

ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	Unit 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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Title :

ANGOSTURA

3 Vertical Francis Turbines

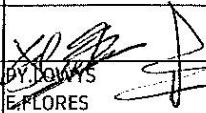
2 x 144.35 MW, Hn = 48.77 mWC, 107.14 rpm

1 x 47.15 MW, Hn = 48.65 mWC, 187.5 rpm


Hydro-mechanical Tests - Unit 1

To : Colbun
Alstom Hydro Power

* PREL : Preliminary
* BPE : Released for execution


A	25/11/2014	X.CORNUT	 J. SAVARITEAU	PREL	Preliminary edition	
Index	Date	Prepared by (Name + sig.)	Checked by (Name + sig.)	Approved by (Name + sig.)	DOC STATUS	Observations

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1. Object

The purpose of these tests, is to study the hydro-mechanical behaviour along with the relative efficiency of the unit. It is also be the opportunity to compare the results with the guaranties.

2. Modification


Index A : Preliminary edition

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3. General

3.1. Glossary


H_1, H_2	upstream and downstream geodesic water levels (m)
$H_b = H_1 - H_2$	gross head (m)
H_n	Net head (m)
FSNL	Full Speed No Load (rpm)
ρ	averaged specific mass of water (kg/m^3)
g	site gravity (m/s^2)
p_{atm}	Ambient pressure
T_{air}	Ambient temperature
pp	Raw Peak to Peak value
O-P	Raw Peak value
ppX	Peak to Peak value at X% threshold (X to be defined to 97%) along finite number of shaft revolution
RMS	Root Mean Squared value (global or at a constant frequency)
f_0	Rotational frequency (1.786 Hz at 107.14 rpm)
$2f_0$	2 times the rotational frequency (2×1.786 Hz at 107.14 rpm)
$0.3f_0$	0.3 time the rotational frequency ($\sim 0.3 \times 1.786$ Hz at 107.14 rpm)
$Z_r f_0$	Is the blabe number ($Z_r = 13$) time the rotational frequency (13×1.786 Hz)
$2Z_r f_0$	2 times the blabe number ($Z_r = 13$) time the rotational frequency ($2 \times 13 \times 1.786$ Hz)
NG	Global level (global level including the analysis range [0-800Hz])

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NGA	Global acceleration level
NG Velocity	Global velocity level
1X, 1Y	refers respectively to an accelerometer on the upper generator guide bearing, on the X or Y direction, on same location as the monitoring system.
2X, 2Y, 2Z	refers respectively to an accelerometer on the lower generator combined thrust and guide bearing, on the X, Y or Z directions, on same location as the monitoring system.
3X, 3Y, 3Z	refers respectively to an accelerometer on the turbine guide bearing, on the X, Y or Z directions, on same location as the monitoring system.
Vib_ConeX, Vib_ConeY	refers to an accelerometer on the draft tube cone, on the X or Y directions, on same location as the monitoring system.
S1X, S1Y, S1Z	refers respectively to a shaft relative displacement on the upper generator guide bearing, on the X, Y or Z directions, on same location as the monitoring system.
S2X, S2Y	refers respectively to a shaft relative displacement on the lower generator combined thrust and guide bearing, on the X or Y directions, on same location as the monitoring system.
S3X, S3Y	refers respectively to a shaft relative displacement on the turbine guide bearing, on the X or Y directions, on same location as the monitoring system.
P_SC_Dyn	Dynamic pressure on spirale case man hole.
P_HC2, P_HC3	Dynamic pressure in between the runner and the guide vane.
P_HC1	Dynamic pressure in between the crown and the head cover.
P_Cone_Dyn	Dynamic pressure on the draft tube cone manhole.
P_membrane	Thrust bearing membrane pressure used to determine the turbine axial thrust.
P_Up_Before	Collected pressure in a single section before the convergent.

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P_Up_After	Collected pressure in a single section after the convergent.
P_Down	Collected pressure in a single section of the draft tube outlet.
P_WK	Spirale case differential pressure used to estimate the flow.
P_WK_Client	Spirale case differential pressure used to estimate the flow (Customer sensor).
TP_Noise	refers to the noise in the turbine pit.
Axial_Valve_pos	refers to the axial valve opening.
Speed	refers to the speed measure with a key phasor.
SMS_GV	refers to the guide vane servomotor stroke.
Power	Generator output power of the unit gathered from the turbine governor.

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3.2. General Characteristics of Turbine-Generator set

Nominal Generator Specifications:

Nominal shaft revolution : $n_0 = 107.14$ rpm
 Combined thrust and guide bearing pads number : 12

Nominal Turbine Specifications:

Turbine type Francis vertical
 Rated output 144.35 MW
 Rated Net Head : $H_{n_0} = 48.77$ m
 Rotation Speed : $n_0 = 107.14$ rpm ($f_0 = 1.786$ Hz) clockwise
 Number of Runner Blades : $Z_r = 13$
 Number of Guide Vanes : $Z_g = 24$

3.3. Description of the Tests


List of Tests ***Appendix 1***
 Description of Instrumentation : ***Appendix 3***
 Calibration Sheets of Instruments : ***Appendix 4 & 5***

Tests have been performed on unit 1 on the 25/08/2014 under the responsibility of Alstom Hydro France, with assistance of Colbun.

4. Measurement process

4.1. Test

A procedure has been made by ALSTOM Hydro France and agreed by Colbun describing the mechanical behavioural tests that have been realised on Unit 1 of Angostura.

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4.2. Analyser Records

Temporal signal have been recorded using 2 portable OROS dynamic analysers (OR38). Sampling has been performed at 2.048 kS/s for all the inputs (which provides analysis range of 800 Hz), except for the microphone that has been set up at 51 kS/s (20 kHz analysis range, roughly the human hearing range). Signal analysis is made using DYNAMX release 8, specific software which enables post processing of all the data recorded.

The 34 channels are recorded simultaneously on the analysers. The record duration has been set at 60 s (enabling maximum analysis observation of around 107.14 shaft revolutions) and each measurement point was recorded after stabilisation of the parameters, either thermal or hydraulic, for each steady state operation point.

We performed measurement as per Test list in ***Appendix 1***.


4.3. Tests conditions

Each parameter has been recorded under 12 steady state load points, from 14 to 144, with the gross head available at the time of the test $H_g = 49.7$ m. For each steady state point 5 air admission and/or injection configurations have been tested:

1. Axial valve free, head cover and bottom ring air injection closed
2. Axial valve closed, head cover and bottom ring air injection closed
3. Axial valve closed, head cover and bottom ring air injection opened (1 compressor running)
4. Axial valve closed, head cover and bottom ring air injection opened (2 compressors running)
5. Axial valve closed, head cover air injection opened only (2 compressors running)

In addition transient operation have also been recorded like mechanical overspeed ,load rejection, normal start-up and shut-down.

The results are presented hereafter.

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5. Hydraulic test results – Index tests

5.1. Principle

By measuring a differential pressure in a single section of the spiral case (ΔH_{WK}) we can build a relation between it and the turbine flow using the model test hill chart.

The ΔH_{WK} difference of pressure measured is related to the relative discharge by the following relation:

$$Q_{\text{rel_turb}} = K(\Delta H_{WK})^n$$

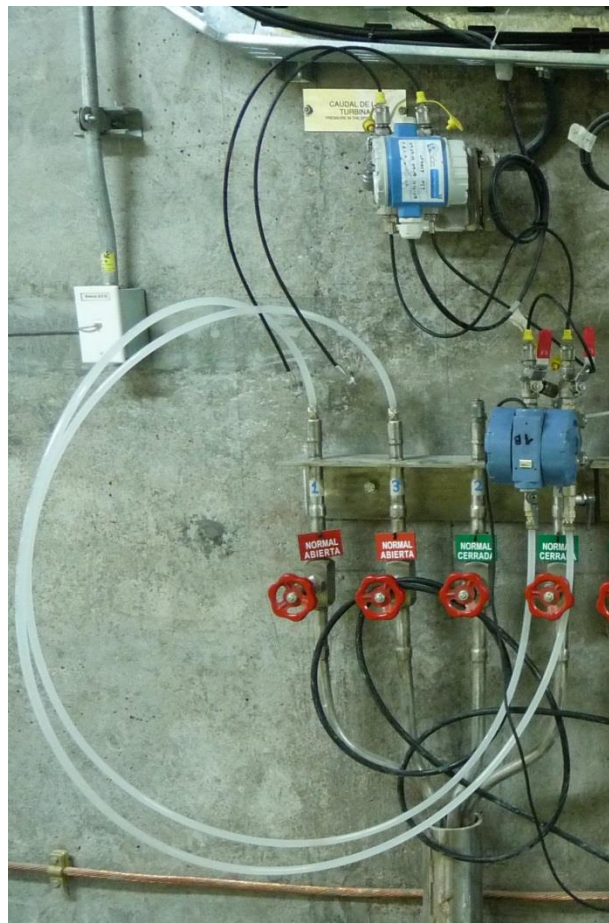
Where:

$Q_{\text{rel_turb}}$: is the relative flow indexed on the hill chart.

K: is a coefficient that will be adjusted to fit with the hill chart flow

n: is a number between 0.48 and 0.52 according to the hydraulic conditions

The differential pressure sensor is from ROSEMOUNT, DP5 E22 model; it is collected near the turbine pit, at the same location than the one from the customer. It was calibrated on site, using a Druck DPI605 calibrator; the calibration sheet is provided in **Annex 4**.



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5.2. Transposition rules

When the grid frequency is stable and corresponds to nominal value (50 Hz in Chile) and if measured heads H_{nm} do not correspond exactly to the guaranteed net heads H_{ng} , within a range of $\pm 2\%$ (considering a 50Hz frequency), IEC 41 code allows to transpose the results, by using following formulas :

$$Q(H_{ng}) = Q(H_{nm}) \times \left(\frac{H_{ng}}{H_{nm}} \right)^{1/2}$$

$$P_m(H_{ng}) = P_m(H_{nm}) \times \left(\frac{H_{ng}}{H_{nm}} \right)^{3/2}$$

$$\eta(H_{ng}) = \eta(H_{nm})$$

5.3. Index test results

The Winter Kennedy coefficients (K and n) were calibrated from the measured differential pressure and in comparison with the guaranteed efficiencies. Customer and Alstom differential pressure sensors are plugged on the same set of pressure tap. Differences at low load between those two sensors are due there operating range, respectively 0-50kPa and 0-16kPa for the customer and Alstom sensors. Given the customer sensor smaller range we will use it as reference for Winter-Kennedy comparison to the guaranties. For downstream pressure measurement we used the topographic value.


Below are presented the results at 49.7m for Alstom WK differential pressure device.

WK Coefficients for Alstom site test team sensor "P_WK":

P_WK (Pa)	
K (m3/s/Pa)	2.255
n (-)	0.5

WK customer sensor "P_WK_Client":

P_WK_Client (Pa)	
K (m3/s/Pa)	2.18
n (-)	0.5

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Main characteristics:

Designation	Value	Unit
Ambiente pressure	98171	Pa
Gravity	9.799	m/s2
Water average density	998.2	kg/m3

Pressure sensors elevations		
P_Up_Before elevation	265.03	m
P_Up_After elevation	265.03	m
P_Down elevation	265.03	m
P_SC_Dyn elevation	256.5	m
P_Cone_Dyn elevation	255.325	m
Upstream measuring section before convergent	72.382	m2
Upstream measuring section after convergent	40.489	m2
Downstream measuring section	100.397	m2

On the following graphs, **we notice a good correlation between WK sensors and guaranteed performances.**



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ANGOSTURA

Unit 1

COLBUN

ALSTOM Hydro France

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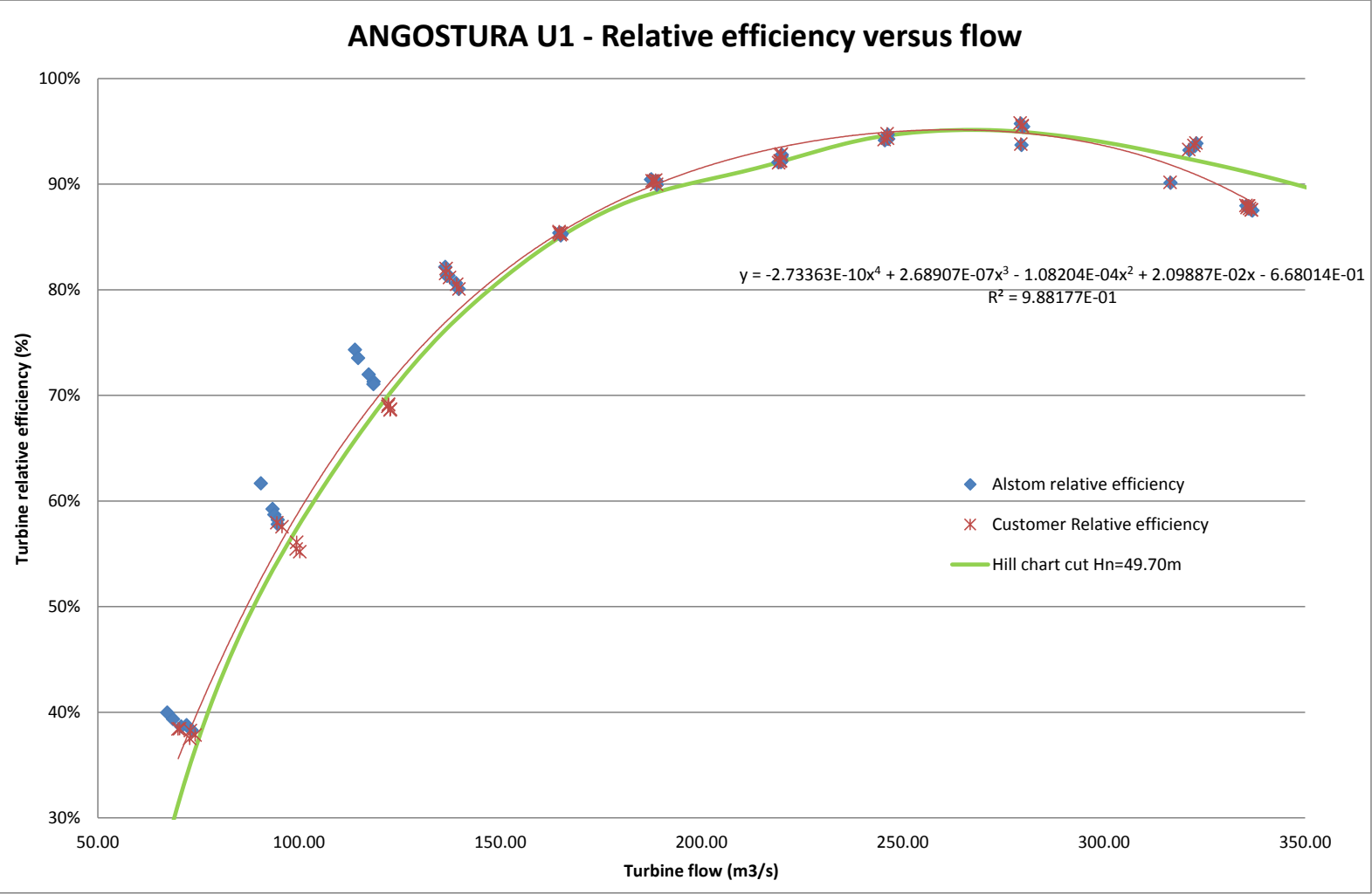
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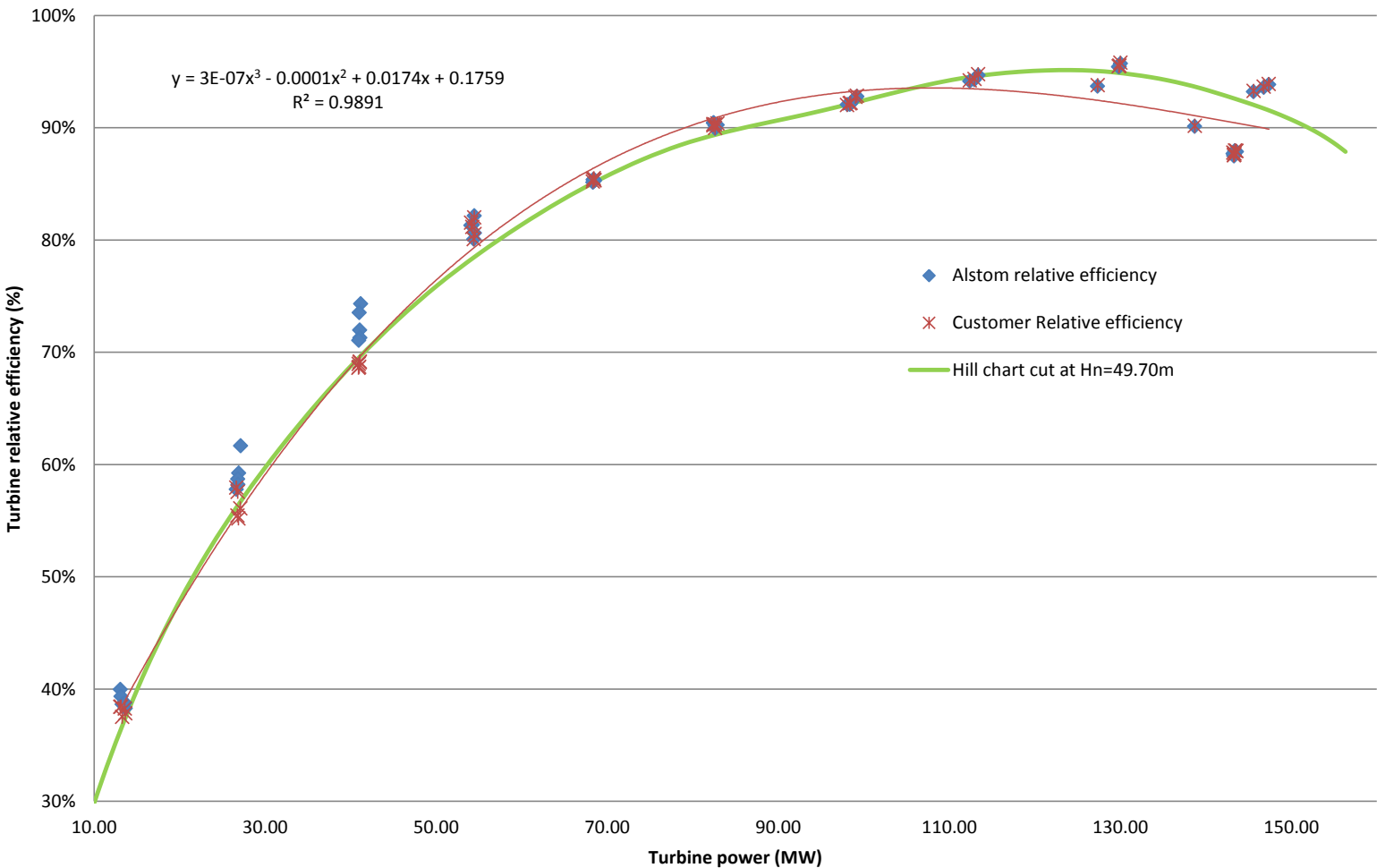
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													Results using Alstom WK sensor:					Results using Colbun WK sensor					
																Results transposed at Hn=					Results transposed at Hn=		
													49.7		m					49.7		m	
Test point	SMS_GV	SMS_GV	Power	TSLG	Turbine power	P_WK_Client	P_WK	P_Up_Before	P_Up_After	P_Up_Before	P_Up_After	Down level topo	WK Flow	Hn	Efficiency	WK Flow	Turbine power	WK Flow Client	Hn Client	Efficiency	WK Flow Client	Turbine power client	
(-)	(mm)	(°)	(MW)	(MW)	(Pa)	(Pa)	(Pa)	(Pa)	(Pa)	(m)	(m)	(m)	(m3/s)	(m)	%	(m3/s)	(MW)	(m3/s)	(m)	Client %	(m3/s)	(MW)	
14MW1	142	10.0	13.453	13.657	1060	916	604528	397915	316.80	295.67	265.71	68.2	51.21	39.96%	67.2	13.058	71.0	51.22	38.40%	69.9	13.054		
14MW2	141	10.0	13.514	13.720	1071	955	604607	397950	316.81	295.68	265.78	69.7	51.15	39.35%	68.7	13.140	71.4	51.16	38.43%	70.3	13.138		
14MW3	142	10.0	13.641	13.889	1150	1013	604531	397894	316.80	295.67	265.74	71.8	51.19	38.65%	70.7	13.287	73.9	51.20	37.52%	72.8	13.283		
14MW4	142	10.0	13.963	14.211	1190	1087	604627	397968	316.81	295.68	265.89	74.3	51.06	38.27%	73.3	13.646	75.2	51.07	37.83%	74.2	13.645		
14MW5	142	10.0	13.739	14.211	1156	1053	604723	398049	316.82	295.69	265.73	73.2	51.23	38.76%	72.1	13.580	74.1	51.23	38.26%	73.0	13.579		
27MW1	181	12.8	27.133	28.111	2131	1649	603201	397671	316.66	295.65	266.00	91.6	50.88	61.68%	90.5	27.138	100.6	50.93	56.08%	99.4	27.102		
27MW2	181	12.8	26.763	27.775	2159	1754	603328	397756	316.67	295.66	266.15	94.4	50.76	59.24%	93.4	26.912	101.3	50.79	55.19%	100.2	26.884		
27MW3	180	12.8	26.728	27.652	2120	1770	603357	397759	316.68	295.66	266.15	94.9	50.76	58.70%	93.9	26.788	100.4	50.79	55.45%	99.3	26.766		
27MW4	180	12.8	26.595	27.534	1966	1796	603445	397783	316.69	295.66	266.33	95.6	50.59	58.21%	94.7	26.806	96.7	50.60	57.55%	95.8	26.802		
27MW5	180	12.8	26.352	27.270	1910	1793	603469	397822	316.69	295.66	266.42	95.5	50.51	57.80%	94.7	26.619	95.3	50.51	57.94%	94.5	26.620		
41MW1	221	15.7	40.963	42.013	3190	2587	601276	397155	316.47	295.60	266.42	114.7	50.39	74.33%	113.9	41.156	123.1	50.44	69.16%	122.2	41.092		
41MW2	221	15.7	40.748	41.833	3182	2621	601181	397100	316.46	295.59	266.42	115.4	50.38	73.53%	114.7	40.985	123.0	50.43	68.96%	122.1	40.928		
41MW3	221	15.7	40.830	41.917	3218	2744	601238	397169	316.46	295.60	266.42	118.1	50.40	71.98%	117.3	41.041	123.7	50.44	68.71%	122.8	40.999		
41MW4	221	15.7	40.913	41.965	3190	2803	601147	397096	316.45	295.59	266.42	119.4	50.40	71.30%	118.6	41.090	123.1	50.43	69.10%	122.2	41.061		
41MW5	221	15.7	40.879	41.812	3212	2800	601159	397110	316.45	295.59	266.42	119.3	50.40	71.07%	118.5	40.939	123.5	50.43	68.61%	122.6	40.906		
54MW1	248	17.7	54.029	55.167	3959	3686	598508	397326	316.18	295.61	266.53	136.9	50.14	82.16%	136.3	54.442	137.2	50.14	82.00%	136.6	54.439		
54MW2	248	17.7	53.888	54.961	3959	3720	598596	397361	316.19	295.62	266.44	137.5	50.24	81.31%	136.8	54.071	137.2	50.24	81.54%	136.4	54.075		
54MW3	248	17.7	53.842	54.925	4008	3729	598720	397335	316.20	295.62	266.57	137.7	50.13	81.35%	137.1	54.223	138.0	50.13	81.16%	137.4	54.219		
54MW4	248	17.7	54.004	55.096	4107	3829	598818	397366	316.21	295.62	266.65	139.5	50.07	80.62%	139.0	54.484	139.7	50.07	80.52%	139.2	54.482		
54MW5	248	17.7	54.010	55.015	4141	3868	598855	397376	316.22	295.62	266.65	140.2	50.08	80.08%	139.7	54.390	140.3	50.08	80.06%	139.7	54.390		
68MW1	283	20.2	67.793	69.040	5774	5396	596170	396581	315.94	295.54	266.71	165.7	49.95	85.31%	165.2	68.526	165.6	49.95	85.31%	165.2	68.526		
68MW2	283	20.2	67.855	69.073	5766	5400	596259	396605	315.95	295.54	266.69	165.7	49.98	85.27%	165.3	68.498	165.5	49.98	85.36%	165.1	68.501		
68MW3	283	20.2	67.511	68.797	5750	5381	596245	396539	315.95	295.53	266.73	165.4	49.93	85.15%	165.0	68.315	165.3	49.93	85.21%	164.9	68.317		
68MW4	283	20.2	67.683	68.880	5733	5361	596203	396486	315.95	295.53	266.70	165.1	49.96	85.38%	164.7	68.350	165.1	49.96	85.40%	164.6	68.350		
68MW5	283	20.2	67.592	68.895	5728	5367	596295	396520	315.96	295.53	266.74	165.2	49.93	85.40%	164.8	68.425	165.0	49.93	85.51%	164.6	68.429		
81MW1	316	22.6	81.264	82.556	7424	6921	593347	395698	315.65	295.45	266.82	187.6	49.75	90.43%	187.5	82.428	187.8	49.75	90.31%	187.7	82.422		
81MW2	316	22.6	80.969	82.263	7424	6904	593317	395656	315.65	295.44	266.94	187.4	49.63	90.45%	187.5	82.446	187.8	49.63	90.21%	188.0	82.435		
81MW3	316	22.7	80.901	82.194	7428	6958	593328	395633	315.65	295.44	267.04	188.1	49.53	90.19%	188.4	82.606	187.9	49.53	90.29%	188.2	82.611		
81MW4	317	22.7	80.810	82.090	7472	6991	593356	395647	315.66	295.44	267.09	188.5	49.49	89.94%	188.9	82.609	188.4	49.49	89.99%	188.8	82.611		
81MW5	317	22.7	80.831	82.118	7443	6973	593300	395592	315.65	295.44	267.18	188.3	49.39	90.26%	188.9	82.882	188.1	49.39	90.38%	188.7	82.888		
95MW1	367	26.3	95.102	96.625	10026	9386	588705	394308	315.18	295.31	267.35	218.5	49.07	92.14%	219.9	98.480	218.3	49.07	92.22%	219.7	98.486		
95MW2	367	26.3	95.029	96.522	10004	9344	588769	394323	315.19	295.31	267.25	218.0	49.17	92.06%	219.1	98.072	218.0	49.18	92.03%	219.2	98.070		
95MW3	367	26.3	95.023	97.437	10046	9409	588680	394266	315.18	295.30	267.26	218.7	49.16	92.63%	219.9	99.034	218.5	49.16	92.74%	219.7	99.042		
95MW4	367	26.3	95.064	97.437	10046	9400	588605	394199	315.17	295.29	267.31	218.6	49.11	92.79%	219.9	99.212	218.5	49.10	92.84%	219.8	99.216		
95MW5	367	26.3	95.014	96.522	10014	9375	588688	394236	315.18	295.30	267.34	218.3	49.08	92.08%	219.7	98.355	218.2	49.08	92.17%	219.5	98.362		
108MW1	412	29.5	108.620	110.435	12524	11722	584151	392933	314.71	295.17	267.43	244.1	48.84	94.69%	246.3	113.372	244.0	48.84	94.76%	246.1	113.380		
108MW21	412	29.5	108.482	110.301	12562	11757	584141	392889	314.71	295.16	267.35	244.5	48.92	94.27%	246.4	112.945	244.3	48.92	94.35%	246.3	112.952		
108MW22	412	29.5	107.949	109.740	12472	11673	584184	392886	314.72	295.16	267.35	243.6	48.91	94.14%	245.6	112.393	243.5	48.91	94.22%	245.4	112.401		
122MW11	477	0.0	#REF!	122.379	15991	14966	578072	391203	314.09	294.99	267.68	275.9	48.40	93.71%	279.6	127.357	275.7	48.39	93.78%	279.4	127.368		
122MW12	477	34.0	122.034	124.441	15995	14976	578033	391142	314.09	294.98	267.78	276.0	48.30	95.45%	279.9	129.896	275.7	48.29	95.55%	279.7	129.911		
122MW21	477	34.0	121.943	124.141	15905	14884	578021	391120	314.09	294.98	267.87	275.1	48.19	95.73%	279.4	130.020	274.9	48.19	95.80%	279.2	130.031		
122MW22	477	34.0	121.816	123.993	15964	14938	578071	391149	314.09	294.98	267.87	275.6	48.20	95.42%	279.9	129.816	275.4	48.20	95.48%	279.7	129.826		
136MW11	589	41.3	134.581	136.950	20830	19485	569054	388567	313.17	294.72	268.04	314.8	47.71	93.22%	321.3	145.593	314.6	47.71	93.27%	321.1	145.603		
136MW12	589	41.3	134.339	136.625	20855	19510	569032	388541	313.17	294.72	268.50	315.0	47.25	93.84%	323.0	147.368	314.8	47.25	93.90%	322.9	147.380		
136MW21	589	41.3	134.360	136.646	20848	19515	569042	388498	313.17	294.71	268.37	315.0	47.39	93.59%	322.6	146.777	314.8	47.38	93.67%	322.4	146.796		
136MW22	589	41.3	134.296	136.680	20864	19518	568967	388489	313.16	294.71	266.54	315.0	49.21	90.13%	316.6	138.711	314.9	49.21	90.17%	316.4	138.721		
137MW11	664	45.7	137.427	139.881	23330	21840	563155	386220	312.57	294.48	266.54	333.3	48.93	87.71%	335.9								

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ANGOSTURA U1 - Relative efficiency versus power



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6. Turbine power guaranties

6.1. Maximum power of the unit

Contract reminder " FCG 6701 Turbinas Francis_RevF":

B1 **TURBINAS N° 1 Y N° 2, de caudal 300 m³/s c/u**

1. **POTENCIA MAXIMA DE LAS TURBINAS**

ALTURA NETA H(m)	POTENCIA MAXIMA (kW)	APERTURA DEL DISTRIBUIDOR EN % DE LA APERTURA NOMINAL (1)
H0=53,21	148000	95.0 (2)
H1=51,80	148000	101.7 (3)
H2=48.77	144351	116.2
H3=48.21	142520	117.3
H4=46,71	137581	120.2

NOTA: (1) = Apertura Nominal = Apertura con Q =300 m³/s y H2 = 48.77 m.

(2): Sólo en carácter informativo. Esta altura neta no es disponible con Q>120 m³/s y nivel de embalse 317 m.


(3): Sólo en carácter informativo. Esta altura neta no es disponible con Q>210 m³/s (para 1 turbina) y nivel de embalse 317 m

La potencia de 148 MW es la potencia máxima indicativa de la máquina con solo un grupo en operación (HWL = 317 m, TWL = 265,4 m, Hn = 49,70 m / Q = 330 m³ / s) - A1_ANGOSTURA_U1U2_graf2-3_Rev3

If we transpose the winter Kennedy results at Hn=51.80m (the closest to the one measured), we obtain:

Test point	Results using Alstom WK sensor:					Results using Colbun WK sensor				
	Results using Alstom WK sensor:			Results transposed at Hn=		Results using Colbun WK sensor:			Results transposed at Hn=	
				51.8	m				51.8	m
	WK Flow	Hn	Efficiency	WK Flow	Turbine power	WK Flow Client	Hn Client	Efficiency	WK Flow Client	Turbine power client
(-)	(m3/s)	(m)	%	(m3/s)	(MW)	(m3/s)	(m)	Client %	(m3/s)	(MW)
144MW11	339.4	50.57	87.62%	343.5	152.516	339.1	50.56	87.71%	343.3	152.539
144MW12	339.8	50.58	87.51%	343.9	152.461	339.6	50.57	87.55%	343.7	152.472
144MW13	339.9	50.59	87.50%	344.0	152.498	339.7	50.58	87.58%	343.7	152.518


During the tests we reached 152.5MW to be compared to the 148MW guaranteed, the guaranty is fulfilled.

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6.2. Power plant

		Mediciones de Nivel											
Unidad	N° de medición	1	Nivel Embalse	QU1	QU2	QU3	Qttotal	Potencia Unidad en Prueba[MW]	Potencia al eje turbina [MW]	% de Carga	Fecha	Hora	Estimacion del Altura neta
U1	1	267.32	316.97	319	321	109	749	141.9	149.33	109%	05/09/2014	08:05	52.44
U2	1	267.15	316.97	322	324	109	755	142.1	149.54		05/09/2014	08:06	52.61
U3	1	267.63	316.97	316	322	109	747	45.9	47.25		05/09/2014	08:07	49.65
									346.12				
U1	2	267.31	316.96	319	322	109	750	142.0	149.43	109%	05/09/2014	08:17	52.44
U2	2	267.27	316.96	319	320	109	748	141.7	149.12		05/09/2014	08:18	52.48
U3	2	267.66	316.96	319	320	109	748	45.9	47.25		05/09/2014	08:19	49.61
									345.80				
U1	1	267.33	316.95	321	320	109	750	142.6	150.06	109%	05/09/2014	08:30	52.41
U2	2	267.24	316.95	319	320	109	748	142.5	149.96		05/09/2014	08:31	52.50
U3	3	267.66	316.94	319	320	109	748	45.9	47.25		05/09/2014	08:32	49.59
									347.27				

During the tests we reached 149MW to be compared to the 148MW guaranteed, the guaranty is fulfilled.

