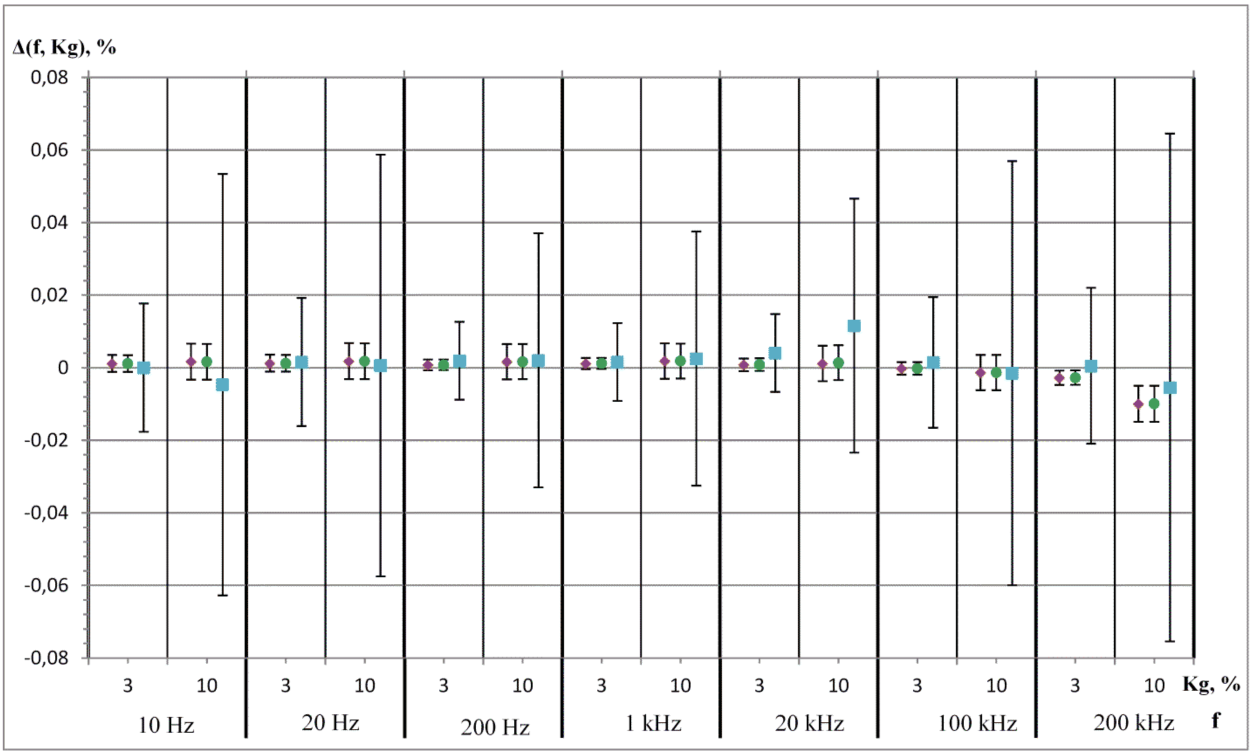

Figure 3 - Comparison data on the measured values of the voltage harmonic coefficient 3 % and 10 %

◆ – GET 188-2010 (VNIIFTRI); ■ – NET (BelGIM); ● – Reference values.

