Comparisons of total power loss measurements performed by an SST using revised measurement procedures at room temperature

Final report

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Table of contents

1 Introduction

Two experimental setups are currently used for the measurement of power losses in magnetic steels – the Epstein frame and the Single Sheet Tester (SST). To date, a number of intercomparisons, promoted by EURAMET and the IEC TC 68 have confirmed good reproducibility for both the Epstein and SST methods, with an uncertainty around 1 % for the power loss measurement. These comparisons, however, were only focused on measurements at 50 Hz and room temperature [1].

Within the HEFMAG project a new reference round robin comparison was performed between Epstein frames and SST at 50 Hz and 100 Hz using non-oriented and grain-oriented samples. In addition, a new Epstein round robin comparison up to higher frequencies of 10 kHz using non-oriented and $Fe_{50}Co_{50}$ sheets was performed.

As an output of the round robin test a number of documents will be drafted in parallel to the conductance of the measurements. At all stages of the round robin test these documents shall reflect the current state of knowledge:

1. Report of measurement results: This document contains the results of measurements and their accuracy for each method and each laboratory and a discussion of the findings during the round robin comparison. This report will be shared through a report to IEC TC 68 and made available to the stakeholders.
2. A Good practice guide on the measurement of power losses in non-oriented steels and grain-oriented materials using standard measurement setups at room temperature will be developed for end users This document will provide the basis for discussions on CMC revisions and updates of some of the IEC 60404 standards within the IEC TC 68.

2 Reference samples

The aim of this comparison was to evaluate and reduce the uncertainty of SST loss measurements up to 100 Hz according to IEC 60404-3 and to provide new data concerning the behaviour of SST. The comparison was conducted using SST circuits made for standard samples with dimensions 500 mm × 500 mm.

Five SST samples were prepared for the comparison. The transfer standards are samples of grain-oriented (GO) and non-oriented (NO) electrical steel:

- two samples of NO steel sheets with dimensions 500×500 mm and a thickness of approximately 0.2 mm (NO 0.2) and 0.3 mm (NO 0.3). These samples were used for measurements at frequencies up to 100 Hz;
- three samples of GO steel sheets with dimensions 500×500 mm and a thickness of approximately 0.18 mm (GO 0.18), 0.2 mm (Laser Scribed 0.2) and 0.3 mm (GO 0.3). These samples were used for measurement from 50 Hz to 100 Hz.

All samples were demagnetized prior to measurement.

3 Measurements to be made

3.1 *Quantity to be measured*

Measurements of specific total power loss P_s (W/kg) of the SST samples were performed according to standard IEC 60404-3 (up to 100 Hz) using optimized experimental SST setups for power loss measurements under standard conditions.

The magnetic polarization J_m was measured at H_m = 800 A/m in the GO sheets and at H_m = 2500 A/m in the NO sheets at 50 Hz.

4 Organisation

4.1 *Pilot Laboratory*

Pilot laboratory:

Czech Metrology Institute
Laboratory of Electromagnetic Quantities
Michal Ulvr
V Botanice 4, CZ-15072 Prague
Czech Republic
Phone: +420 734 522 098
E-mail: mulvr@cmi.cz

4.2 *Participants*

The following national metrology institutes (NMIs) participated the comparison:

Acronym	Laboratory	Country	Contact
INRIM	Istituto Nazionale di Ricerca Metrologica	Italy	Massimo Pasquale m.pasquale@inrim.it Carlo Appino c.appino@inrim.it
PTB	Physikalisch-Technische Bundesanstalt	Germany	Franziska Weickert franziska.weickert@ptb.de Korbinian Pfnuer korbinian.pfnuer@ptb.de
NPL	National Physical Laboratory	United Kingdom	Stuart Harmon stuart.harmon@npl.co.uk Daniel Brunt daniel.brunt@npl.co.uk

4.3 *Comparison schedule*

The comparison was carried out by a circulation scheme. The organization of the comparison follows: 1. INRIM, 2. PTB, 3. NPL and then the samples were returned to INRIM.

Each participant covered the freight charges from his location to the next one in the list. Each participant was responsible for insurance of the samples from arrival in their laboratory until arrival in the subsequent laboratory.

The transport of the travelling standards was arranged by door-to-door parcel service.

5 Measurement instructions

5.1 *Measurements of the samples*

Each participant performed the following measurements using their standard equipment and measurement procedure. The specific total losses were measured stepwise from the lowest to the highest peak polarization value J_m given below at given frequencies. The measuring temperature was 23 ± 1 °C. If not, an appropriate correcting of the coefficient was applied.

Parameters for the SST NO samples	
frequency (Hz)	**specific total power loss at J_m**
50	1 T, 1.5 T
100	1 T, 1.5 T

Parameters for the SST GO samples	
frequency (Hz)	**specific total power loss at J_m**
50	1 T, 1.5 T, 1.7 T, 1.8
100	1 T, 1.5 T, 1.7 T, 1.8 T

6 Measurement results

6.1 *Calculation of the reference value and its uncertainty*

For all measurements of total losses and $J_m(H_m)$ measurements, the evaluation of this comparison was performed following procedure B in [2]. The Mandel-Paule (M-P) mean [3] was chosen for the analysis of the data. On its basis the following characteristics were calculated:

- the modified reduced observed chi-squared value by the formula:

$$\tilde{\chi}_{obs} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\frac{(x_i - x_{ref})^2}{u_i^2 + s^2}} \quad (1)$$

where N is the number of participants, x_i is the results of the total losses of the i-th participant of the comparisons and u_i is the declared standard uncertainty of the i-th participant of the comparison for coverage factor k = 1 (68%). The value of the unexplained variance s^2 is chosen such that chi-squared value < 1.

- the reference value of total losses x_{ref} by the formula:

$$\boldsymbol{x_{ref} = u^2(x_{ref}) \sum_{i=1}^{N} \frac{x_i}{u_i^2+s^2}} \tag{2}$$

- standard uncertainty of the reference value of total losses $u(x_{\mathrm{ref}})$ by the formula:

$$\boldsymbol{u(x_{ref}) = \left[\sum_{i=1}^{N} \frac{1}{u_i^2+s^2}\right]^{-1/2}} \tag{3}$$

- the degree of equivalence of the measurement standard d_i by the formula (4) with a corresponding uncertainty by the formulas (5), (6):

$$d_i = x_i - x_{ref} \tag{4}$$

$$u(d_i) = \sqrt{u^2(x_i) + u^2(x_{ref})} \tag{5}$$

$$E_n = \frac{|d_i|}{2u(d_i)}, \tag{6}$$

where d_i is degree of equivalence and $u(d_i)$ is the standard uncertainty of the degree of equivalence.

The declared uncertainties are judged as confirmed if equation $E_n < 1$ is satisfied, that is a confirmation of the relevant rows from CMC.

6.2 *Evaluation of comparison results*

Parameters of measured samples:

Sample	**Density (kg/m^3)**	**Cross section (mm^2)**	**Weight (kg)**	**Length L (m)**	**Width W (m)**
Laser scribed GO 0.2	7650	93.571	0.35793	0.50003	×
GO 0.18	7650	87.823	0.33587	0.49992	×
NO 0.3	7600	147.28 (L)/147.17 (W)	0.5592	0.49959	0.49995
GO 0.3	7650	144.11	0.55161	0.50036	×
NO 0.2	7650	97.397 (L)/97.413 (W)	0.37244	0.49986	0.49978

6.2.1 Total losses results

Losses (longitudinal direction)	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	0.7381	0.20	0.7343	0.29	0.736	0.85	0.7367	0.0013	0.0014	-0.0024	-0.0007	0.004	0.005	0.013	**0.347**	**0.484**	**0.057**
$P_{1,5/50}$	1.935	0.20	1.9329	0.32	1.978	1.00	1.943	0.013	-0.0083	-0.0104	0.0347	0.027	0.029	0.047	**0.308**	**0.363**	**0.733**
$P_{1,0/100}$	1.776	0.20	1.7633	0.27	1.761	0.85	1.7694	0.0049	0.0066	-0.0061	-0.0084	0.012	0.014	0.032	**0.546**	**0.445**	**0.266**
$P_{1,5/100}$	4.536	0.20	4.534	0.33	4.736	1.00	4.60	0.066	-0.0592	-0.0612	0.1408	0.132	0.134	0.162	**0.447**	**0.455**	**0.871**

Losses (transversal direction)	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	1.079	0.28	1.084	0.27	1.076	0.85	1.0813	0.0022	-0.0023	0.0027	-0.0053	0.007	0.007	0.019	**0.305**	**0.376**	**0.280**
$P_{1,5/50}$	2.443	0.28	2.463	0.34	2.487	1.00	2.458	0.011	-0.0145	0.0055	0.0295	0.026	0.028	0.054	**0.561**	**0.198**	**0.542**
$P_{1,0/100}$	2.485	0.28	2.5041	0.26	2.467	0.85	2.491	0.010	-0.0055	0.0136	-0.0235	0.024	0.023	0.046	**0.234**	**0.587**	**0.511**
$P_{1,5/100}$	5.640	0.28	5.735	0.34	5.820	1.00	5.72	0.053	-0.0819	0.0131	0.0981	0.110	0.112	0.157	**0.744**	**0.116**	**0.624**

Results of the NO 0.3 sample

Losses (longitudinal direction)	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			$\boldsymbol{E_n}$		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	0.757	0.20	0.7586	0.29	0.759	0.85	0.7576	0.0012	-0.0006	0.0010	0.0014	0.004	0.005	0.013	**0.146**	**0.205**	**0.109**
$P_{1,5/50}$	2.016	0.33	2.0182	0.32	2.020	1.30	2.017	0.0050	-0.0012	0.0010	0.0028	0.016	0.016	0.053	**0.076**	**0.062**	**0.052**
$P_{1,0/100}$	1.695	0.20	1.6976	0.27	1.689	0.85	1.6957	0.0027	-0.0007	0.0019	-0.0067	0.009	0.011	0.029	**0.079**	**0.181**	**0.229**
$P_{1,5/100}$	4.419	0.20	4.455	0.33	4.554	1.00	4.467	0.040	-0.0479	-0.0119	0.0871	0.082	0.086	0.122	**0.581**	**0.139**	**0.716**

Losses (transversal direction)	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			$\boldsymbol{E_n}$		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	1.152	0.28	1.158	0.27	1.141	1.35	1.1545	0.0030	-0.0025	0.0035	-0.0135	0.009	0.009	0.031	**0.285**	**0.399**	**0.431**
$P_{1,5/50}$	2.533	0.43	2.5513	0.34	2.546	1.00	2.544	0.0070	-0.0112	0.0071	0.0018	0.026	0.022	0.053	**0.440**	**0.322**	**0.033**
$P_{1,0/100}$	2.507	0.28	2.5286	0.26	2.471	0.85	2.507	0.016	0.0004	0.0220	-0.0356	0.035	0.035	0.053	**0.011**	**0.636**	**0.675**
$P_{1,5/100}$	5.527	0.30	5.629	0.34	5.645	1.00	5.593	0.039	-0.0656	0.0364	0.0524	0.085	0.087	0.137	**0.773**	**0.420**	**0.382**

Results of the NO 0.2 sample

Losses	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			$\boldsymbol{E_n}$		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	0.2010	0.20	0.2023	0.29	0.201	0.65	0.2015	0.00050	-0.0005	0.0008	-0.0005	0.001	0.001	0.003	**0.385**	**0.552**	**0.171**
$P_{1,5/50}$	0.4915	0.20	0.4906	0.30	0.486	0.60	0.490	0.0010	0.0013	0.0004	-0.0042	0.003	0.004	0.006	**0.365**	**0.086**	**0.657**
$P_{1,7/50}$	0.693	0.28	0.6916	0.34	0.680	0.75	0.689	0.0039	0.0037	0.0023	-0.0093	0.009	0.009	0.013	**0.426**	**0.255**	**0.722**
$P_{1,8/50}$	0.884	0.38	0.8835	0.34	0.865	1.20	0.881	0.0050	0.0032	0.0027	-0.0158	0.012	0.012	0.023	**0.269**	**0.234**	**0.685**
$P_{1,0/100}$	0.5793	0.20	0.5822	0.29	0.576	0.65	0.5799	0.0015	-0.0006	0.0023	-0.0039	0.004	0.005	0.008	**0.170**	**0.498**	**0.489**
$P_{1,5/100}$	1.381	0.20	1.3784	0.29	1.357	0.60	1.374	0.0080	0.0074	0.0048	-0.0166	0.016	0.017	0.022	**0.461**	**0.282**	**0.748**
$P_{1,7/100}$	1.891	0.28	×	×	1.843	0.75	1.869	0.025	0.0225	×	-0.0255	0.051	×	0.057	**0.438**	×	**0.446**
$P_{1,8/100}$	2.337	0.38	×	×	2.276	1.20	2.312	0.031	0.0254	×	-0.0356	0.065	×	0.083	**0.391**	×	**0.428**