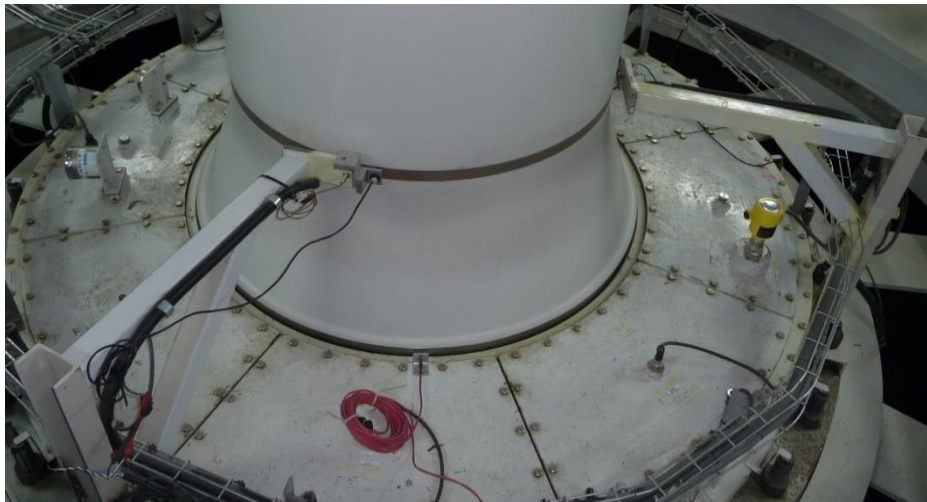
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7. Mechanical test results

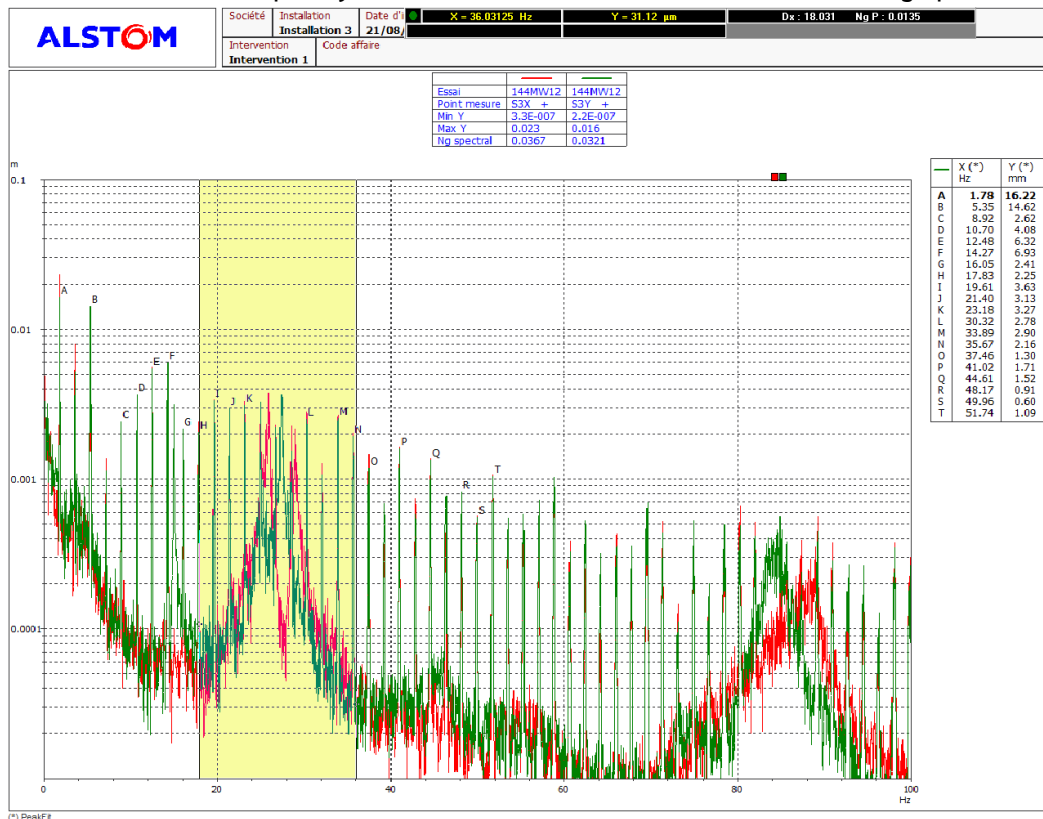
7.1. Key remarks on test results


7.1.1. Remarks on turbine shaft displacement

As we can see on the following picture the displacement sensors in the turbine pit (S3X and S3Y) are installed on supports.

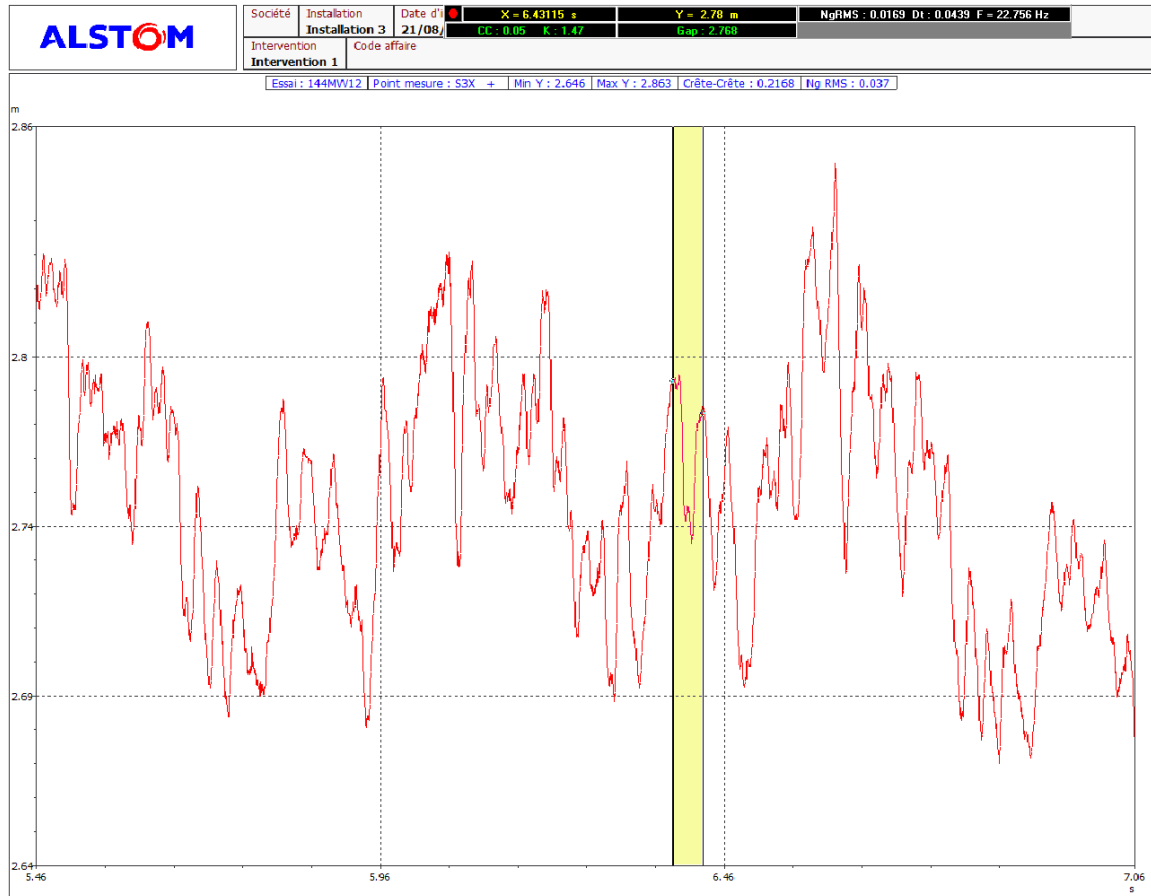


Those supports have a natural frequency between 20-36Hz as shown on the following spectrums.




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This excitation could also be seen on temporal records:



In this report, so as to get rid of the displacement of the support, all results of turbine shaft displacement will be post processed with a low pass filter of 20 Hz, given that most of the level is below 20Hz the signal won't be too much affected.


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7.2. Results for Steady State Operation


Hereafter are presented tables issued from either time or frequency domain analysis.

7.2.1. Time Domain shaft relative displacement signals

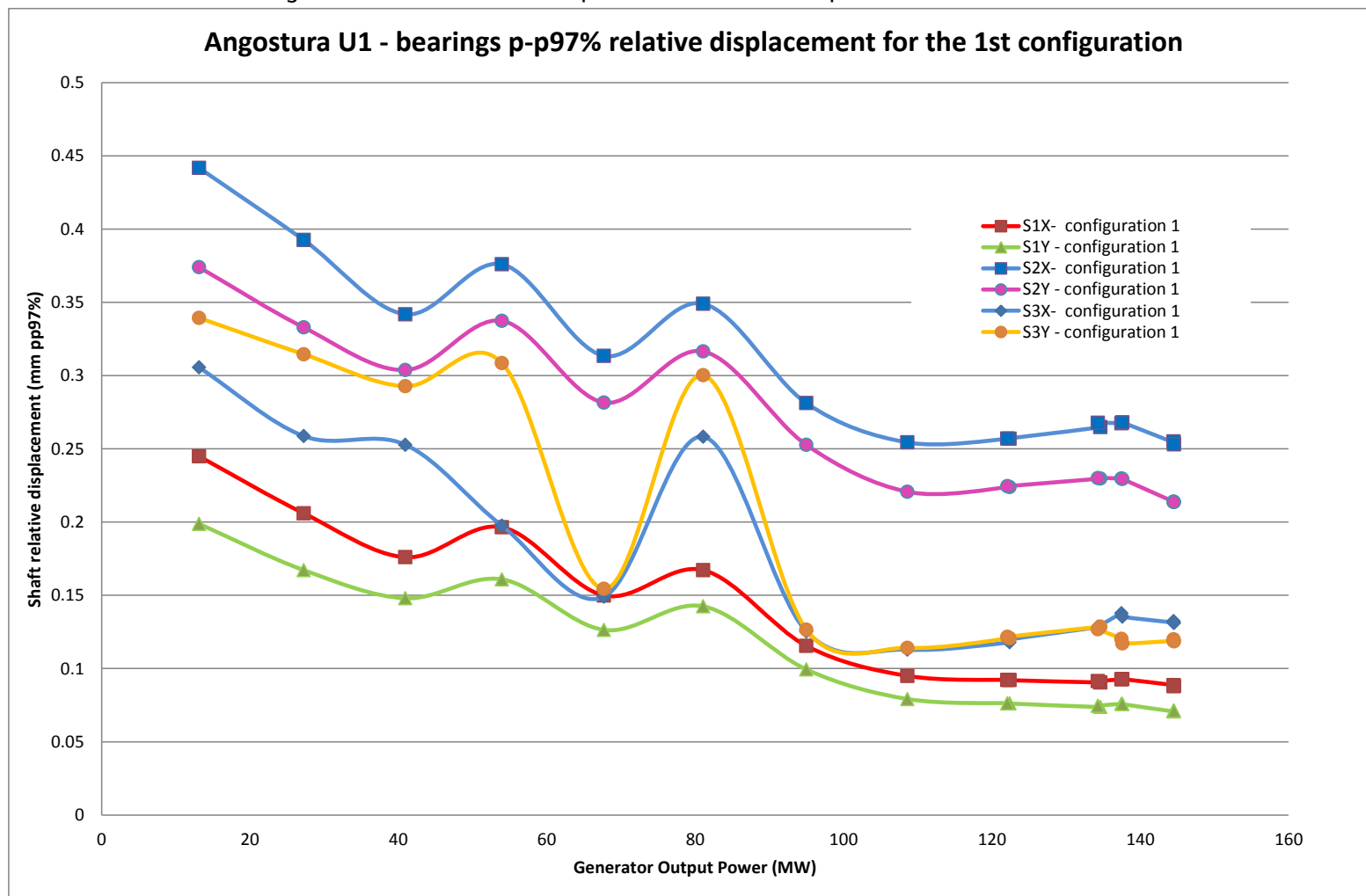
Following results are given in PP97 values. PP97 values have been calculated along 10 shaft revolutions (approximately 5.6 s of temporal record). Average along entire temporal record is calculated and presented in the table. Orbit statistic as S_{\max} and $S_{pp\max}$ are also presented.


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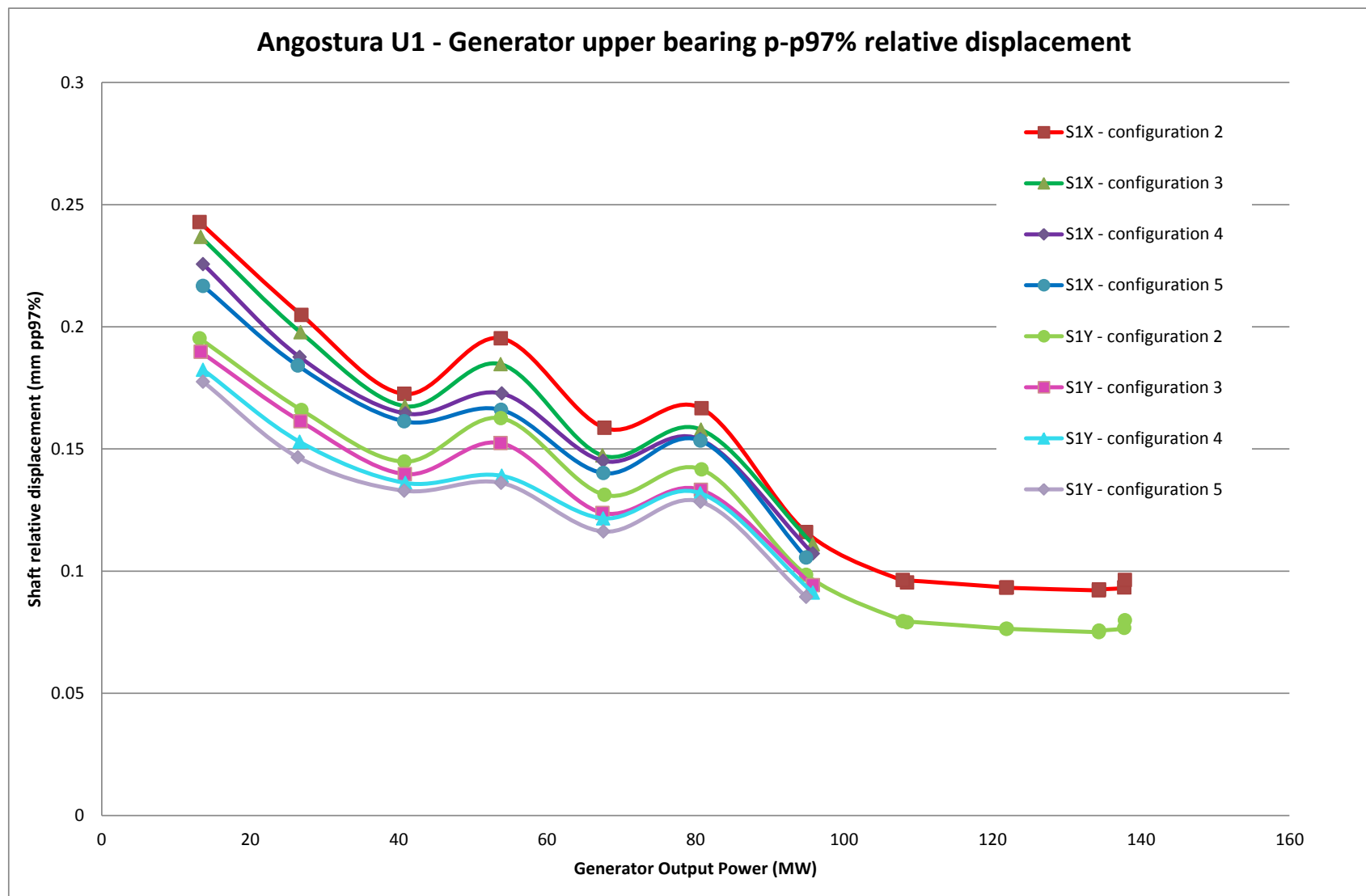
Test point (-)	Generator output power (MW)	S1X pp97% (mm)	S1Y pp97% (mm)	S1Z pp97% (mm)	S2X pp97% (mm)	S2Y pp97% (mm)	S3X pp97% LPF20Hz (mm)	S3Y pp97% LPF20Hz (mm)
14MW1	13.120	0.2449	0.1988	0.8091	0.4418	0.374	0.3056	0.3394
14MW2	13.181	0.2428	0.1953	0.8042	0.4435	0.3662	0.3015	0.3272
14MW3	13.345	0.2368	0.1897	0.7946	0.4291	0.3802	0.2665	0.317
14MW4	13.657	0.2256	0.1824	0.768	0.4094	0.3508	0.2666	0.3252
14MW5	13.657	0.2167	0.1775	0.7752	0.3985	0.3531	0.2846	0.3388
27MW1	27.237	0.206	0.1672	0.8302	0.3926	0.3329	0.2587	0.3146
27MW2	26.907	0.2048	0.1659	0.8255	0.3816	0.3301	0.285	0.3044
27MW3	26.786	0.1977	0.1613	0.7988	0.3719	0.3197	0.2568	0.3246
27MW4	26.670	0.1876	0.1529	0.7907	0.3584	0.2976	0.2583	0.2937
27MW5	26.411	0.1841	0.1466	0.8005	0.3512	0.2947	0.2464	0.3178
41MW1	40.943	0.176	0.148	0.7832	0.3419	0.3038	0.2528	0.2927
41MW2	40.764	0.1725	0.1448	0.7866	0.338	0.3019	0.232	0.2741
41MW3	40.848	0.1675	0.1397	0.77	0.3309	0.2906	0.2185	0.2521
41MW4	40.895	0.1645	0.1361	0.7576	0.3221	0.2845	0.2347	0.2791
41MW5	40.744	0.1613	0.1329	0.7561	0.3206	0.2824	0.2349	0.2855
54MW1	53.963	0.1965	0.1609	0.7594	0.376	0.3374	0.1975	0.3085
54MW2	53.759	0.1953	0.1626	0.7591	0.3793	0.3421	0.224	0.3099
54MW3	53.723	0.1847	0.1524	0.7562	0.3632	0.3223	0.2366	0.3064
54MW4	53.893	0.1727	0.139	0.7465	0.3445	0.3031	0.2196	0.2778
54MW5	53.813	0.166	0.1361	0.7386	0.3355	0.2953	0.2034	0.2696
68MW1	67.709	0.1499	0.1264	0.7331	0.3135	0.2816	0.149	0.1544
68MW2	67.741	0.1586	0.1312	0.7426	0.3318	0.2957	0.1609	0.1653
68MW3	67.468	0.1473	0.1238	0.7337	0.3091	0.2802	0.1643	0.177
68MW4	67.551	0.1451	0.1216	0.7336	0.309	0.2741	0.1608	0.1829
68MW5	67.565	0.1401	0.1162	0.7331	0.3016	0.2651	0.1551	0.1787
81MW1	81.090	0.1672	0.1425	0.7387	0.3491	0.3165	0.2583	0.3003
81MW2	80.800	0.1666	0.1416	0.7415	0.3491	0.3149	0.255	0.2943
81MW3	80.732	0.1579	0.1332	0.7386	0.3344	0.2984	0.2477	0.2911
81MW4	80.629	0.1539	0.1319	0.7302	0.333	0.2961	0.2537	0.2964
81MW5	80.656	0.1534	0.1284	0.7331	0.3289	0.2917	0.2581	0.2969
95MW1	94.995	0.1155	0.0994	0.7262	0.2812	0.2527	0.1253	0.1266
95MW2	94.893	0.1159	0.0985	0.7226	0.2802	0.2553	0.1264	0.126
95MW3	95.797	0.111	0.0942	0.7271	0.2707	0.2422	0.1214	0.1212
95MW4	95.797	0.1072	0.0912	0.7252	0.2632	0.2351	0.1176	0.1211
95MW5	94.894	0.1055	0.0894	0.7246	0.2601	0.2312	0.1178	0.1213
108MW1	108.612	0.095	0.0792	0.7079	0.2544	0.2207	0.1129	0.1141
108MW2	108.480	0.0953	0.079	0.7087	0.256	0.223	0.113	0.1159
108MW3	107.927	0.0963	0.0795	0.7085	0.2582	0.2235	0.1143	0.1148
122MW1	122.379	0.0922	0.0763	0.7077	0.2569	0.2239	0.1179	0.1207
122MW2	122.085	0.0921	0.0762	0.7095	0.257	0.2245	0.1196	0.1216
122MW3	121.939	0.0933	0.0764	0.7076	0.2573	0.2245	0.1201	0.1005
122MW4	121.851	0.0932	0.0764	0.7069	0.258	0.2251	0.1184	0.1227
136MW1	134.620	0.0905	0.0737	0.7137	0.2649	0.2297	0.1285	0.1285
136MW2	134.303	0.0914	0.0746	0.7142	0.2677	0.2301	0.1285	0.1269
136MW3	134.323	0.0921	0.075	0.7236	0.2681	0.2317	0.129	0.129
136MW4	134.356	0.0925	0.0756	0.7157	0.268	0.2322	0.1291	0.1279
137MW1	137.478	0.0926	0.0759	0.7264	0.2675	0.2298	0.1377	0.1203
137MW2	137.582	0.0928	0.0757	0.7262	0.2681	0.2295	0.1354	0.1171
137MW3	137.749	0.0933	0.0767	0.7314	0.2693	0.2301	0.1363	0.1181
137MW4	137.831	0.0963	0.0799	0.8567	0.2781	0.2372	0.1399	0.1255
144MW1	144.499	0.0887	0.0707	0.728	0.2544	0.2139	0.1315	0.119
144MW2	144.484	0.088	0.0713	0.7266	0.255	0.2138	0.1324	0.1199
144MW3	144.568	0.0881	0.0712	0.7257	0.253	0.2137	0.1312	0.1186


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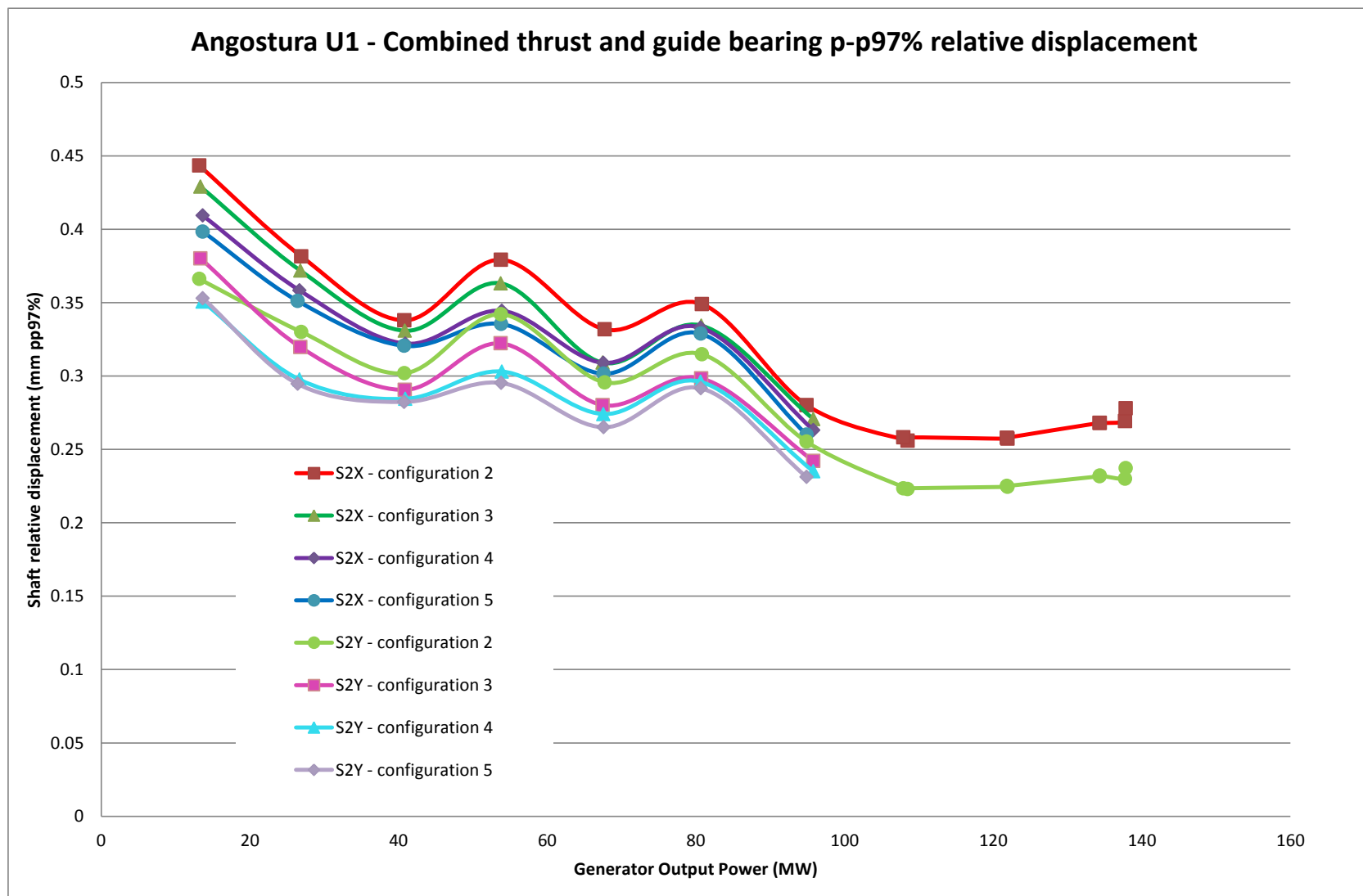
Statistic values have been calculated during 10 shaft revolutions. We plot the trend of PP97 parameter hereafter:




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Comparison with ISO 7919-5 (2005) standard:


ISO 7919-5:2005 standard define vibration limitation versus shaft rotation. Two main zones have been defined according to Smax or PP values:

A-B: Machines magnitudes within this major range are considered acceptable for unrestricted long-term operation.


C-D: For machines in this major range, Alstom has to check if the measured values are permissible for long-term continuous operation considering the specific design and operating conditions. In this aim, in the following part, we will compare the shaft relative displacement to the bearing running diametrical clearance.

The boundarie between A-B and C-D zones given by the ISO 7919-5:2005 standard for machines running under 107.14 rpm nominal speed are **0.143 mm** for the **Smax** and **0.265 mm pp** for the **Spp**.


Hereafter are presented the orbit results of the shaft relative displacements:

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Test point (-)	Generator output power (MW)	S1 Spp max (mm)	ISO7919-5 standard zone	S2 Spp max (mm)	ISO7919-5 standard zone	S3 Spp max LPF 20Hz (mm)	ISO7919-5 standard zone
14MW1	13.120	0.221	A-B	0.3748	C-D	0.211	A-B
14MW2	13.181	0.2184	A-B	0.388	C-D	0.2144	A-B
14MW3	13.345	0.2023	A-B	0.3654	C-D	0.2014	A-B
14MW4	13.657	0.2032	A-B	0.3718	C-D	0.2084	A-B
14MW5	13.657	0.2141	A-B	0.4154	C-D	0.2533	A-B
27MW1	27.237	0.1995	A-B	0.3735	C-D	0.2729	C-D
27MW2	26.907	0.1804	A-B	0.3278	C-D	0.215	A-B
27MW3	26.786	0.1822	A-B	0.3249	C-D	0.1971	A-B
27MW4	26.670	0.1661	A-B	0.3047	C-D	0.227	A-B
27MW5	26.411	0.1706	A-B	0.3128	C-D	0.1875	A-B
41MW1	40.943	0.1522	A-B	0.2914	C-D	0.1624	A-B
41MW2	40.764	0.1631	A-B	0.3097	C-D	0.1942	A-B
41MW3	40.848	0.1662	A-B	0.308	C-D	0.2585	A-B
41MW4	40.895	0.1386	A-B	0.2661	C-D	0.134	A-B
41MW5	40.744	0.1399	A-B	0.2725	C-D	0.1507	A-B
54MW1	53.963	0.172	A-B	0.322	C-D	0.1614	A-B
54MW2	53.759	0.1641	A-B	0.3175	C-D	0.1773	A-B
54MW3	53.723	0.148	A-B	0.2966	C-D	0.1622	A-B
54MW4	53.893	0.1381	A-B	0.2777	C-D	0.1475	A-B
54MW5	53.813	0.1396	A-B	0.2829	C-D	0.1394	A-B
68MW1	67.709	0.1321	A-B	0.2817	C-D	0.1472	A-B
68MW2	67.741	0.1342	A-B	0.2869	C-D	0.166	A-B
68MW3	67.468	0.126	A-B	0.277	C-D	0.1368	A-B
68MW4	67.551	0.1201	A-B	0.262	A-B	0.1401	A-B
68MW5	67.565	0.1222	A-B	0.2726	C-D	0.1566	A-B
81MW1	81.090	0.1207	A-B	0.2744	C-D	0.1431	A-B
81MW2	80.800	0.1174	A-B	0.2675	C-D	0.1485	A-B
81MW3	80.732	0.1327	A-B	0.2903	C-D	0.1865	A-B
81MW4	80.629	0.1124	A-B	0.2638	A-B	0.2816	C-D
81MW5	80.656	0.1107	A-B	0.2522	A-B	0.1379	A-B
95MW1	94.995	0.1055	A-B	0.2607	A-B	0.1312	A-B
95MW2	94.893	0.1056	A-B	0.2618	A-B	0.1335	A-B
95MW3	95.797	0.1024	A-B	0.2509	A-B	0.1274	A-B
95MW4	95.797	0.099	A-B	0.2447	A-B	0.1246	A-B
95MW5	94.894	0.0954	A-B	0.2403	A-B	0.1273	A-B
108MW1	108.612	0.0956	A-B	0.2541	A-B	0.1374	A-B
108MW21	108.480	0.0962	A-B	0.2563	A-B	0.137	A-B
108MW22	107.927	0.0973	A-B	0.2577	A-B	0.139	A-B
122MW11	122.379	0.0942	A-B	0.2571	A-B	0.1488	A-B
122MW12	122.085	0.0942	A-B	0.2605	A-B	0.1476	A-B
122MW21	121.939	0.0956	A-B	0.2608	A-B	0.1539	A-B
122MW22	121.851	0.0948	A-B	0.2591	A-B	0.1479	A-B
136MW11	134.620	0.0933	A-B	0.3092	C-D	0.2255	A-B
136MW12	134.303	0.0925	A-B	0.266	C-D	0.1588	A-B
136MW21	134.323	0.094	A-B	0.2664	C-D	0.1648	A-B
136MW22	134.356	0.0994	A-B	0.2784	C-D	0.1636	A-B
137MW11	137.478	0.0975	A-B	0.272	C-D	0.1645	A-B
137MW12	137.582	0.0938	A-B	0.2664	C-D	0.1529	A-B
137MW21	137.749	0.0958	A-B	0.2702	C-D	0.1495	A-B
137MW22	137.831	0.0963	A-B	0.2772	C-D	0.1541	A-B
144MW11	144.499	0.0929	A-B	0.2601	A-B	0.1607	A-B
144MW12	144.484	0.0929	A-B	0.2601	A-B	0.1606	A-B
144MW13	144.568	0.0927	A-B	0.2581	A-B	0.1568	A-B