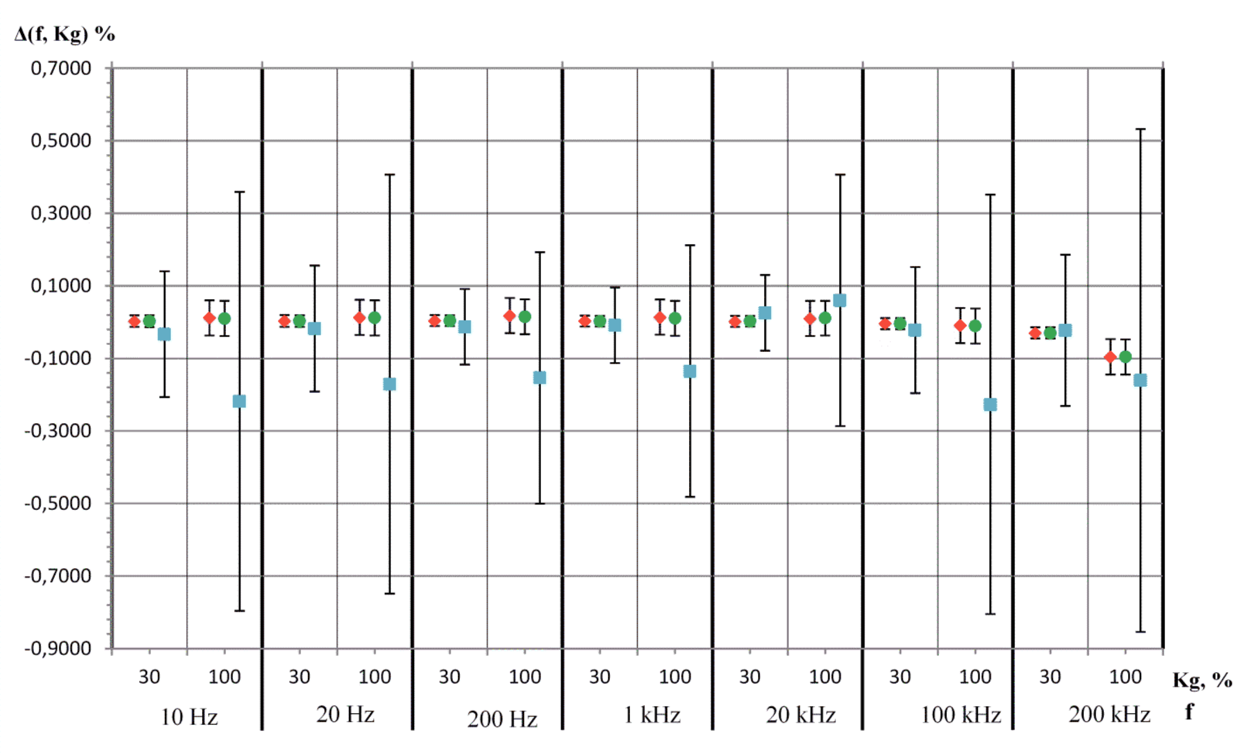

Figure 4 - Comparison data on the measured values of the voltage harmonic coefficient 30 % and 100 %

◆ – GET 188-2010 (VNIIFTRI); ■ – NET (BelGIM); ● – Reference values.

On the basis of the measurement results $\Delta_{GET}(f, Kg)$, $\Delta_{NET}(f, Kg)$ and corresponding uncertainties $u_{GET}(f, Kg)$ and $u_{NET}(f, Kg)$, claimed by the comparisons participants, the chi-squared value χ^2 was calculated for all measured voltage harmonic coefficients and at all frequencies of the fundamental voltage harmonic according to the formula (Guideline on COOMET supplementary comparison evaluation. COOMET R/GM/19)

$$\chi 2(f, Kg) = \frac{\left(\Delta_{GET}(f, Kg) - \Delta_{ref}(f, Kg)\right)^2}{u_{GET}^2(f, Kg)} + \frac{\left(\Delta_{NET}(f, Kg) - \Delta_{ref}(f, Kg)\right)^2}{u_{NET}^2(f, Kg)}. \quad (4)$$

None of the χ^2-values exceeds the critical value $\chi^2_{cr} = 3.84$ (for $P = 95\%$ for bilateral comparisons).

Analysis of the results of the comparisons according to the χ^2-criterion showed that the data obtained in the comparisons can be acknowledged as consistent, which is the objective confirmation of the announced uncertainties. The results of the comparison will be used for confirmation of CMCs in the area of voltage harmonic distortion measurements provided by BelGIM (Republic of Belarus). The results of the comparison are displayed in the Appendix.

Project COOMET 709/RU-a/16 "Carrying out supplementary bilateral comparison for the standards of the voltage harmonic coefficient" was completed in July 2019.