Results of the GO 0.18 sample

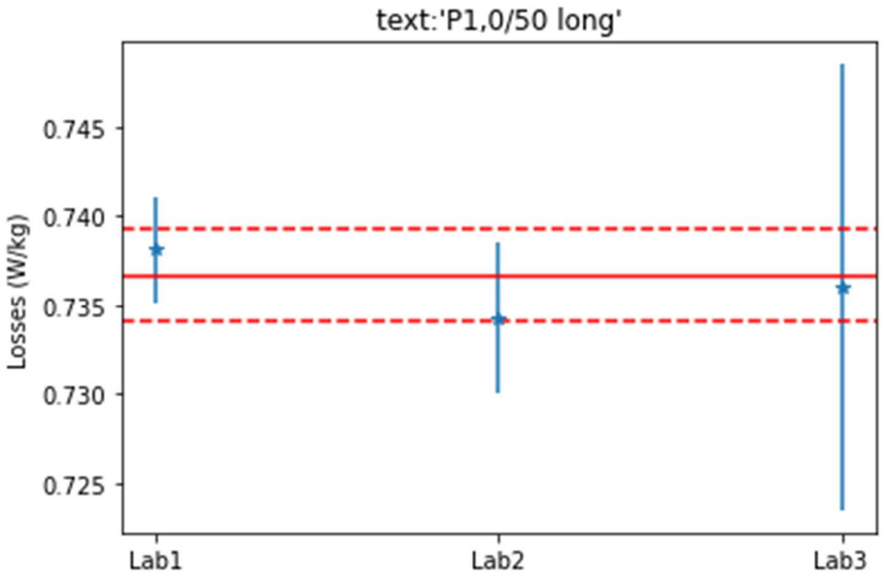
Losses	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			$\boldsymbol{E_n}$		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	0.3456	0.20	0.3417	0.29	0.342	0.65	0.3434	0.0014	0.0022	-0.0017	-0.0014	0.003	0.003	0.005	**0.722**	**0.500**	**0.266**
$P_{1,5/50}$	0.773	0.20	0.768	0.29	0.767	0.60	0.7702	0.0020	0.0028	-0.0022	-0.0036	0.005	0.006	0.010	**0.550**	**0.363**	**0.355**
$P_{1,7/50}$	1.043	0.28	1.0384	0.32	1.033	0.75	1.0402	0.0023	0.0028	-0.0018	-0.0075	0.007	0.008	0.016	**0.372**	**0.224**	**0.466**
$P_{1,8/50}$	1.285	0.38	1.2784	0.40	1.257	1.20	1.278	0.0070	0.0070	0.0004	-0.0214	0.017	0.017	0.033	**0.418**	**0.021**	**0.650**
$P_{1,0/100}$	1.054	0.20	1.0436	0.27	1.035	0.65	1.046	0.0054	0.0085	-0.0019	-0.0102	0.012	0.012	0.017	**0.730**	**0.156**	**0.591**
$P_{1,5/100}$	2.332	0.20	2.3069	0.29	×	×	2.320	0.013	0.0121	-0.0130	×	0.027	0.029	×	**0.448**	**0.453**	×

Results of the GO 0.3 sample

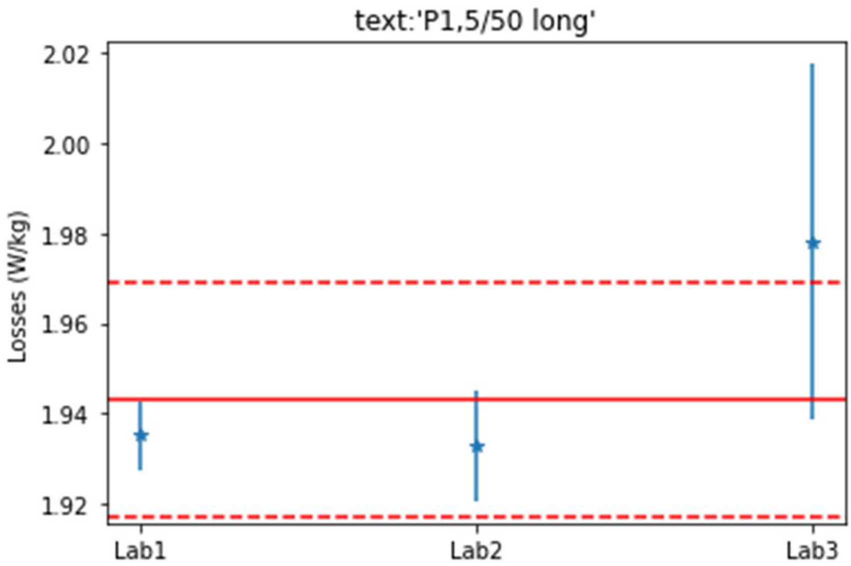
Losses	Lab1		Lab2		Lab3		x_{ref} (W/kg)	$u(x_{ref})$ (W/kg)	d_i			$u(d_i)$			E_n		
	X	u_{x}, %	X	u_{x}, %	X	u_{x}, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
$P_{1,0/50}$	0.2246	0.20	0.22465	0.30	0.224	0.65	0.2246	0.00040	0.0000	0.0001	-0.0010	0.001	0.002	0.003	**0.043**	**0.065**	**0.328**
$P_{1,5/50}$	0.5349	0.20	0.5359	0.32	0.529	0.60	0.5339	0.0020	0.0010	0.0020	-0.0051	0.005	0.005	0.008	**0.220**	**0.377**	**0.680**
$P_{1,7/50}$	0.754	0.28	0.7552	0.34	0.742	0.75	0.7516	0.0040	0.0024	0.0036	-0.0097	0.009	0.009	0.014	**0.267**	**0.381**	**0.706**
$P_{1,8/50}$	0.955	0.38	0.9564	0.46	0.936	1.20	0.953	0.0050	0.0024	0.0038	-0.0163	0.013	0.014	0.025	**0.186**	**0.275**	**0.658**
$P_{1,0/100}$	0.6632	0.20	0.6608	0.30	0.656	0.65	0.6611	0.0019	0.0021	-0.0003	-0.0055	0.005	0.006	0.009	**0.439**	**0.060**	**0.587**
$P_{1,5/100}$	1.544	0.20	1.5356	0.29	1.513	0.60	1.532	0.0090	0.0117	0.0033	-0.0194	0.020	0.021	0.026	**0.597**	**0.159**	**0.747**
$P_{1,7/100}$	2.099	0.28	×	×	2.045	0.75	2.074	0.029	0.0254	×	-0.0285	0.060	×	0.066	**0.423**	×	**0.430**
$P_{1,8/100}$	2.566	0.38	×	×	2.505	1.20	2.541	0.032	0.0246	×	-0.0364	0.067	×	0.088	**0.370**	×	**0.416**

Results of the Laser scribed GO 0.2 sample

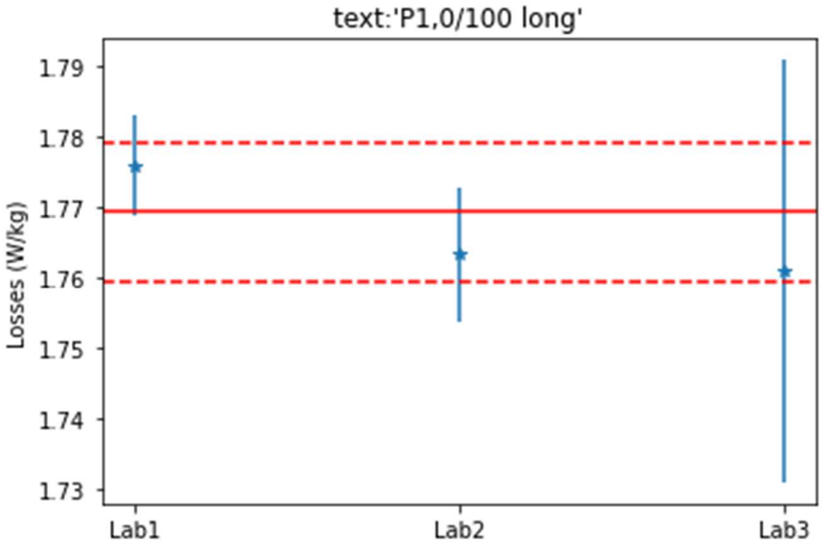
NO 0.3 sample

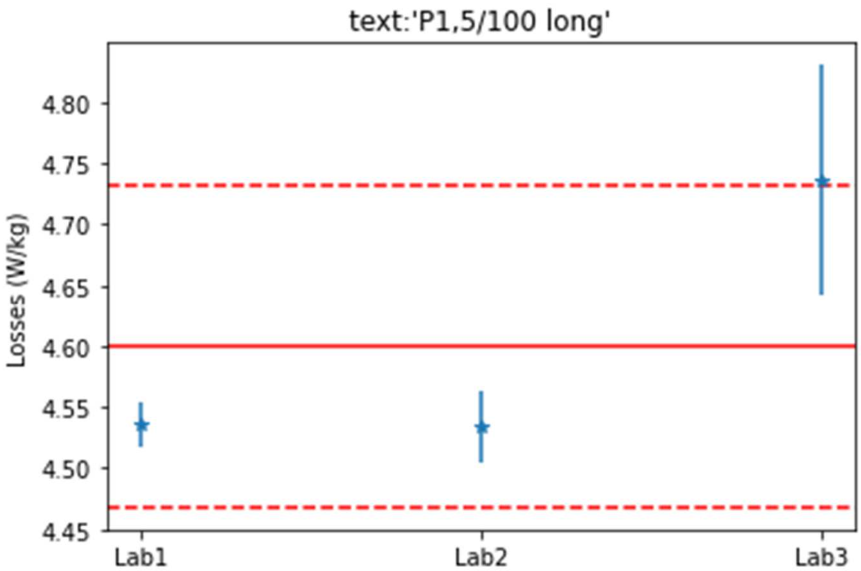


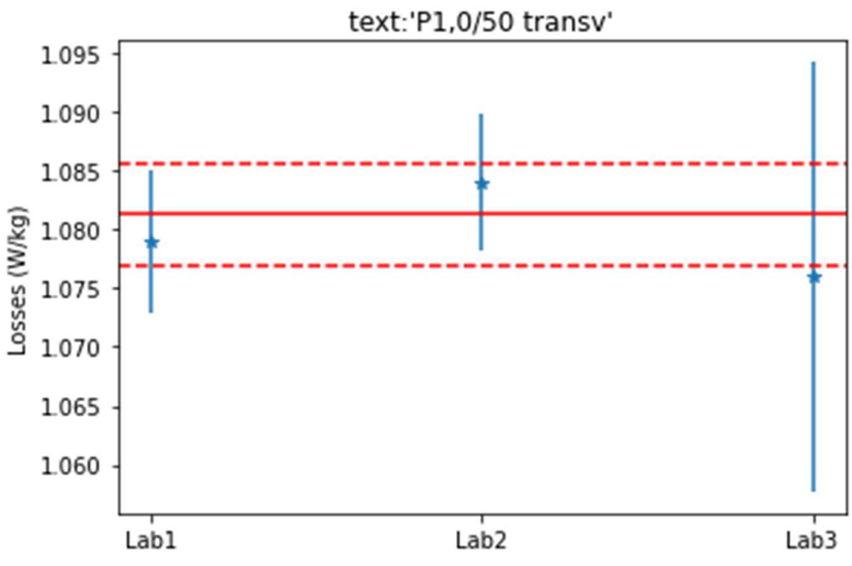
text:'P1,0/50 long'
Losses (W/kg)
0.745
0.740
0.735
0.730
0.725
Lab1
Lab2
Lab3