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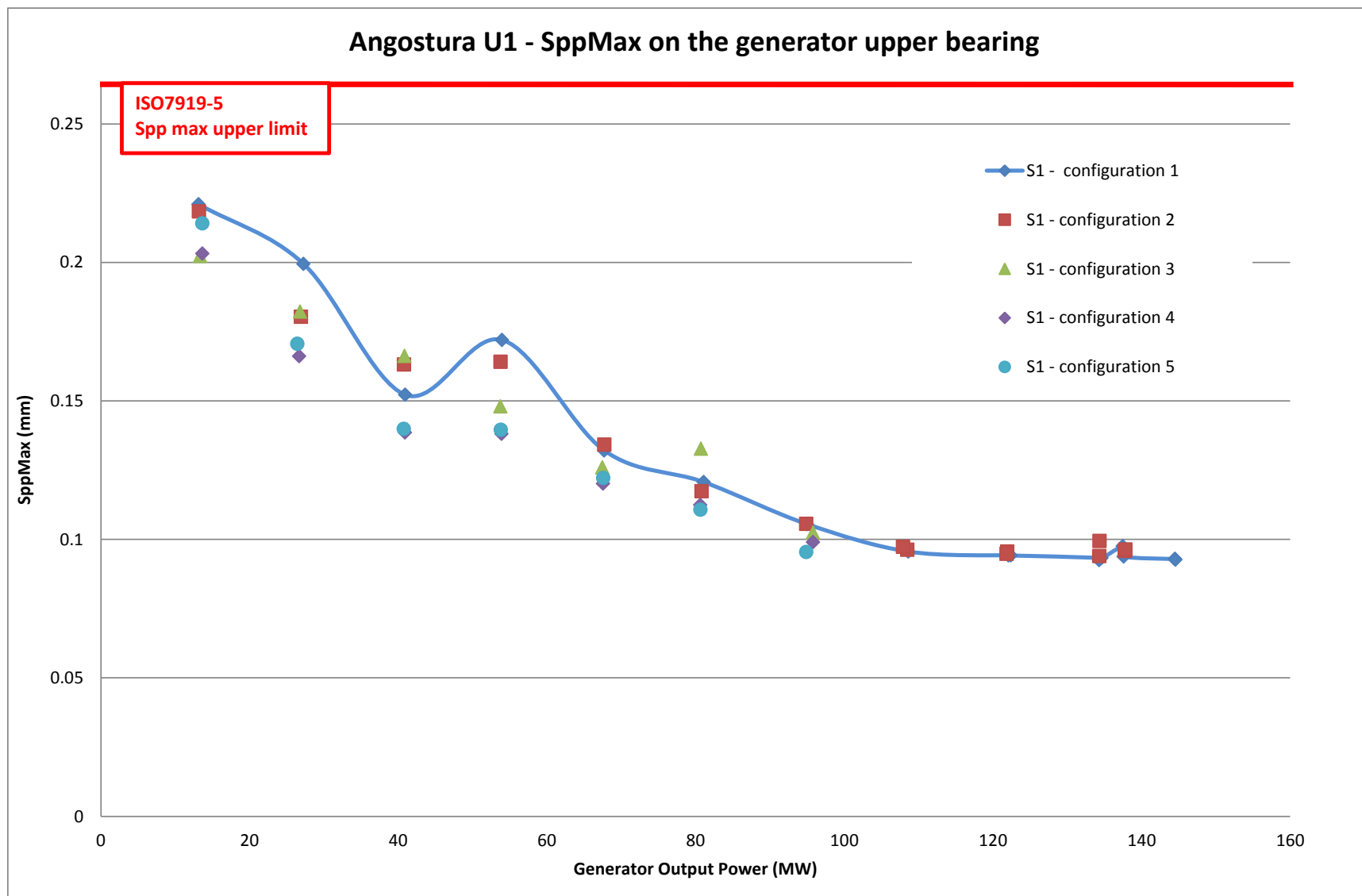
Test point (-)	Generator output power (MW)	S1 Smax (mm)	ISO7919-5 standard zone	S2 Smax (mm)	ISO7919-5 standard zone	S3 Smax LPF 20Hz (mm)	ISO7919-5 standard zone
14MW1	13.120	0.1153	A-B	0.2027	C-D	0.1229	A-B
14MW2	13.181	0.1146	A-B	0.2061	C-D	0.115	A-B
14MW3	13.345	0.1056	A-B	0.1876	C-D	0.1082	A-B
14MW4	13.657	0.1091	A-B	0.1951	C-D	0.1186	A-B
14MW5	13.657	0.1155	A-B	0.2201	C-D	0.1676	C-D
27MW1	27.237	0.1082	A-B	0.1966	C-D	0.1699	C-D
27MW2	26.907	0.0935	A-B	0.1758	C-D	0.1261	A-B
27MW3	26.786	0.0916	A-B	0.1739	C-D	0.1083	A-B
27MW4	26.670	0.0855	A-B	0.1593	C-D	0.1152	A-B
27MW5	26.411	0.0868	A-B	0.1682	C-D	0.1086	A-B
41MW1	40.943	0.0802	A-B	0.1508	C-D	0.0846	A-B
41MW2	40.764	0.0896	A-B	0.1595	C-D	0.1147	A-B
41MW3	40.848	0.09	A-B	0.1727	C-D	0.1855	C-D
41MW4	40.895	0.074	A-B	0.1406	A-B	0.0768	A-B
41MW5	40.744	0.0714	A-B	0.1415	A-B	0.0857	A-B
54MW1	53.963	0.0869	A-B	0.1668	C-D	0.086	A-B
54MW2	53.759	0.083	A-B	0.168	C-D	0.1104	A-B
54MW3	53.723	0.0762	A-B	0.1583	C-D	0.0898	A-B
54MW4	53.893	0.0718	A-B	0.1474	C-D	0.0763	A-B
54MW5	53.813	0.0712	A-B	0.1516	C-D	0.0819	A-B
68MW1	67.709	0.0691	A-B	0.1455	C-D	0.0774	A-B
68MW2	67.741	0.0709	A-B	0.1486	C-D	0.0942	A-B
68MW3	67.468	0.0663	A-B	0.1457	C-D	0.075	A-B
68MW4	67.551	0.0633	A-B	0.136	A-B	0.0789	A-B
68MW5	67.565	0.063	A-B	0.1422	A-B	0.081	A-B
81MW1	81.090	0.0629	A-B	0.1429	C-D	0.073	A-B
81MW2	80.800	0.0619	A-B	0.1396	A-B	0.0788	A-B
81MW3	80.732	0.0759	A-B	0.1634	C-D	0.1166	A-B
81MW4	80.629	0.058	A-B	0.133	A-B	0.1597	C-D
81MW5	80.656	0.0582	A-B	0.1307	A-B	0.0734	A-B
95MW1	94.995	0.0563	A-B	0.1351	A-B	0.0707	A-B
95MW2	94.893	0.0562	A-B	0.1352	A-B	0.0712	A-B
95MW3	95.797	0.0549	A-B	0.1298	A-B	0.0689	A-B
95MW4	95.797	0.052	A-B	0.1269	A-B	0.0685	A-B
95MW5	94.894	0.0516	A-B	0.1249	A-B	0.0692	A-B
108MW1	108.612	0.0511	A-B	0.1315	A-B	0.0736	A-B
108MW21	108.480	0.0514	A-B	0.1324	A-B	0.0735	A-B
108MW22	107.927	0.0521	A-B	0.1328	A-B	0.075	A-B
122MW11	122.379	0.0501	A-B	0.1323	A-B	0.0774	A-B
122MW12	122.085	0.0505	A-B	0.134	A-B	0.0789	A-B
122MW21	121.939	0.0508	A-B	0.1362	A-B	0.0805	A-B
122MW22	121.851	0.0505	A-B	0.1343	A-B	0.0767	A-B
136MW11	134.620	0.0493	A-B	0.1619	C-D	0.1267	A-B
136MW12	134.303	0.0493	A-B	0.1383	A-B	0.0832	A-B
136MW21	134.323	0.0507	A-B	0.1382	A-B	0.085	A-B
136MW22	134.356	0.053	A-B	0.1438	C-D	0.0843	A-B
137MW11	137.478	0.0498	A-B	0.1399	A-B	0.0866	A-B
137MW12	137.582	0.0483	A-B	0.138	A-B	0.0841	A-B
137MW21	137.749	0.0489	A-B	0.141	A-B	0.0833	A-B
137MW22	137.831	0.0502	A-B	0.1406	A-B	0.0832	A-B
144MW11	144.499	0.0491	A-B	0.1326	A-B	0.0833	A-B
144MW12	144.484	0.0485	A-B	0.1328	A-B	0.0865	A-B
144MW13	144.568	0.0489	A-B	0.1314	A-B	0.0811	A-B


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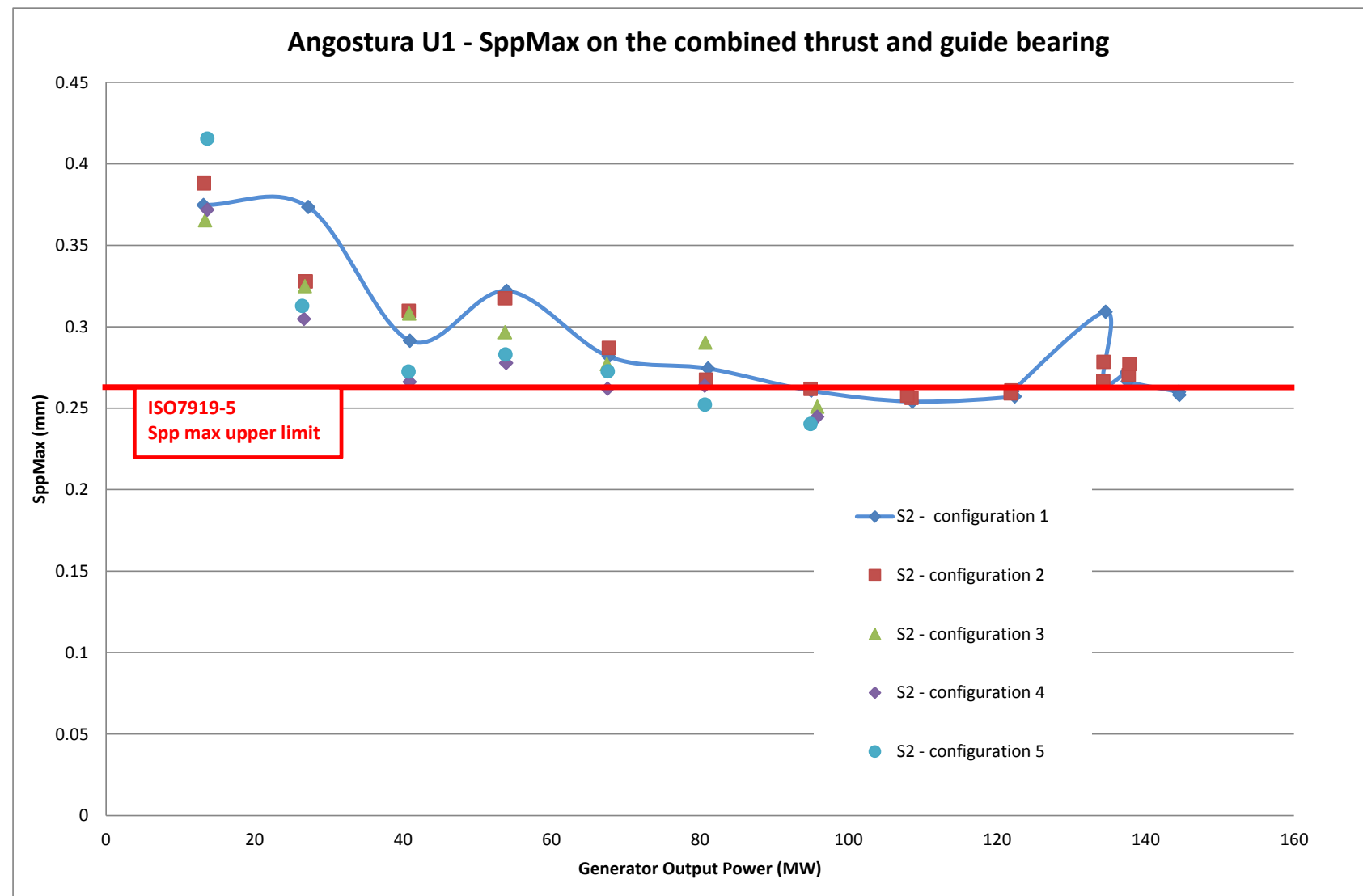
Test point (-)	Generator output power (MW)	S1 Spp max (mm)	Comparison with running clearance (%)	S2 Spp max (mm)	Comparison with running clearance (%)	S3 Spp max LPF 20Hz (mm)	Comparison with running clearance (%)
14MW1	13.120	0.221	34.33%	0.3748	36.05%	0.2110	33.95%
14MW2	13.181	0.218	34.37%	0.388	35.47%	0.2144	28.78%
14MW3	13.345	0.202	35.62%	0.3654	39.62%	0.2014	29.05%
14MW4	13.657	0.203	31.33%	0.3718	33.76%	0.2084	25.73%
14MW5	13.657	0.214	30.72%	0.4154	33.62%	0.2533	30.97%
27MW1	27.237	0.200	30.65%	0.3735	33.68%	0.2729	26.75%
27MW2	26.907	0.180	30.10%	0.3278	33.54%	0.2150	29.65%
27MW3	26.786	0.182	28.55%	0.3249	31.43%	0.1971	27.97%
27MW4	26.670	0.166	28.38%	0.3047	32.13%	0.2270	27.38%
27MW5	26.411	0.171	26.85%	0.3128	30.05%	0.1875	24.30%
41MW1	40.943	0.152	25.07%	0.2914	28.46%	0.1624	27.72%
41MW2	40.764	0.163	25.55%	0.3097	28.85%	0.1942	29.72%
41MW3	40.848	0.166	23.15%	0.308	27.02%	0.2585	21.23%
41MW4	40.895	0.139	22.62%	0.2661	27.02%	0.1340	25.63%
41MW5	40.744	0.140	22.30%	0.2725	26.02%	0.1507	23.67%
54MW1	53.963	0.172	26.73%	0.322	30.56%	0.1614	19.62%
54MW2	53.759	0.164	28.27%	0.3175	32.73%	0.1773	35.78%
54MW3	53.723	0.148	27.37%	0.2966	33.00%	0.1622	34.52%
54MW4	53.893	0.138	28.10%	0.2777	33.76%	0.1475	38.87%
54MW5	53.813	0.140	23.48%	0.2829	29.66%	0.1394	24.55%
68MW1	67.709	0.132	22.33%	0.2817	28.40%	0.1472	18.35%
68MW2	67.741	0.134	22.25%	0.2869	28.73%	0.1660	21.30%
68MW3	67.468	0.126	21.98%	0.277	28.11%	0.1368	21.45%
68MW4	67.551	0.120	19.22%	0.262	25.40%	0.1401	14.18%
68MW5	67.565	0.122	20.27%	0.2726	27.02%	0.1566	19.98%
81MW1	81.090	0.121	18.92%	0.2744	26.40%	0.1431	18.63%
81MW2	80.800	0.117	18.07%	0.2675	25.75%	0.1485	16.30%
81MW3	80.732	0.133	17.93%	0.2903	25.24%	0.1865	17.60%
81MW4	80.629	0.112	16.97%	0.2638	24.01%	0.2816	14.33%
81MW5	80.656	0.111	16.00%	0.2522	23.23%	0.1379	14.90%
95MW1	94.995	0.106	19.60%	0.2607	28.44%	0.1312	25.88%
95MW2	94.893	0.106	17.32%	0.2618	26.14%	0.1335	15.93%
95MW3	95.797	0.102	18.75%	0.2509	27.37%	0.1274	22.22%
95MW4	95.797	0.099	18.38%	0.2447	27.21%	0.1246	21.65%
95MW5	94.894	0.095	17.73%	0.2403	26.11%	0.1273	18.58%
108MW1	108.612	0.096	15.38%	0.2541	24.77%	0.1374	16.83%
108MW21	108.480	0.096	15.78%	0.2563	25.50%	0.1370	20.83%
108MW22	107.927	0.097	15.55%	0.2577	25.21%	0.1390	16.37%
122MW11	122.379	0.094	14.90%	0.2571	24.95%	0.1488	18.50%
122MW12	122.085	0.094	14.58%	0.2605	24.88%	0.1476	17.65%
122MW21	121.939	0.096	15.30%	0.2608	25.27%	0.1539	17.98%
122MW22	121.851	0.095	14.43%	0.2591	24.74%	0.1479	17.37%
136MW11	134.620	0.093	14.20%	0.3092	25.55%	0.2255	14.18%
136MW12	134.303	0.093	14.97%	0.266	26.08%	0.1588	21.17%
136MW21	134.323	0.094	15.20%	0.2664	26.18%	0.1648	23.77%
136MW22	134.356	0.099	14.52%	0.2784	25.45%	0.1636	19.35%
137MW11	137.478	0.098	14.37%	0.272	25.74%	0.1645	20.18%
137MW12	137.582	0.094	14.52%	0.2664	25.67%	0.1529	18.25%
137MW21	137.749	0.096	14.50%	0.2702	25.77%	0.1495	19.52%
137MW22	137.831	0.096	15.08%	0.2772	26.22%	0.1541	20.47%
144MW11	144.499	0.093	13.93%	0.2601	24.25%	0.1607	18.38%
144MW12	144.484	0.093	12.68%	0.2601	23.23%	0.1606	15.42%
144MW13	144.568	0.093	14.28%	0.2581	24.67%	0.1568	19.82%


According to the shaft running clearances (please refer to Appendix 2 for running clearance values), following graphs show results of Spp and Smax.

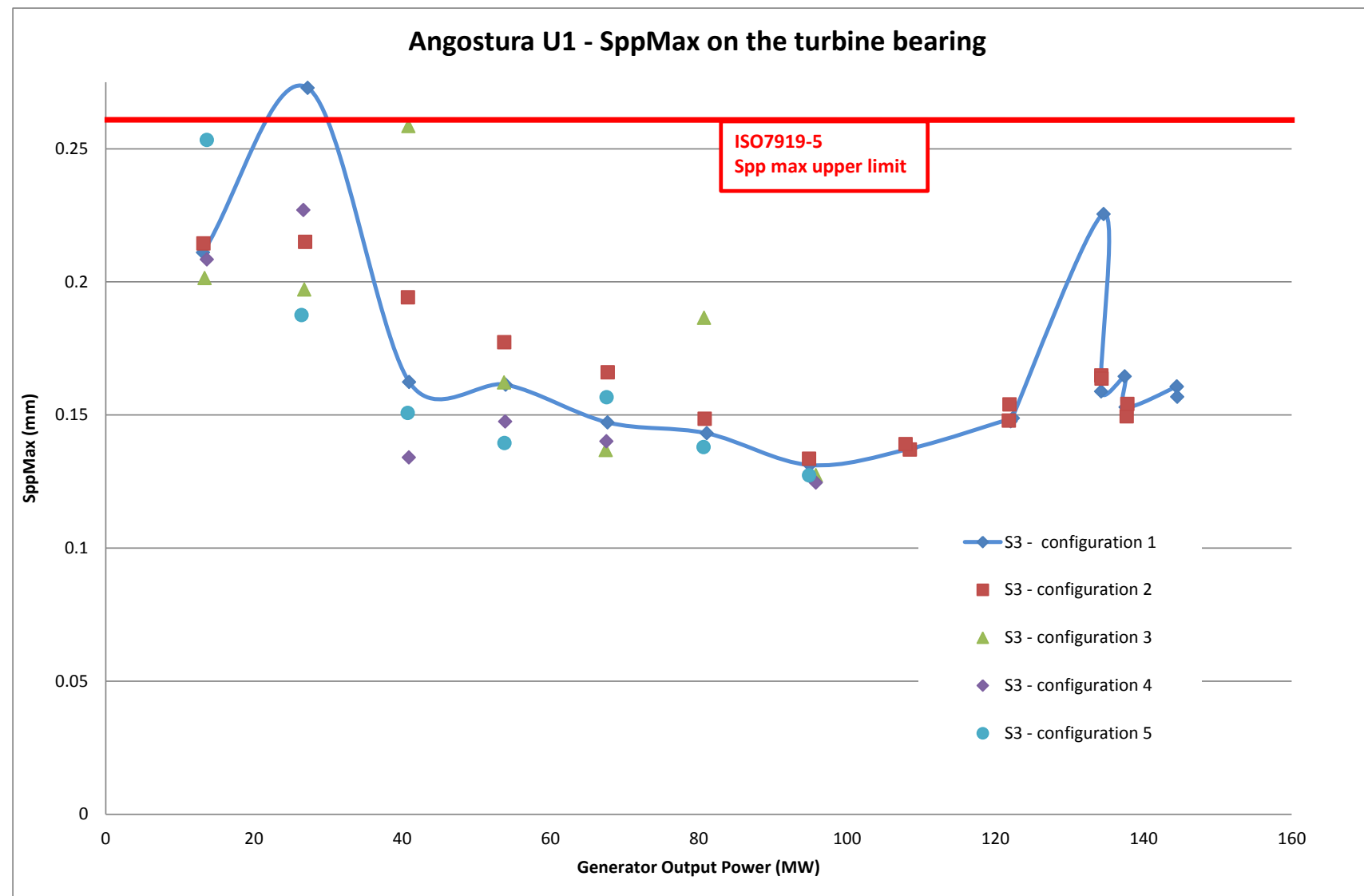
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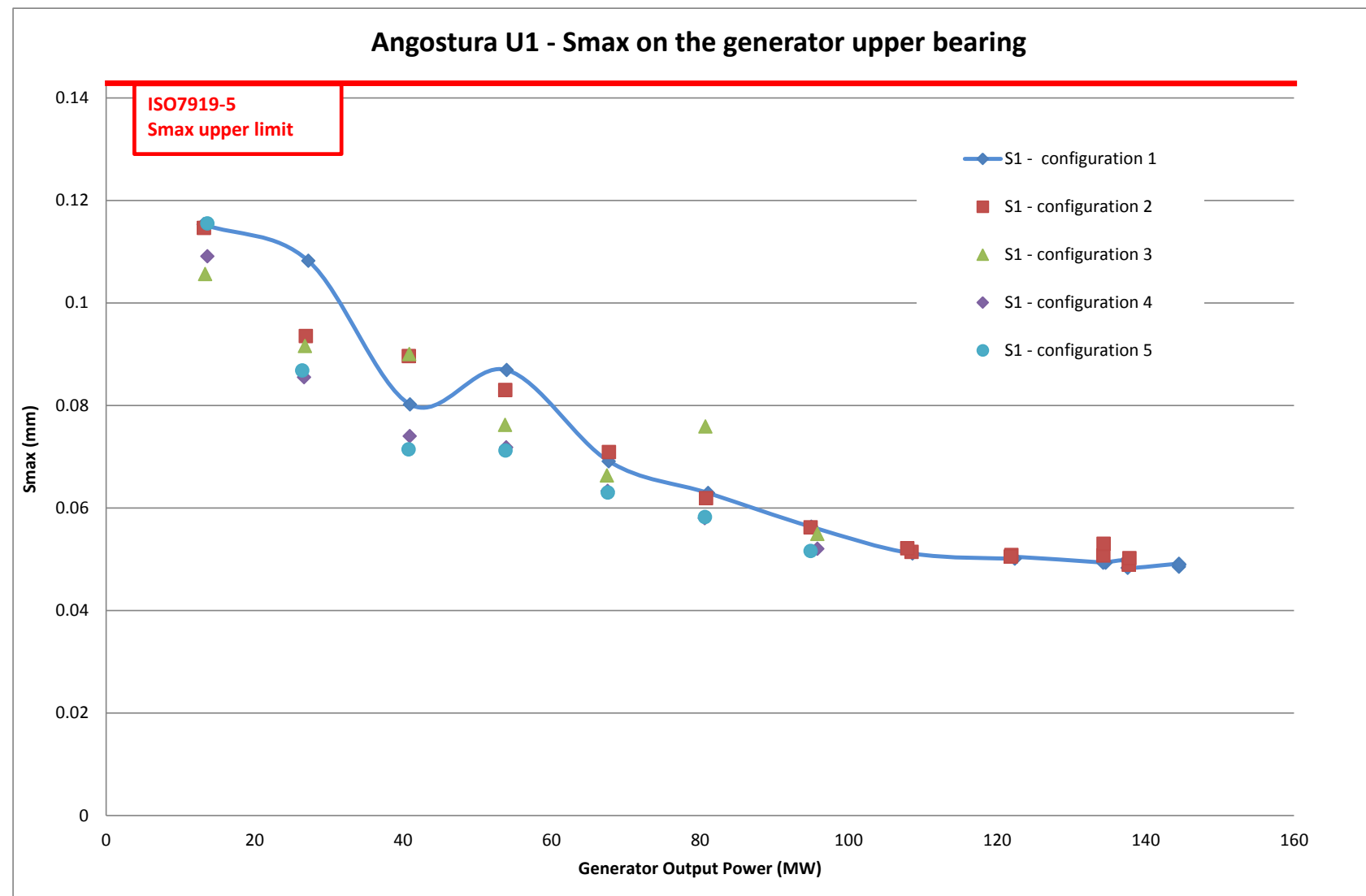
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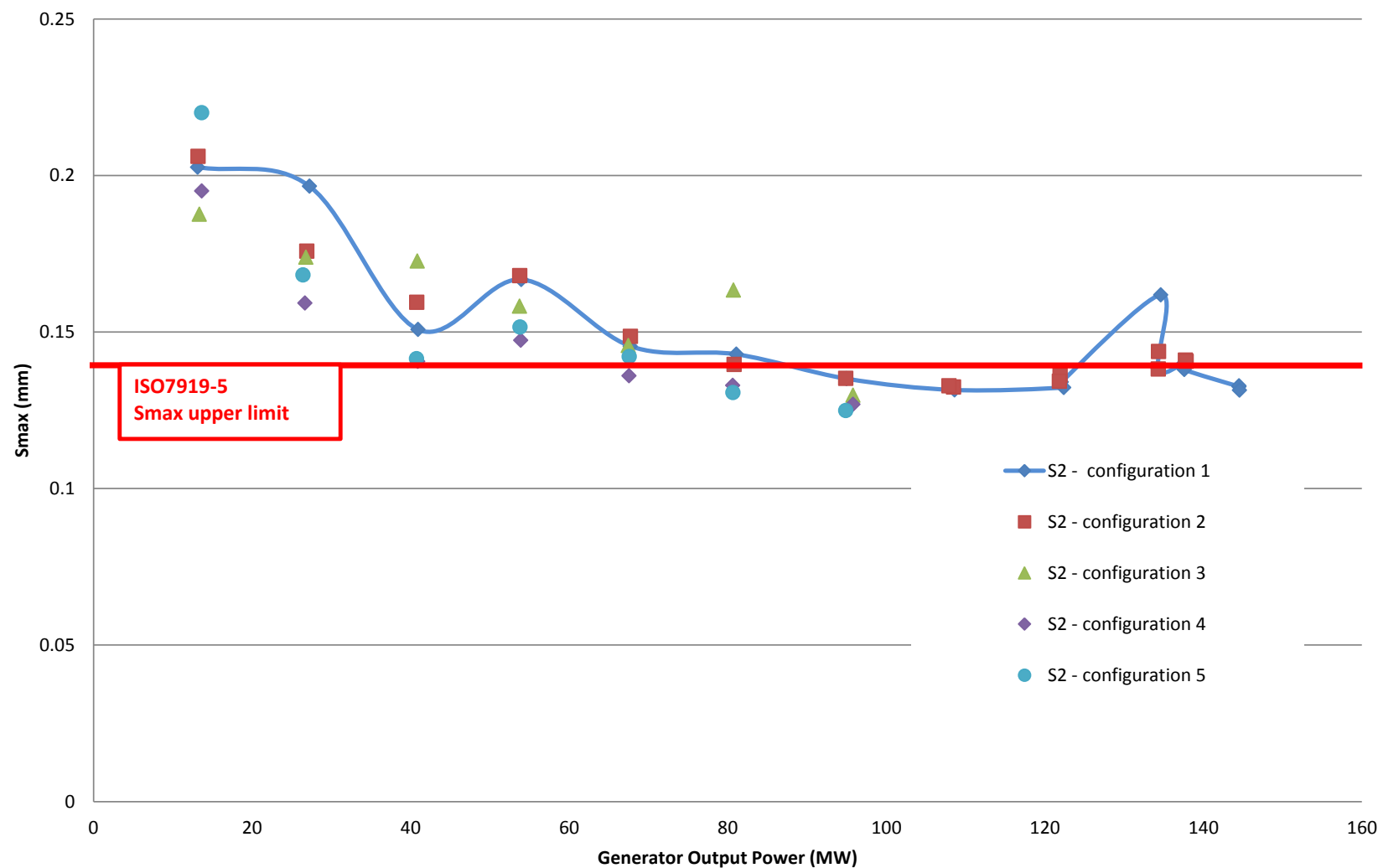



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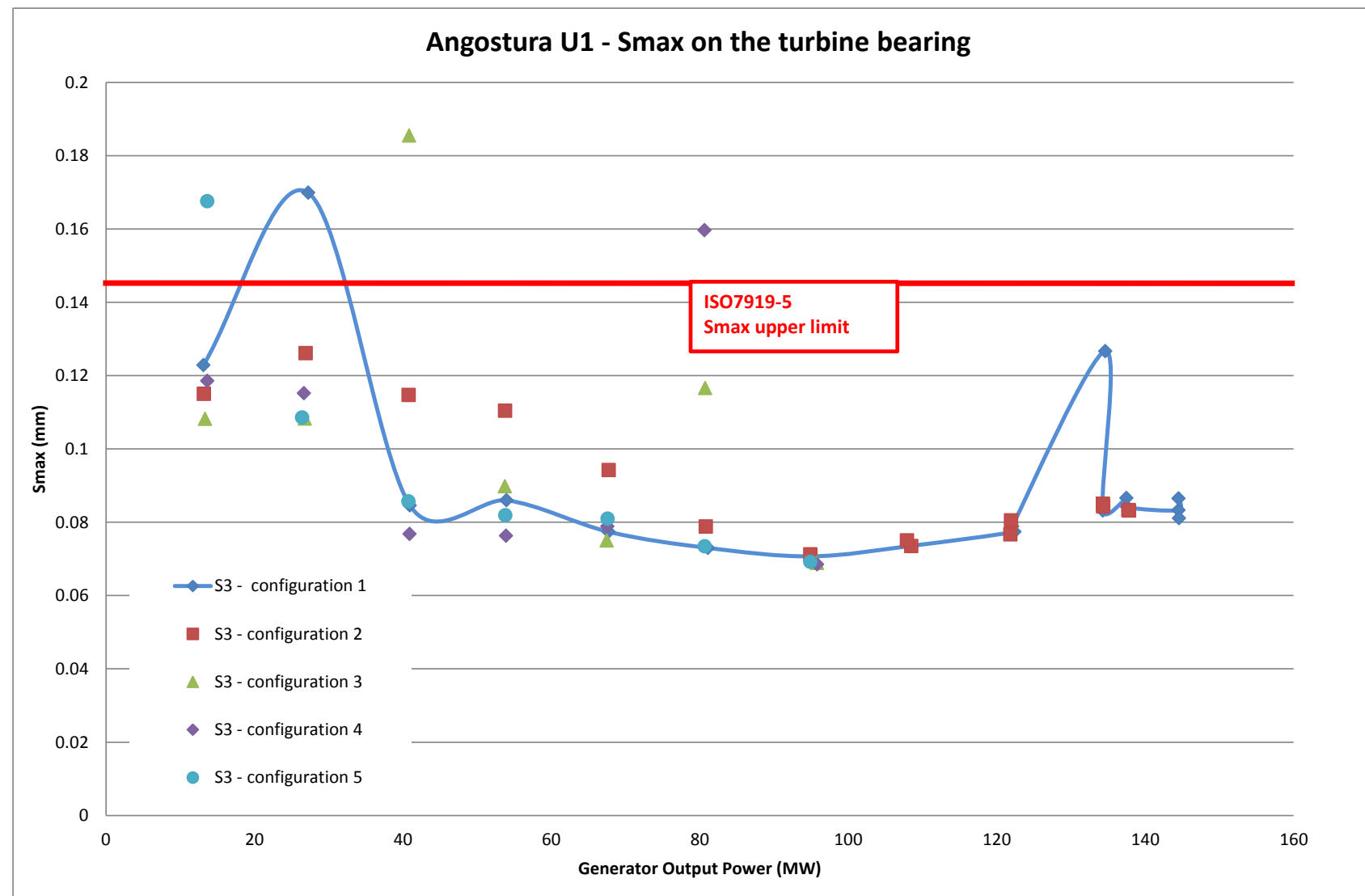



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Angostura U1 - Smax on the combined thrust and guide bearing



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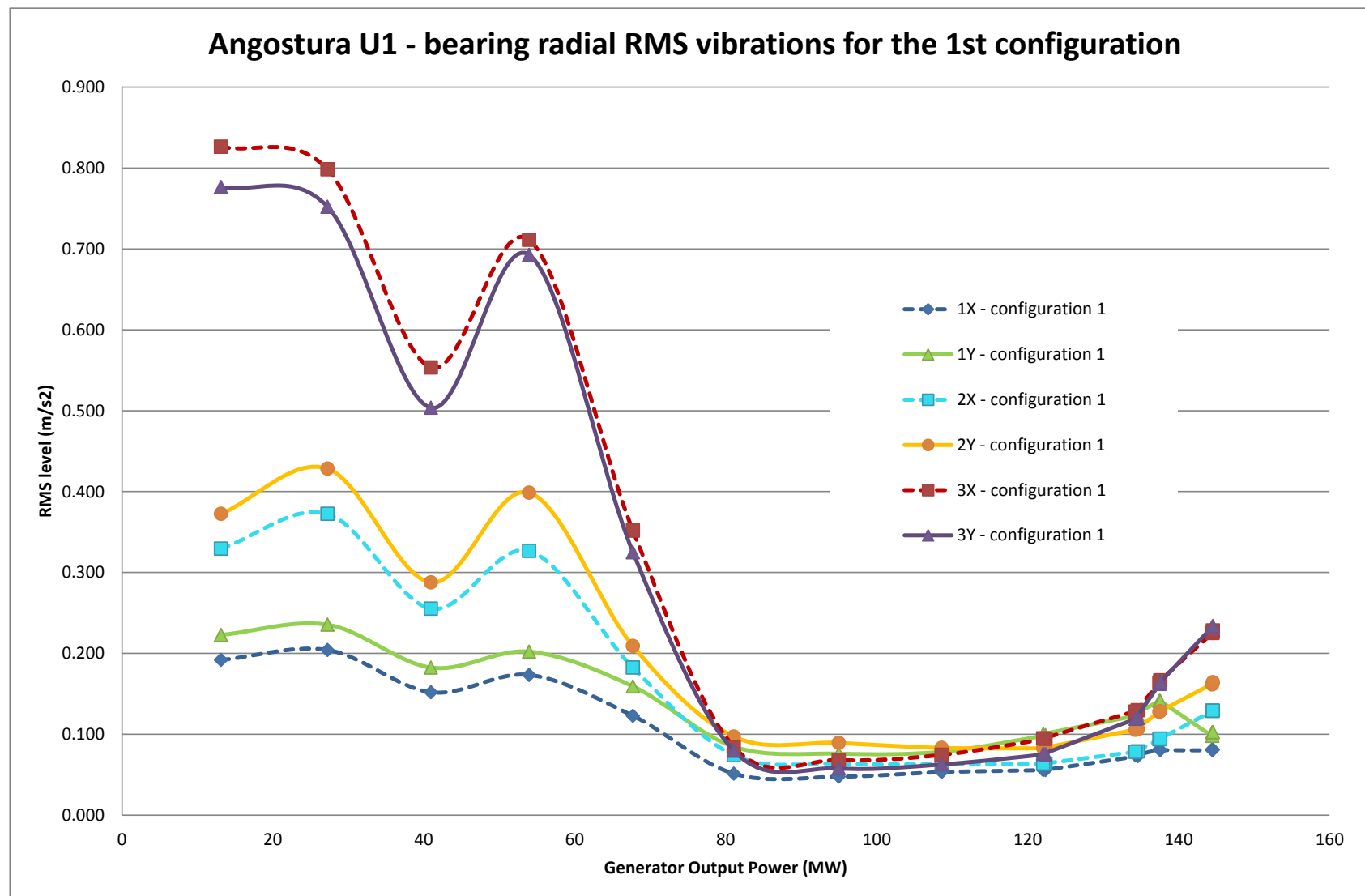
7.2.2. Time Domain acceleration signals


Global RMS values are calculated on the time domain signal and presented in m/s^2 . Integrated values of acceleration are part of Spectrum analysis paragraph.