References

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Appendix. Tables of the results of the comparison of primary standard of voltage harmonic coefficient VNIIFTRI (Russia) and the national standard of voltage harmonic coefficient BelGIM (Republic of Belarus)..

f, Hz	*Kg*, %	$u_{GET}(f, Kg)$, %	$u_{NET}(f, Kg)$, %	$\Delta_{GET}(f, Kg)$, %	$\Delta_{NET}(f, Kg)$, %	$\Delta_{ref}(f, Kg)$, %	$u_{ref}(f, Kg)$, %	χ^2
10	0,003	0,00042	0,00027	0,00174	0,00110	0,00129	0,00023	1,64
10	0,01	0,00042	0,00025	0,00134	0,00079	0,00093	0,00021	1,27
10	0,03	0,00042	0,00030	0,00113	0,00067	0,00083	0,00024	0,79
10	0,1	0,00042	0,00051	0,00107	0,00068	0,00091	0,00032	0,35
10	0,3	0,00042	0,00105	0,00104	0,00067	0,00099	0,00039	0,11
10	1	0,00049	0,00306	0,00105	0,00077	0,00104	0,00048	0,01
10	3	0,00116	0,00884	0,00118	0,00005	0,00116	0,00115	0,02
10	10	0,00248	0,02904	0,00170	-0,00467	0,00165	0,00247	0,05
10	30	0,00808	0,08678	0,00298	-0,03312	0,00267	0,00805	0,17
10	100	0,02425	0,28885	0,01188	-0,21819	0,01027	0,02416	0,63
20	0,003	0,00042	0,00023	0,00193	0,00110	0,00129	0,00020	3,00
20	0,01	0,00042	0,00025	0,00137	0,00081	0,00096	0,00021	1,31
20	0,03	0,00042	0,00032	0,00119	0,00073	0,00090	0,00025	0,76
20	0,1	0,00043	0,00048	0,00108	0,00076	0,00094	0,00032	0,25
20	0,3	0,00042	0,00105	0,00104	0,00079	0,00101	0,00039	0,05
20	1	0,00049	0,00306	0,00107	0,00128	0,00108	0,00048	0,00
20	3	0,00116	0,00884	0,00124	0,00156	0,00125	0,00115	0,00
20	10	0,00248	0,02905	0,00179	0,00063	0,00178	0,00247	0,00
20	30	0,00808	0,08679	0,00341	-0,01752	0,00323	0,00805	0,06
20	100	0,02425	0,28893	0,01309	-0,17063	0,01180	0,02417	0,40
200	0,003	0,00012	0,00023	0,00098	0,00100	0,00098	0,00011	0,01
200	0,01	0,00013	0,00025	0,00076	0,00071	0,00075	0,00012	0,03
200	0,03	0,00018	0,00027	0,00053	0,00062	0,00056	0,00015	0,08
200	0,1	0,00015	0,00038	0,00041	0,00067	0,00045	0,00014	0,41
200	0,3	0,00018	0,00070	0,00044	0,00080	0,00046	0,00017	0,25
200	1	0,00027	0,00191	0,00051	0,00132	0,00053	0,00027	0,18
200	3	0,00074	0,00537	0,00079	0,00194	0,00081	0,00073	0,05
200	10	0,00243	0,01750	0,00165	0,00205	0,00166	0,00241	0,00