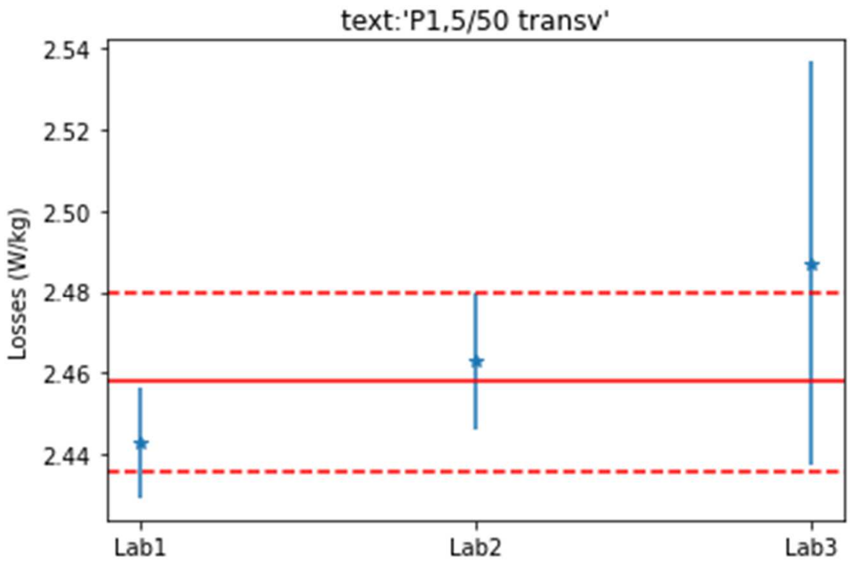


text:'P1,5/50 long'
Losses (W/kg)
2.02
2.00
1.98
1.96
1.94
1.92
Lab1
Lab2
Lab3

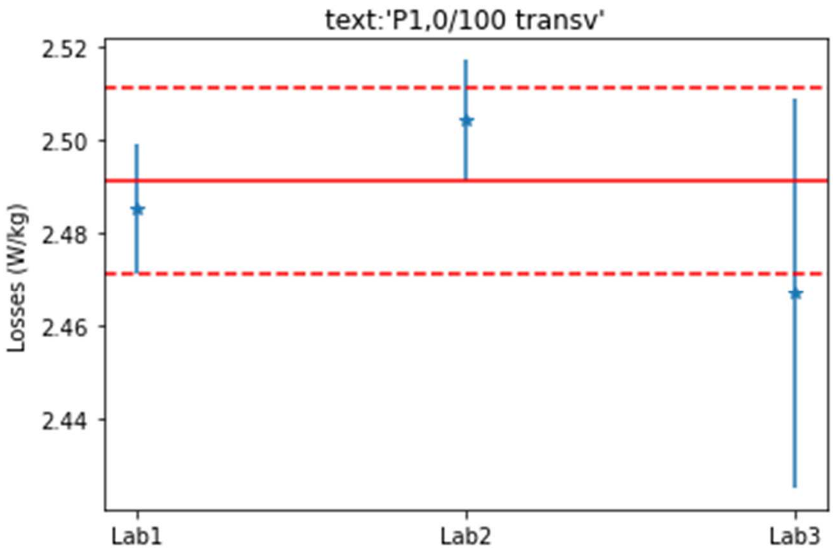

text:'P1,0/100 long'
Losses (W/kg)
1.79
1.78
1.77
1.76
1.75
1.74
1.73
Lab1
Lab2
Lab3


text:'P1,5/100 long'
Losses (W/kg)
4.80
4.75
4.70
4.65
4.60
4.55
4.50
4.45
Lab1
Lab2
Lab3

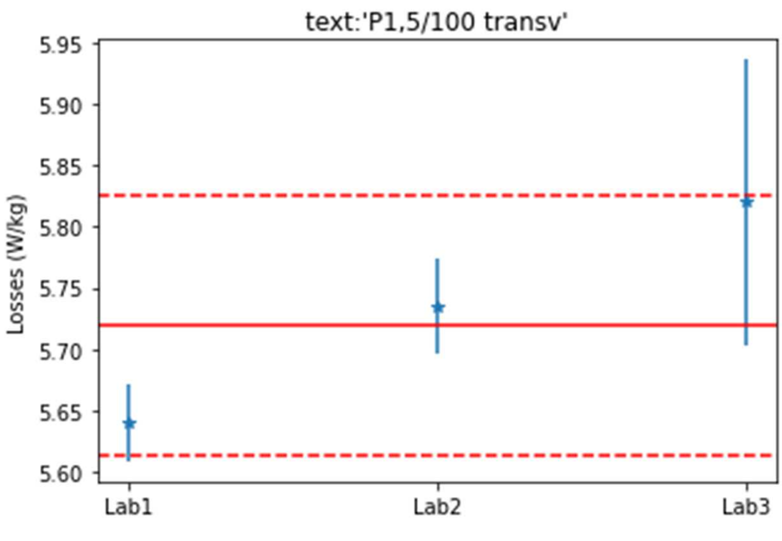

text:'P1,0/50 transv'
Losses (W/kg)
1.095
1.090
1.085
1.080
1.075
1.070
1.065
1.060
Lab1
Lab2
Lab3



text:'P1,5/50 transv'
Losses (W/kg)
2.54
2.52
2.50
2.48
2.46
2.44
Lab1
Lab2
Lab3

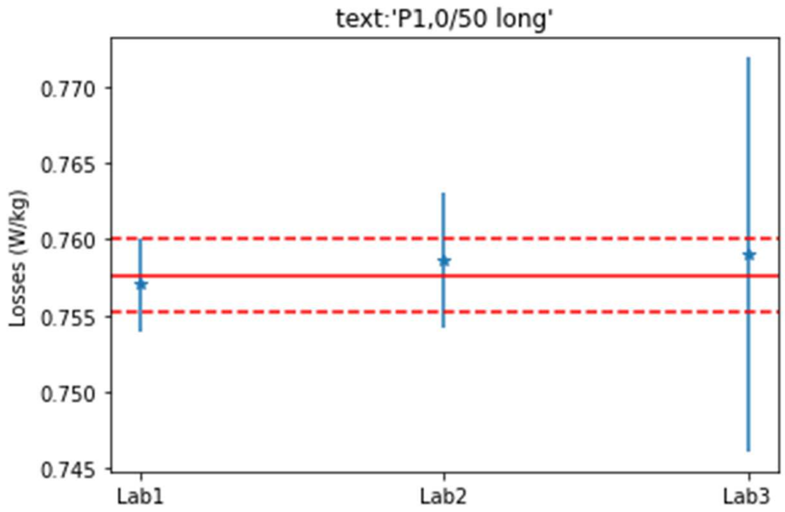


text:'P1,0/100 transv'
Losses (W/kg)
2.52
2.50
2.48
2.46
2.44
Lab1
Lab2
Lab3

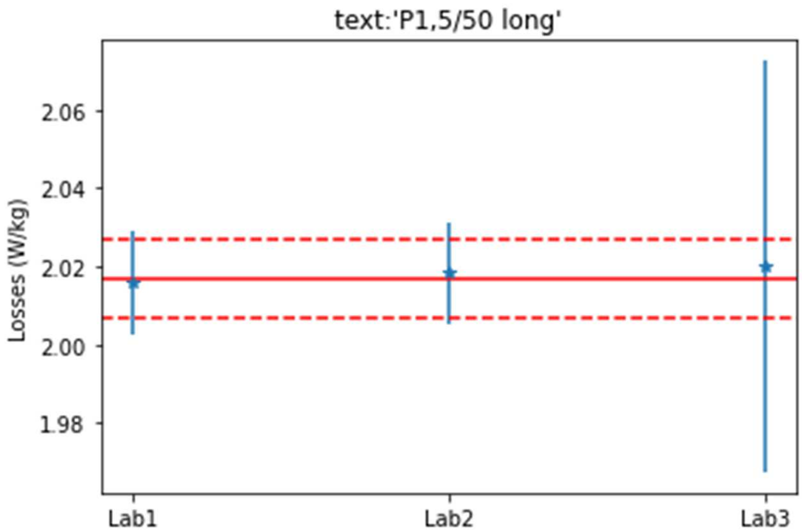


text:'P1,5/100 transv'
Losses (W/kg)
5.95
5.90
5.85
5.80
5.75
5.70
5.65
5.60
Lab1
Lab2
Lab3

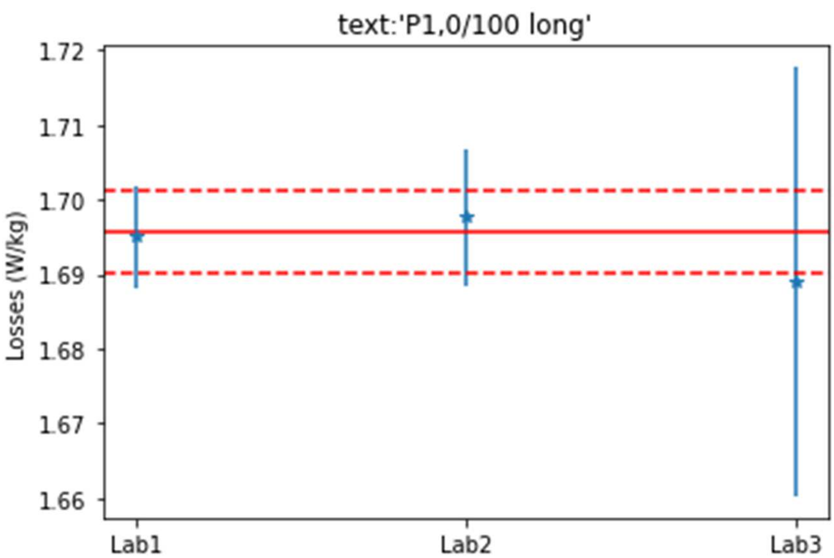
NO 0.2 sample



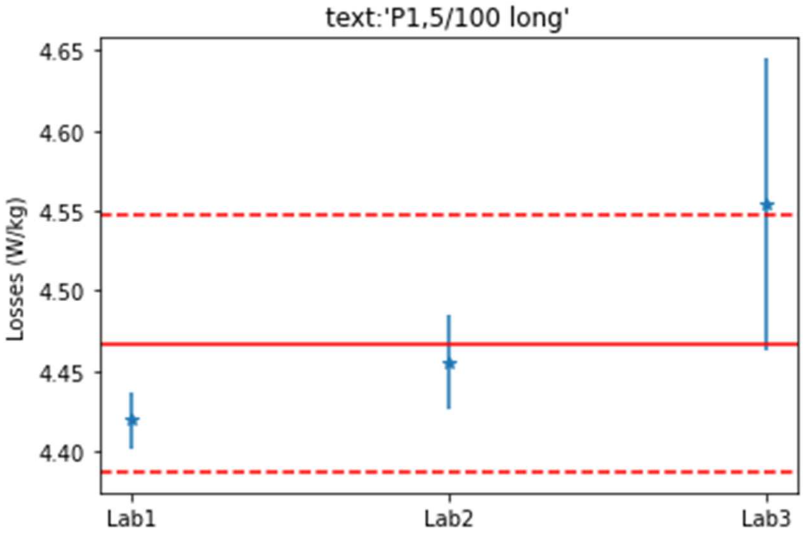
text:'P1,0/50 long'
Losses (W/kg)
0.770
0.765
0.760
0.755
0.750
0.745
Lab1
Lab2
Lab3

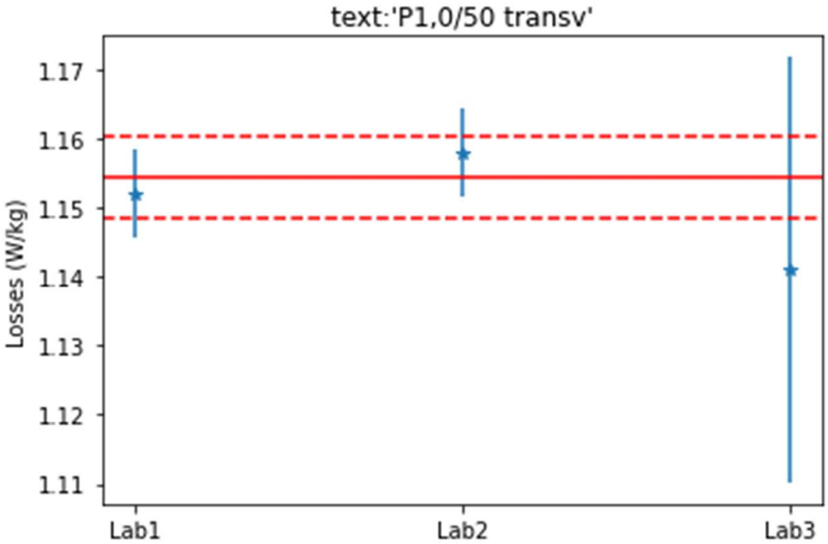


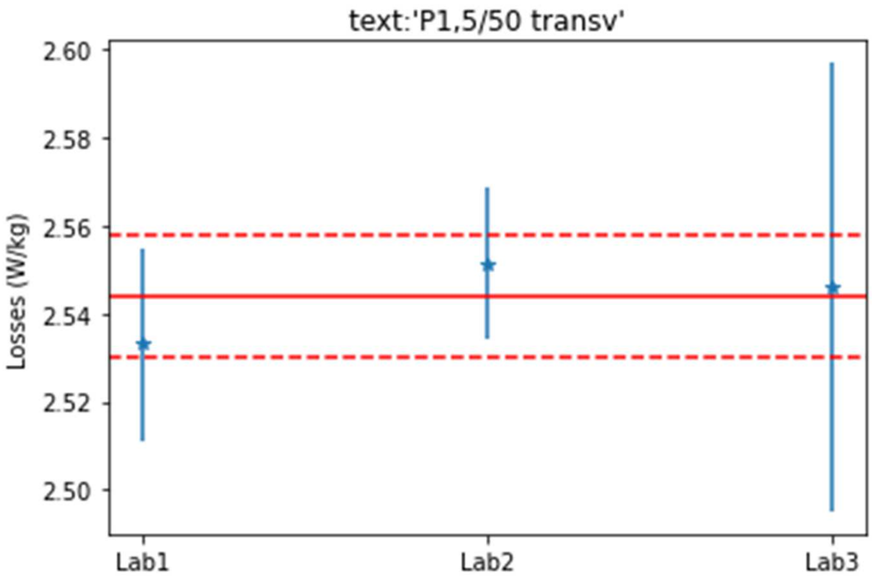
text:'P1,5/50 long'
Losses (W/kg)
2.06
2.04
2.02
2.00
1.98
Lab1
Lab2
Lab3

