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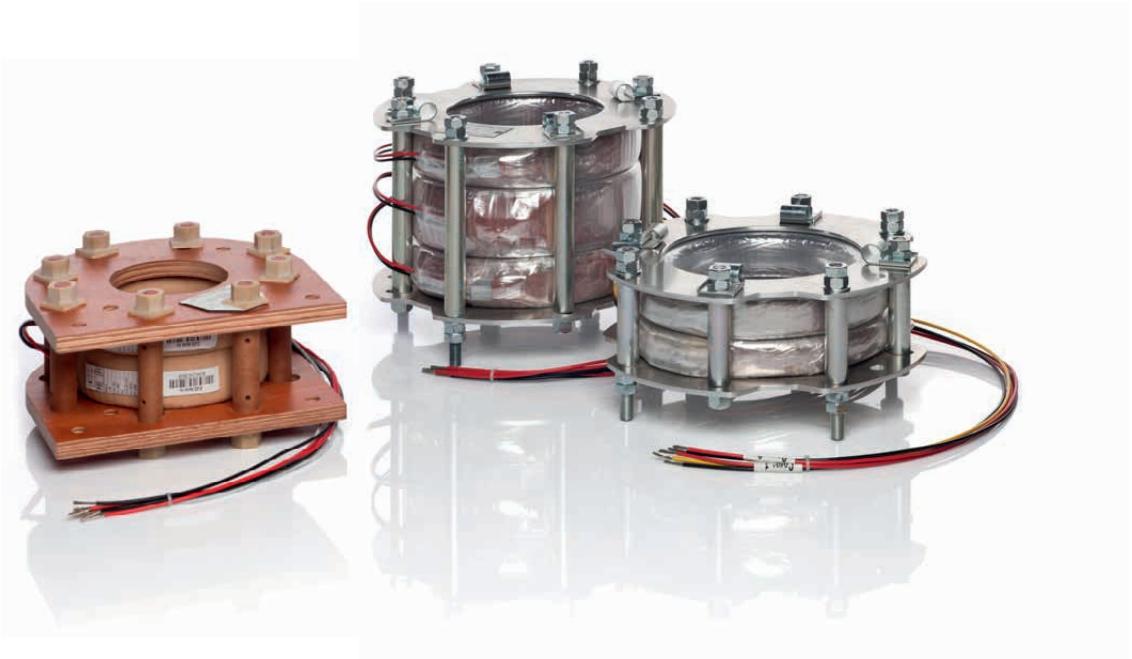
Vibration and Shock tests on a typical Current Transformer Set



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Vibration and Shock tests on a typical Current Transformer Set

Issue_

R.A. Grijpma

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Summary

This document contains the description and the results of vibration and Shock tests, performed for ELEQ Steenwijk B.V. on a typical current transformer set.

The tests have been executed in order to verify the performance characteristics of the transformer in environmental conditions representative of those which may be encountered during transport and operation of the equipment.

The tests were performed on August 5th and 6th, 2009, in accordance with IEC 60068-2-6, IEC-60068-2-27 and MIL-STD-810G.

The transformer successfully completed the vibration and shock tests according to IEC 60068-2-6, IEC-60068-2-27 and MIL-STD-810G. The test in accordance with MIL-STD-810G represented a vibration profile corresponding to 500 miles transportation in a composite wheeled vehicle.

Before and after the vibration and shock test the transformer was electrically characterized. These measurements for this characterization were performed at the ELEQ Steenwijk B.V. premises under witnessing of Mr. E. Wegkamp of the ASAS department of the NLR. No significant change was indicated during these measurements. The measured values were within the normal expected distribution. The unit under test successfully passed the referenced vibration and shock tests, without measurable or visible loss of functional or physical characteristics.

Mr. D. Baars and Mr. R. Zelhorst of ELEQ Steenwijk B.V. witnessed the vibration and shock tests in the longitudinal direction.

Contents

Abbreviations

Acc.	Acceleration
APSD	Acceleration Power Spectral Density
ASAS	Aerospace Systems & applications; Avionics Systems
ASAQ	Aerospace Systems & applications; Avionics development and Qualification
AvC	Average Control
dB	deciBel
g	Acceleration due to gravity, equal to 9.81 $m.s^{-2}$
Hz	Hertz
Manuf.	Manufacturer
Oper	Operational
OS	Operational Shock
PK	Peak
Res	Resonance
RS	Resonance Survey
RMS	Root Mean Square
Seq	Sequence
S/N	Serial Number
TS	Test Sequence

1 Introduction

1.1 Background

The test object is a typical example of a Current Transformer Set. ELEQ Steenwijk B.V. produces a range of transformers differentiating in weight and dimensions. The selected Current Transformer Set is of average weight and has a relative high "height to width ratio", which is expected to be worst case for vibration and shock testing. The used transformers are also average in wire thickness, winding numbers and core material.