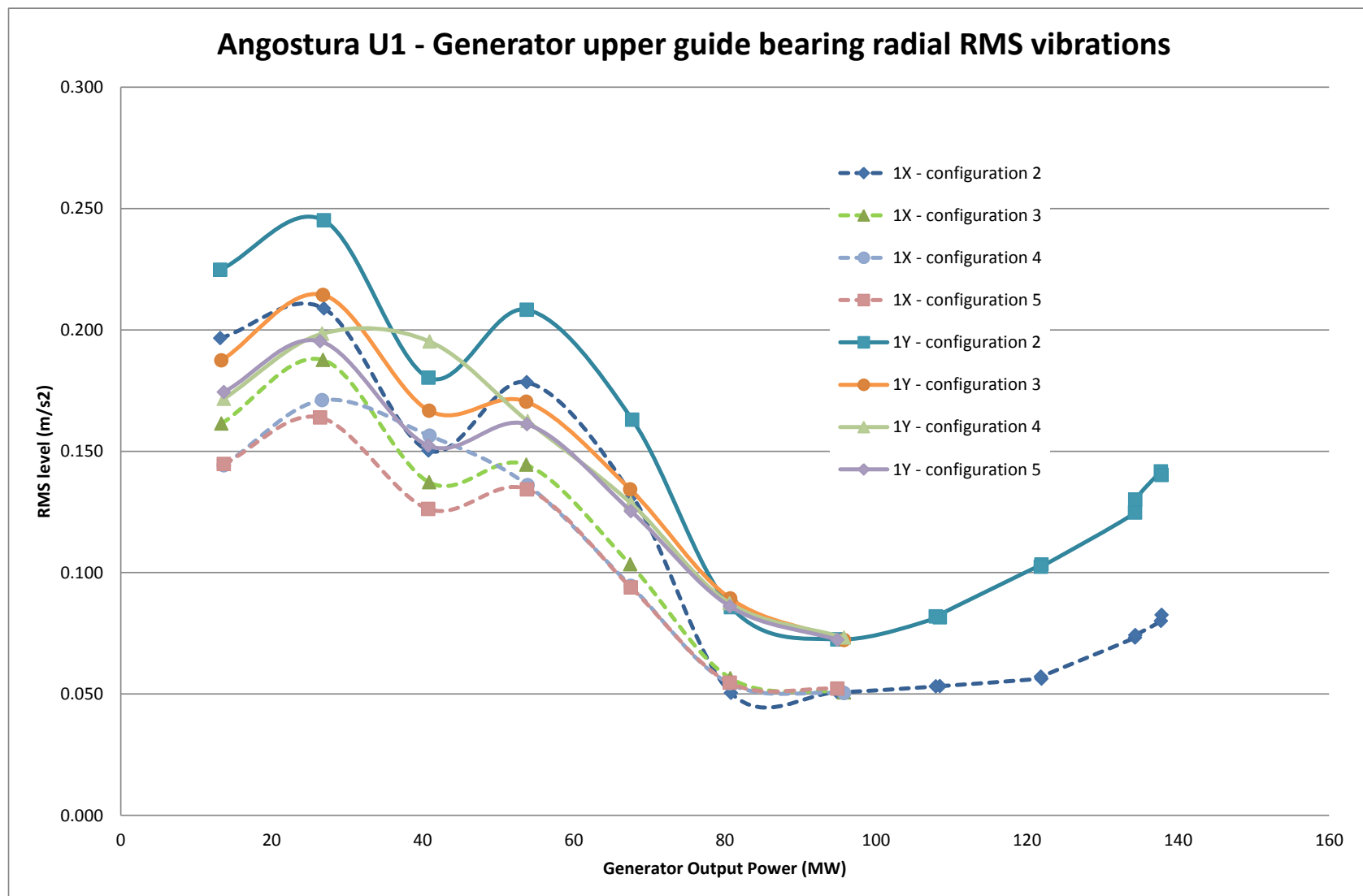
Test point (-)	1X RMS level m/s^2	1Y RMS level m/s^2	2X RMS level m/s^2	2Y RMS level m/s^2	2Z RMS level m/s^2	3X RMS level m/s^2	3Y RMS level m/s^2	3Z RMS level m/s^2	Vib_ConeX RMS level m/s^2	Vib_ConeY RMS level m/s^2
14MW1	0.192	0.223	0.329	0.372	0.559	0.826	0.777	1.428	4.678	5.888
14MW2	0.197	0.225	0.331	0.362	0.562	0.823	0.763	1.413	4.948	5.886
14MW3	0.161	0.187	0.230	0.248	0.435	0.512	0.467	0.860	3.433	3.498
14MW4	0.144	0.172	0.189	0.203	0.379	0.454	0.420	0.768	2.305	2.305
14MW5	0.145	0.174	0.188	0.203	0.378	0.457	0.422	0.763	2.360	2.300
27MW1	0.204	0.236	0.373	0.428	0.597	0.798	0.752	1.279	6.855	7.978
27MW2	0.209	0.245	0.381	0.437	0.633	0.834	0.779	1.314	6.760	7.880
27MW3	0.188	0.214	0.266	0.286	0.531	0.600	0.540	1.022	4.384	4.235
27MW4	0.171	0.198	0.226	0.239	0.477	0.533	0.477	0.899	2.952	2.673
27MW5	0.164	0.195	0.216	0.231	0.447	0.521	0.477	0.877	2.831	2.578
41MW1	0.152	0.182	0.255	0.288	0.406	0.554	0.504	0.959	5.540	6.124
41MW2	0.150	0.180	0.251	0.289	0.413	0.548	0.498	0.946	5.387	5.912
41MW3	0.137	0.167	0.187	0.198	0.356	0.408	0.355	0.789	3.556	3.206
41MW4	0.156	0.195	0.175	0.185	0.327	0.370	0.326	0.659	2.638	2.317
41MW5	0.126	0.152	0.163	0.176	0.312	0.359	0.318	0.692	2.405	2.102
54MW1	0.173	0.202	0.327	0.399	0.435	0.711	0.693	1.163	4.819	5.554
54MW2	0.178	0.208	0.334	0.412	0.441	0.734	0.714	1.187	4.906	5.646
54MW3	0.144	0.170	0.210	0.236	0.374	0.442	0.415	0.780	3.457	3.420
54MW4	0.136	0.162	0.177	0.193	0.307	0.362	0.350	0.623	2.368	2.190
54MW5	0.134	0.161	0.169	0.187	0.289	0.363	0.342	0.643	2.349	2.163
68MW1	0.123	0.159	0.182	0.209	0.271	0.352	0.325	0.663	1.762	2.045
68MW2	0.132	0.163	0.192	0.218	0.279	0.376	0.351	0.684	1.820	2.162
68MW3	0.103	0.134	0.136	0.151	0.208	0.293	0.257	0.507	1.075	1.138
68MW4	0.095	0.129	0.114	0.131	0.164	0.278	0.269	0.436	0.920	0.838
68MW5	0.094	0.125	0.107	0.131	0.166	0.272	0.260	0.434	0.899	0.839
81MW1	0.051	0.085	0.074	0.097	0.092	0.084	0.080	0.142	0.606	0.741
81MW2	0.050	0.086	0.075	0.099	0.093	0.092	0.086	0.149	0.625	0.755
81MW3	0.057	0.089	0.070	0.091	0.076	0.075	0.073	0.126	0.322	0.301
81MW4	0.054	0.087	0.070	0.095	0.066	0.084	0.080	0.139	0.230	0.196
81MW5	0.055	0.086	0.069	0.088	0.070	0.080	0.075	0.143	0.212	0.190
95MW1	0.048	0.076	0.064	0.089	0.042	0.068	0.058	0.107	0.191	0.204
95MW2	0.051	0.073	0.065	0.085	0.044	0.074	0.062	0.114	0.279	0.312
95MW3	0.051	0.072	0.068	0.090	0.042	0.074	0.072	0.107	0.162	0.155
95MW4	0.050	0.073	0.068	0.090	0.046	0.080	0.080	0.127	0.147	0.155
95MW5	0.052	0.072	0.065	0.083	0.050	0.070	0.067	0.121	0.139	0.131
108MW1	0.053	0.078	0.063	0.083	0.036	0.075	0.063	0.115	0.136	0.155
108MW21	0.053	0.082	0.064	0.083	0.036	0.084	0.068	0.128	0.138	0.159
108MW22	0.053	0.082	0.063	0.084	0.035	0.077	0.064	0.120	0.136	0.150
122MW11	0.056	0.099	0.064	0.083	0.040	0.094	0.075	0.138	0.193	0.238
122MW12	0.0557	0.1003	0.0637	0.083	0.0414	0.0949	0.0757	0.1401	0.19	0.231
122MW21	0.0563	0.1033	0.0637	0.0829	0.0417	0.0979	0.0782	0.1438	0.1929	0.2329
122MW22	0.0571	0.1024	0.0628	0.0829	0.0403	0.0973	0.0777	0.1446	0.1902	0.2277
136MW11	0.0729	0.1236	0.0787	0.1063	0.0488	0.1295	0.1201	0.1773	0.6054	0.7875
136MW12	0.0738	0.1249	0.0783	0.1056	0.048	0.1281	0.119	0.1754	0.6014	0.7614
136MW21	0.0732	0.1247	0.0772	0.1045	0.0481	0.1286	0.1183	0.1743	0.6038	0.7938
136MW22	0.0742	0.1301	0.0776	0.1052	0.0511	0.1299	0.1198	0.177	0.5871	0.7663
137MW11	0.0812	0.1413	0.0939	0.1278	0.0601	0.1639	0.1621	0.2122	0.8957	1.2787
137MW12	0.0805	0.1411	0.0947	0.1286	0.0589	0.1666	0.1643	0.2171	0.9039	1.284
137MW21	0.0801	0.1417	0.096	0.1311	0.0596	0.1684	0.1639	0.2188	0.9214	1.3035
137MW22	0.0826	0.1402	0.0993	0.133	0.0646	0.1742	0.171	0.2285	0.9969	1.4495
144MW11	0.0802	0.0979	0.1287	0.1624	0.0799	0.2252	0.233	0.2973	1.3604	1.8533
144MW12	0.0813	0.1024	0.1292	0.1617	0.0802	0.2253	0.232	0.2957	1.3546	1.853
144MW13	0.0809	0.1027	0.129	0.1644	0.0805	0.2283	0.2337	0.3008	1.3651	1.8671


As we can see in graphs hereunder, the head cover and bottom ring air injection reduce drastically the vibration levels.

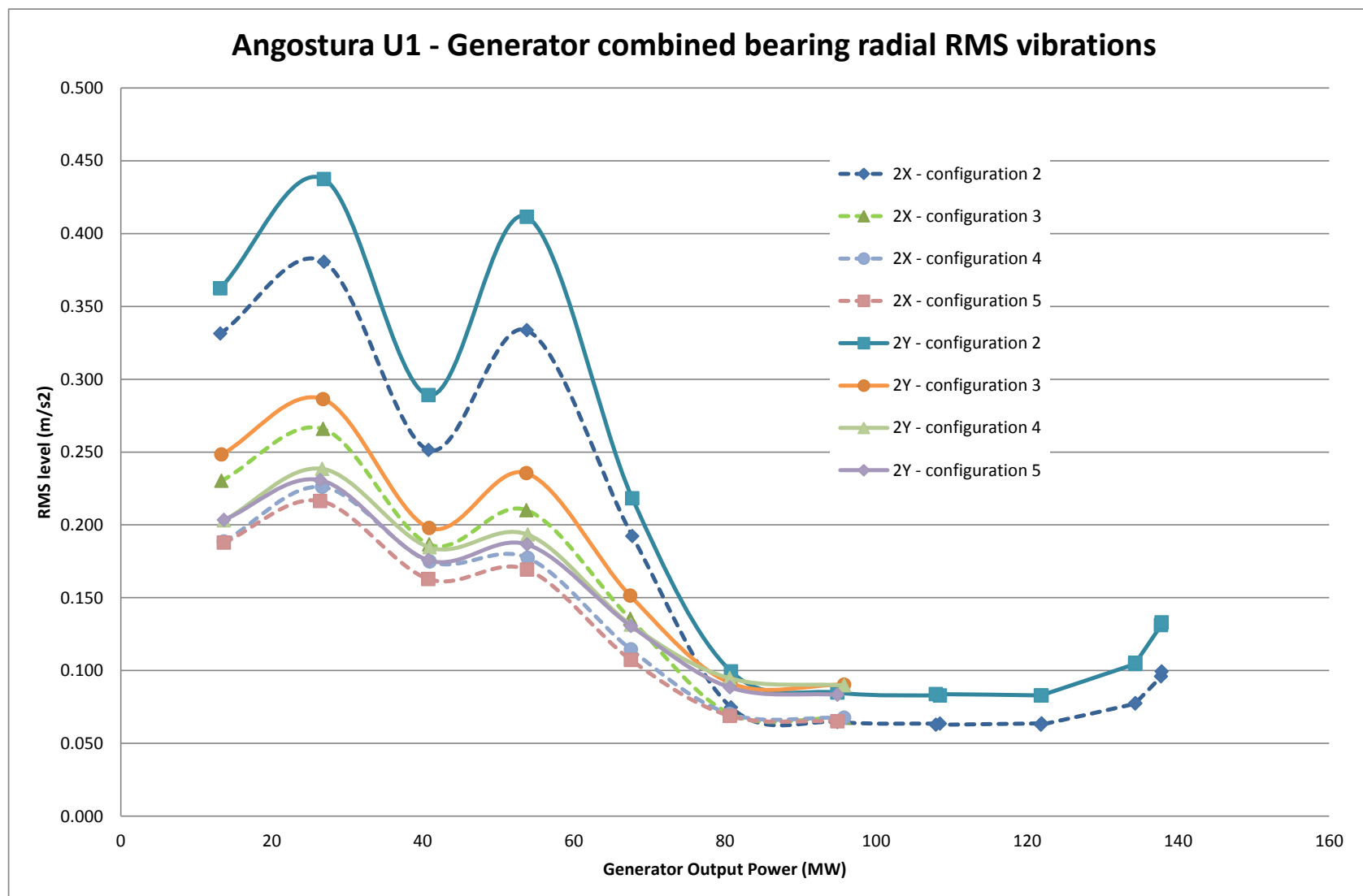
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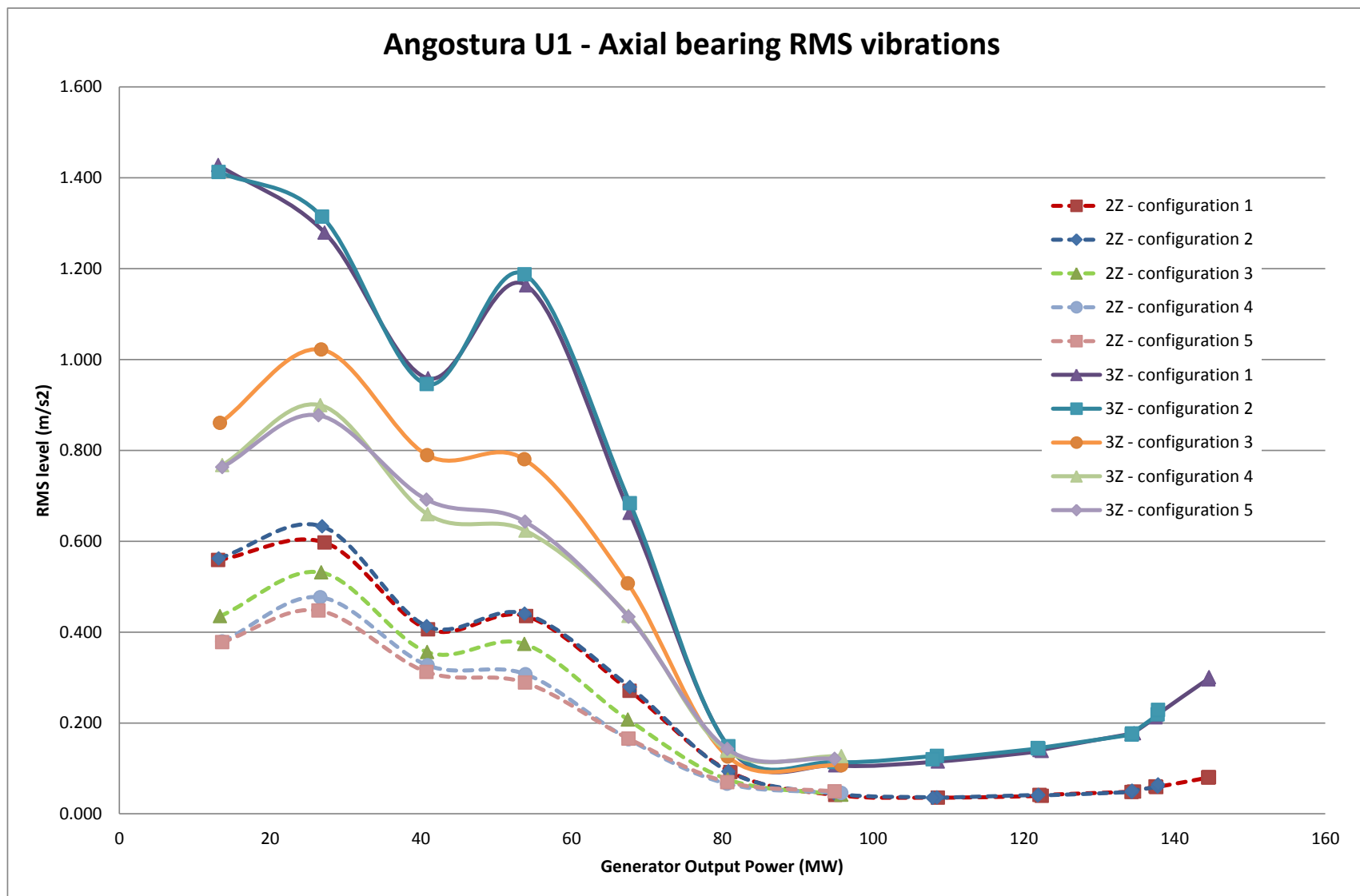
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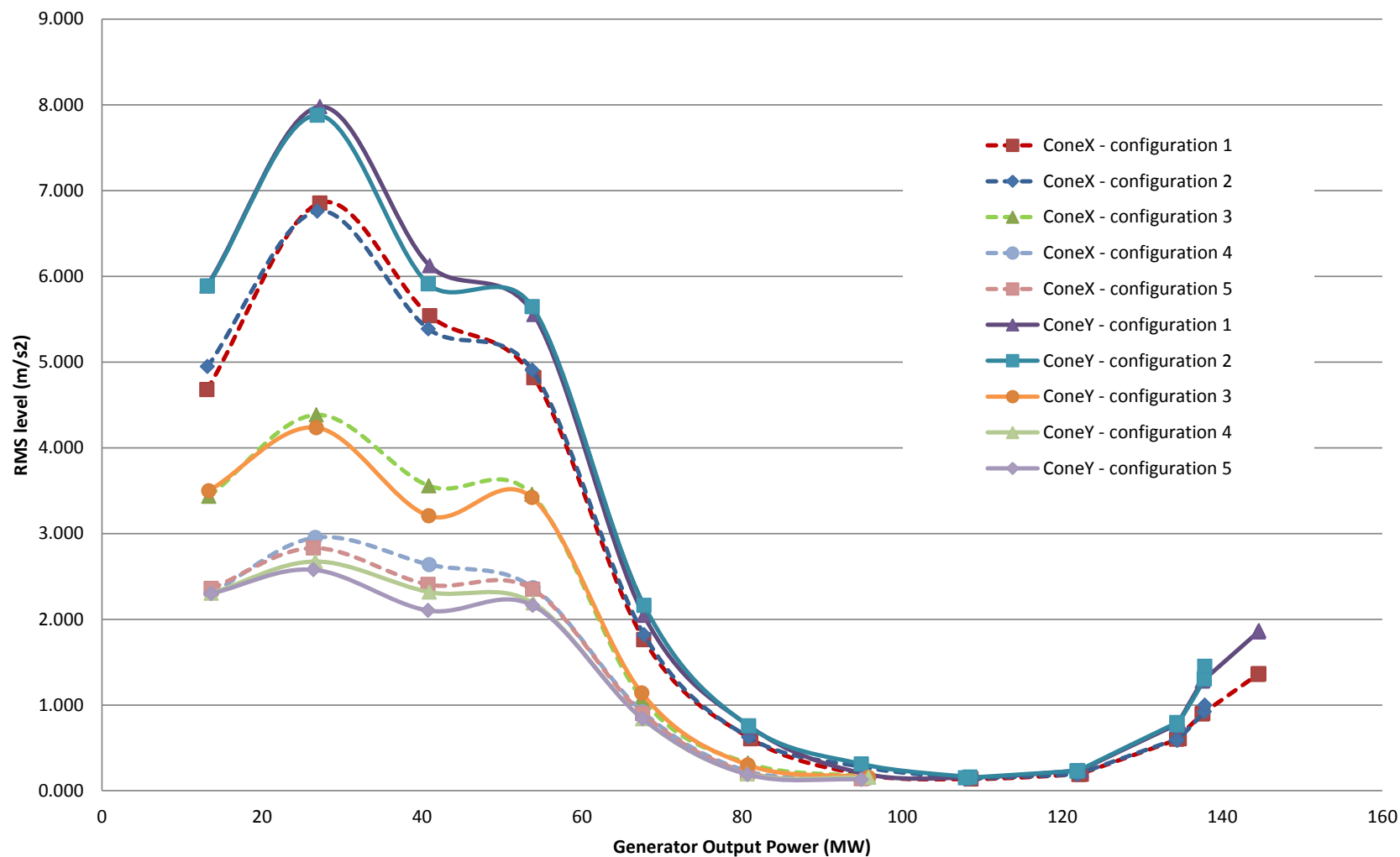



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Angostura U1 - Draft tube cone RMS vibrations




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7.2.3. Time Domain pressures

Hereafter are presented peak to peak 97% results on 10 shaft revolutions.

Test point	Net Head from WK	P_SC_Dyn pp97%	P_SC_Dyn /Net Head	P_Cone_Dyn pp97% LPF 20Hz	P_Cone_Dyn /Net Head
(-)	(m)	(Pa)	(%)	(Pa)	(%)
14MW1	51.14	22442	4.49%	81201	16.23%
14MW2	51.08	22409	4.49%	80057	16.02%
14MW3	51.12	20317	4.06%	74785	14.96%
14MW4	50.98	20081	4.03%	70661	14.17%
14MW5	51.15	18570	3.71%	72803	14.55%
27MW1	50.76	24846	5.00%	102258	20.60%
27MW2	50.63	25192	5.09%	101736	20.54%
27MW3	50.63	22099	4.46%	91711	18.52%
27MW4	50.46	20665	4.19%	77317	15.66%
27MW5	50.37	21755	4.42%	78160	15.86%
41MW1	50.20	22992	4.68%	95706	19.49%
41MW2	50.19	27571	5.62%	94856	19.32%
41MW3	50.20	20609	4.20%	77725	15.83%
41MW4	50.20	21211	4.32%	67406	13.73%
41MW5	50.20	18215	3.71%	64531	13.14%
54MW1	49.87	18401	3.77%	40284	8.26%
54MW2	49.97	18848	3.86%	40727	8.33%
54MW3	49.85	18971	3.89%	45448	9.32%
54MW4	49.79	16887	3.47%	37563	7.71%
54MW5	49.79	15247	3.13%	38545	7.91%
68MW1	49.55	10091	2.08%	29399	6.07%
68MW2	49.58	12949	2.67%	29648	6.11%
68MW3	49.53	12744	2.63%	29369	6.06%
68MW4	49.56	12650	2.61%	28512	5.88%
68MW5	49.53	12646	2.61%	26985	5.57%
81MW1	49.24	15796	3.28%	28141	5.84%
81MW2	49.11	14630	3.05%	28787	5.99%
81MW3	49.02	14103	2.94%	27864	5.81%
81MW4	48.97	12978	2.71%	28674	5.99%
81MW5	48.88	12366	2.59%	27413	5.73%
95MW1	48.38	9827	2.08%	17085	3.61%
95MW2	48.48	10136	2.14%	18294	3.86%
95MW3	48.47	9659	2.04%	17073	3.60%
95MW4	48.41	10111	2.14%	16170	3.41%
95MW5	48.38	10367	2.19%	17021	3.60%
108MW1	47.97	1625	0.35%	2302	0.49%
108MW2	48.05	1654	0.35%	2271	0.48%
108MW22	48.05	1680	0.36%	2404	0.51%
122MW11	47.29	1103	0.24%	1878	0.41%
122MW12	47.19	1091	0.24%	1837	0.40%
122MW21	47.09	1091	0.24%	1871	0.41%
122MW22	47.09	1060	0.23%	1866	0.41%
136MW11	46.27	2894	0.64%	2977	0.66%
136MW12	45.81	2780	0.62%	2872	0.64%
136MW21	45.94	8976	2.00%	7009	1.56%
136MW22	47.77	3546	0.76%	3515	0.75%
137MW11	47.31	3057	0.66%	4023	0.87%
137MW12	47.29	2873	0.62%	4098	0.89%
137MW21	47.28	4986	1.08%	4710	1.02%
137MW22	47.32	63619	13.75%	46532	10.05%
144MW11	48.89	3549	0.74%	5048	1.06%
144MW12	48.89	3332	0.70%	4955	1.04%
144MW13	48.90	3396	0.71%	4892	1.02%

We can see that the pressure fluctuation is higher at high load (137MW22) for the temporary test with the closed axial valve. However, for normal operation of the unit, the axial valve is open.


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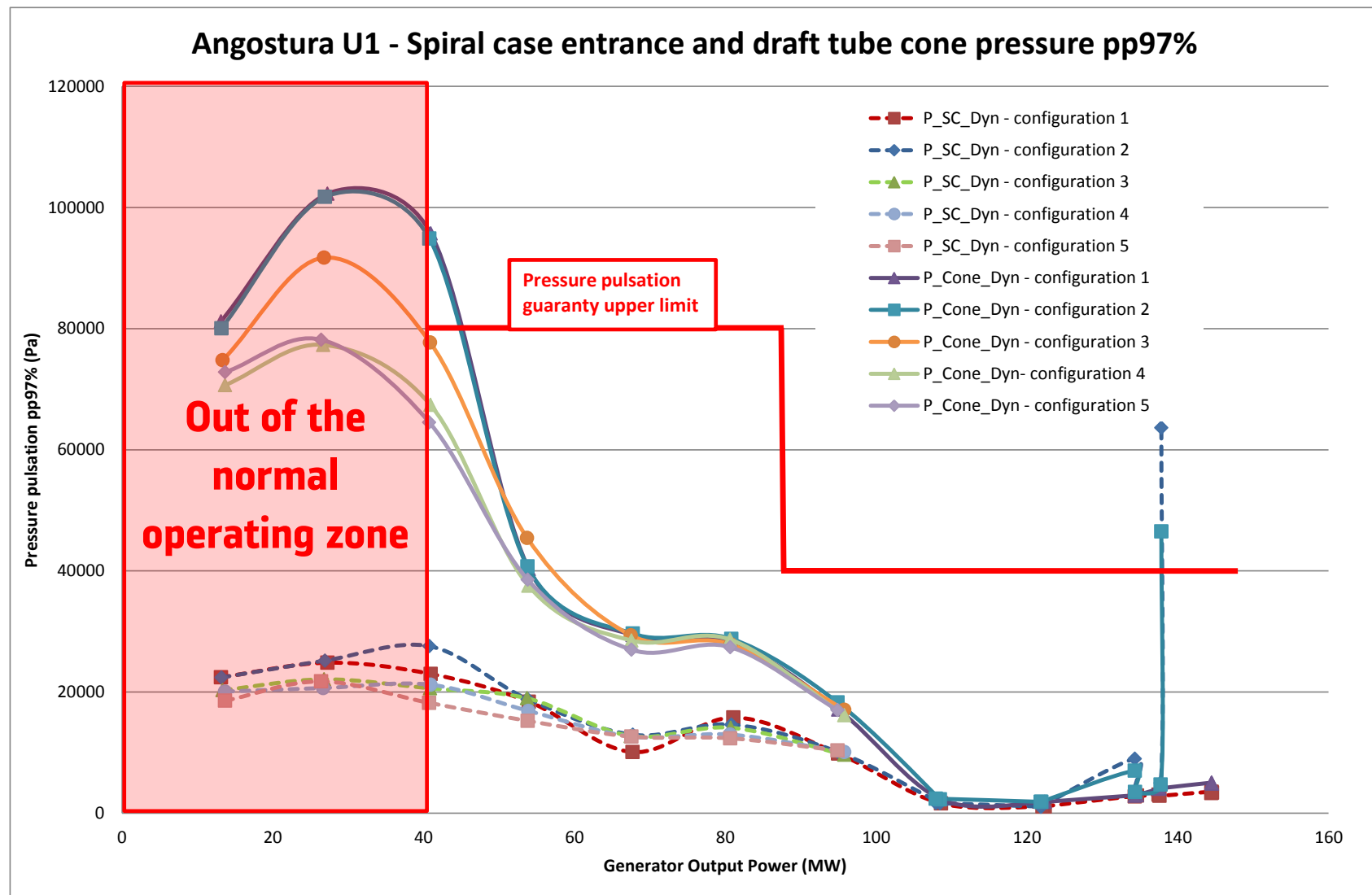
According to the contract, the peak to peak shall not exceed the following values:

From el "ACTA de Acuerdos N°1 Rev1":


2.2 Fluctuaciones de presión en el difusor. ALSTOM confirma las garantías de fluctuaciones de presión dentro de la zona de funcionamiento continuo, contempladas en su propuesta:

- U1/U2 : [210 m³/s – 330 m³/s] 4 mca peak-to-peak.
[120 m³/s – 210 m³/s] 8 mca peak-to-peak.
- U3 : [70 m³/s – 110 m³/s] 4 mca peak-to-peak.
[40 m³/s – 70 m³/s] 8 mca peak-to-peak.

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As we can see on the previous graphs, the guaranty is fulfilled.


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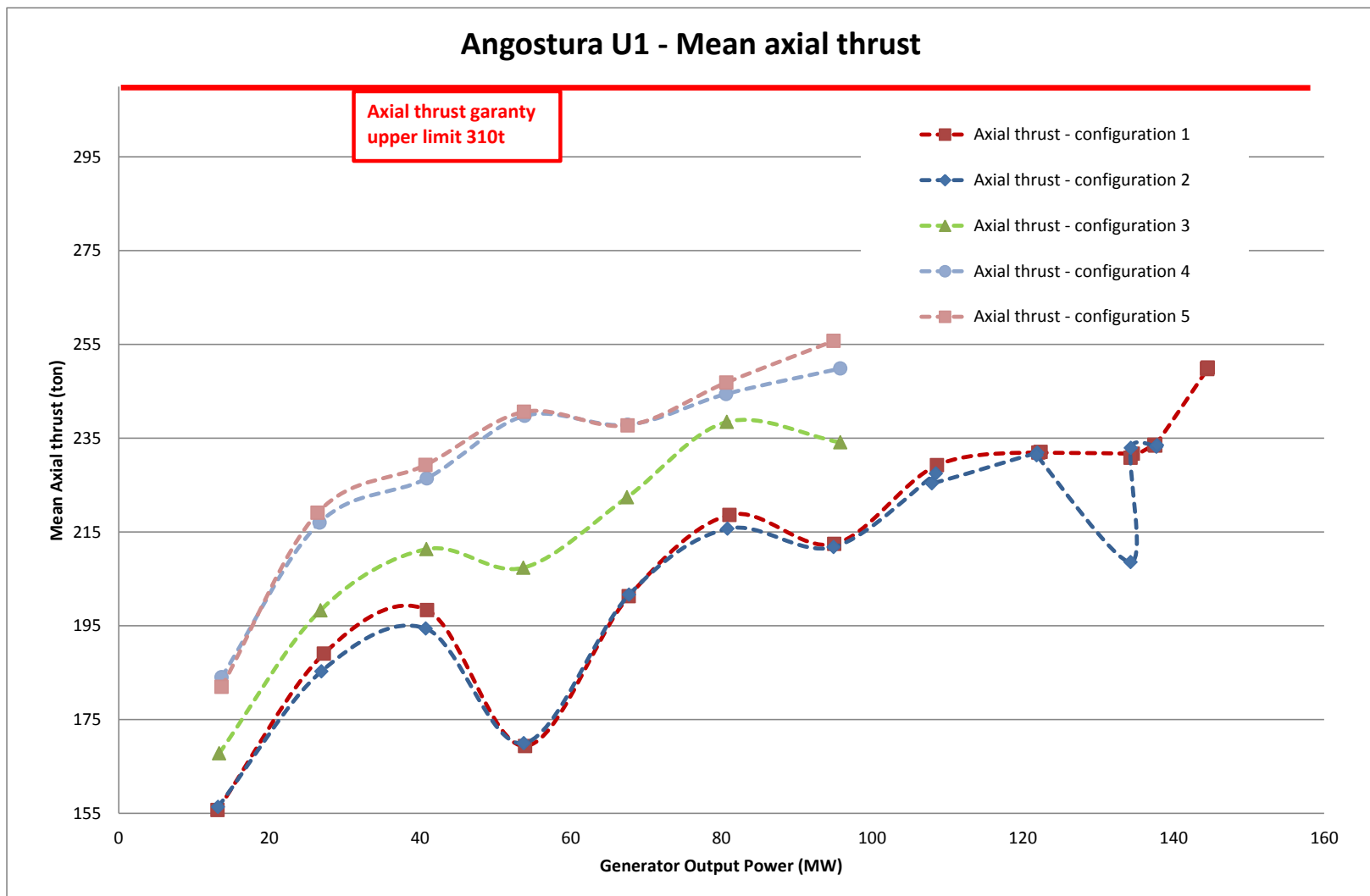
7.2.4. Time Domain axial thrust


Test name (-)	Generator output power (MW)	P_membrane mean (N)	Axial thrust mean (ton)	P_membrane pp97% 10rev (N)	Axial thrust pp97% 10rev (ton)
14MW1	13.120	6305080	155.709	790667	80.689
14MW2	13.181	6311564	156.370	782640	79.869
14MW3	13.345	6423495	167.793	647624	66.091
14MW4	13.657	6582555	184.025	618596	63.128
14MW5	13.657	6562293	181.957	595558	60.777
27MW1	27.237	6631710	189.042	795959	81.229
27MW2	26.907	6594826	185.277	815669	83.240
27MW3	26.786	6722295	198.286	720921	73.571
27MW4	26.670	6905695	217.002	711588	72.618
27MW5	26.411	6926163	219.091	661229	67.479
41MW1	40.943	6722807	198.338	584616	59.661
41MW2	40.764	6684262	194.405	636295	64.935
41MW3	40.848	6850206	211.339	550825	56.212
41MW4	40.895	6998204	226.443	537799	54.883
41MW5	40.744	7026328	229.313	493448	50.357
54MW1	53.963	6438786	169.353	481723	49.160
54MW2	53.759	6444734	169.960	502295	51.260
54MW3	53.723	6811408	207.380	510860	52.134
54MW4	53.893	7128951	239.786	477849	48.765
54MW5	53.813	7137185	240.626	445934	45.508
68MW1	67.709	6751714	201.288	375210	38.291
68MW2	67.741	6755044	201.628	413888	42.238
68MW3	67.468	6958528	222.394	368158	37.571
68MW4	67.551	7110038	237.856	366684	37.421
68MW5	67.565	7108750	237.724	341441	34.844
81MW1	81.090	6921773	218.643	465785	47.534
81MW2	80.800	6892864	215.693	435062	44.399
81MW3	80.732	7116068	238.471	391546	39.958
81MW4	80.629	7174541	244.438	344639	35.171
81MW5	80.656	7198426	246.876	372451	38.009
95MW1	94.995	6861125	212.454	322847	32.947
95MW2	94.893	6854596	211.787	311245	31.763
95MW3	95.797	7073294	234.106	328409	33.514
95MW4	95.797	7227734	249.866	328220	33.495
95MW5	94.894	7285274	255.739	337720	34.465
108MW1	108.612	7025524	229.231	236659	24.151
108MW21	108.480	7008188	227.462	235988	24.083
108MW22	107.927	6987895	225.391	233485	23.827
122MW11	122.379	7053365	232.072	238950	24.385
122MW12	122.085	7051967	231.929	235509	24.034
122MW21	121.939	7051749	231.907	234754	23.957
122MW22	121.851	7046173	231.338	236855	24.171
136MW11	134.620	7049373	231.665	240302	24.523
136MW12	134.303	7041168	230.827	238075	24.296
136MW21	134.323	6823348	208.598	39039	3.984
136MW22	134.356	7061653	232.918	242462	24.743
137MW11	137.478	7068357	233.602	239375	24.428
137MW12	137.582	7066536	233.416	243988	24.899
137MW21	137.749	7064352	233.193	255058	26.029
137MW22	137.831	7067228	233.487	1089759	111.211
144MW11	144.499	7226214	249.711	260977	26.633
144MW12	144.484	7227794	249.873	258580	26.388
144MW13	144.568	7229574	250.054	266370	27.183

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As per with pressure fluctuation we can see that the Axial thrust fluctuation is higher at high load (137MW22) when the axial valve has been closed temporarily for the purpose of the test.