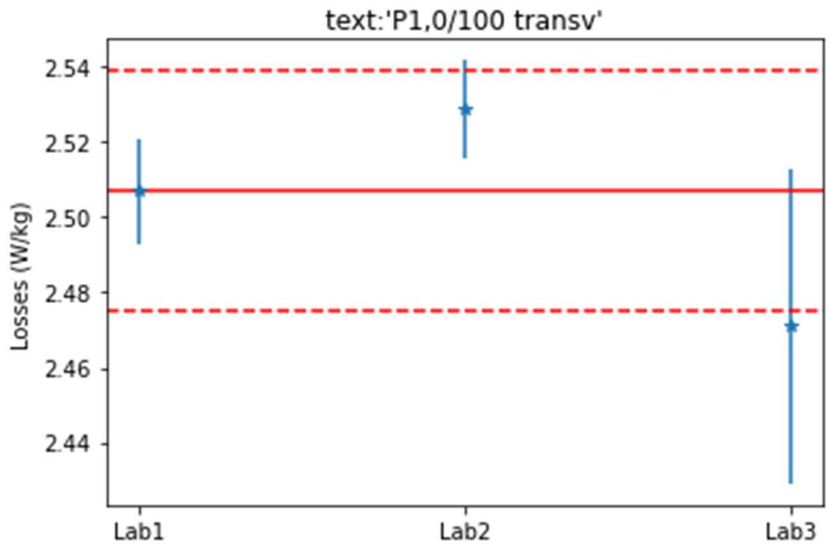


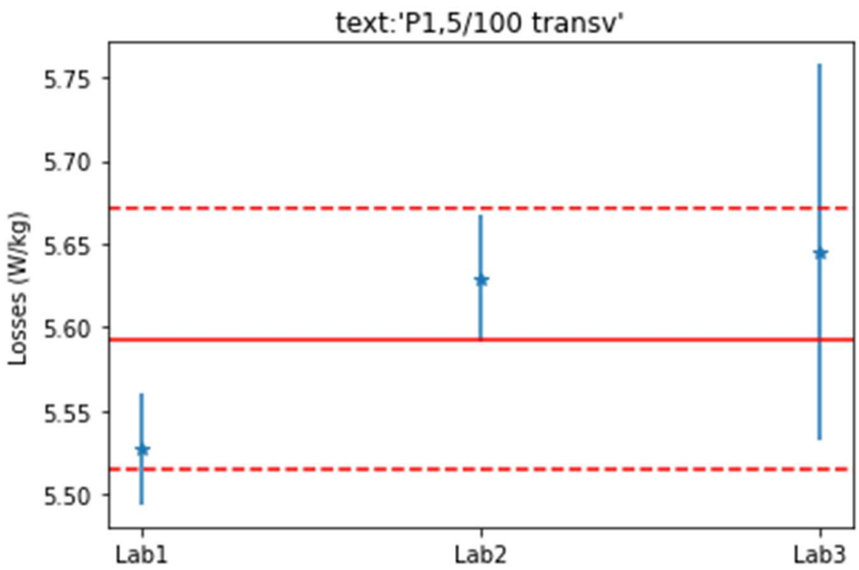
text:'P1,0/100 long'
Losses (W/kg)
1.72
1.71
1.70
1.69
1.68
1.67
1.66
Lab1
Lab2
Lab3


text:'P1,5/100 long'
Losses (W/kg)
4.65
4.60
4.55
4.50
4.45
4.40
Lab1
Lab2
Lab3

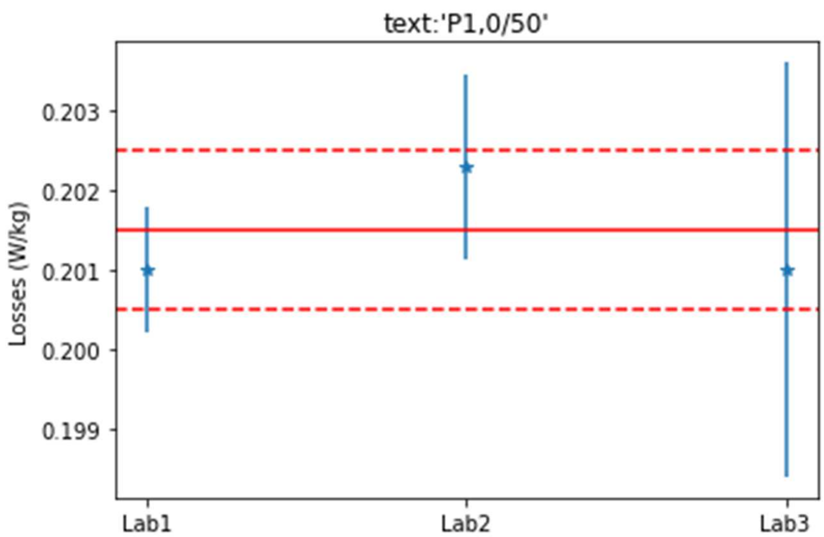

text:'P1,0/50 transv'
Losses (W/kg)
1.17
1.16
1.15
1.14
1.13
1.12
1.11
Lab1
Lab2
Lab3