1.2 Test object identification

Under contract of ELEQ Steenwijk B.V., vibration and shock tests were performed on the test sample, identified as:

Type : Current transfomer set
Ref : CTS 43096, Project DS4087
Serial number : 09902309

This current transformer set consists of three individual current transfomers identified as:

Table 1 identification of transfomers

Transformer position	Type	S/N
1	BER 42702	09643953
2	BER 42702	09643954
3	BER 42703	09643955

In chapter 2, the test procedures and applicable specifications are indicated, while chapter 3 gives the test results. Chapter 4 discusses the conclusions. Finally, chapter 5 lists the references.

2 Test procedures and specifications

The standard test specifications were derived form IEC 60068-2-6, IEC-60068-2-27 and MIL-STD-810G.

To successfully pass the tests, the equipment shall show no visual damage after the tests. No significant change in electrical behaviour is allowed. The electrical behaviour of the transformer will be measured (characterized) before and after the vibration and shock tests.

The vibration and shock tests are to be applied in the vertical and longitudinal axis only since the transformer is almost symmetrical in longitudinal and transversal axes. Refer to figure B 1 and B 2 for pictures of the test sample and the definition of its orientations.

2.1 Test conditions

Ambient temperature, relative humidity and barometric pressure shall be measured during the test.

2.2 Resonance survey test

The objective of the resonance survey test is to identify the resonance frequencies of the test object and the characteristic behavior of the test object during these resonances.

For the purpose of this test, a flat spectrum is defined:

- From 5 to 2000 Hz: 0.5 g-PK.

The test procedure comprises one sweep upwards, at 1.0 octave/minute sweep rate. Refer to figure B 3 for a graphical representation of this reference (target) spectrum.

2.3 Sine vibration test

From document IEC 60068-2-6, table B.1 the category '*General purpose land-based and transport*' was selected. According document IEC 60068-2-6 the sine vibration reference spectrum of the transformer is defined as:

• From 10 – 60 Hz: ± 0.35 mm
• From 60 – 500 Hz: 5 g

The test procedure comprises ten sweeps up and down (f1 $\rightarrow$ f2 $\rightarrow$ f1) at 1 octaves/minute sweep rate in each of the applicable directions. Ten up and down sweep results in a test time per axis of approximately 2 hours. Refer to figure B 4 for a graphical representation of this reference (target) spectrum.

2.4 Random vibration test

From MIL-STD 810G, Method 514.6, Category 4, Table 514.5-VI was selected to expose the test object to composite wheeled vehicle vibration. The random vibration test is performed to simulate the transport of the transformer by a wheeled vehicle over a distance up to 804 km (500 miles).

From MIL-STD 810G, the reference spectrum of random vibration test, Category 4, Composite Wheeled Vehicle, Table 514.6C-VII, is defined as:

Table 2 Composite wheeled vehicle vibration levels

Vertical		Longitudinal	
Frequency (Hz)	**PSD (g^3/Hz)**	**Frequency (Hz)**	**PSD (g^3/Hz)**
5	0.1759	5	0.0441
8	0.512	7	0.039
11	0.066	8	0.0576
12	0.0585	9	0.043
13	0.0348	10	0.0293
15	0.1441	13	0.0221
16	0.1237	15	0.0558
20	0.0241	16	0.0585
23	0.0536	18	0.016
26	0.0124	20	0.0099
27	0.0118	23	0.0452
30	0.0331	25	0.011
34	0.0086	35	0.0036
39	0.0347	37	0.0098
43	0.0073	40	0.004
45	0.0141	41	0.0044
49	0.0084	45	0.0023
52	0.0089	47	0.0047
57	0.0045	50	0.0016
67	0.016	54	0.0017
80	0.0037	64	0.001
90	0.0077	69	0.003
93	0.0053	77	0.0007
98	0.0065	85	0.0015
99	0.0063	90	0.0012
111	0.0046	97	0.0015
123	0.0069	104	0.0036
128	0.0055	114	0.004
164	0.0031	122	0.0015
172	0.0035	132	0.0013
215	0.0133	206	0.0033
264	0.0056	247	0.0226
276	0.0096	257	0.0041
292	0.0032	264	0.0054

Vertical		Longitudinal	
Frequency (Hz)	PSD (g^3/Hz)	Frequency (Hz)	PSD (g^3/Hz)
348	0.0044	276	0.004
417	0.0031	303	0.0073
500	0.0008	332	0.0092
		353	0.0172
		382	0.0071
		428	0.0157
		500	0.0016
rms =2.24 g		rms = 1.90 g	

This spectrum was imposed on the test sample for 120 minutes in each of the applicable directions.
Refer to figure B 5 (longitudinal) and B 6 (vertical) for a graphical representation of this reference (target) spectrum.