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7.2.5. Accelerometers spectrum analysis

Hereunder are summed-up the global acceleration and velocity levels under each steady state point.


Comparison with ISO 10816-5 standard:

ISO 10816-5 standard defines radial vibration limitation for bearing housing under normal operating conditions. Four zones have been defined according to RMS velocity levels and Peak to Peak relative displacement.


- A:** New machines
- B:** acceptable without restriction
- C:** Bearable for limited time operation
- D:** abnormal

Hereafter, the A,B,C and D zone boundaries given by the ISO 10816-5 standard :


Zone	RMS Velocity (mm/s)
A-B	1.6
B-C	2.5
C-D	4

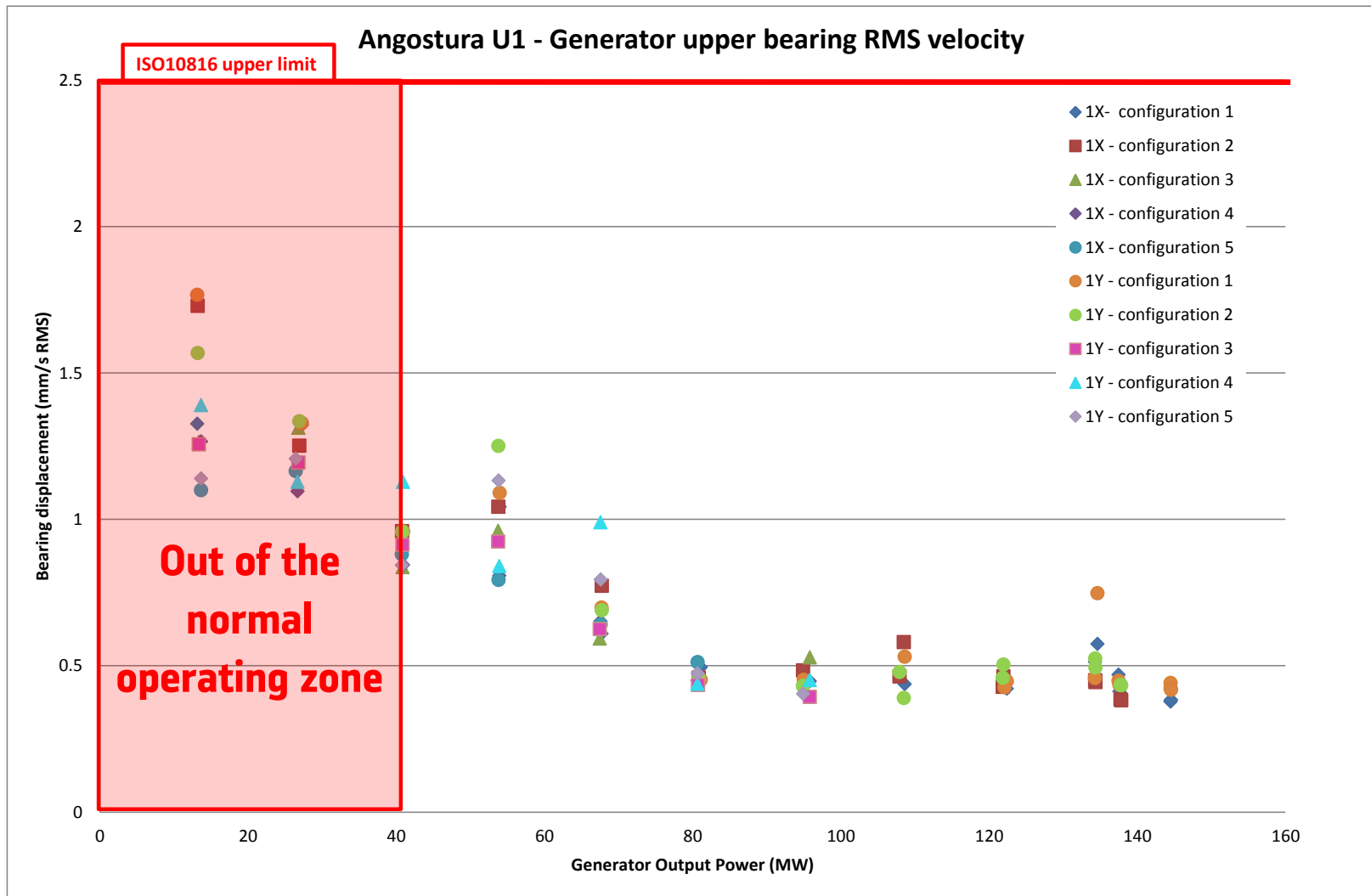
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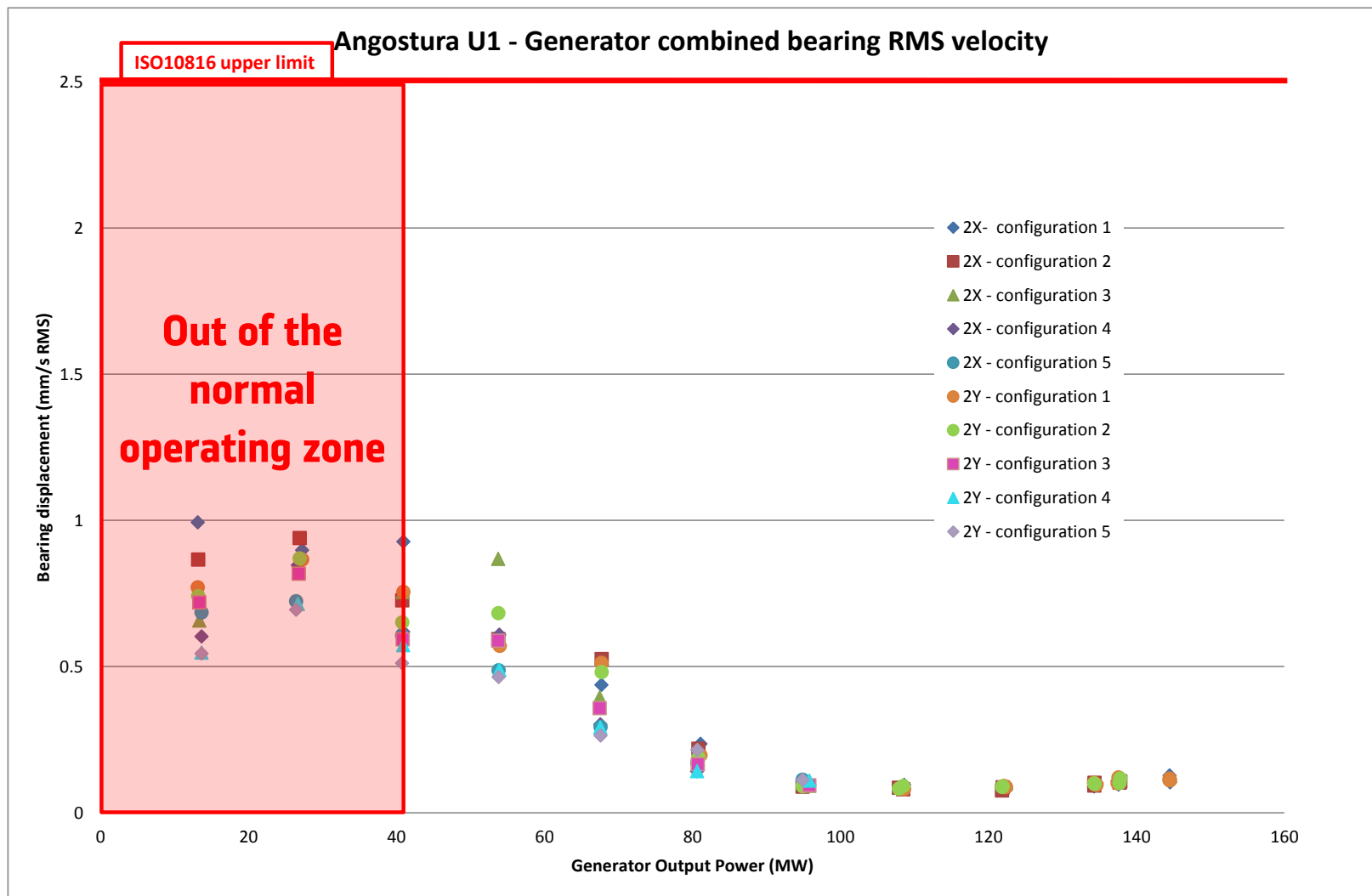
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14MW1	1.3267	1.7664	0.9927	0.7706	3.9149	3.0213
14MW2	1.7293	1.5678	0.8661	0.7409	3.2007	3.269
14MW3	1.2641	1.2559	0.6574	0.7194	3.3105	2.3357
14MW4	1.266	1.3899	0.6029	0.5474	2.4889	2.1149
14MW5	1.0995	1.1397	0.685	0.5448	2.5256	2.3716
27MW1	1.3218	1.3289	0.898	0.8655	3.3871	3.1094
27MW2	1.2511	1.3352	0.9395	0.8698	4.4376	3.6308
27MW3	1.3125	1.194	0.8381	0.8173	3.1732	2.6329
27MW4	1.0959	1.128	0.8466	0.7139	2.8338	2.8542
27MW5	1.1651	1.2073	0.7229	0.6942	2.7228	2.574
41MW1	0.9611	0.9588	0.9272	0.7551	2.4615	2.2488
41MW2	0.9594	0.9576	0.7263	0.6511	2.3221	1.9939
41MW3	0.8363	0.9135	0.7548	0.5924	2.0156	1.8725
41MW4	0.8439	1.128	0.6189	0.5732	1.8111	2.5029
41MW5	0.88	0.8433	0.6066	0.5116	2.1865	1.6607
54MW1	1.0426	1.0904	0.5713	0.5705	1.9897	1.8546
54MW2	1.0426	1.2509	0.5932	0.6823	2.089	2.1032
54MW3	0.961	0.9243	0.8677	0.5885	1.8915	1.6288
54MW4	0.8077	0.8402	0.6085	0.4884	1.5901	1.4435
54MW5	0.7926	1.1322	0.487	0.4643	1.5711	1.382
68MW1	0.6096	0.6984	0.437	0.5121	1.1377	0.9787
68MW2	0.773	0.6891	0.5255	0.4807	1.2096	1.0945
68MW3	0.593	0.625	0.394	0.3572	1.2755	1.1169
68MW4	0.6516	0.9897	0.3023	0.2916	1.3302	1.103
68MW5	0.6414	0.7946	0.293	0.2641	1.3101	1.0322
81MW1	0.495	0.452	0.2353	0.1965	0.2124	0.1883
81MW2	0.4592	0.4563	0.2187	0.188	0.2027	0.182
81MW3	0.4549	0.4337	0.1831	0.1659	0.2462	0.2432
81MW4	0.4504	0.4377	0.1421	0.1416	0.3776	0.2669
81MW5	0.5123	0.4737	0.1693	0.2145	0.3238	0.296
95MW1	0.4329	0.452	0.0958	0.0962	0.1324	0.1213
95MW2	0.4842	0.4312	0.089	0.0908	0.1527	0.1257
95MW3	0.5285	0.3936	0.0917	0.0935	0.1428	0.125
95MW4	0.4468	0.4509	0.0965	0.1096	0.1589	0.1479
95MW5	0.4313	0.404	0.1128	0.1117	0.1689	0.1888
108MW1	0.4369	0.5305	0.0955	0.0803	0.1452	0.1536
108MW21	0.5808	0.3894	0.0795	0.091	0.1685	0.1168
108MW22	0.4633	0.4788	0.0855	0.0822	0.1473	0.1503
122MW11	0.4217	0.4468	0.0794	0.0871	0.1739	0.1376
122MW12	0.4363	0.4265	0.076	0.0916	0.1567	0.138
122MW21	0.4631	0.5039	0.0866	0.0901	0.1548	0.1528
122MW22	0.4279	0.4586	0.0758	0.0882	0.1566	0.1642
136MW11	0.5743	0.7476	0.1016	0.0951	0.1897	0.1744
136MW12	0.5127	0.4579	0.0895	0.1019	0.2366	0.1793
136MW21	0.45	0.5242	0.0925	0.0997	0.2059	0.2133
136MW22	0.4437	0.4935	0.1024	0.0981	0.2086	0.1862
137MW11	0.4695	0.4483	0.1087	0.1007	0.2327	0.1876
137MW12	0.4126	0.4349	0.0956	0.1204	0.1975	0.1793
137MW21	0.385	0.4347	0.1026	0.101	0.2487	0.1751
137MW22	0.3821	0.4332	0.1068	0.1163	0.203	0.1823
144MW11	0.3813	0.4233	0.1082	0.1113	0.2138	0.2064
144MW12	0.3773	0.4411	0.1274	0.1168	0.2776	0.2115
144MW13	0.3831	0.4176	0.1037	0.1103	0.2247	0.201

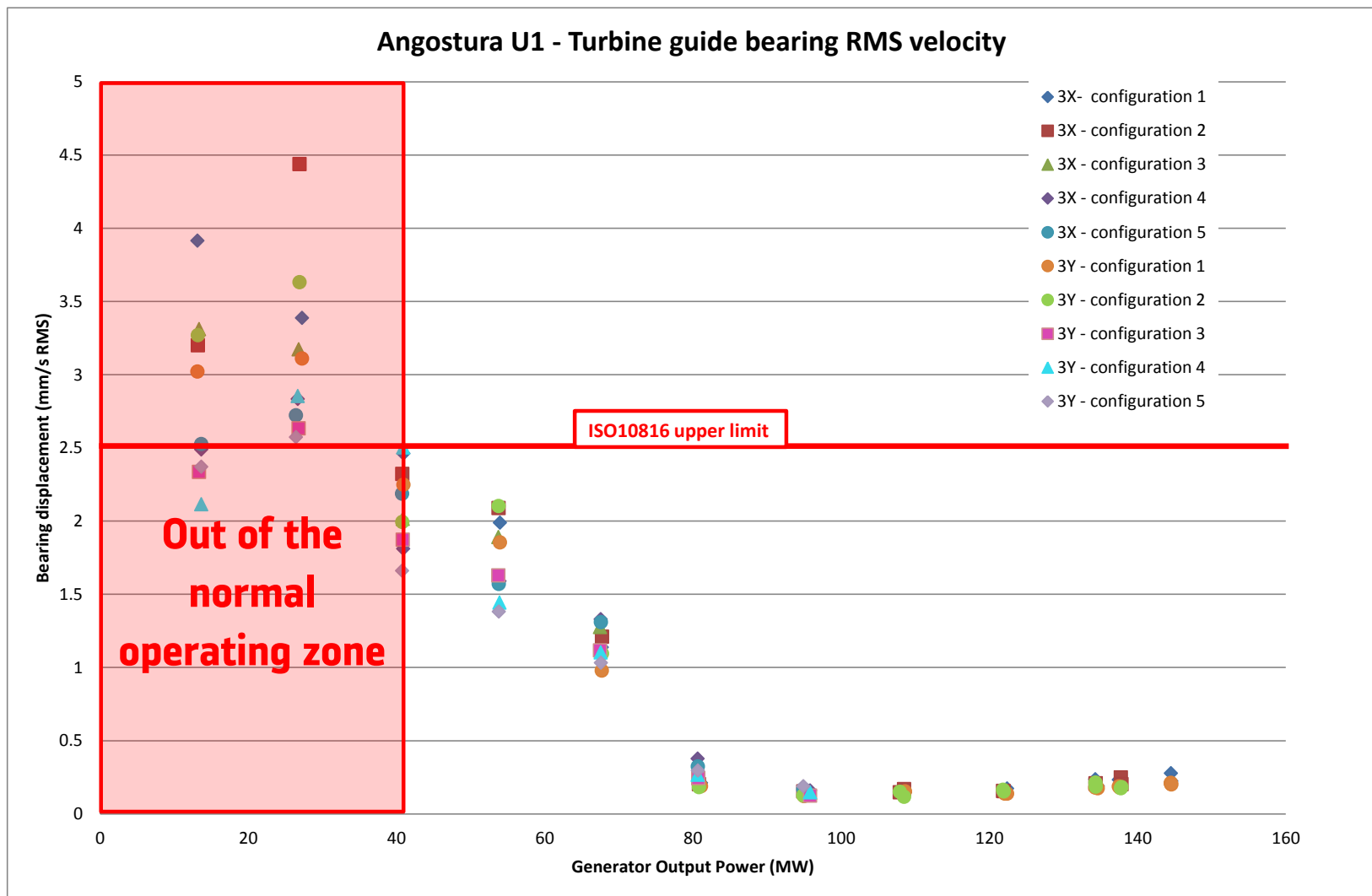
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Test name (-)	1X 1 - 800 Hz (mm pp)	1Y 1 - 800 Hz (mm pp)	2X 1 - 800 Hz (mm pp)	2Y 1 - 800 Hz (mm pp)	3X 1 - 800 Hz (mm pp)	3Y 1 - 800 Hz (mm pp)
14MW1	0.2526	0.2252	0.0681	0.0717	0.2941	0.24
14MW2	0.2558	0.2658	0.0702	0.0625	0.3501	0.2663
14MW3	0.2677	0.2252	0.0678	0.0679	0.3244	0.2627
14MW4	0.2249	0.2154	0.0542	0.0561	0.3745	0.2677
14MW5	0.2469	0.2162	0.062	0.0512	0.3058	0.2716
27MW1	0.2564	0.1912	0.0833	0.0753	0.2751	0.2426
27MW2	0.2271	0.1989	0.0703	0.0635	0.3299	0.2777
27MW3	0.2163	0.1941	0.0743	0.073	0.2434	0.2193
27MW4	0.1998	0.1892	0.0661	0.0646	0.2496	0.2019
27MW5	0.1836	0.1938	0.0609	0.0643	0.2256	0.2627
41MW1	0.1686	0.1561	0.0727	0.053	0.141	0.1352
41MW2	0.1875	0.1537	0.0591	0.0521	0.1529	0.1343
41MW3	0.1621	0.1451	0.0523	0.0541	0.1416	0.1435
41MW4	0.1372	0.1461	0.0525	0.0433	0.136	0.1182
41MW5	0.1623	0.1556	0.0577	0.0604	0.1329	0.1212
54MW1	0.1781	0.1775	0.0712	0.0579	0.1567	0.185
54MW2	0.1737	0.1732	0.0574	0.0624	0.1673	0.1694
54MW3	0.1636	0.1552	0.0554	0.0588	0.149	0.1301
54MW4	0.1498	0.143	0.0476	0.0477	0.1192	0.1204
54MW5	0.1564	0.1384	0.0479	0.0468	0.1123	0.1126
68MW1	0.1413	0.1292	0.0522	0.0586	0.09	0.0683
68MW2	0.2004	0.147	0.0621	0.0563	0.0993	0.0878
68MW3	0.1267	0.1373	0.0403	0.0439	0.093	0.0844
68MW4	0.1423	0.1422	0.049	0.0615	0.0974	0.1032
68MW5	0.1458	0.1515	0.0544	0.0549	0.0974	0.0914
81MW1	0.1495	0.1433	0.0633	0.0635	0.0732	0.0573
81MW2	0.1302	0.1305	0.0474	0.0464	0.0519	0.0522
81MW3	0.1238	0.111	0.0401	0.0395	0.0454	0.0447
81MW4	0.1222	0.1108	0.0335	0.0371	0.0524	0.0486
81MW5	0.1234	0.1128	0.0355	0.035	0.0457	0.0478
95MW1	0.1167	0.1102	0.026	0.0282	0.0325	0.0325
95MW2	0.1152	0.1066	0.0258	0.0293	0.0316	0.0327
95MW3	0.1178	0.1032	0.0229	0.0274	0.0386	0.0342
95MW4	0.1157	0.1023	0.0258	0.0264	0.0332	0.0347
95MW5	0.1157	0.1007	0.0248	0.0271	0.0326	0.0341
108MW1	0.1139	0.1021	0.0231	0.0264	0.0324	0.0292
108MW21	0.116	0.1007	0.0227	0.0272	0.031	0.0317
108MW22	0.1116	0.1	0.0238	0.0268	0.0333	0.0297
122MW11	0.1147	0.1099	0.0246	0.0279	0.0357	0.0309
122MW12	0.1145	0.1071	0.0234	0.0253	0.0368	0.0343
122MW21	0.1162	0.1055	0.0244	0.0293	0.0345	0.0312
122MW22	0.1156	0.1059	0.0232	0.0298	0.0351	0.0297
136MW11	1.2205	1.674	0.0258	0.0266	0.0428	0.0368
136MW12	0.1133	0.1095	0.0252	0.0292	0.0373	0.04
136MW21	0.1157	0.1073	0.0249	0.0289	0.0373	0.0366
136MW22	0.1152	0.108	0.0271	0.0284	0.0413	0.0403
137MW11	0.1069	0.0996	0.0252	0.0266	0.0331	0.0314
137MW12	0.1073	0.1058	0.0257	0.0294	0.0325	0.0289
137MW21	0.1042	0.0998	0.0253	0.0271	0.0321	0.0304
137MW22	0.1063	0.1053	0.0365	0.0284	0.0384	0.0339
144MW11	0.1005	0.1006	0.0233	0.0268	0.0309	0.0334
144MW12	0.1026	0.1036	0.0235	0.0258	0.0328	0.032
144MW13	0.1078	0.1028	0.0232	0.027	0.0351	0.0312

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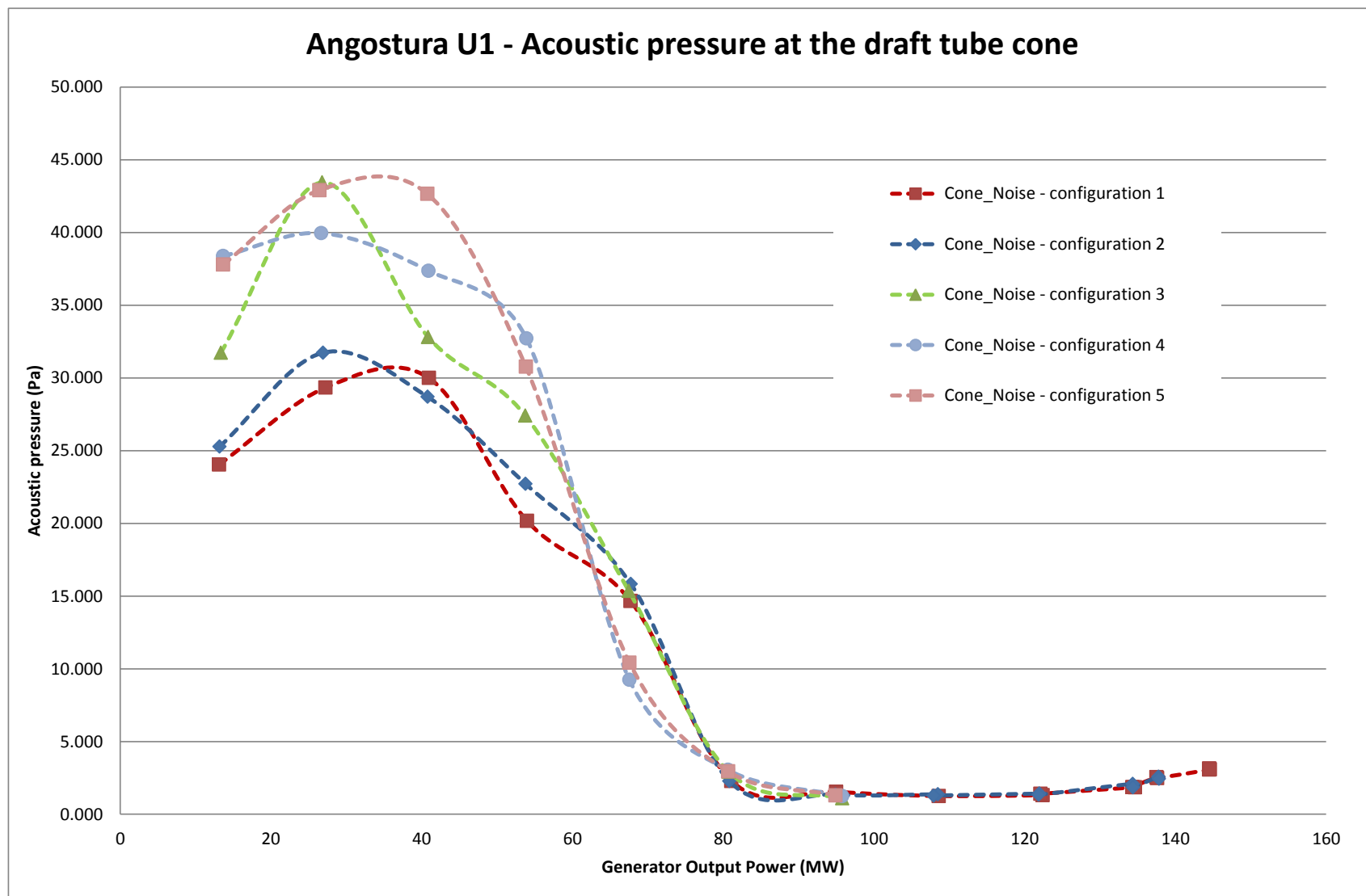
7.2.6. Noise


The noise has been measured at the draft tube cone entrance. We used a microphone B&K 4189 type. Temporal domain signals and associated spectrum analysis are performed using DynamX software, the results are presented hereafter.

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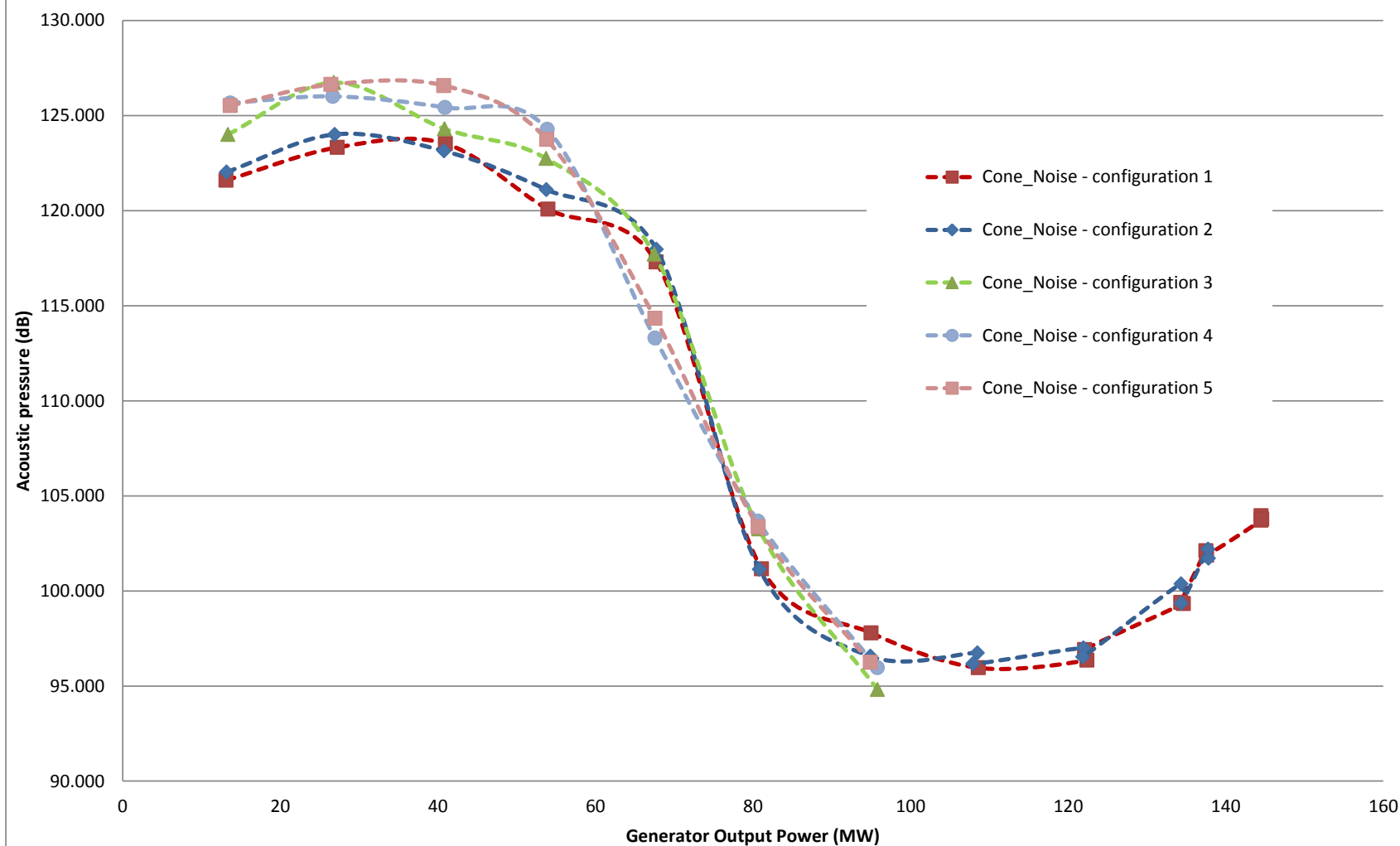
Test name	Generator output power (MW)	Cone_Noise RMS (Pa)	Cone_Noise (dB)	Cone_Noise (dBA)
14MW1	13.120	24.047	121.601	105.391
14MW2	13.181	25.283	122.036	105.393
14MW3	13.345	31.739	124.011	101.853
14MW4	13.657	38.388	125.663	99.706
14MW5	13.657	37.798	125.529	99.802
27MW1	27.237	29.335	123.327	107.574
27MW2	26.907	31.737	124.011	107.461
27MW3	26.786	43.443	126.738	103.692
27MW4	26.670	39.956	126.011	101.016
27MW5	26.411	42.910	126.631	101.079
41MW1	40.943	29.998	123.521	104.755
41MW2	40.764	28.702	123.138	104.692
41MW3	40.848	32.816	124.301	100.518
41MW4	40.895	37.365	125.429	98.564
41MW5	40.744	42.656	126.579	99.124
54MW1	53.963	20.171	120.074	104.962
54MW2	53.759	22.719	121.107	105.131
54MW3	53.723	27.418	122.740	100.888
54MW4	53.893	32.717	124.275	98.296
54MW5	53.813	30.776	123.744	98.346
68MW1	67.709	14.666	117.305	96.851
68MW2	67.741	15.833	117.971	97.446
68MW3	67.468	15.357	117.705	92.108
68MW4	67.551	9.244	113.297	90.518
68MW5	67.565	10.421	114.337	90.617
81MW1	81.090	2.286	101.159	87.457
81MW2	80.800	2.279	101.133	87.750
81MW3	80.732	2.912	103.263	85.426
81MW4	80.629	3.051	103.667	85.471
81MW5	80.656	2.947	103.367	85.621
95MW1	94.995	1.551	97.792	78.728
95MW2	94.893	1.347	96.566	85.287
95MW3	95.797	1.101	94.814	84.929
95MW4	95.797	1.257	95.967	85.238
95MW5	94.894	1.298	96.247	84.766
108MW1	108.612	1.256	95.958	85.371
108MW21	108.480	1.374	96.738	85.353
108MW22	107.927	1.287	96.171	85.342
122MW11	122.379	1.315	96.356	86.429
122MW12	122.0846198	1.4015	96.9115	86.3778
122MW21	121.9393215	1.4168	97.0054	86.4507
122MW22	121.8505201	1.3413	96.5301	86.2838
136MW11	134.6201666	1.8517	99.3307	90.8831
136MW12	134.3025215	1.8662	99.3983	90.833
136MW21	134.3234871	2.0875	100.3718	90.7568
136MW22	134.3559174	1.8574	99.3573	90.7671
137MW11	137.477679	2.5524	102.1184	93.2428
137MW12	137.5820001	2.4824	101.8767	93.2836
137MW21	137.7486788	2.5747	102.1938	93.2587
137MW22	137.8309817	2.4371	101.7167	93.6269
144MW11	144.498511	3.067	103.7138	96.159
144MW12	144.4835855	3.1533	103.9548	96.1699
144MW13	144.5678751	3.0922	103.7847	96.2347