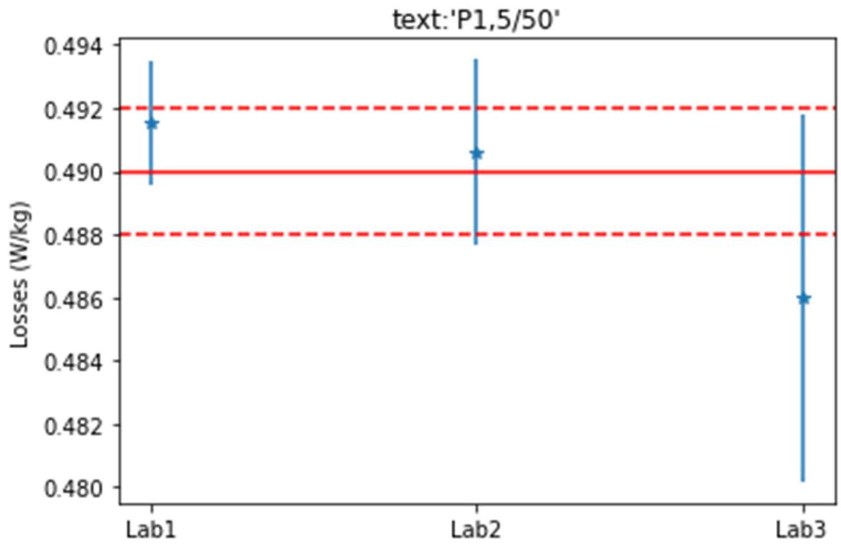

text:'P1,5/50 transv'
Losses (W/kg)
2.60
2.58
2.56
2.54
2.52
2.50
Lab1
Lab2
Lab3

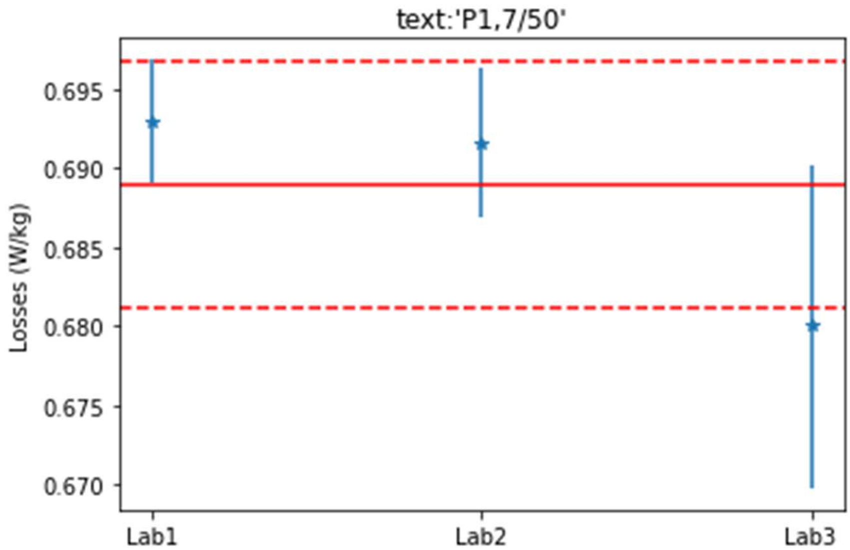


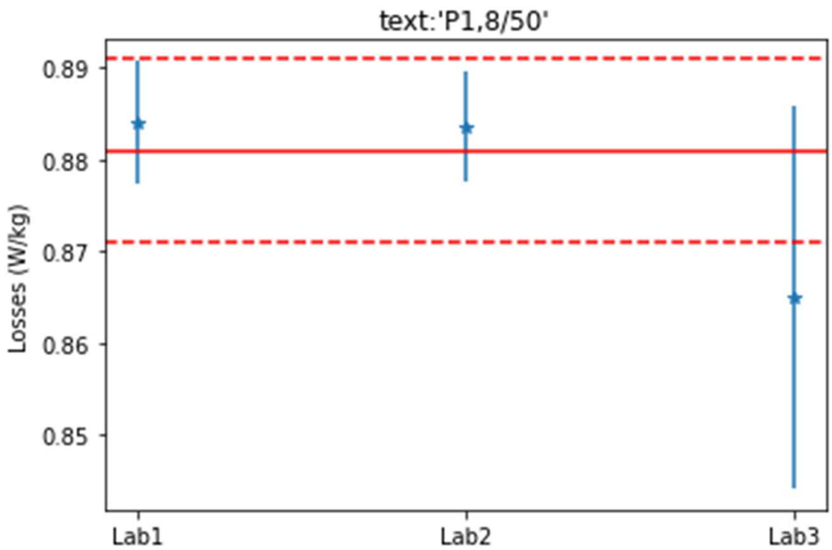


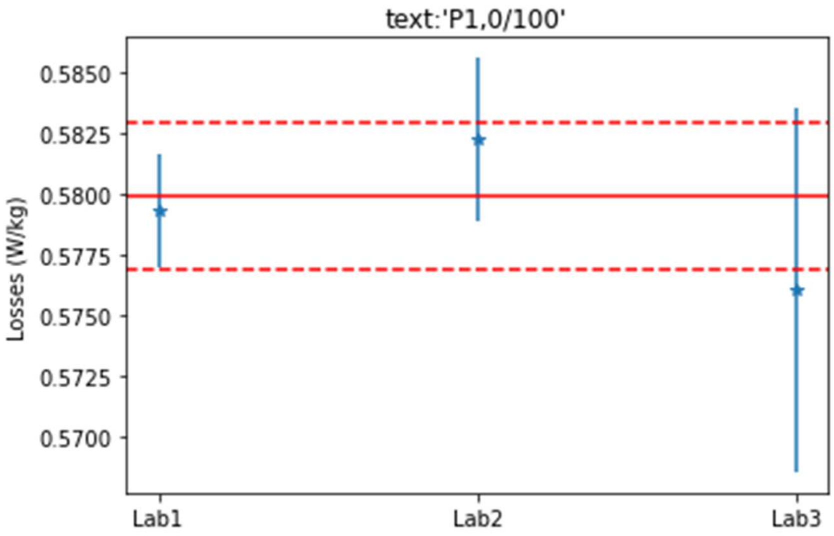
GO 0.18 sample

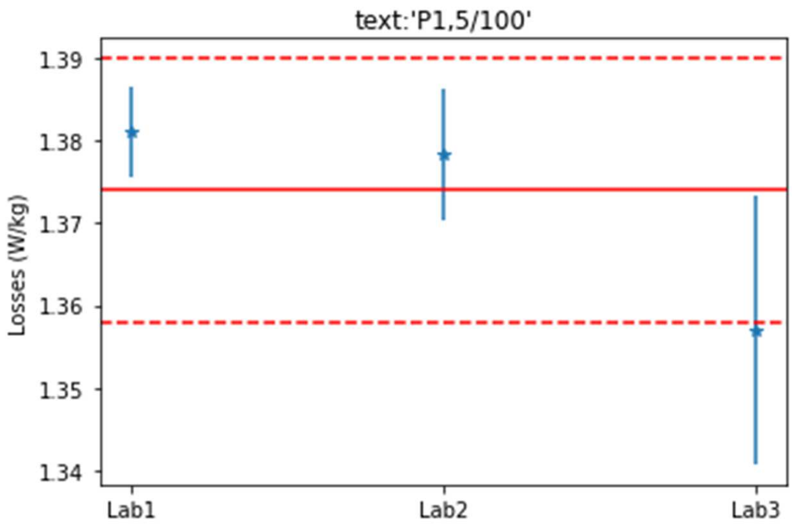


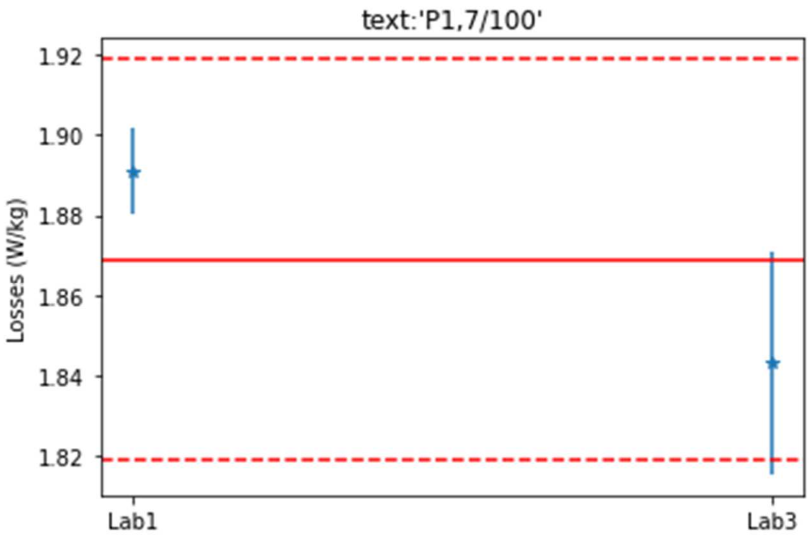

text:'P1,5/50'
Losses (W/kg)
0.494
0.492
0.490
0.488
0.486
0.484
0.482
0.480
Lab1
Lab2
Lab3

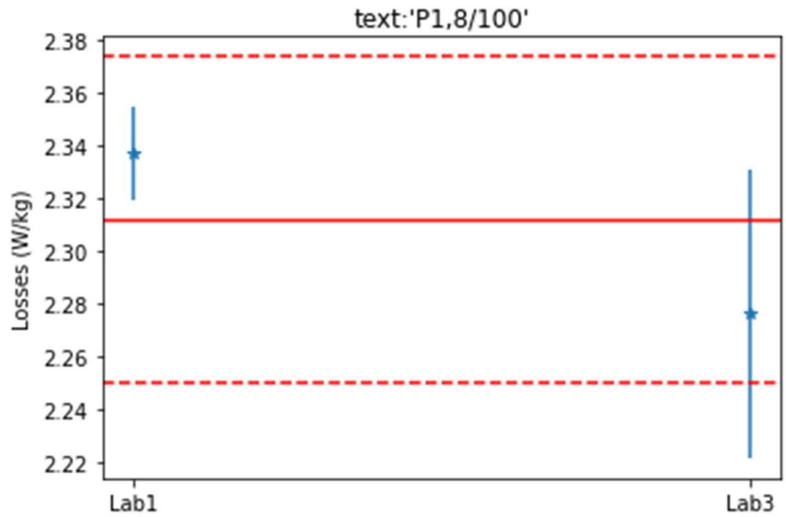

text:'P1,7/50'
Losses (W/kg)
0.695
0.690
0.685
0.680
0.675
0.670
Lab1
Lab2
Lab3


text:'P1,8/50'
Losses (W/kg)
0.89
0.88
0.87
0.86
0.85
Lab1
Lab2
Lab3

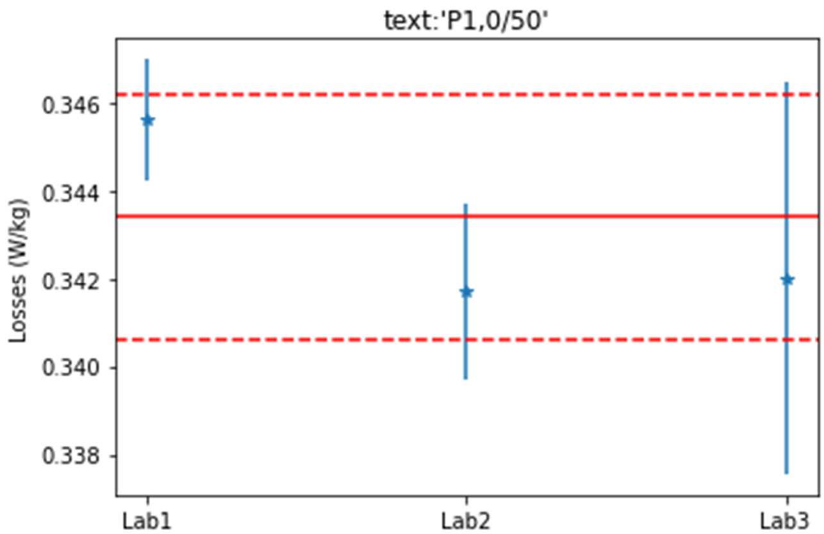

text:'P1,0/100'
Losses (W/kg)
0.5850
0.5825
0.5800
0.5775
0.5750
0.5725
0.5700
Lab1
Lab2
Lab3

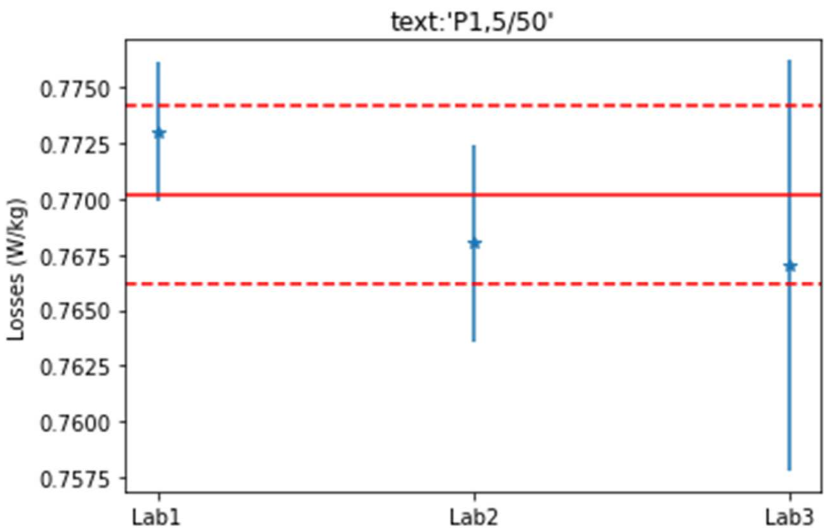

text:'P1,5/100'
Losses (W/kg)
1.39
1.38
1.37
1.36
1.35
1.34
Lab1
Lab2
Lab3

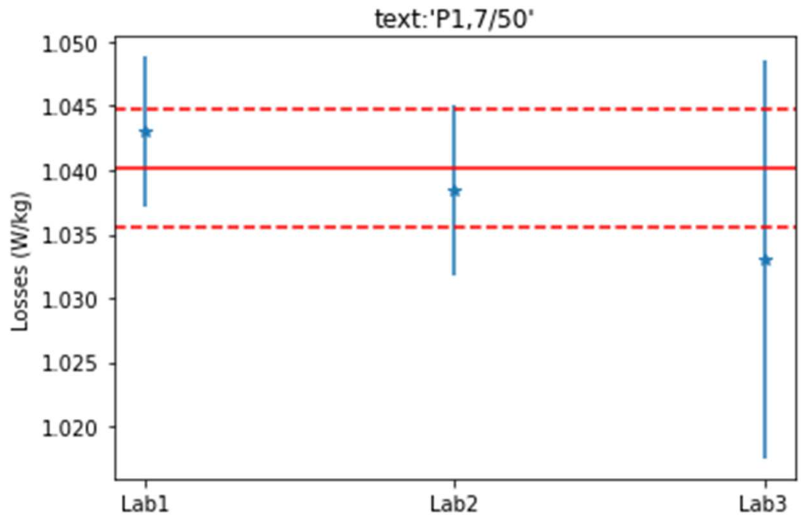

text:'P1,7/100'
Losses (W/kg)
1.92
1.90
1.88
1.86
1.84
1.82
Lab1
Lab3


text:'P1,8/100'
Losses (W/kg)
2.38
2.36
2.34
2.32
2.30
2.28
2.26
2.24
2.22
Lab1
Lab3

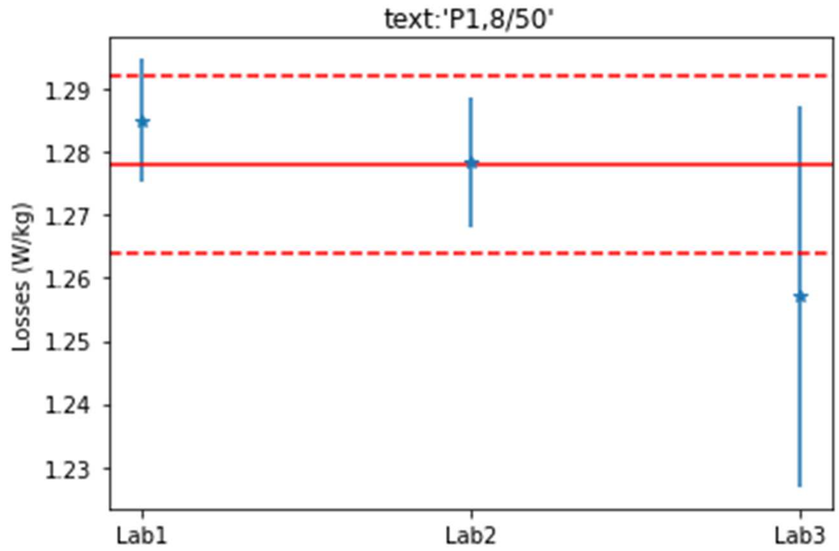
GO 0.3 sample


text:'P1,0/50'
Losses (W/kg)
0.346
0.344
0.342
0.340
0.338
Lab1
Lab2
Lab3

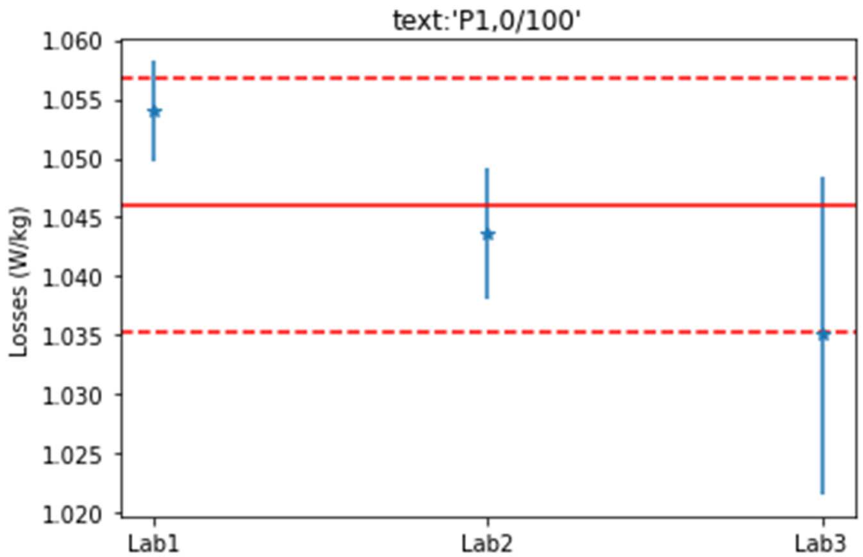

text:'P1,5/50'
Losses (W/kg)
0.7750
0.7725
0.7700
0.7675
0.7650
0.7625
0.7600
0.7575
Lab1
Lab2
Lab3