f, Hz	*Kg*, %	$u_{GET}(f, Kg)$, %	$u_{NET}(f, Kg)$, %	$\Delta_{GET}(f, Kg)$, %	$\Delta_{NET}(f, Kg)$, %	$\Delta_{ref}(f, Kg)$, %	$u_{ref}(f, Kg)$, %	χ^2
200	30	0,00751	0,05214	0,00433	-0,01290	0,00398	0,00743	0,11
200	100	0,02425	0,17343	0,01804	-0,15352	0,01475	0,02402	0,96
1000	0,003	0,00011	0,00022	0,00088	0,00047	0,00080	0,00010	2,78
1000	0,01	0,00009	0,00024	0,00048	0,00009	0,00043	0,00008	2,32
1000	0,03	0,00010	0,00027	0,00050	0,00004	0,00044	0,00009	2,55
1000	0,1	0,00010	0,00038	0,00079	0,00009	0,00074	0,00010	3,17
1000	0,3	0,00013	0,00071	0,00098	0,00022	0,00096	0,00013	1,11
1000	1	0,00024	0,00191	0,00109	0,00083	0,00109	0,00024	0,02
1000	3	0,00076	0,00537	0,00118	0,00160	0,00119	0,00075	0,01
1000	10	0,00243	0,01750	0,00183	0,00252	0,00184	0,00241	0,00
1000	30	0,00751	0,05214	0,00310	-0,00860	0,00286	0,00743	0,05
1000	100	0,02425	0,17339	0,01376	-0,13502	0,01091	0,02402	0,72
20000	0,003	0,00033	0,00022	0,00040	0,00045	0,00043	0,00018	0,02
20000	0,01	0,00034	0,00023	0,00063	0,00009	0,00026	0,00019	1,73
20000	0,03	0,00033	0,00027	0,00068	-0,00001	0,00027	0,00021	2,62
20000	0,1	0,00033	0,00037	0,00063	0,00006	0,00038	0,00025	1,32
20000	0,3	0,00036	0,00070	0,00063	0,00035	0,00057	0,00032	0,13
20000	1	0,00041	0,00191	0,00064	0,00150	0,00068	0,00040	0,19
20000	3	0,00087	0,00537	0,00079	0,00403	0,00087	0,00086	0,35
20000	10	0,00243	0,01750	0,00118	0,01160	0,00138	0,00241	0,35
20000	30	0,00751	0,05216	0,00224	0,02562	0,00271	0,00743	0,20
20000	100	0,02425	0,17346	0,01007	0,06018	0,01103	0,02402	0,08
100000	0,003	0,00033	0,00038	0,00121	0,00116	0,00119	0,00025	0,01
100000	0,01	0,00033	0,00040	0,00051	0,00093	0,00068	0,00025	0,66
100000	0,03	0,00034	0,00045	0,00032	0,00083	0,00051	0,00027	0,82
100000	0,1	0,00034	0,00065	0,00022	0,00085	0,00036	0,00030	0,74
100000	0,3	0,00035	0,00122	0,00019	0,00092	0,00025	0,00034	0,33
100000	1	0,00041	0,00324	0,00008	0,00110	0,00010	0,00041	0,10
100000	3	0,00087	0,00901	-0,00021	0,00148	-0,00019	0,00087	0,03
100000	10	0,00243	0,02922	-0,00133	-0,00150	-0,00133	0,00242	0,00

f, Hz	Kg, %	$u_{GET}(f, Kg)$, %	$u_{NET}(f, Kg)$, %	$\Delta_{GET}(f, Kg)$, %	$\Delta_{NET}(f, Kg)$, %	$\Delta_{ref}(f, Kg)$, %	$u_{ref}(f, Kg)$, %	χ^2
100000	30	0,00751	0,08696	-0,00399	-0,02205	-0,00412	0,00748	0,04
100000	100	0,02425	0,28903	-0,00911	-0,22703	-0,01063	0,02417	0,56
200000	0,003	0,00049	0,00040	0,00048	0,00100	0,00079	0,00031	0,68
200000	0,01	0,00049	0,00042	0,00024	0,00075	0,00053	0,00032	0,62
200000	0,03	0,00049	0,00046	0,00024	0,00072	0,00050	0,00034	0,51
200000	0,1	0,00049	0,00071	0,00000	0,00073	0,00024	0,00040	0,72
200000	0,3	0,00050	0,00139	-0,00013	0,00073	-0,00003	0,00047	0,34
200000	1	0,00055	0,00381	-0,00079	0,00062	-0,00076	0,00054	0,13
200000	3	0,00099	0,01074	-0,00276	0,00054	-0,00273	0,00099	0,09
200000	10	0,00248	0,03499	-0,00995	-0,00547	-0,00993	0,00247	0,02
200000	30	0,00751	0,10427	-0,02953	-0,02238	-0,02949	0,00749	0,00
200000	100	0,02426	0,34676	-0,09554	-0,16045	-0,09586	0,02420	0,03