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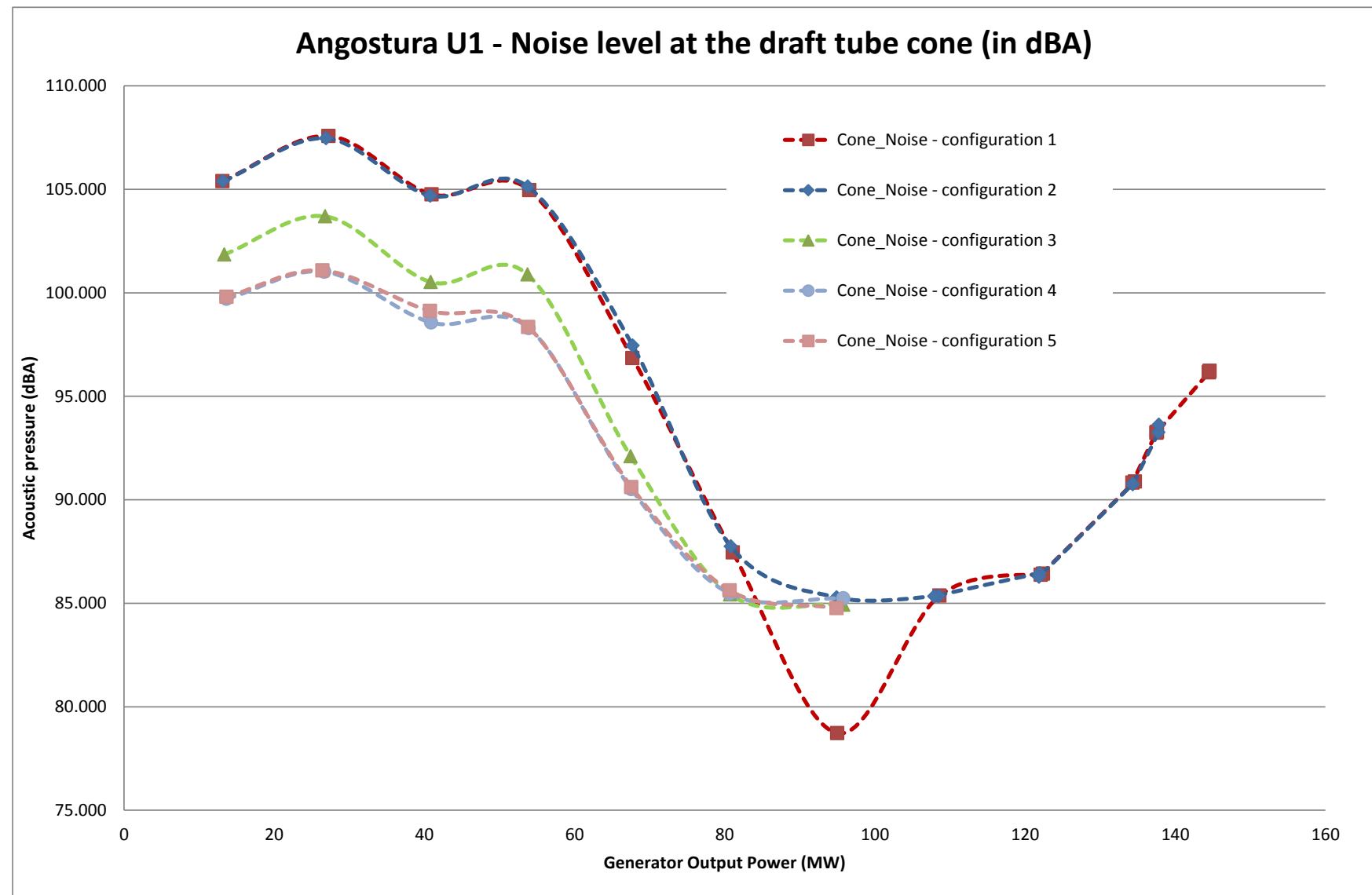



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Angostura U1 - Noise level at the draft tube cone (in dB)



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7.3. Results for Transient Operation

7.3.1. Load rejection guaranties

Guaranteed maximum pressure at the spiral case entrance during a load rejection:

1.2	COMPORTAMIENTO EN CASO DE RECHAZOS DE CARGA	
(1.2.1)	Sobrepresión máxima debida al golpe de ariete medido a la entrada del caracol :	0.90 Mpa
1.2.2	Maniobra que produce el golpe de ariete máximo :	Cierre de emergencia (1)
1.2.3	Sobrevelocidad máxima del grupo :	174.1 rpm (< 162.5% de la velocidad nominal)
1.2.4	Sobrevelocidad y sobrepresiones en los siguientes casos:	

RECHAZO DE CARGA CON	Altura Neta H0 = 53,21 m		Altura Neta H1 = 51,80 m		Altura Neta H2 = 48,77 m	
	Velocidad (rpm)	Presión en la Entrada del Caracol (mca)	Velocidad (rpm)	Presión en la Entrada del Caracol (mca)	Velocidad (rpm)	Presión en la Entrada del Caracol (mca)
25% DE LA CARGA NOMINAL	<174	< 90	<174	< 90	< 174	< 90
50% DE LA CARGA NOMINAL	na	na	<174	< 90	< 174	< 90
75% DE LA CARGA NOMINAL	na	na	<174	< 90	< 174	< 90
100% DE LA CARGA NOMINAL	na	na	na	na	< 174	< 90
POTENCIA MAXIMA PERMANENTE	na	na	na	na	< 174	< 90

Nota: Completar según corresponda

(1) Ver el cálculo y el análisis de los casos críticos en el estudio transitorio detallado

k) Golpe de ariete en el difusor

Con la disposición propuesta para la turbina, el golpe de ariete negativo en el difusor (zona bajo rodete) en régimen transitorio no debe ser inferior a **-6 m.c.a.**

Extract from the transient analysis for U1 and U2 :

4.2 Garantías iniciales

Presión máxima admisible en disparos 90 mCA [1]

Presión mínima en el tubo de aspiración -6 mCA [2]

Máxima sobrevelocidad admisible en disparos < 62.5% [3]

[1] Los valores (resultados) en esta nota están indicados al nivel del distribuidor (260.27 m).

[2] -6 mCA es una presión relativa que corresponde a una presión absoluta de +4 mCA.

[3] Sobrevelocidad actualizada con los nuevos valores de alturas netas y el nuevo diseño tubería aducción según CA-CH22-4-23d-003_V1.pdf.

Hydraulic thrust guaranties:

4.	EMPUJE HIDRAULICO	
4.1	Peso de las partes rotatorias de la turbina :	140 t
4.2	Empuje hidráulico máximo sobre el rodete con sellos sin desgaste :	310 t
4.3	Empuje hidráulico máximo posible sobre el rodete cuando el claro original de los sellos haya aumentado en un 100% por desgaste :	< 450 t

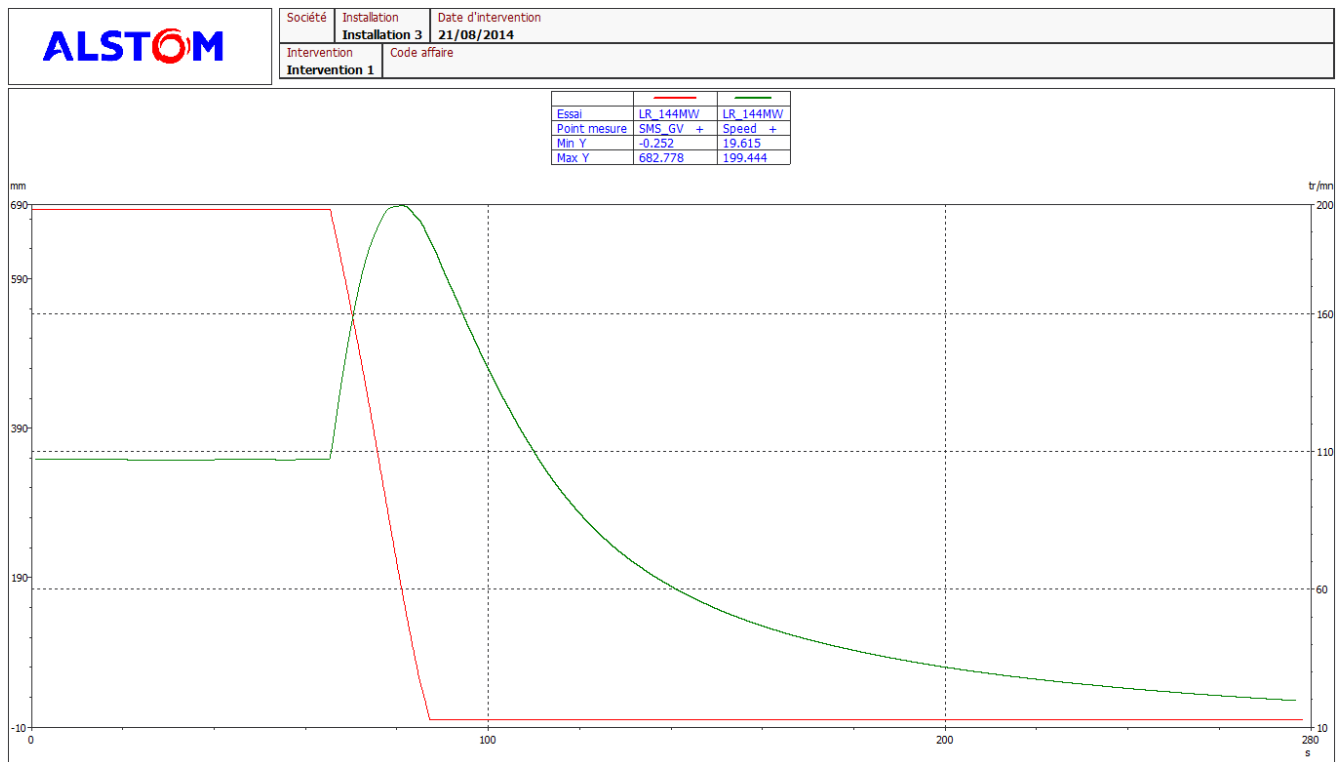
ALSTOM		PROJECT :	ANGOSTURA			ALSTOM Hydro France	
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7.3.2. Unit load rejection from 144MW

Steady state value before the load rejection:

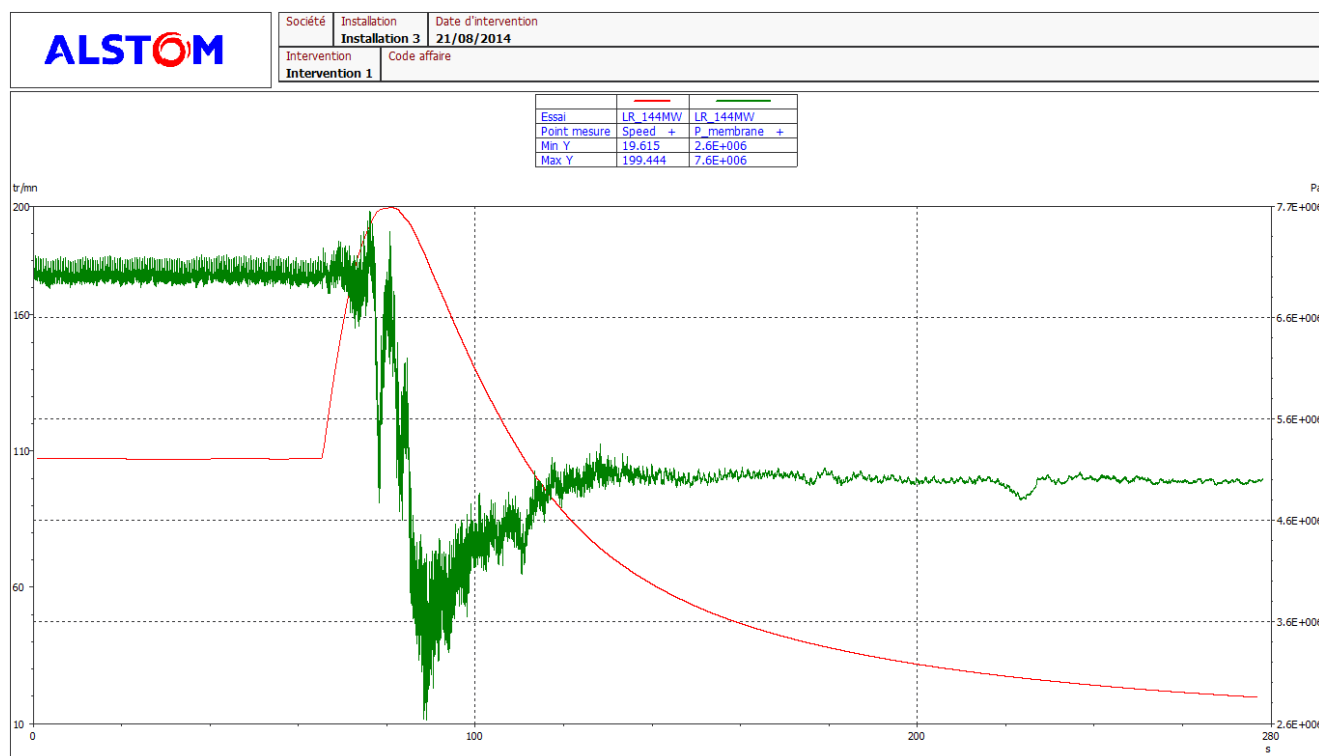
Angostura U1 Steady state parameters before load rejection		
parameter	value	unit
Servomotor stroke	682.7	mm
Wicket gate opening	46.76	°
Generator output power	144.6	MW
Net head (from index tests)	49.5	m

Temporal raw signals



We reached an overspeed of 199.4 rpm validated by Alstom.


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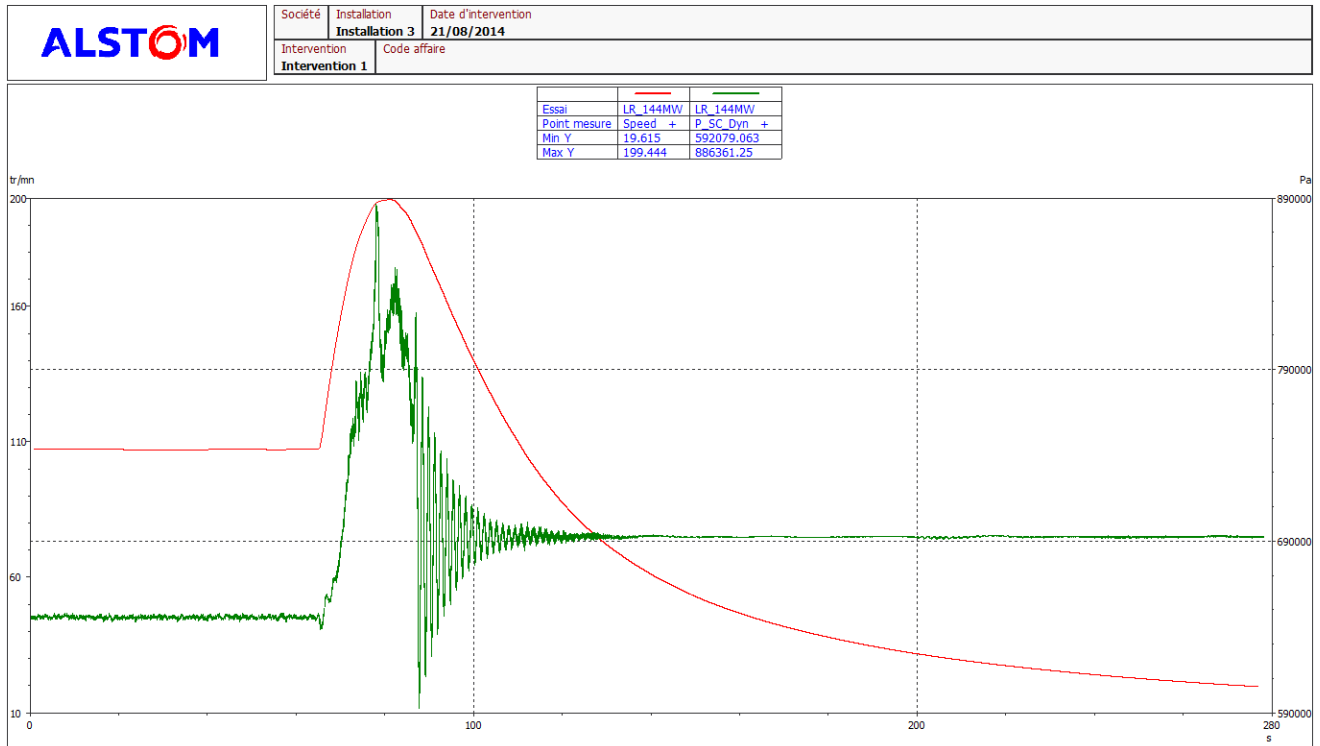


The mean thrust bearing load “P_membrane” before and after load rejection are respectively, 7221194 and 5131861 N.

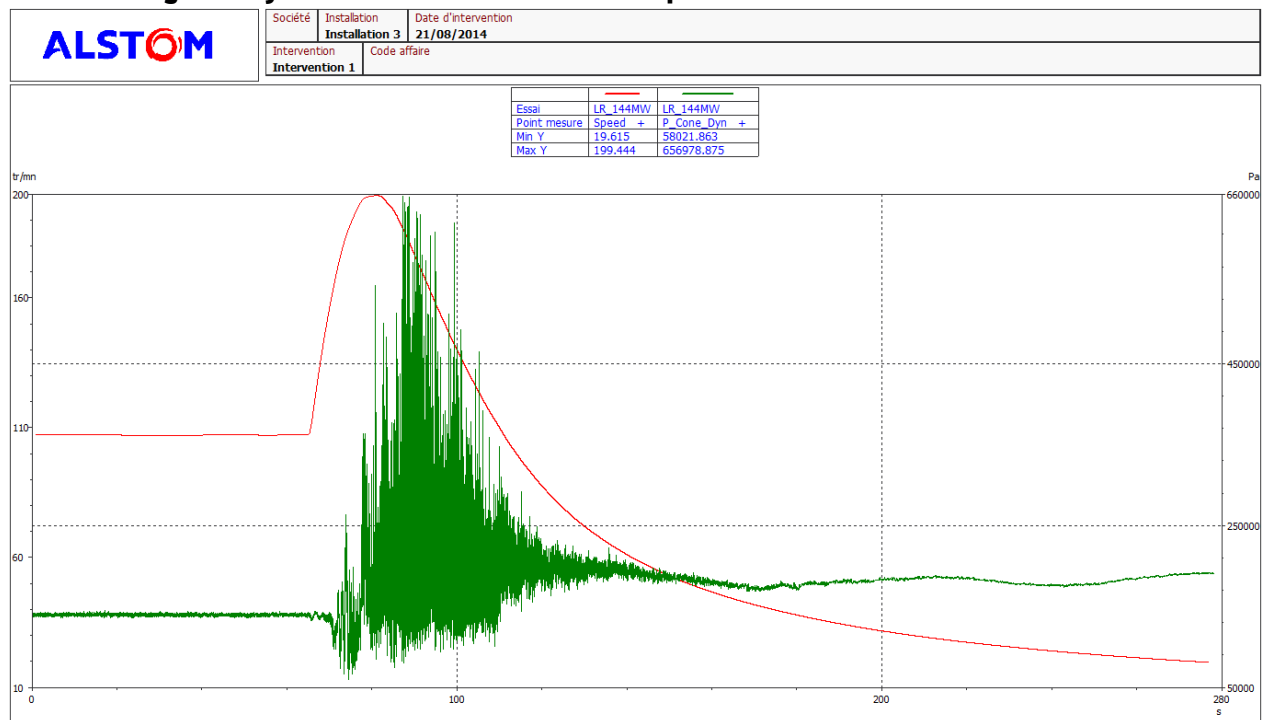
Hereafter are presented the calculation for axial thrust:

Load rejection at 144MW		
g	9.799	
Thrust bearing load before LR 144MW	7221194	N
Thrust bearing load at standstill	4779291	N
Thrust bearing load before LR 144MW	736.931728	t
Thrust bearing load at standstill	487.732524	t
Axial thrust prior LR 144MW	249.199204	t


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The maximum pressure reached in the spirale case entrance is 886361Pa abs, which is approximatively equal to 78 mWC. **The guaranty of 90 mWC maximum in the spiral case is fulfilled.**



The minimum pressure reached in the draft tube is 58021Pa abs, which is approximatively equal to -4.3mWC. **The guaranty of -6 mWC minimum in the draft tube cone is fulfilled.**


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8. Conclusions

In terms of turbine performances, Angostura **Unit 1 fulfills the guaranties**. We reached 152.5MW when only unit 1 was running and 149MW with the 3 units running.

In terms of hydromechanical behaviour, **we fit with the guaranties** and ISO standards (ISO7919, ISO10816).

The bottom ring/head cover air injection has a significant impact on the head cover and bearings vibrations (up to twice lower) and in a less significant way, on the shaft displacement, noise and pressure pulsations. The configuration 5 shall be used for loads lower than 40% of the maximum load and at maximum load to reduce the stress on the machine.

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9. Appendix

Appendix 1 : List of Tests


Appendix 2 : Unit bearing running clearances

Appendix 3 : Instrumentation and pictures

Appendix 4 : Sensors calibrations

Appendix 5 : Axial thrust calculation

Appendix 6 : Topographic manual records

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9.1. Appendix 1 : List of tests

	Test name	Date	Hour
1	14-26MW	25/08/2014	23:57:23
2	14MW1	25/08/2014	23:31:26
3	14MW2	25/08/2014	23:40:19
4	14MW2->3	25/08/2014	23:45:32
5	14MW3	25/08/2014	23:47:24
6	14MW3->4	25/08/2014	23:51:46
7	14MW4	25/08/2014	23:52:44
8	14MW4->5	25/08/2014	23:54:06
9	14MW5	25/08/2014	23:55:48
10	27-40MW	26/08/2014	00:18:20
11	27MW1	26/08/2014	00:00:10
12	27MW2	26/08/2014	00:01:28
13	27MW3	26/08/2014	00:04:03
14	27MW4	26/08/2014	00:06:59
15	27MW5	26/08/2014	00:13:47
16	41MW1	26/08/2014	00:24:14
17	41MW2	26/08/2014	00:26:19
18	41MW3	26/08/2014	00:29:11
19	41MW4	26/08/2014	00:33:20
20	41MW5	26/08/2014	00:35:54
21	54->68MW	25/08/2014	19:14:38
22	54MW1	25/08/2014	19:09:02
23	54MW2	25/08/2014	19:10:41
24	54MW3	25/08/2014	19:11:19
25	54MW4	25/08/2014	19:11:59
26	54MW5	25/08/2014	19:12:49
27	68->81MW	25/08/2014	19:35:04
28	68MW1	25/08/2014	19:16:30
29	68MW2	25/08/2014	19:17:18
30	68MW3	25/08/2014	19:27:36
31	68MW4	25/08/2014	19:30:03
32	68MW5	25/08/2014	19:33:34
33	81-95MW	25/08/2014	19:53:25
34	81MW1	25/08/2014	19:37:34
35	81MW2	25/08/2014	19:39:44
36	81MW3	25/08/2014	19:43:04
37	81MW4	25/08/2014	19:45:37
38	81MW5	25/08/2014	19:52:17
39	95->108MW	25/08/2014	20:03:46
40	95MW1	25/08/2014	19:55:32
41	95MW2	25/08/2014	19:56:47
42	95MW3	25/08/2014	19:57:53
43	95MW4	25/08/2014	19:59:03
44	95MW5	25/08/2014	20:01:17
45	108MW1	25/08/2014	20:09:17
46	108MW21	25/08/2014	20:10:05
47	108MW22	25/08/2014	20:12:29
48	122->136MW	25/08/2014	20:35:19
49	122MW11	26/11/2014	10:48:34
50	122MW12	25/08/2014	20:26:09
51	122MW21	25/08/2014	20:28:16
52	122MW22	25/08/2014	20:32:31
53	136->137MW	25/08/2014	21:22:09
54	136MW11	25/08/2014	20:38:57
55	136MW12	25/08/2014	20:40:30
56	136MW21	25/08/2014	20:41:40
57	136MW22	25/08/2014	20:43:23
58	137MW11	25/08/2014	21:29:36
59	137MW12	25/08/2014	21:30:48
60	137MW21	25/08/2014	21:31:38
61	137MW22	25/08/2014	21:32:43
62	140MW C->O axial valve	25/08/2014	21:46:11
63	144MW11	25/08/2014	22:53:33
64	144MW12	25/08/2014	22:54:22
65	144MW13	25/08/2014	22:56:29
66	FSNlExcited	25/08/2014	19:06:33
67	FSNlNotExcited	25/08/2014	19:05:40
68	LR_144MW	25/08/2014	22:57:53
69	Startup-14MW	25/08/2014	23:29:44
70	Startup_FSNL	25/08/2014	19:02:19
71	Synchro->54MW	25/08/2014	19:07:36
72	mechanical overspeed	27/08/2014	15:55:13
73	mechanical overspeed	27/08/2014	15:55:13
74	point zero	25/08/2014	19:00:44
75	point zero2	25/08/2014	23:16:56

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9.2. Appendix 2 : Unit bearings running clearances

Radial running clearance:


	Unit 1 & 2		Unit 3	
	Theoretical	Site Adjustment	Theoretical	Site Adjustment
Upper generator guide bearing	0.3mm	0.3mm	0.22mm	0.22mm
Generator combined bearing	0.5mm	0.5mm	0.4mm	-
Turbine bearing	0.3mm	0.3mm	0.3mm	0.3mm

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9.3. Appendix 3 : Instrumentation and pictures :

9.3.1. Sensors list


	Measured points	Description
1	S1X	Generator upper bearing displacement on X axis
2	S1Y	Generator upper bearing displacement on Y axis
3	S1Z	Generator upper bearing displacement on Z axis
4	S2X	Combined thrust and guide bearing displacement on X axis
5	S2Y	Combined thrust and guide bearing displacement on Y axis
6	S3X	Turbine guide bearing displacement on X axis
7	S3Y	Turbine guide bearing displacement on Y axis
8	1X	Generator upper bearing vibration on X axis
9	1Y	Generator upper bearing vibration on Y axis
10	3X	Turbine guide bearing vibration on X axis
11	3Y	Turbine guide bearing vibration on Y axis
12	3Z	Turbine guide bearing vibration on Z axis
13	2X	Combined thrust and guide bearing vibration on X axis
14	2Y	Combined thrust and guide bearing vibration on Y axis
15	2Z	Combined thrust and guide bearing vibration on Z axis
16	Vib_ConeX	Draft tube cone vibration on X axis
17	Vib_ConeY	Draft tube cone vibration on Y axis
18	P_SC_Dyn	Spiral case inlet pressure pulsation
19	P_Cone_Dyn	Draft tube cone pressure pulsation
20	P_HC3	Head cover pressure 3
21	P_HC1	Head cover pressure 1
22	P_HC2	Head cover pressure 2
23	P_WK_Client	Colbun Winter-Kennedy differential pressure
24	P_membrane	Thrust membrane pressure
25	Speed	Key phasor
26	P_Up_After	Collected pressure after the convergent
27	P_Down	Draft tube outlet pressure
28	Cone_Noise	Draft tube cone noise
29	P_Up_Before	Collected pressure before the convergent
30	SMS_GV	Guide vane servomotor stroke
31	GV_Opening	Guide vane opening angle
32	P_WK	Alstom Site Winter-Kennedy differential pressure
33	Power	Turbine power from the turbine governor

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Inputs												
	Label	Component	Node	Direction	Type	Transducer	Physical qty.	Sensitivity	Range pk	External Gain	Polarity	Offset comp.
Input 1	S1X	None	0	Scalar	Translation	S1_X	Displacement	1 k(V)/(m)	10.0 mm	1	Normal	0 V
Input 2	S1Y	None	0	Scalar	Translation	S1_Y	Displacement	1 k(V)/(m)	10.0 mm	1	Normal	0 V
Input 3	S1Z	None	0	Scalar	Translation	Default Voltmeter	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Input 4	S2X	None	0	Scalar	Translation	S2_X	Displacement	1 k(V)/(m)	10.0 mm	1	Normal	0 V
Input 5	S2Y	None	0	Scalar	Translation	S2_Y	Displacement	1 k(V)/(m)	10.0 mm	1	Normal	0 V
Input 6	S3X	None	0	Scalar	Translation	S3_X	Displacement	1.1618 (V)/(m)	8.61 m	1	Normal	-955.9 mV
Input 7	S3Y	None	0	Scalar	Translation	S3_Y	Displacement	1.0804 (V)/(m)	9.26 m	1	Normal	-1.0271 V
Input 8	1X	None	0	Scalar	Translation	DYNAE_B4220	Acceleration	52.495 m(V)/(m/s²)	190 m/s²	1	Normal	0 V
Input 9	1Y	None	0	Scalar	Translation	DYNAE_B4221	Acceleration	49.868 m(V)/(m/s²)	201 m/s²	1	Normal	0 V
Input 10	3X	None	0	Scalar	Translation	DYNAE_B4221	Acceleration	52.868 m(V)/(m/s²)	189 m/s²	1	Normal	0 V
Input 11	3Y	None	0	Scalar	Translation	DYNAE_B4218	Acceleration	50.632 m(V)/(m/s²)	198 m/s²	1	Normal	0 V
Input 12	3Z	None	0	Scalar	Translation	DYNAE_B4215	Acceleration	51.505 m(V)/(m/s²)	194 m/s²	1	Normal	0 V
Input 13	2X	None	0	Scalar	Translation	DYNAE_B3061	Acceleration	49.887 m(V)/(m/s²)	200 m/s²	1	Normal	0 V
Input 14	2Y	None	0	Scalar	Translation	DYNAE_B3060	Acceleration	52.819 m(V)/(m/s²)	189 m/s²	1	Normal	0 V
Input 15	2Z	None	0	Scalar	Translation	DYNAE_B4216	Acceleration	50.559 m(V)/(m/s²)	198 m/s²	1	Normal	0 V
Input 16	Vib_ConeX	None	0	Scalar	Translation	DYNAE_B4224	Acceleration	53.048 m(V)/(m/s²)	189 m/s²	1	Normal	0 V
Input 17	Vib_ConeY	None	0	Scalar	Translation	DYNAE_B4223	Acceleration	49.365 m(V)/(m/s²)	203 m/s²	1	Normal	0 V
Input 18	P_SC_Dyn	None	0	Scalar	Translation	PTX_631_1669792	Pressure	3.1938E-06 (V)/(N/m²)	3130000 N/m²	1	Normal	-1.996 V
Input 19	P_Cone_Dyn	None	0	Scalar	Translation	PTX631_1605429	Pressure	16.03E-06 (V)/(N/m²)	624000 N/m²	1	Normal	-1.9913 V
Input 20	P_HC3	None	0	Scalar	Translation	PTX_631_2926858	Pressure	3.1944E-06 (V)/(N/m²)	3130000 N/m²	1	Normal	-1.9938 V
Input 21	P_HC1	None	0	Scalar	Translation	PTX_631_2919186	Pressure	3.1924E-06 (V)/(N/m²)	3130000 N/m²	1	Normal	-1.9924 V
Input 22	P_HC2	None	0	Scalar	Translation	PTX_631_2962348	Pressure	3.1929E-06 (V)/(N/m²)	3130000 N/m²	1	Normal	-1.9929 V
Input 23	not_used	None	0	Scalar	Translation	Default Voltmeter	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Input 24	P_WK_Client	None	0	Scalar	Translation	P_WK_Client	Pressure	200E-06 (V)/(N/m²)	50000 N/m²	1	Normal	0 V
Input 25	P_membrane	None	0	Scalar	Translation	P_membrane_Client	Pressure	625E-09 (V)/(N/m²)	16000000 N/m²	1	Normal	0 V
Input 26	not_used1	None	0	Scalar	Translation	Default Voltmeter	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Input 27	not_used2	None	0	Scalar	Translation	Default Voltmeter	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Input 28	Speed	None	0	Scalar	Translation	Default Voltmeter	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Input 29	P_Lip_After	None	0	Scalar	Translation	PTX_631_1774816	Pressure	3.1991E-06 (V)/(N/m²)	3130000 N/m²	1	Normal	-1.9535 V
Input 30	P_Down	None	0	Scalar	Translation	PTX_631_2192271	Pressure	16.042E-06 (V)/(N/m²)	623000 N/m²	1	Normal	-2.0112 V
Input 31	Cone_Noise	None	0	Scalar	Translation	4189_A_2749242	Acoustic pressure	53.887E-03 (V)/(Pa)	139.3 dB	1	Normal	0 V
Input 32	P_Up_Before	None	0	Scalar	Translation	PTX_1400_135/14	Pressure	7.9955E-06 (V)/(N/m²)	1250000 N/m²	1	Normal	-1.9676 V

Aux. DC Inputs

Aux. DC Inputs							
Label	Transducer	Physical qty.	Sensitivity	Range pk	External Gain	Polarity	Offset comp.
Aux. DC Input 1	SMS_GV	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Aux. DC Input 2	GV_Opening	Voltage	1 (V)/(V)	10 V	1	Normal	0 V
Aux. DC Input 3	P_WK	Pressure	54.184E-06 (V)/(N/m²)	185000 N/m²	1	Normal	-2.0393 V
Aux. DC Input 4	Power	Voltage	1 (V)/(V)	10 V	1	Normal	0 V