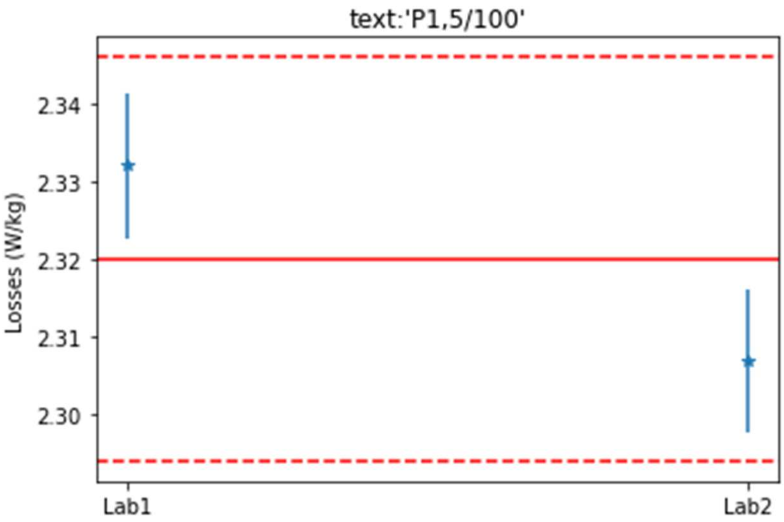
text:'P1,7/50'
Losses (W/kg)
1.050
1.045
1.040
1.035
1.030
1.025
1.020
Lab1
Lab2
Lab3



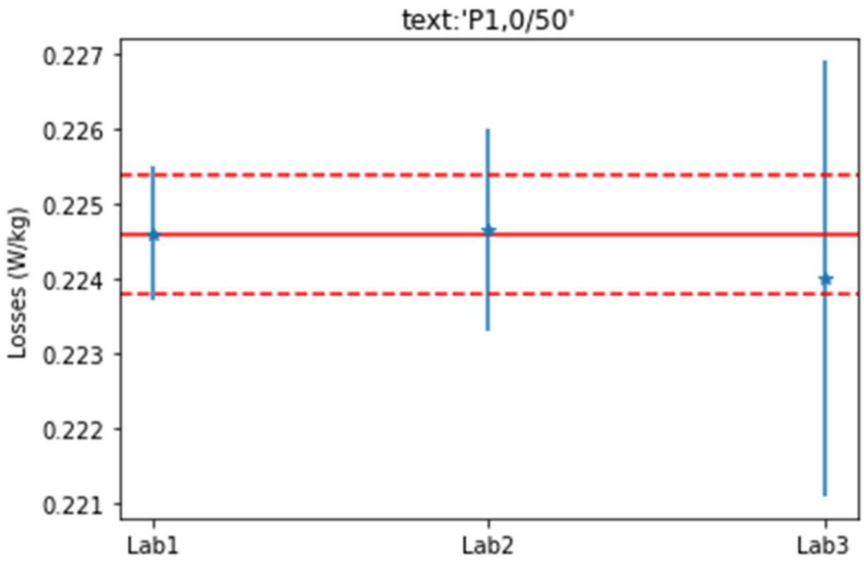
text:'P1,8/50'
Losses (W/kg)
1.29
1.28
1.27
1.26
1.25
1.24
1.23
Lab1
Lab2
Lab3

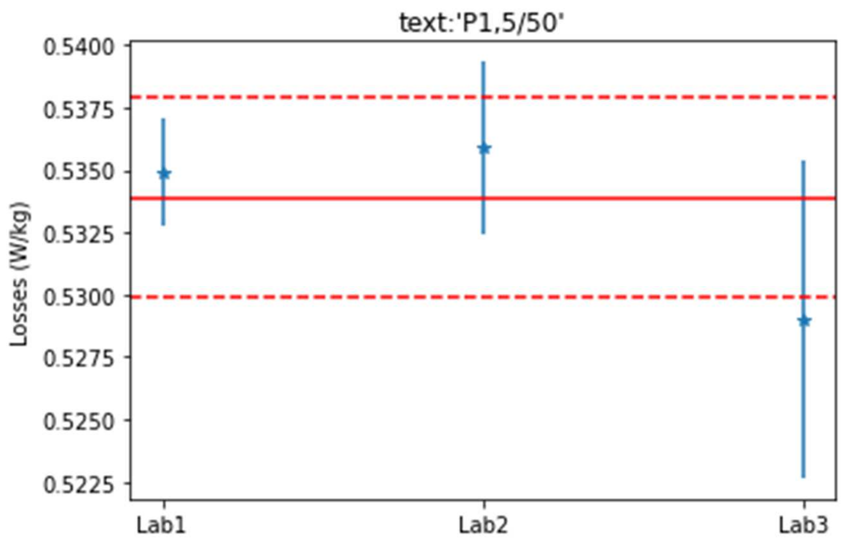


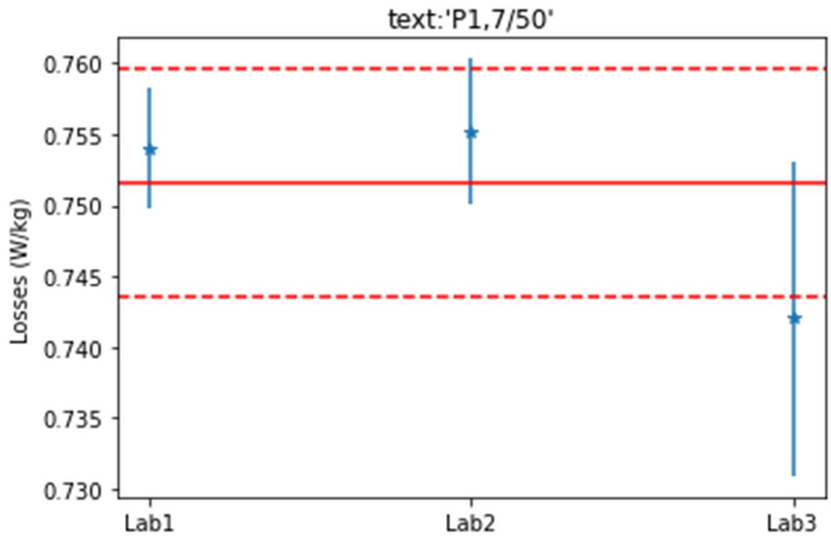
text:'P1,0/100'
Losses (W/kg)
1.060
1.055
1.050
1.045
1.040
1.035
1.030
1.025
1.020
Lab1
Lab2
Lab3

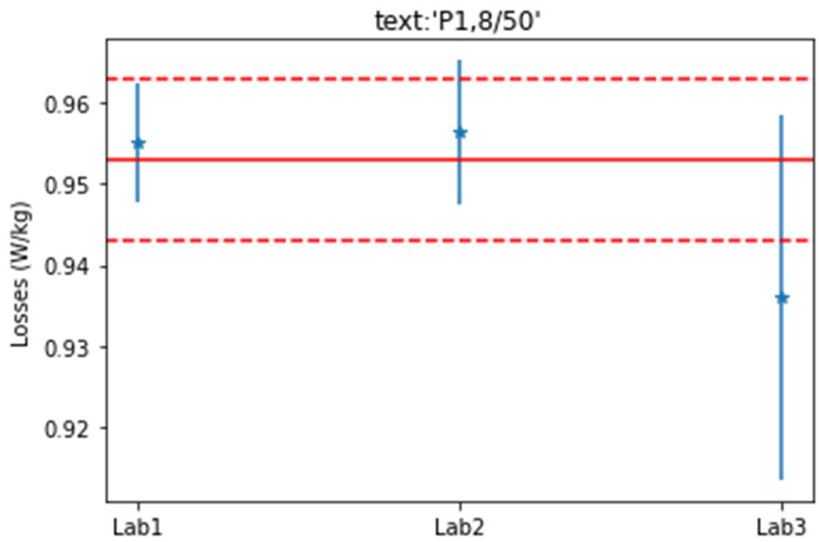


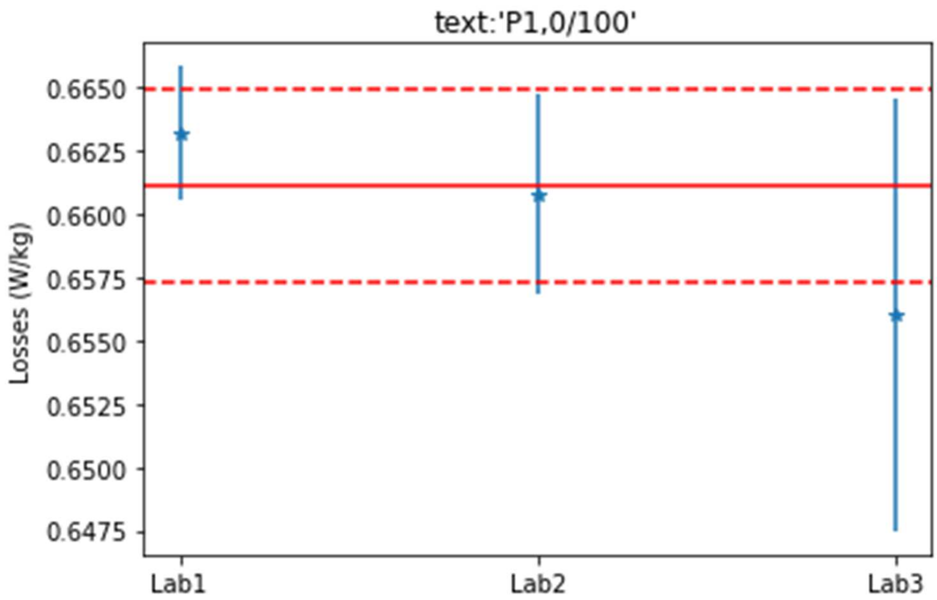
Laser scribed GO 0.2

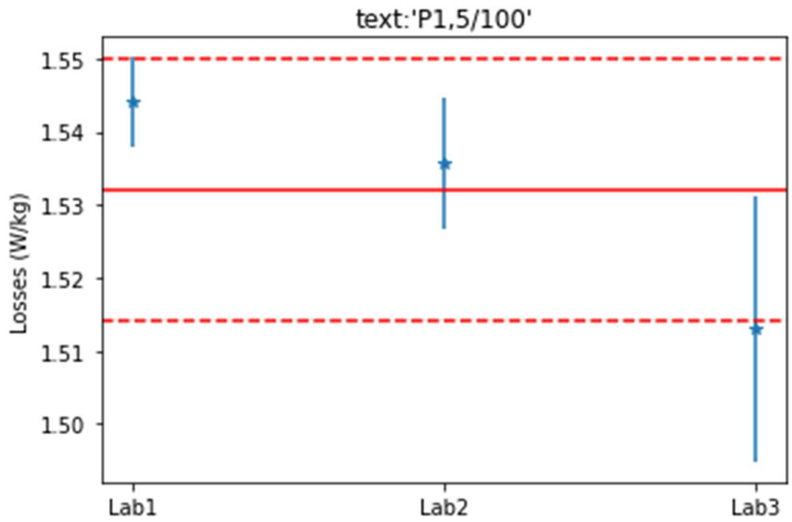


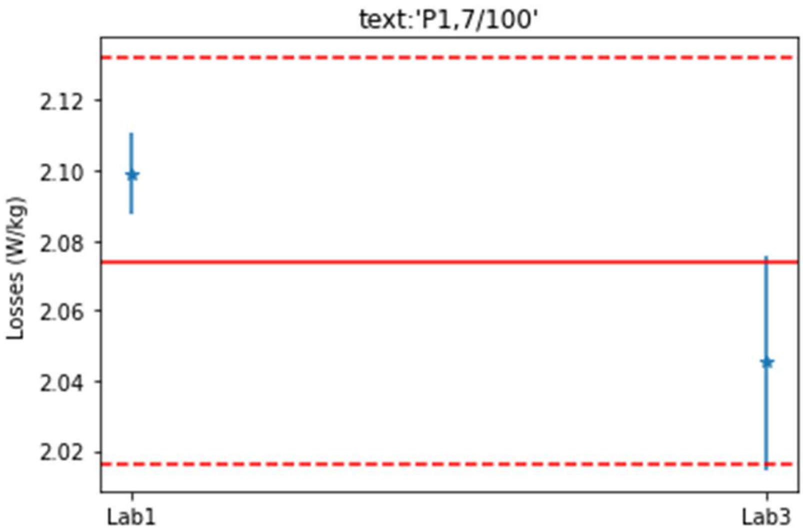


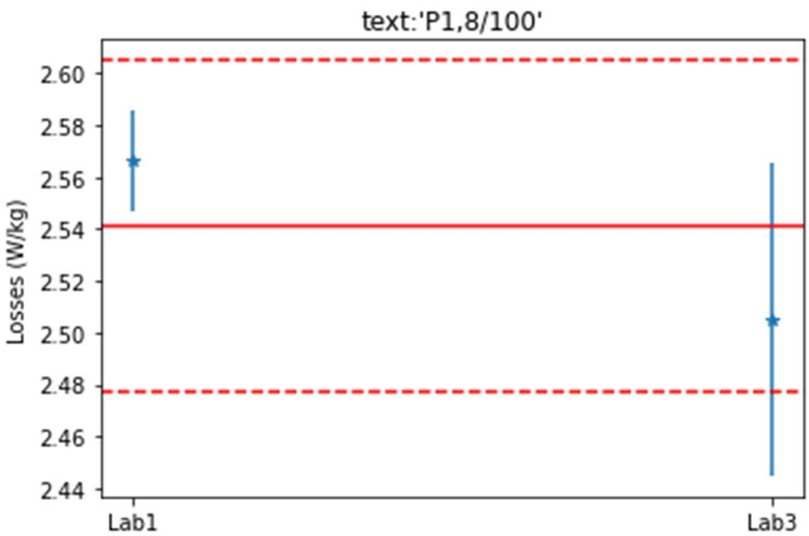

text:'P1,7/50'
Losses (W/kg)
0.760
0.755
0.750
0.745
0.740
0.735
0.730
Lab1
Lab2
Lab3


text:'P1,8/50'
Losses (W/kg)
0.96
0.95
0.94
0.93
0.92
Lab1
Lab2
Lab3


text:'P1,0/100'
Losses (W/kg)
0.6650
0.6625
0.6600
0.6575
0.6550
0.6525
0.6500
0.6475
Lab1
Lab2
Lab3


text:'P1,5/100'
1.55
1.54
1.53
1.52
1.51
1.50
Losses (W/kg)
Lab1
Lab2
Lab3


text:'P1,7/100'
2.12
2.10
2.08
2.06
2.04
2.02
Losses (W/kg)
Lab1
Lab3


text:'P1,8/100'
2.60
2.58
2.56
2.54
2.52
2.50
2.48
2.46
2.44
Losses (W/kg)
Lab1
Lab3