2.5 Shock test

From document IEC-60068-2-27, table A.1 the category '*General test for robustness, handling and transport/ Land-based items permanently installed or only transported by road*' was selected
The Shock test is defined as three half sine shocks being applied to the test sample in each applicable orthogonal direction, in both the positive and negative senses. This totals to 12 shocks per test sample. Each shock has an amplitude of 15 g and a duration of 11 ms.

Figure B 7 (negative) and B 8 (positive) gives the reference Shock, applied at the test sample.

2.6 Concluding functional testing

ELEQ Steenwijk B.V. is responsible for the pre and post measurements to characterize the test item. These measurements will be witnessed by NLR personnel. The difference of these measurements before and after the vibration and shock tests shall be within the normal distribution to qualify the test object

3 Test results

The following sections present the test sequences performed, the corresponding test configuration and the figure numbers presenting the results. The abbreviation 'AvC' means the Averaged Control signal, M1 through M3 depicts the measurement signal from the Base of the transformer. M4 through M6 depicts the measurement signal from the Top of the transformer. Finally M7 and M8 depict the individual channels used for the average control signal.

The following table presents the accelerometer definitions:

Table 3 Accelerometer definitions

Manuf.	Type	S/N	X-axis	Z-axis
Endevco	233E	NA06	Sliptable_A	Extender_A
Endevco	233E	NA11	Sliptable_B	Extender_B
Endevco	65HT10	11280	Base_(X,Y,Z)	Base_(X,Y,Z)
Endevco	65HT10	11279	Top_(X,Y,Z)	Top_(X,Y,Z)

The table below contains the figure identifications for the applicable vibration tests. The number in the last columns indicates the number of the figure in appendix B presenting the results of the indicated test sequence.

Table 4 Test result figure numbers

TEST SEQ	CONFIGU-RATION	DIRECTION	METHOD	AVC	M1	M2	M3	M4	M5	M6	M7	M8
TS-01	transformer	X-axis	Res. Survey	9	10	11	12	13	14	15	16	17
TS-02	transformer	X-axis	Sine	18	19	20	21	22	23	24	25	26
TS-03	transformer	X-axis	Random	27	28	29	30	31	32	33	34	35
TS-04	transformer	X-axis	Oper. S -	36	-	37	38	39	40	41	42	43
			Oper. S +	44	-	45	46	47	48	49	50	51
TS-05	transformer	X-axis	Res. Survey	52	53	54	55	56	57	58	59	60
			Comparison	61	62	63	64	65	66	67	68	69
TS-06	transformer	Z-axis	Res. Survey	70	71	72	73	74	75	76	77	78
TS-07	transformer	Z-axis	Sine	79	80	81	82	83	84	85	86	87
TS-08	transformer	Z-axis	Random	88	89	90	91	92	93	94	95	96
TS-09	transformer	Z-axis	Oper. S -	97	98	99	-	100	101	102	103	104
			Oper. S +	105	106	107	-	108	109	110	111	112
TS-10	transformer	Z-axis	Res. Survey	113	114	115	116	117	118	119	120	121
			Comparison	122	123	124	125	126	127	128	129	130

The tests were performed in the following order: TS-01 through TS-10.

The tests were executed in the operational state adequately representing the operational environment of the transformer.

The test results are contained on the accompanying DVD of this report. The results are presented as Microsoft Word files in the 'LMS Vibration data' Directory. These Word files contain active pictures which can be accessed by use of a Word plug in. This plug in is also on the DVD in the directory 'LMS active picture plug in'. With the use of the plug in cursors can be set on the signals and data can be copied to Excel.

The DVD contains also the raw data collected during the test about the environmental data, the list of test runs, run logging files and the pictures taken during the test.

The name in the table below indicates the name of the figure presenting the results of the indicated test sequence. All filenames have the .doc extension.