		PROJECT :	ANGOSTURA UNIT 1 COLBUN			ALSTOM Hydro France	
		CLIENT :				N° DOCUMENT : LTESS-14505	
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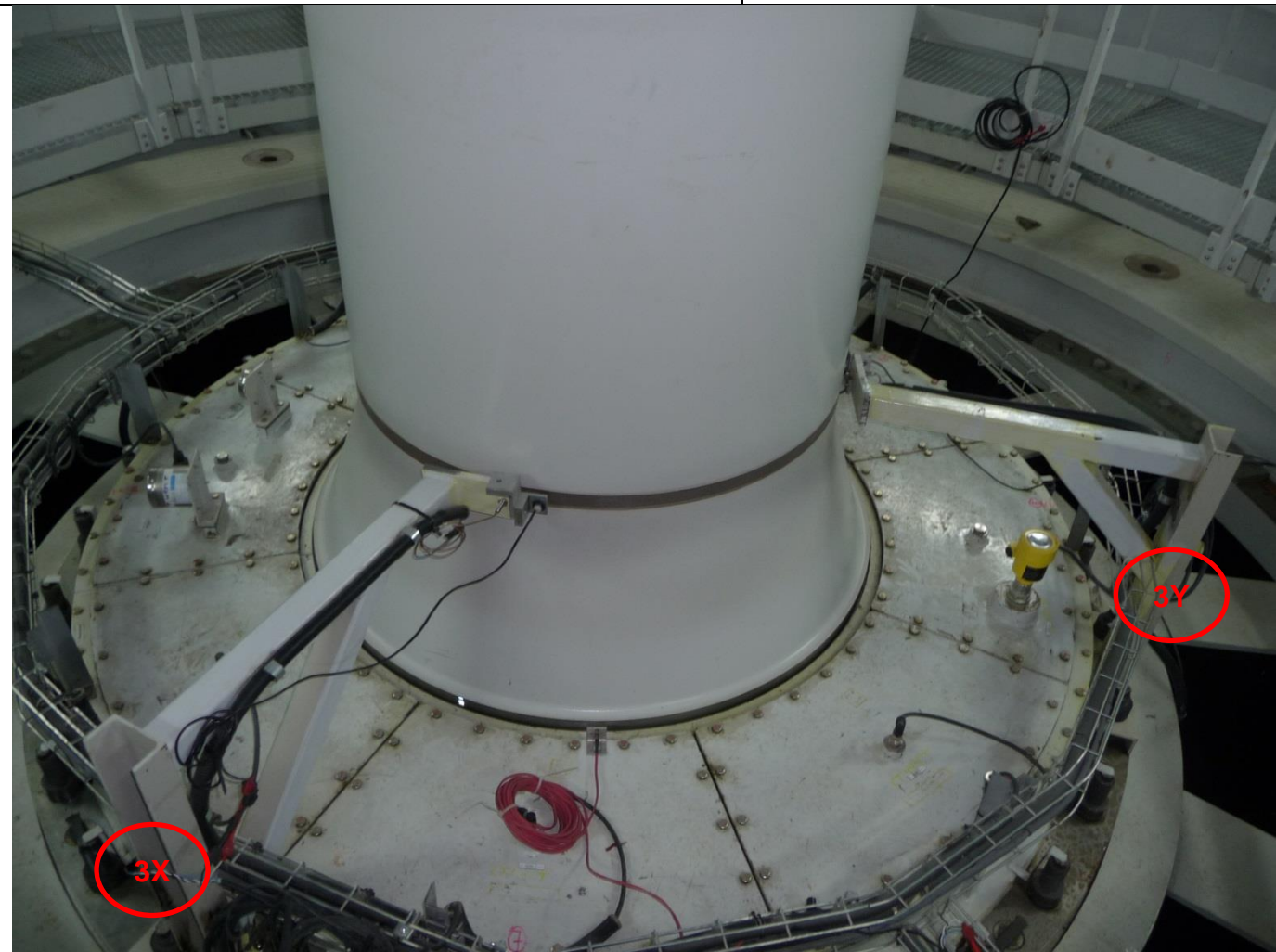
9.3.2. Sensors pictures




Generator upper bearing vibration 1Y

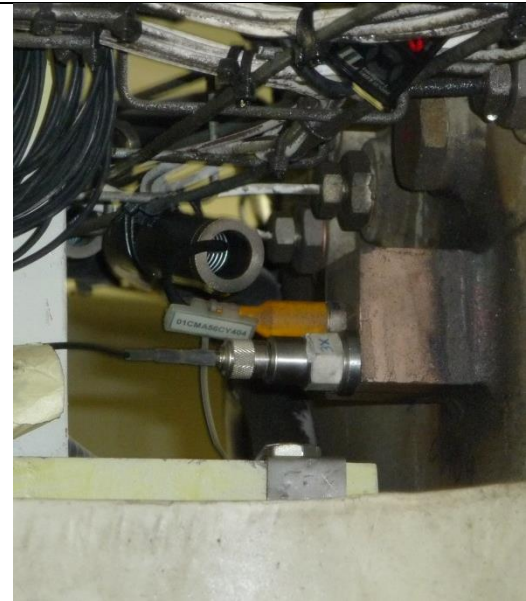


Generator upper bearing vibration 1X

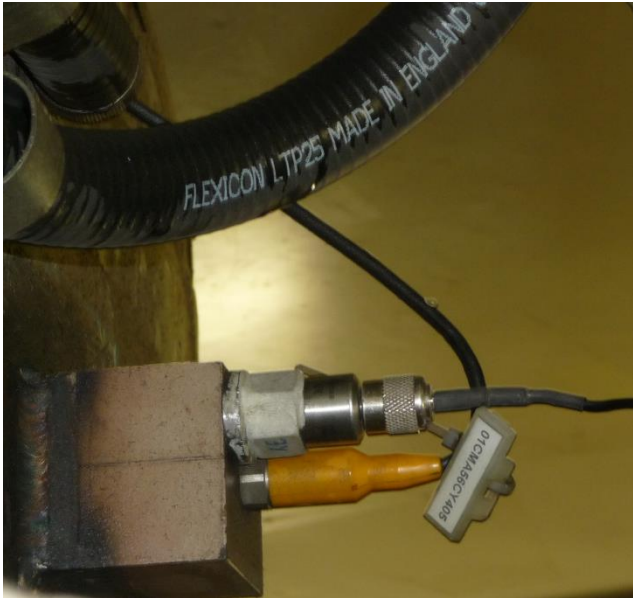


Generator upper bearing displacement S3X, S3Y, 3X, 3Y and Key phasor

		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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Combined thrust and guide bearing vibration 2X




Combined thrust and guide bearing vibration 2Y



Combined thrust and guide bearing vibration 2Z



Combined thrust and guide bearing displacement
S2X

		PROJECT :	ANGOSTURA UNIT 1 COLBUN			ALSTOM Hydro France	
		CLIENT :				N° DOCUMENT : LTESS-14505	
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Combined thrust and guide bearing displacement S2Y




Head cover pressure P_HC3



Guide vane servomotor stroke



Head cover pressure P_HC1 and P_HC2

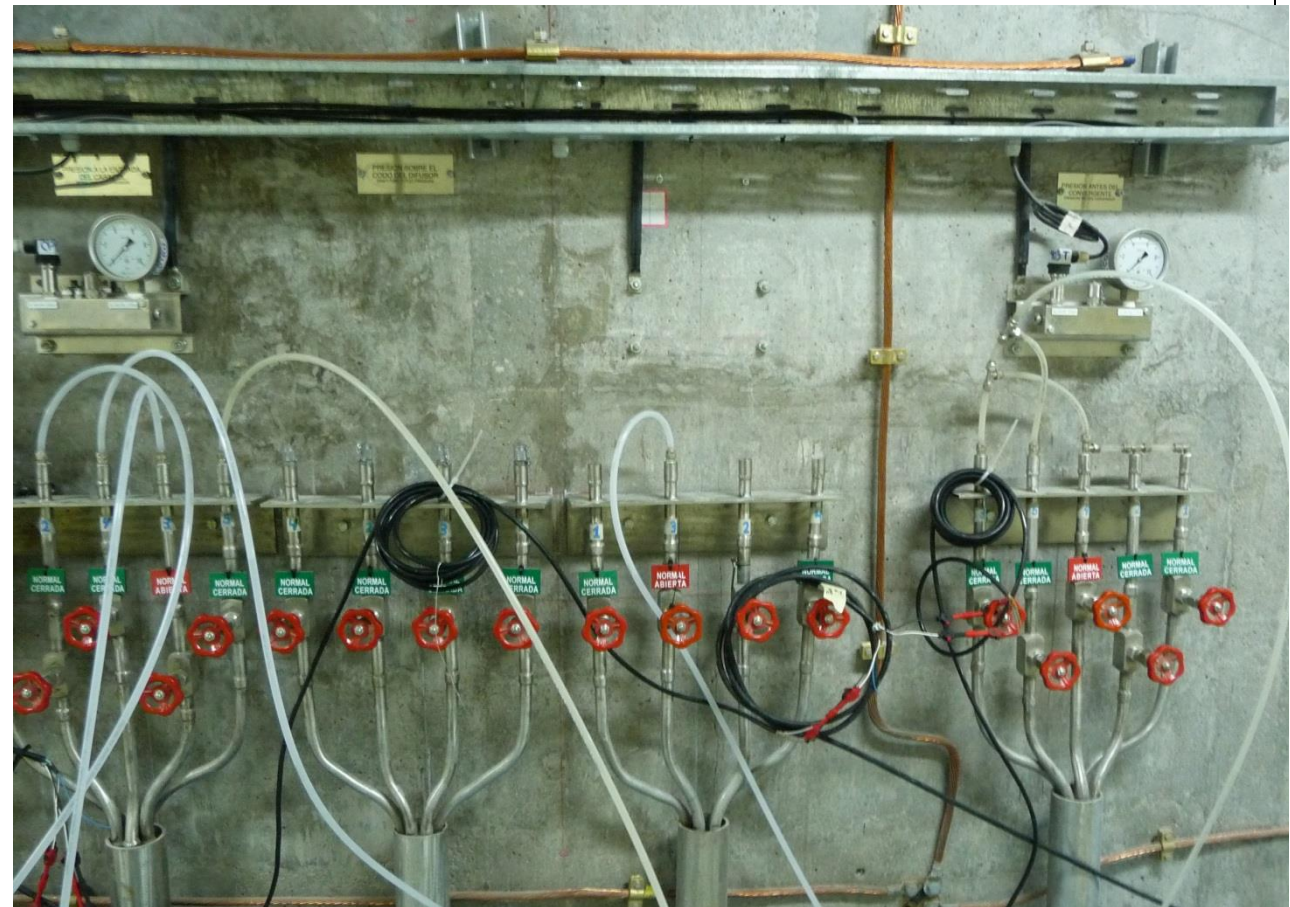
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		CLIENT :				N° DOCUMENT : LTESS-14505	
Study N° :		Contract N°		N° O.E. :		Page :	73




Spiral case entrance dynamic pressure



Winter Kennedy differential pressure



P_Up_After, P_Down and P_Up_Before

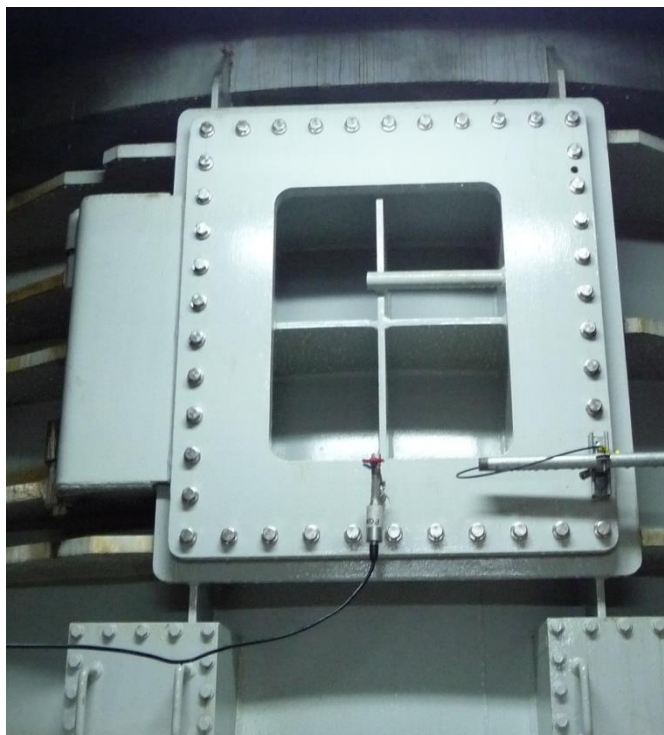
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		CLIENT :				N° DOCUMENT : LTESS-14505	
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Draft tube cone vibration Vib_ConeX



Draft tube cone vibration Vib_ConeY



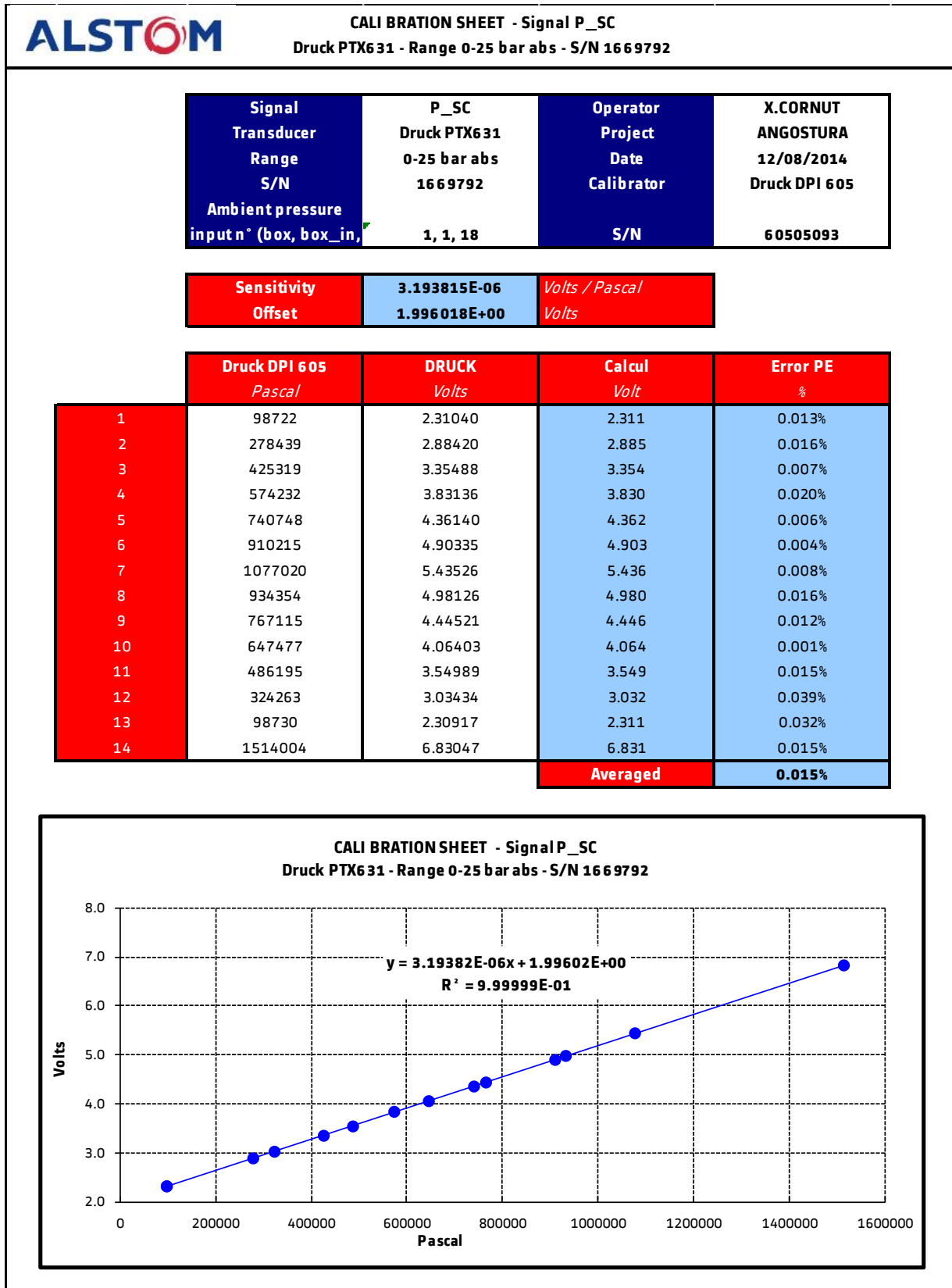
Draft tube cone pressure pulsation



Guide vanne angle

ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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9.4. Appendix 4 : Sensors calibrations



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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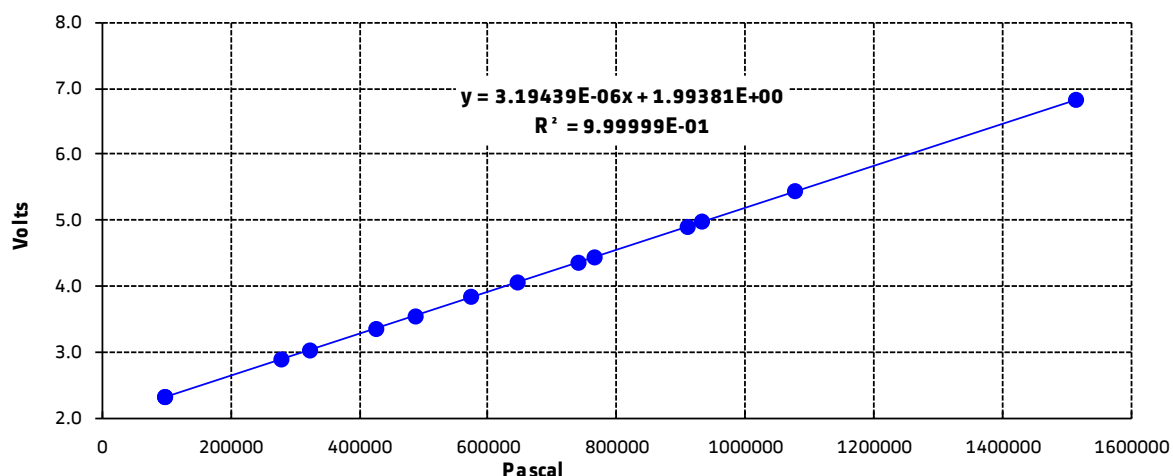
CALIBRATION SHEET - Signal P_HC3
Druck PTX631 - Range 0-25 bar abs - S/N 2926858

Signal Transducer	P_HC3	Operator	X.CORNUT
Range	Druck PTX631	Project	ANGOSTURA
S/N	0-25 bar abs	Date	12/08/2014
Ambient pressure input n° (box, box_in, ...)	2926858	Calibrator	Druck DPI 605
	1, 2, 20	S/N	60505093

Sensitivity	3.194394E-06	<i>Volts / Pascal</i>
Offset	1.993812E+00	<i>Volts</i>

	Druck DPI 605 <i>Pascal</i>	DRUCK <i>Volts</i>	Calcul <i>Volt</i>	Error PE <i>%</i>
1	98722	2.30832	2.309	0.012%
2	278439	2.88098	2.883	0.033%
3	425319	3.35510	3.352	0.039%
4	574232	3.82870	3.828	0.008%
5	740748	4.35949	4.360	0.008%
6	910215	4.90015	4.901	0.018%
7	1077020	5.43189	5.434	0.034%
8	934354	4.97848	4.979	0.000%
9	767115	4.44573	4.444	0.021%
10	647477	4.06187	4.062	0.003%
11	486195	3.54846	3.547	0.023%
12	324263	3.03113	3.030	0.022%
13	98730	2.30819	2.309	0.015%
14	1514004	6.83098	6.830	0.012%
		Averaged		0.018%

CALIBRATION SHEET - Signal P_HC3
Druck PTX631 - Range 0-25 bar abs - S/N 2926858



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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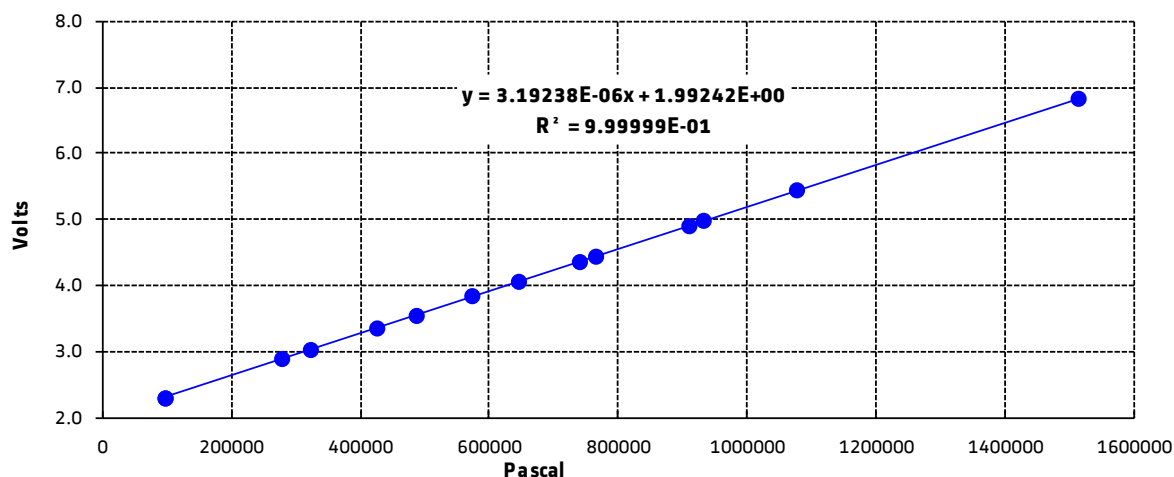
CALI BRATION SHEET - Signal P_HC1
Druck PTX631 - Range 0-25 bar abs - S/N 2919186

Signal	P_HC1	Operator	X.CORNUT
Transducer	Druck PTX631	Project	ANGOSTURA
Range	0-25 bar abs	Date	12/08/2014
S/N	2919186	Calibrator	Druck DPI 605
Ambient pressure		S/N	60505093
input n° (box, box_in, ...)	1, 3, 21		

Sensitivity	3.192377E-06	<i>Volts / Pascal</i>
Offset	1.992421E+00	<i>Volts</i>

	Druck DPI 605	DRUCK	Calcul	Error PE
	<i>Pascal</i>	<i>Volts</i>	<i>Volt</i>	<i>%</i>
1	98722	2.30548	2.308	0.031%
2	278439	2.88016	2.881	0.017%
3	425319	3.35137	3.350	0.017%
4	574232	3.82779	3.826	0.032%
5	740748	4.35742	4.357	0.004%
6	910215	4.89761	4.898	0.008%
7	1077020	5.42973	5.431	0.014%
8	934354	4.97450	4.975	0.011%
9	767115	4.44184	4.441	0.007%
10	647477	4.05996	4.059	0.008%
11	486195	3.54472	3.545	0.003%
12	324263	3.02973	3.028	0.031%
13	98730	2.30650	2.308	0.016%
14	1514004	6.82528	6.826	0.006%
		Averaged		0.015%

CALI BRATION SHEET - Signal P_HC1
Druck PTX631 - Range 0-25 bar abs - S/N 2919186



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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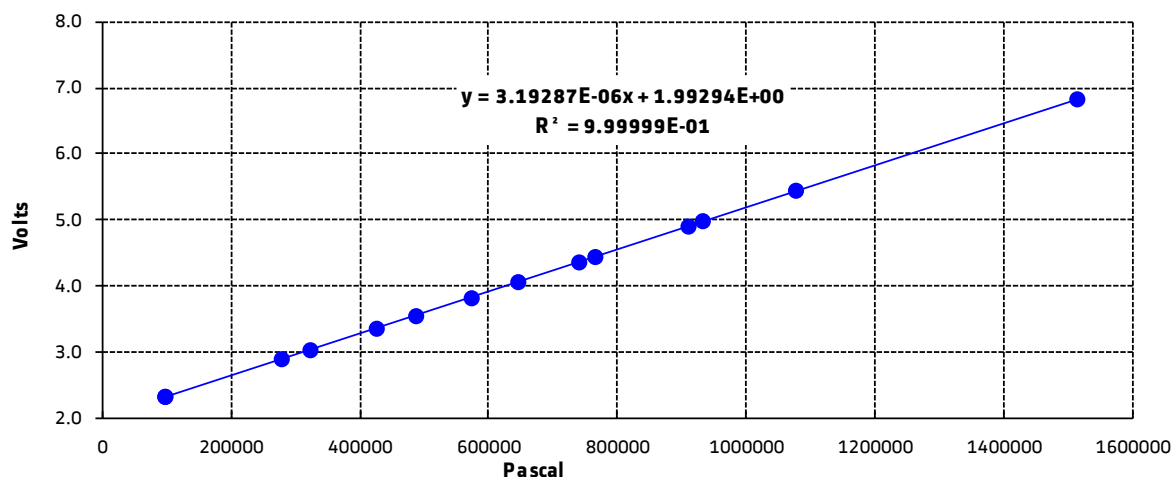
CALI BRATION SHEET - Signal P_HC2
Druck PTX631 - Range 0-25 bar abs - S/N 2962348

Signal	P_HC2	Operator	X.CORNUT
Transducer	Druck PTX631	Project	ANGOSTURA
Range	0-25 bar abs	Date	12/08/2014
S/N	2962348	Calibrator	Druck DPI 605
Ambient pressure		S/N	60505093
input n° (box, box_in, ...)	1, 4, 22		

Sensitivity	3.192867E-06	<i>Volts / Pascal</i>
Offset	1.992945E+00	<i>Volts</i>

	Druck DPI 605	DRUCK	Calcul	Error PE
	<i>Pascal</i>	<i>Volts</i>	<i>Volt</i>	<i>%</i>
1	98722	2.30716	2.308	0.015%
2	278439	2.87957	2.882	0.035%
3	425319	3.35311	3.351	0.032%
4	574232	3.82704	3.826	0.010%
5	740748	4.35851	4.358	0.007%
6	910215	4.89857	4.899	0.008%
7	1077020	5.43132	5.432	0.006%
8	934354	4.97460	4.976	0.024%
9	767115	4.44226	4.442	0.000%
10	647477	4.06157	4.060	0.019%
11	486195	3.54656	3.545	0.018%
12	324263	3.02977	3.028	0.022%
13	98730	2.30694	2.308	0.018%
14	1514004	6.82679	6.827	0.002%
		Averaged		0.015%

CALI BRATION SHEET - Signal P_HC2
Druck PTX631 - Range 0-25 bar abs - S/N 2962348



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
Study N° :		Contract N°		N° O.E. :	Page :	79



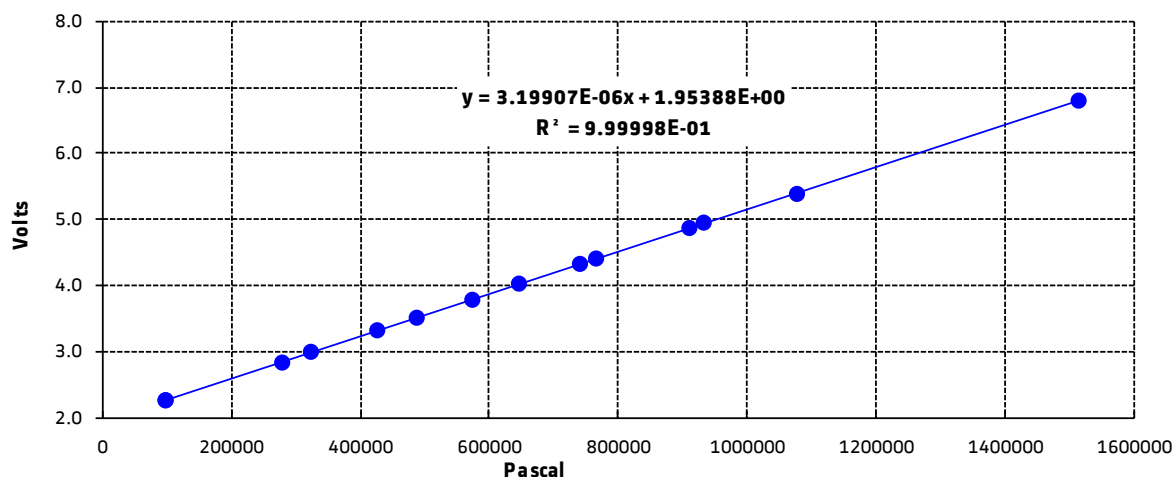
CALIBRATION SHEET - Signal P_Up_After
Druck PTX631 - Range 0-25 bar abs - S/N 1774816

Signal Transducer	P_Up_After	Operator	X.CORNUT
Range	Druck PTX631	Project	ANGOSTURA
S/N	0-25 bar abs	Date	12/08/2014
Ambient pressure input n° (box, box_in, ...)	1774816	Calibrator	Druck DPI 605
	1, 5, 29	S/N	60505093

Sensitivity	3.199069E-06	<i>Volts / Pascal</i>
Offset	1.953883E+00	<i>Volts</i>

	Druck DPI 605	DRUCK	Calcul	Error PE
	<i>Pascal</i>	<i>Volts</i>	<i>Volt</i>	<i>%</i>
1	98722	2.26785	2.270	0.027%
2	278439	2.84133	2.845	0.049%
3	425319	3.31478	3.315	0.004%
4	574232	3.79044	3.791	0.007%
5	740748	4.32167	4.324	0.028%
6	910215	4.86497	4.866	0.011%
7	1077020	5.39824	5.399	0.016%
8	934354	4.94466	4.943	0.025%
9	767115	4.40968	4.408	0.026%
10	647477	4.02736	4.025	0.032%
11	486195	3.51139	3.509	0.031%
12	324263	2.99409	2.991	0.042%
13	98730	2.26936	2.270	0.005%
14	1514004	6.79615	6.797	0.017%
		Averaged		0.023%

CALIBRATION SHEET - Signal P_Up_After
Druck PTX631 - Range 0-25 bar abs - S/N 1774816



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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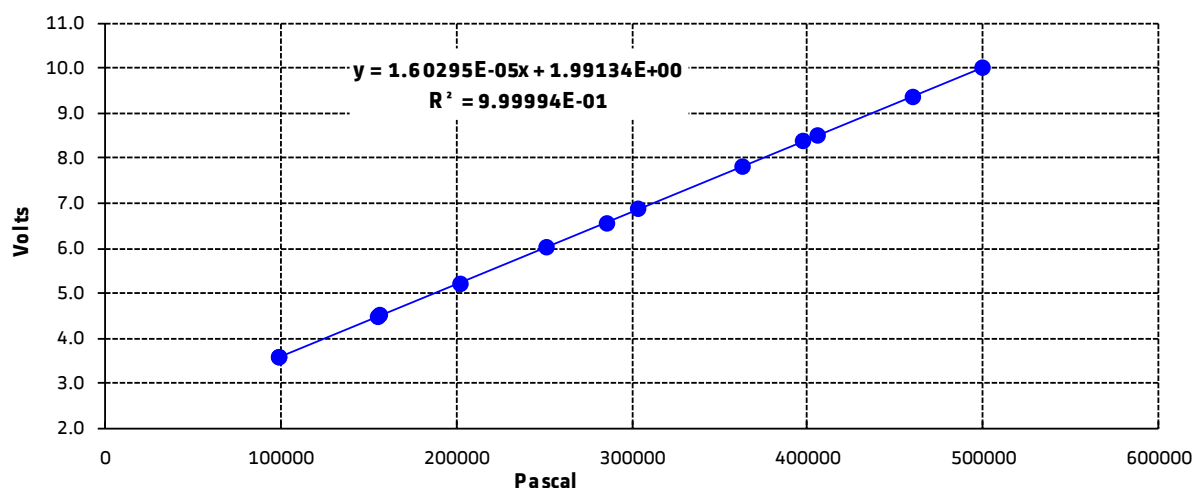
CALI BRATION SHEET - Signal P_Cone_Dyn
Druck PTX631 - Range 0-5 bar abs - S/N 1605429

Signal Transducer	P_Cone_Dyn	Operator	X.CORNUT
Range	Druck PTX631	Project	ANGOSTURA
S/N	0-5 bar abs	Date	12/08/2014
Ambient pressure input n° (box, box_in,	1605429	Calibrator	Druck DPI 605
	1, 6, 19	S/N	60505093

Sensitivity	1.602953E-05	<i>Volts / Pascal</i>
Offset	1.991337E+00	<i>Volts</i>

	Druck DPI 605	DRUCK	Calcul	Error PE
	<i>Pascal</i>	<i>Volts</i>	<i>Volt</i>	<i>%</i>
1	98804	3.57800	3.575	0.029%
2	155275	4.47963	4.480	0.007%
3	202160	5.22636	5.232	0.055%
4	251531	6.01790	6.023	0.054%
5	303168	6.86429	6.851	0.133%
6	363410	7.81980	7.817	0.032%
7	405502	8.49355	8.491	0.022%
8	460511	9.37267	9.373	0.004%
9	499975	9.99852	10.006	0.072%
10	397565	8.36622	8.364	0.021%
11	285767	6.57124	6.572	0.008%
12	156737	4.49955	4.504	0.042%
13	98802	3.57562	3.575	0.005%
		Averaged		0.037%

CALI BRATION SHEET - Signal P_Cone_Dyn
Druck PTX631 - Range 0-5 bar abs - S/N 1605429