6.2.2 $J_m(H_m)$ curve results at 50 Hz

H_m (A/m) (longitudinal direction)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
2500	1.5550	0.23	1.5632	0.07	1.556	0.23	1.5590	0.0028	-0.004	0.004	-0.003	0.009	0.006	0.009	**0.441**	**0.697**	**0.331**

H_m (A/m) (transversal direction)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
2500	1.507	0.23	1.513	0.08	1.507	0.23	1.5102	0.0023	-0.003	0.003	-0.003	0.008	0.005	0.008	**0.386**	**0.617**	**0.386**

Results of the NO 0.3 sample

H_m (A/m) (longitudinal direction)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
2500	1.563	0.23	1.571	0.06	1.563	0.35	1.5671	0.0029	-0.004	0.004	-0.004	0.009	0.006	0.012	**0.441**	**0.631**	**0.330**

H_m (A/m) (transversal direction)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
2500	1.522	0.23	1.527	0.06	1.523	0.23	1.5253	0.0017	-0.003	0.002	-0.002	0.008	0.004	0.008	**0.425**	**0.427**	**0.297**

Results of the NO 0.2 sample

H_m (A/m)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
800	1.8850	0.23	1.8887	0.06	1.885	0.23	1.8867	0.0035	-0.002	0.002	-0.002	0.011	0.007	0.011	0.152	0.277	0.152

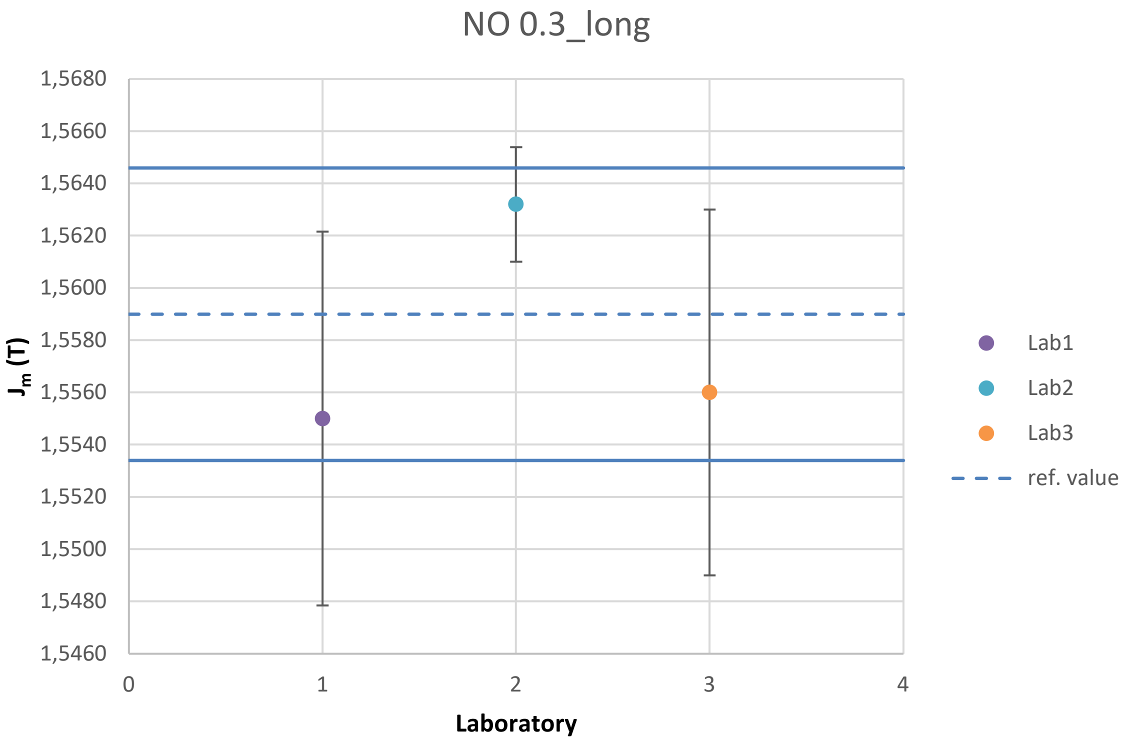
Results of the GO 0.18 sample

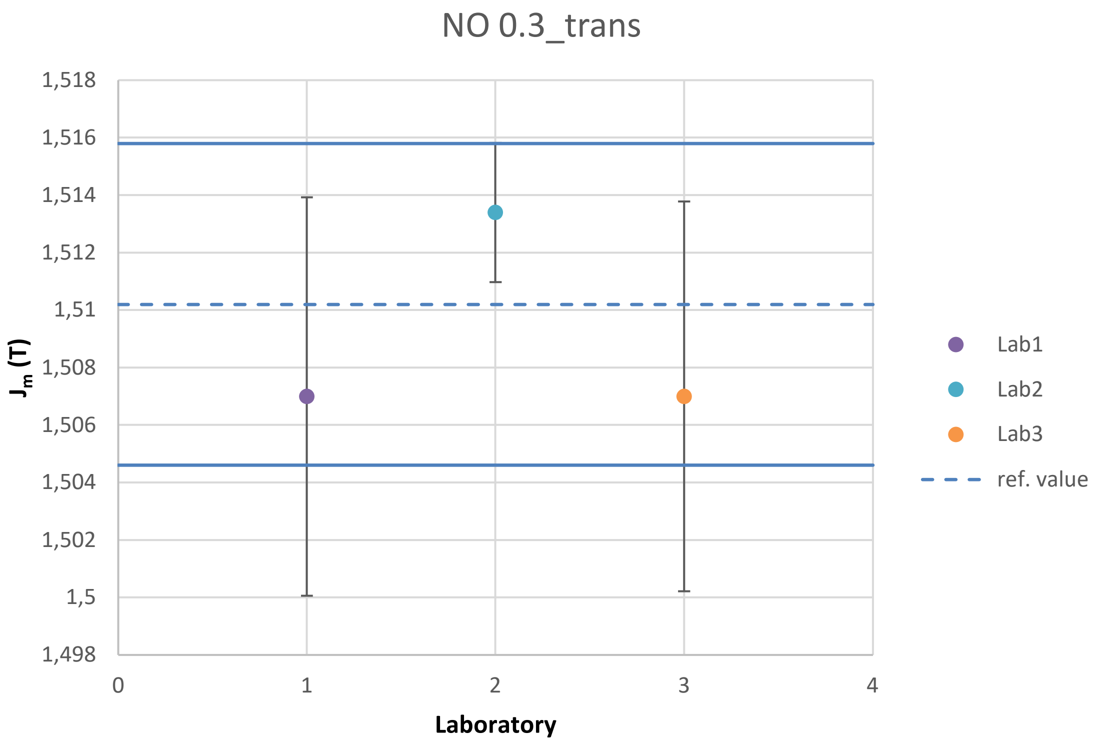
H_m (A/m)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
800	1.893	0.23	1.902	0.06	1.893	0.23	1.8971	0.0035	-0.004	0.005	-0.004	0.011	0.007	0.011	**0.368**	**0.673**	**0.368**