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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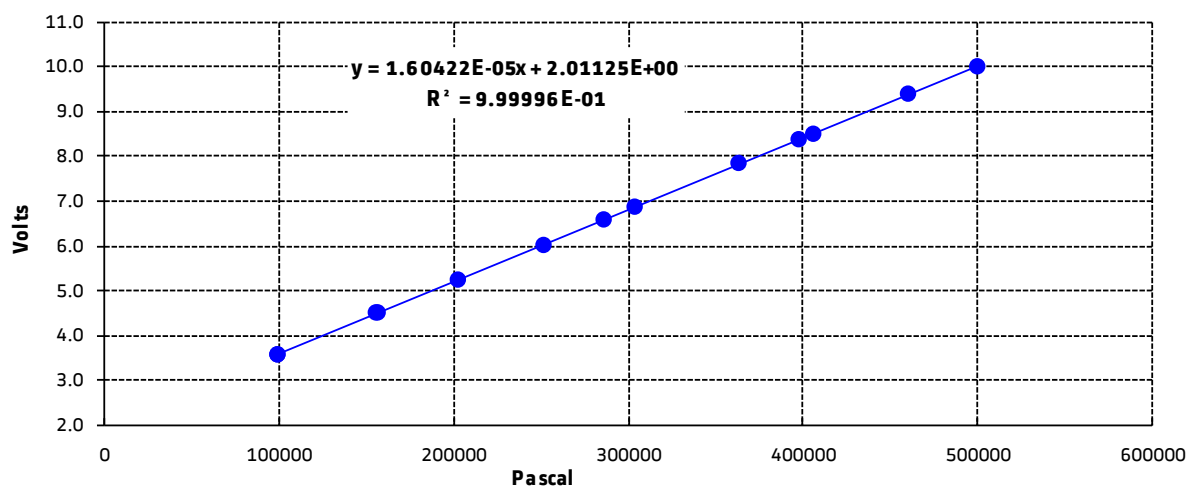
CALIBRATION SHEET - Signal P_Down
Druck PTX631 - Range 0-5 bar abs - S/N 2192271

Signal Transducer	P_Down	Operator	X.CORNUT
Range	Druck PTX631	Project	ANGOSTURA
S/N	0-5 bar abs	Date	12/08/2014
Ambient pressure input n° (box, box_in, ...)	2192271	Calibrator	Druck DPI 605
	1, 7, 30	S/N	60505093

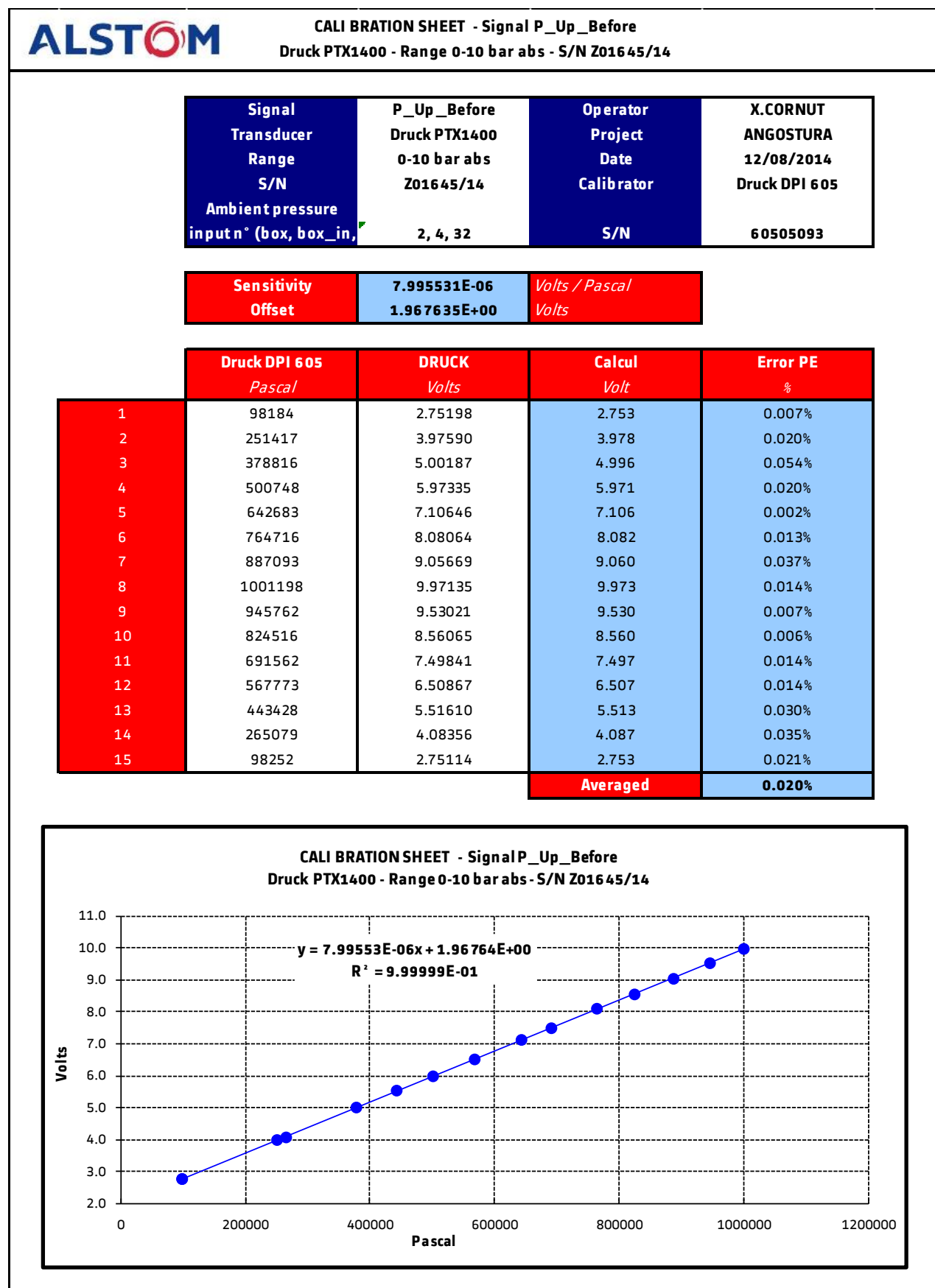
Sensitivity	1.604225E-05	<i>Volts / Pascal</i>
Offset	2.011249E+00	<i>Volts</i>

	Druck DPI 605	DRUCK	Calcul	Error PE
	<i>Pascal</i>	<i>Volts</i>	<i>Volt</i>	<i>%</i>
1	98804	3.59580	3.596	0.005%
2	155275	4.50303	4.502	0.008%
3	202160	5.24927	5.254	0.051%
4	251531	6.04049	6.046	0.059%
5	303168	6.88515	6.875	0.104%
6	363410	7.84726	7.841	0.061%
7	405502	8.51842	8.516	0.020%
8	460511	9.39659	9.399	0.023%
9	499975	10.02655	10.032	0.054%
10	397565	8.38960	8.389	0.005%
11	285767	6.59568	6.596	0.001%
12	156737	4.52321	4.526	0.024%
13	98802	3.59795	3.596	0.017%
		Averaged		0.033%

CALIBRATION SHEET - Signal P_Down
Druck PTX631 - Range 0-5 bar abs - S/N 2192271



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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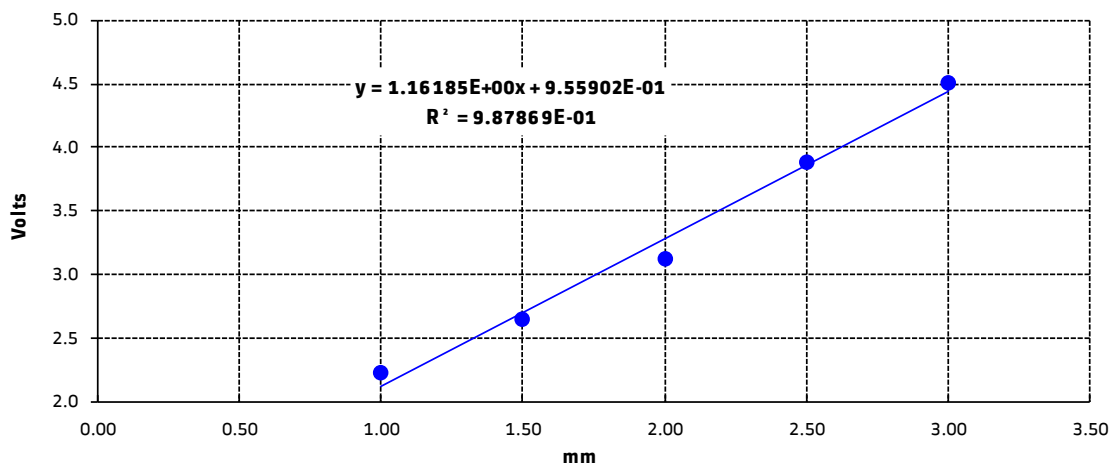
CALIBRATION SHEET - Signal S3X
Telemechanique - Range 0-5mm - S/N -

Signal Transducer	S3X	Operator	X.CORNUT
Range	Telemechanique	Project	ANGOSTURA
S/N	0-5mm	Date	22/08/2014
Ambient pressure input n° (box, box_in,	-	Calibrator	juego de calas
		S/N	-

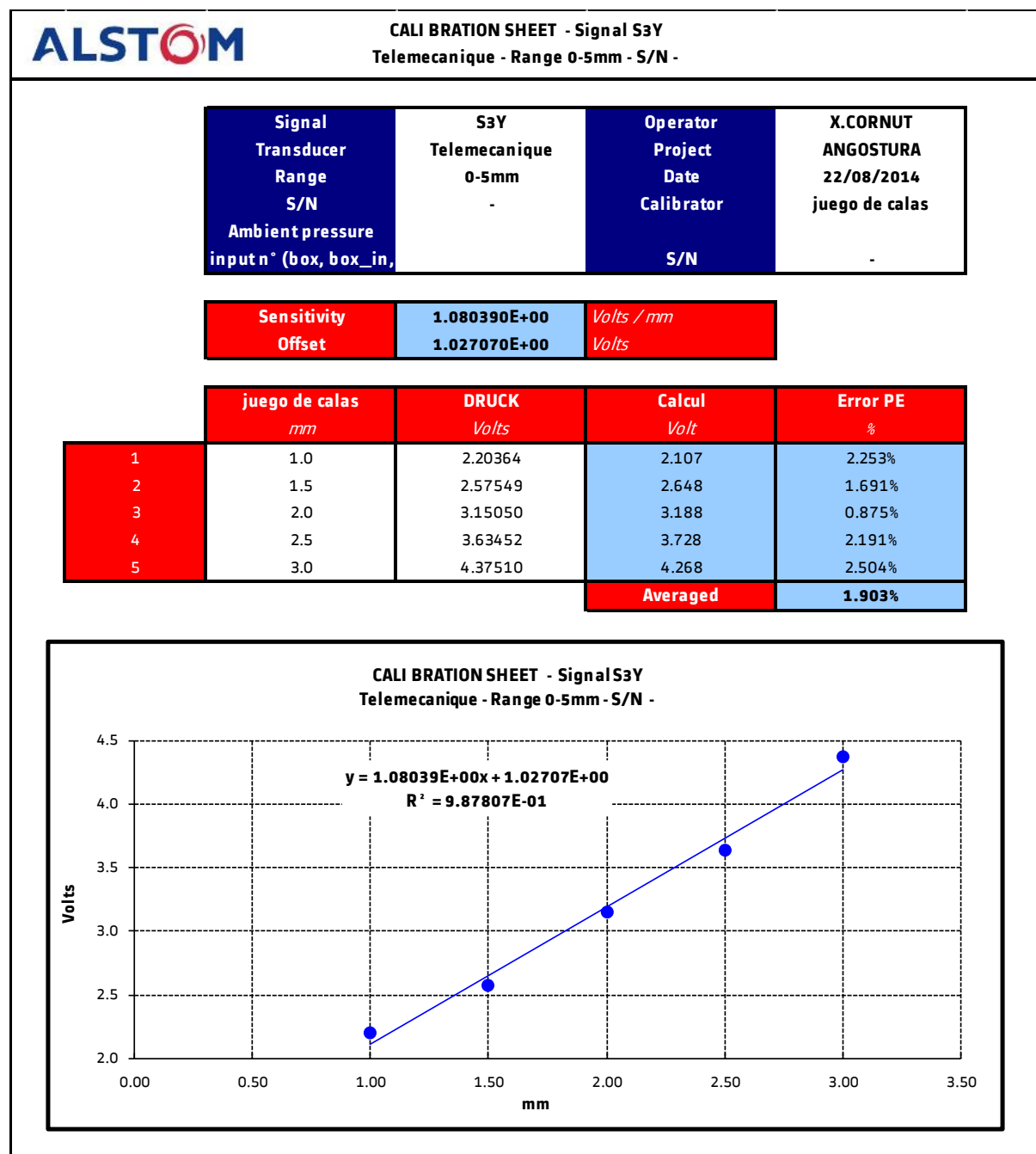
Sensitivity	1.161848E+00	<i>Volts / mm</i>
Offset	9.559020E-01	<i>Volts</i>

	juego de calas <i>mm</i>	DRUCK <i>Volts</i>	Calcul <i>Volt</i>	Error PE <i>%</i>
1	1.0	2.22289	2.118	2.367%
2	1.5	2.65256	2.699	1.038%
3	2.0	3.12922	3.280	3.386%
4	2.5	3.87906	3.861	0.417%
5	3.0	4.51426	4.441	1.639%
			Averaged	1.770%

CALIBRATION SHEET - Signal S3X
Telemechanique - Range 0-5mm - S/N -



ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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ALSTOM		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
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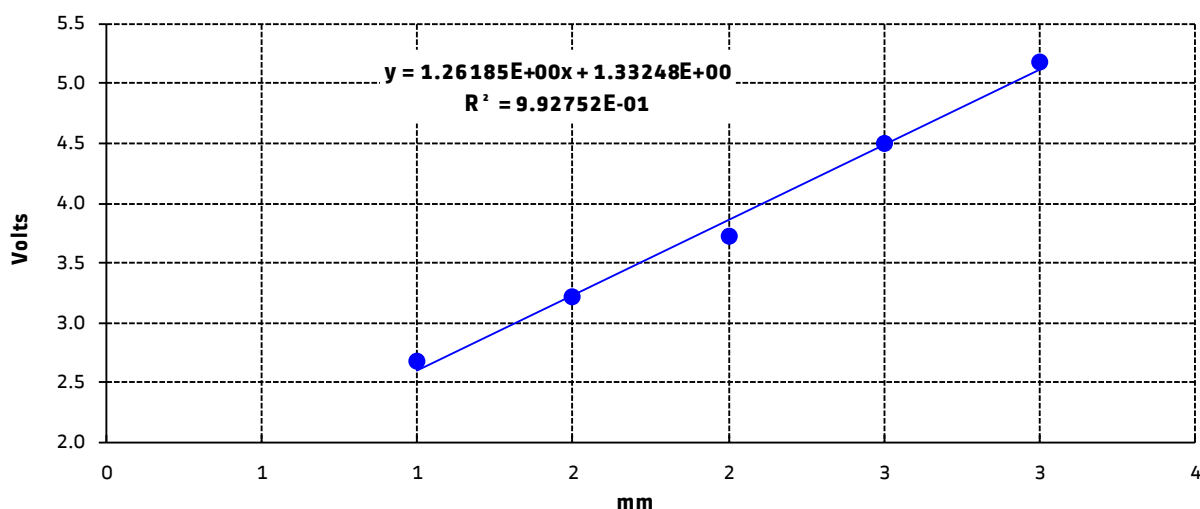
CALIBRATION SHEET - Signal S1Z
Telemechanique - Range 0-5mm - S/N -

Signal	S1Z	Operator	X.CORNUT
Transducer	Telemechanique	Project	ANGOSTURA
Range	0-5mm	Date	22/08/2014
S/N	-	Calibrator	juego de calas
Ambient pressure		S/N	-
input n° (box, box_in,			

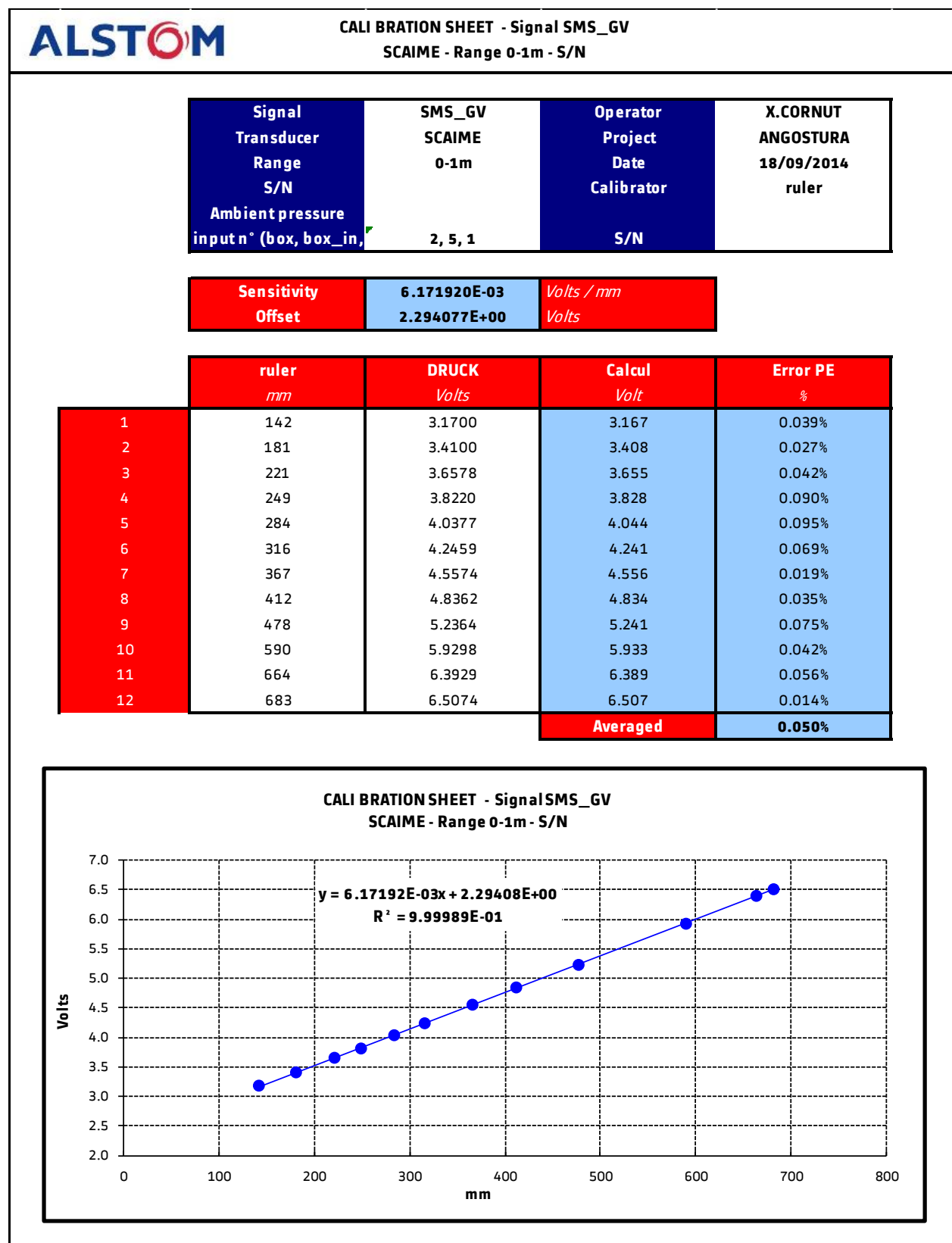
Sensitivity	1.261846 E+00	<i>Volts / mm</i>
Offset	1.332476 E+00	<i>Volts</i>


	juego de calas <i>mm</i>	DRUCK <i>Volts</i>	Calcul <i>Volt</i>	Error PE <i>%</i>
1	1.0	2.67045	2.594	1.487%
2	1.5	3.21151	3.225	0.268%
3	2.0	3.71859	3.856	2.688%
4	2.5	4.49894	4.487	0.232%
5	3.0	5.18135	5.118	1.238%
			Averaged	1.183%

CALIBRATION SHEET - Signal S1Z
Telemechanique - Range 0-5mm - S/N -



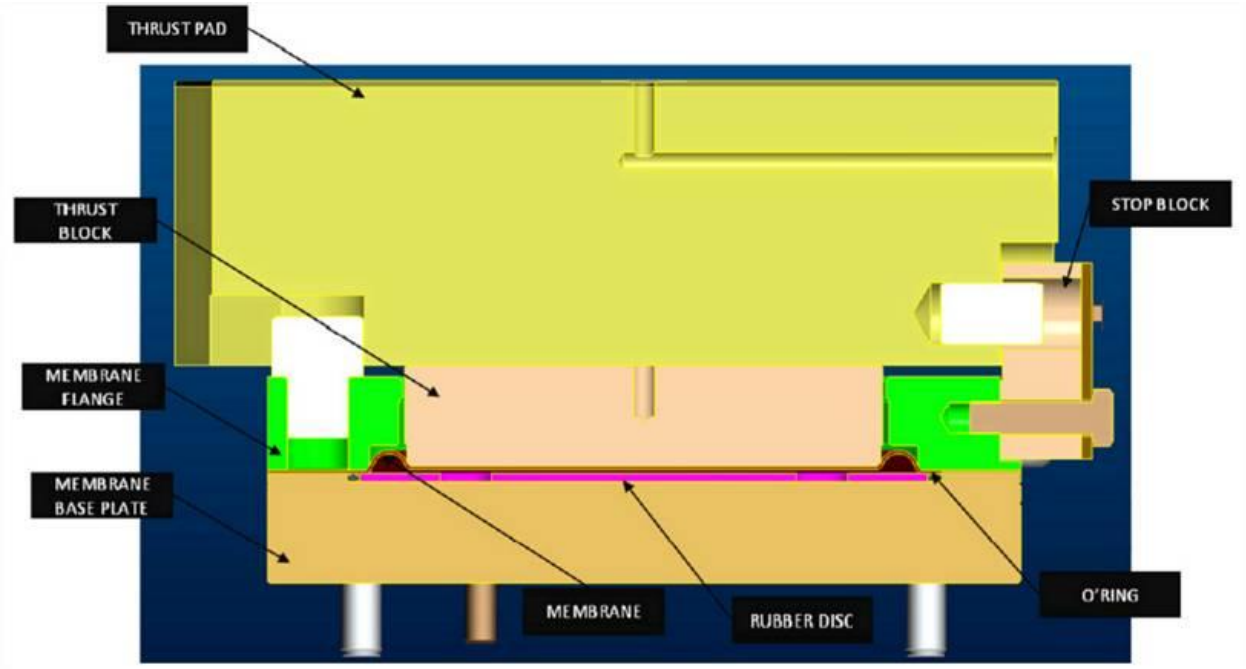
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		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
Study N° :		Contract N°		N° O.E. :	Page :	86



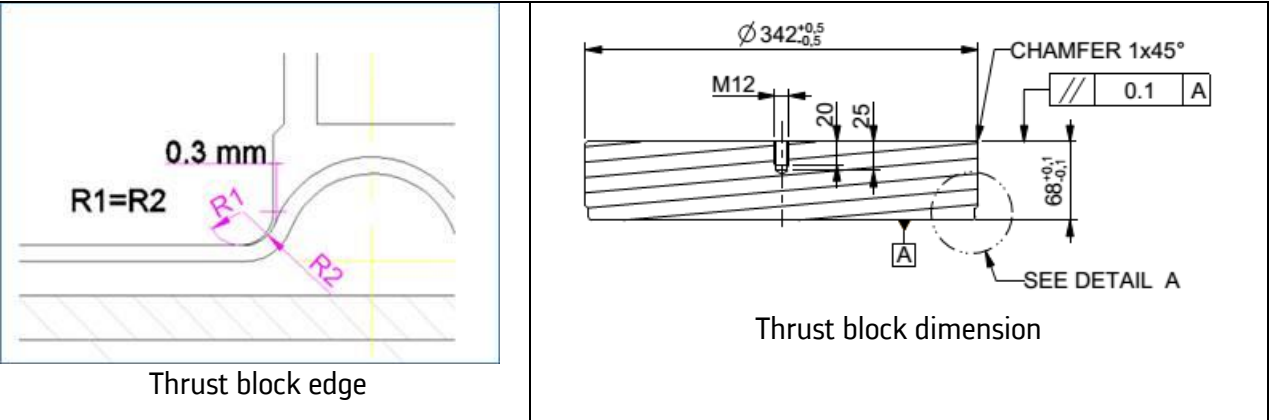
		PROJECT :	ANGOSTURA		ALSTOM Hydro France	
		CLIENT :	UNIT 1		N° DOCUMENT :	
			COLBUN		LTESS-14505	
Study N° :		Contract N°		N° O.E. :	Page :	87


9.5. Appendix 5: Axial thrust calculation

Hereafter the cut view of a thrust pad:



Here on the drawing, the thrust pad transmit the load on the membrane through the thrust block. If we enlarge the corner of the thrust block, we can see that the folding radius of the membrane isn't in contact with the thrust bock. Therefore we will only consider the flat surface of the thrust block in the thrust calculation.



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Hereafter the thrust block surface to be considered in the thrust calculation :

Thrust block number "n"	12	-	Record name	static load
Thrust block diameter "D _b "	330	mm		(N)
Thrust block surface "S _b "	85529.85999	mm ²	point_zero1	4772483
Total thrust blocks surface "S _{bt} "	1026358.32	mm ²	point_zero2	4786100.5
Total thrust blocks surface "S _{bt} "	1.02635832	m ²	Average "L _s "	4779291.75

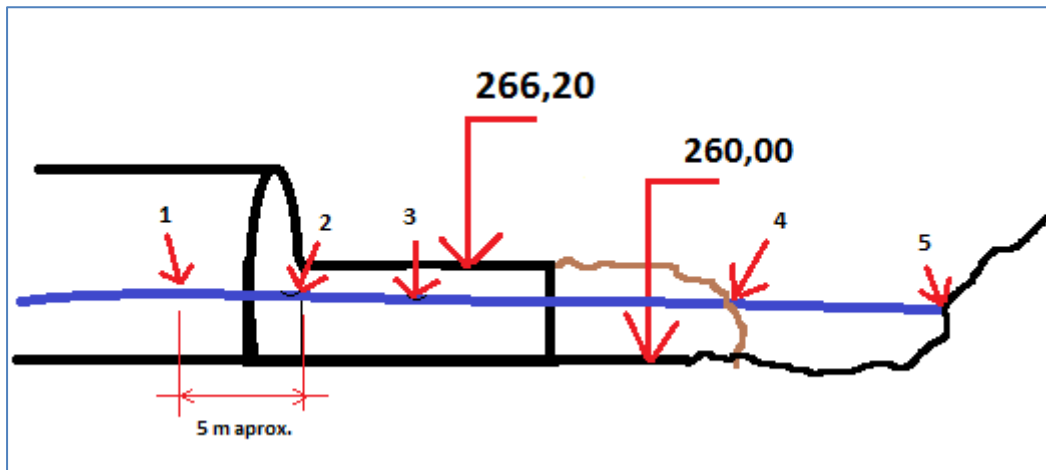
$$S_{bt} = n \times \frac{(\pi \times D_b)}{4}$$

So that the dynamic axial thrust equal $F_Z = \frac{(P_{membrane} - L_s)}{S_{bt}}$


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9.6. Appendix 6: Topographic manual records

9.6.1. Measurement locations



1. Medición a 5 m aprox AAr del portal del tunel de Descarga.
2. Medición en la salida del Portal de descarga.
3. Medición a la mitad del canalon de salida.
4. Medición al fibal de camellon de piedra en la descarga.
5. Medición al frente, rivera Sur del río.

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9.6.2. Manual records

Unidad	N° de medición	1	2	3	4	5	DCS	Nivel Embalse	QU1	QU2	QU3	Qtotol	Potencia Unidad en Prueba[MW]	Fecha	Hora
U1	1	265.80	265.11	265.11	265.20	264.90	265.10	317.03	0	307	105	412	0	25/08/2014	11:20
U1	2	265.70	265.26	265.09	265.26	264.94	265.04	317.05	0	307	105	412	0	25/08/2014	11:24
U1	3	265.84	265.42	265.28	265.46	265.10	265.20	317.07	47	307	105	459	SNL	25/08/2014	11:28
U1	4	265.84					265.20	317.07	47	307	105	459	SNL	25/08/2014	11:29
U1	5	265.93					265.41	317.07	47	307	105	459	SNL	25/08/2014	11:30
U1	6	265.95	265.55	265.43	265.55	265.05	265.50	317.07	47	307	105	459	SNLE	25/08/2014	11:37
U1	7	265.94			265.54		265.56	317.08	52	307	105	464	SNLE	25/08/2014	11:39
U1															
U1	1	266.53	265.82	266.05	266.12	265.60	265.90	317.10	130	305	105	540	54	25/08/2014	
U1	2	266.44			266.10		265.98	317.10	130	305	103	538	54	25/08/2014	11:55
U1	3	266.57			266.25		266.17	317.11	132	304	103	539	54	25/08/2014	12:10
U1	4	266.65	266.00	266.20	266.25	265.67	266.11	317.12	132	307	103	542	54.4	25/08/2014	12:18
U1	5	266.65	266.19	266.20	266.10	265.74	265.98	317.12	132	305	103	540	54	25/08/2014	
U1															
U1	1	266.71	266.33	266.30	266.32	265.81	266.30	317.12	155	305	103	563	68	25/08/2014	12:29
U1	2	266.69	266.28	266.30	266.34	265.81	266.26	317.12	155	307	103	565	68	25/08/2014	
U1	3	266.73	266.20	266.25	266.42	265.79	266.35	317.12	157	307	103	567	68	25/08/2014	12:42
U1	4	266.70	266.24	266.26	266.31	265.80	266.26	317.12	155	307	103	565	67.8	25/08/2014	12:46
U1	5	266.74	266.28	266.35	266.27	265.76	266.27	317.12	155	307	103	565	67.9	25/08/2014	
U1															
U1	1	266.82	266.32	266.40	266.63	266.18	266.40	317.13	178	306	103	587	81	25/08/2014	13:00
U1	1'	266.94			266.69		266.70	317.13	178	306	103	637	81	25/08/2014	13:00
U1	2	267.04	266.70	266.57	266.61	266.41	266.65	317.13	176	312	103	641	81	25/08/2014	13:06
U1	3	267.09	266.76	266.70	266.69	266.37	266.74	317.13	177	310	103	640	81	25/08/2014	13:10
U1	4	267.18	266.76	266.73	266.78	266.43	266.85	317.13	177	312	103	642	81	25/08/2014	13:16
U1	5	267.16	266.67	266.63	266.69	266.44	266.70	317.13	178	310	103	641	81	25/08/2014	13:20
U1															
U1	1	267.35	266.89	266.65	267.00	266.82	266.90	317.13	207	312	103	672	95	25/08/2014	13:30
U1	2	267.25	266.95	266.99	267.00	266.90	266.91	317.13	207	310	103	670	95	25/08/2014	13:34
U1	3	267.26	266.87	266.85	266.95	266.85	266.80	317.12	207	312	103	672	95	25/08/2014	13:38
U1	4	267.31	266.95	266.63	266.98	266.89	266.95	317.12	205	311	103	669	95	25/08/2014	13:41
U1	5	267.34	266.91	266.86	267.02	266.80	266.89	317.12	205	311	103	669	95	25/08/2014	13:44
U1															
U1	1	267.43	267.04	266.87	267.20	267.03	267.00	317.12	230	313	103	696	108	25/08/2014	13:55
U1	2	267.35	266.96	266.63	267.18	267.08	266.91	317.13	230	313	103	696	108	25/08/2014	13:58
U1															
U1	1	267.68	267.38	267.55	267.55	267.55	267.37	317.11	260	314	103	777	122	25/08/2014	14:07
U1	2	267.87	267.52	267.40	267.66	267.45	267.46	317.10	260	315	103	778	122	25/08/2014	14:14
U1															
U1	1	268.04	267.65	_____	267.79	267.77	267.60	317.08	297	313	103	863	134	25/08/2014	14:24
U1	2	268.50	268.13	_____	_____	268.14	267.93	317.07	294	313	103	860	134.1	25/08/2014	14:30
U1	1	268.37	268.02	_____	_____	268.00	267.88	316.88	315	311	103	829	139.4	25/08/2014	15:32
U1	PRC	264.70	264.12	263.31	264.94	265.18	266.50	316.93	320	0	0	320	144.2	25/08/2014	16:26
U1	PRC	264.70	264.35	263.15	264.36	265.04	266.53	316.97	320	0	0	320	144.6	25/08/2014	16:32
U1	DRC	263.71	263.58	264.06	264.55	263.58	263.43	317.01	0	0	0	0	0	25/08/2014	16:48
U1															
U1	1	265.71	265.79	265.64	265.62	265.71	265.54	317.10	70	307	103	480	13.19	25/08/2014	17:26
U1	2	265.78	265.60	265.62	265.68	265.76	265.68	317.11	70	306	105	481	13	25/08/2014	17:30
U1	3	265.74	265.54	265.65	265.65	265.76	265.57	317.11	70	307	103	480	13	25/08/2014	17:35
U1	4	265.89	265.70	265.54	265.72	265.89	265.40	317.11	70	308	103	481	13	25/08/2014	17:39
U1	5	265.73	265.79	265.48	265.67	265.86	265.48	317.17	70	307	105	482	13	25/08/2014	17:44
U1															
U1	1	266.00	265.67	265.99	265.92	266.05	266.02	317.13	95	308	103	556	27	25/08/2014	17:55
U1	2	266.15	266.19	266.05	266.10	266.24	265.86	317.13	95	309	103	557	27	25/08/2014	17:58
U1	3	266.15	266.14	266.14	266.14	266.34	266.10	317.14	95	307	103	555	27	25/08/2014	18:02
U1	4	266.33	266.41	266.33	266.41	266.46	266.19	317.16	90	307	103	550	27	25/08/2014	18:05
U1	5	266.42	266.48	266.37	266.43	266.60	266.30	317.14	90	306	103	549	27	25/08/2014	18:10
U1															
U1	1	_____	267.16	_____	_____	_____	267.00	317.15	113	311	103	727	40.9	25/08/2014	18:19
U1	2	_____	_____	_____	_____	_____	267.07	317.14	112	315	103	730	40.9	25/08/2014	18:23
U1	3	_____	_____	_____	_____	_____	267.07	317.13	118	316	103	737	40.9	25/08/2014	18:25
U1	4	_____	_____	_____	_____	_____	267.19	317.13	116	315	103	734	40.9	25/08/2014	18:29
U1	5	_____	_____	_____	_____	_____	267.09	317.13	113	315	103	731	40.9	25/08/2014	18:36