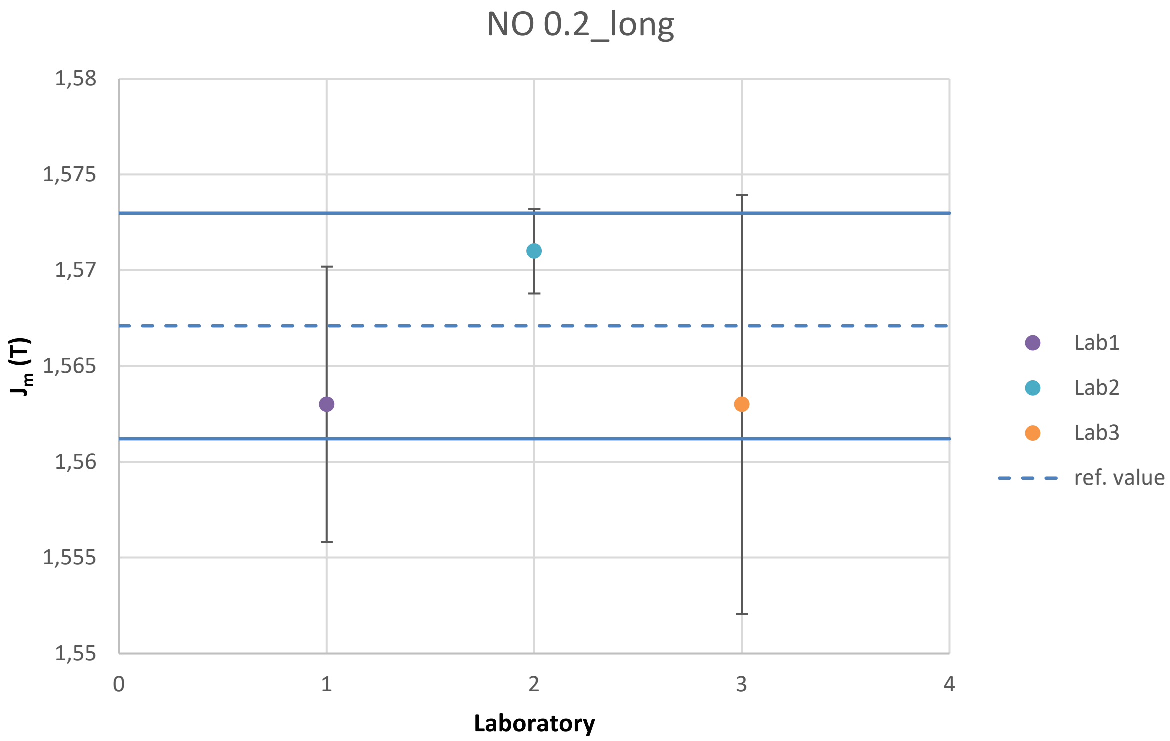
Results of the GO 0.3 sample

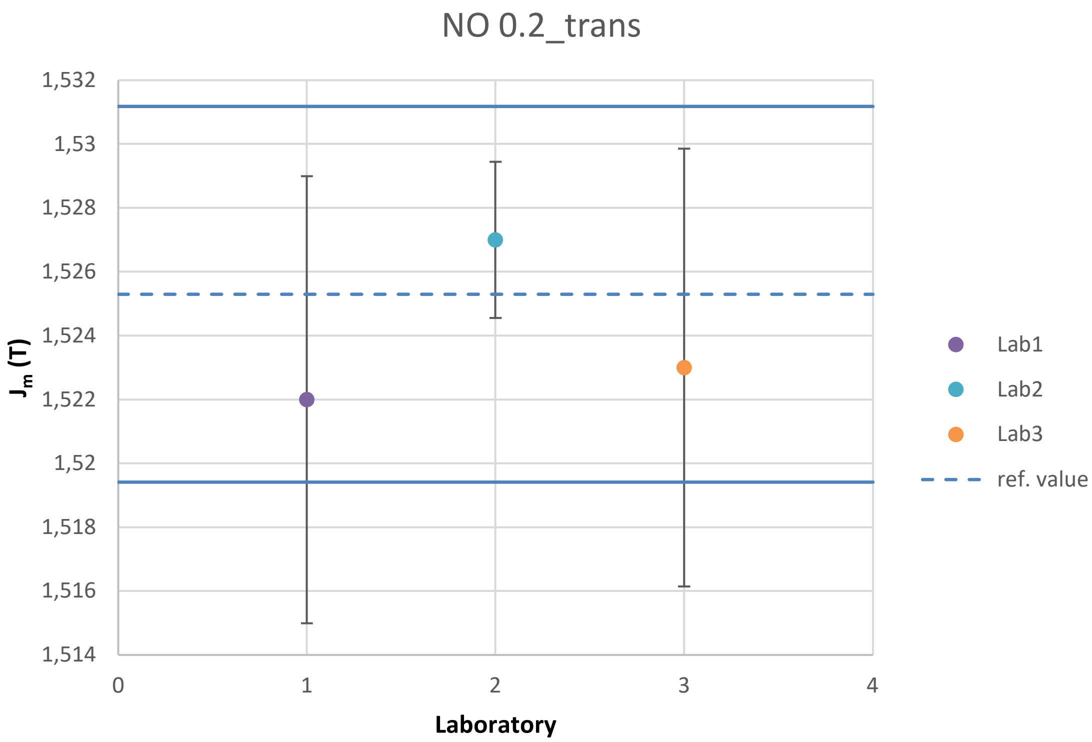
H_m (A/m)	Lab1		Lab2		Lab3		x_{ref} (T)	$u(x_{ref})$ (T)	d_i			$u(d_i)$			E_n		
	X	u_x, %	X	u_x, %	X	u_x, %			Lab1	Lab2	Lab3	Lab1	Lab2	Lab3	**Lab1**	**Lab2**	**Lab3**
800	1.891	0.23	1.8992	0.07	1.891	0.23	1.8951	0.0030	-0.004	0.004	-0.004	0.011	0.007	0.011	**0.386**	**0.636**	**0.386**

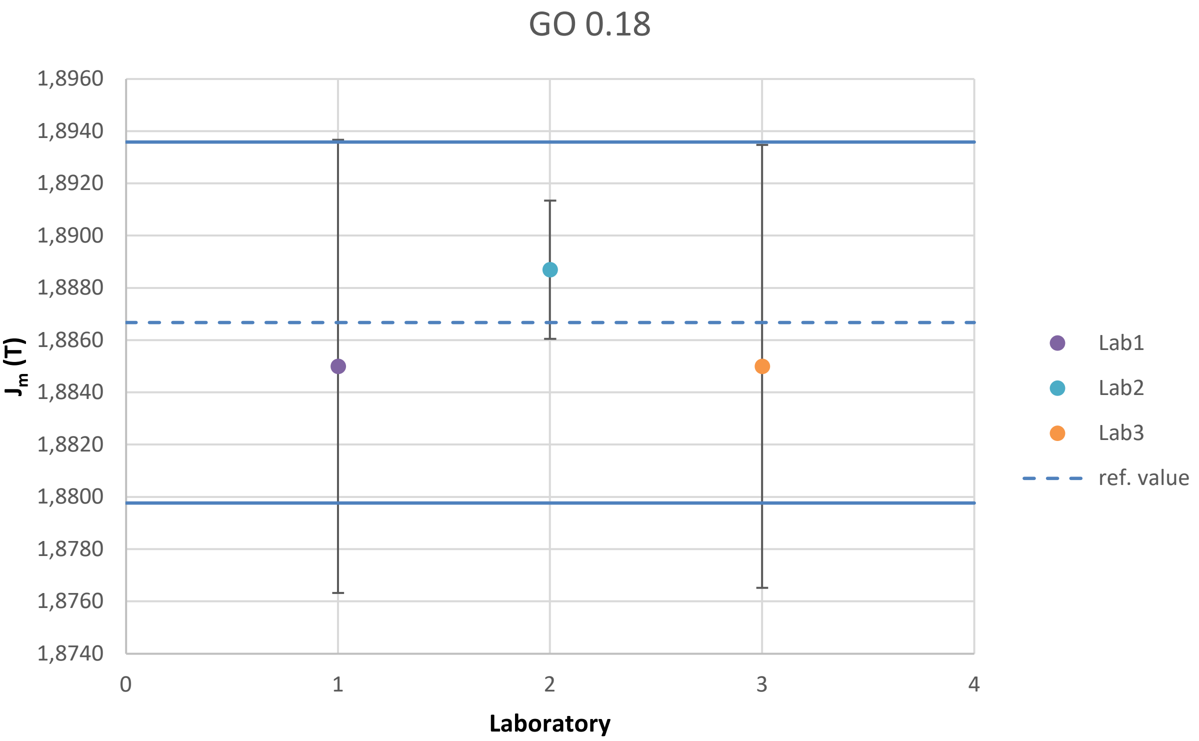
Results of the Laser scribed GO 0.2 sample

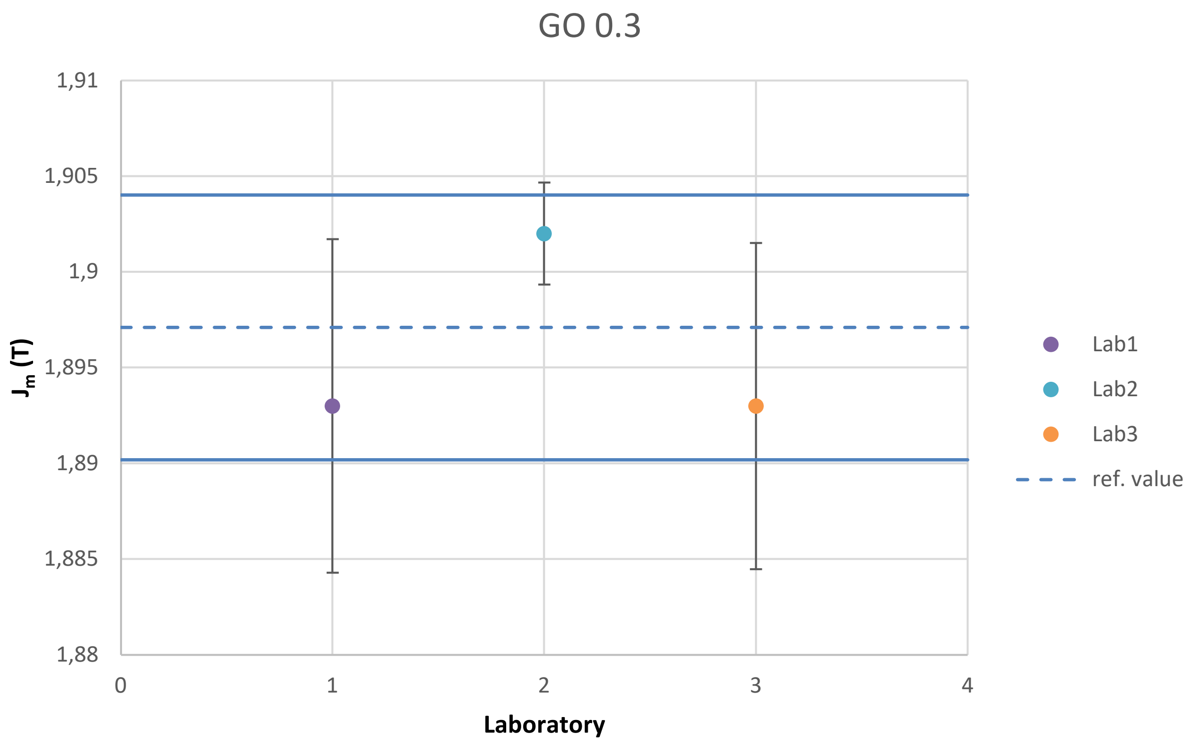

NO 0.3_long
1,5680
1,5660
1,5640
1,5620
1,5600
1,5580
1,5560
1,5540
1,5520
1,5500
1,5480
1,5460
J_m (T)
0
1
2
3
4
Laboratory
Lab1
Lab2
Lab3
ref. value

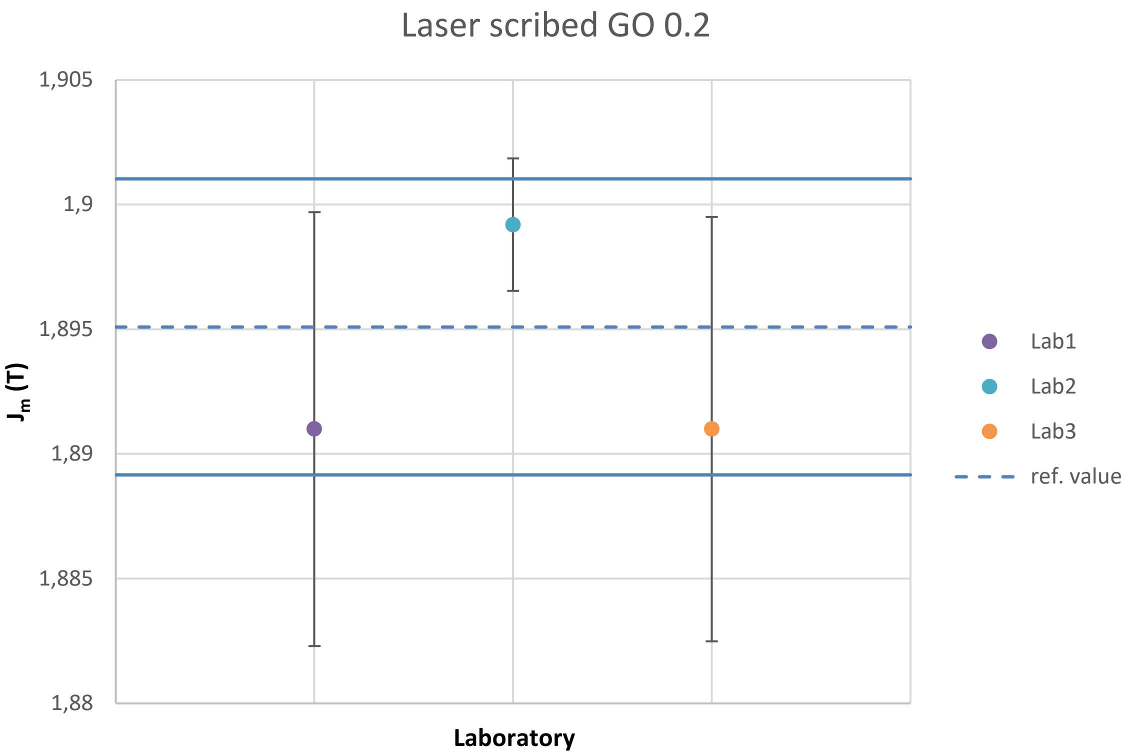

NO 0.3_trans
1,518
1,516
1,514
1,512
1,51
1,508
1,506
1,504
1,502
1,5
1,498
J_m (T)
0
1
2
3
4
Laboratory
Lab1
Lab2
Lab3
ref. value


NO 0.2_long
1,58
1,575
1,57
1,565
1,56
1,555
1,55
J_m (T)
0
1
2
3
4
Laboratory
Lab1
Lab2
Lab3
ref. value


NO 0.2_trans
1,532
1,53
1,528
1,526
1,524
1,522
1,52
1,518
1,516
1,514
J_m (T)
0
1
2
3
4
Laboratory
Lab1
Lab2
Lab3
ref. value


GO 0.18
1,8960
1,8940
1,8920
1,8900
1,8880
1,8860
1,8840
1,8820
1,8800
1,8780
1,8760
1,8740
J_m (T)
0
1
2
3
4
Laboratory
Lab1
Lab2
Lab3
ref. value


GO 0.3
1,91
1,905
1,9
1,895
1,89
1,885
1,88
J_m (T)
0
1
2
3
4
Laboratory
Lab1
Lab2
Lab3
ref. value



7 Summary and conclusions

After the evaluation of the data in agreement with the rules of EURAMET the agreement of the comparison is very good, because E_n values smaller than 1 are obtained for all data points. This report also confirmed that the results are consistent with the declared uncertainty.

8 References

[1] C. Appino et al.: “International Comparison on SST and Epstein Measurements in Grain-oriented Fe-Si Sheet Steel”, International Journal of Applied Electromagnetics and Mechanics 48, pp. 123 – 133, 2015.

[2] M. G. Cox: “The evaluation of key comparison data”, Metrologia, vol. 39, no. 6, 2002.

[3] S. Pommé and J. Keightley: “Determination of a reference value and its uncertainty through a power-moderated mean”, Metrologia, vol. 52, no. 3, 2015, pp. S200–S212.