Table 5 Figure name 'Base' sensor

TEST SEQ	FIGURE NAME		
	BASE_X	BASE_Y	BASE_Z
TS-01	TS-01 (X) Pre RS_2	TS-01 (X) Pre RS_3	TS-01 (X) Pre RS_4
TS-02	TS-02 (X) Sine_2	TS-02 (X) Sine_3	TS-02 (X) Sine_4
TS-03	TS-03 (X) Random_2	TS-03 (X) Random_3	TS-03 (X) Random_4
TS-04	(is control)	TS-04 (X) OS pos_2	TS-04 (X) OS pos_3
	(is control)	TS-04 (X) OS neg_2	TS-04 (X) OS neg_3
TS-05	TS-05 (X) Post RS_2	TS-05 (X) Post RS_3	TS-05 (X) Post RS_4
TS-06	TS-06 (Z) Pre RS_2	TS-06 (Z) Pre RS_3	TS-06 (Z) Pre RS_4
TS-07	TS-07 (Z) Sine_2	TS-07 (Z) Sine_3	TS-07 (Z) Sine_4
TS-08	TS-08 (Z) Random_2	TS-08 (Z) Random_3	TS-08 (Z) Random_4
TS-09	TS-09 (Z) OS pos_2	TS-09 (Z) OS pos_3	TS-09 (Z) OS pos_4
	TS-09 (Z) OS neg_2	TS-09 (Z) OS neg_3	TS-09 (Z) OS neg_4
TS-10	TS-10 (Z) Post RS_2	TS-10 (Z) Post RS_3	TS-10 (Z) Post RS_4

Table 6 Figure name 'Top' sensor

TEST SEQ	FIGURE NAME		
	TOP_X	TOP_Y	TOP_Z
TS-01	TS-01 (X) Pre RS_5	TS-01 (X) Pre RS_6	TS-01 (X) Pre RS_7
TS-02	TS-02 (X) Sine_5	TS-02 (X) Sine_6	TS-02 (X) Sine_7
TS-03	TS-03 (X) Random_5	TS-03 (X) Random_6	TS-03 (X) Random_7
TS-04	TS-04 (X) OS pos_4	TS-04 (X) OS pos_5	TS-04 (X) OS pos_6
	TS-04 (X) OS neg_4	TS-04 (X) OS neg_5	TS-04 (X) OS neg_6
TS-05	TS-05 (X) Post RS_5	TS-05 (X) Post RS_6	TS-05 (X) Post RS_7

TEST SEQ	FIGURE NAME		
	TOP_X	TOP_Y	TOP_Z
TS-06	TS-06 (Z) Pre RS_5	TS-06 (Z) Pre RS_6	TS-06 (Z) Pre RS_7
TS-07	TS-07 (Z) Sine_5	TS-07 (Z) Sine_6	TS-07 (Z) Sine_7
TS-08	TS-08 (Z) Random_5	TS-08 (Z) Random_6	TS-08 (Z) Random_7
TS-09	TS-09 (Z) OS pos_5	TS-09 (Z) OS pos_6	(is control)
	TS-09 (Z) OS neg_5	TS-09 (Z) OS neg_6	(is control)
TS-10	TS-10 (Z) Post RS_5	TS-10 (Z) Post RS_6	TS-10 (Z) Post RS_7

Table 7 Figure name 'Control' sensor

TEST SEQ	FIGURE NAME
	AVERAGE CONTROL
TS-01	TS-01 (X) Pre RS_1
TS-02	TS-02 (X) Sine_1
TS-03	TS-03 (X) Random_1
TS-04	TS-04 (X) OS pos_1
	TS-04 (X) OS neg_1
TS-05	TS-05 (X) Post RS_1
TS-06	TS-06 (Z) Pre RS_1
TS-07	TS-07 (Z) Sine_1
TS-08	TS-08 (Z) Random_1
TS-09	TS-09 (Z) OS pos_1
	TS-09 (Z) OS neg_1
TS-10	TS-10 (Z) Post RS_1

Comparison of resonance survey tests before and after the qualification tests.

Table 8 Comparison of resonance survey results for 'Base' sensor

TEST SEQ	FIGURE NAME		
	BASE_X	BASE_Y	BASE_Z
TS-05	TS-05 Compare RS TS-01 (X)_2	TS-05 Compare RS TS-01 (X)_3	TS-05 Compare RS TS-01 (X)_4
TS-10	TS-10 Compare RS TS-06 (Z)_2	TS-10 Compare RS TS-06 (Z)_3	TS-10 Compare RS TS-06 (Z)_4

Table 9 Comparison of resonance survey results for 'Top' sensor

TEST SEQ	FIGURE NAME		
	TOP_X	TOP_Y	TOP_Z
TS-05	TS-05 Compare RS TS-01 (X)_5	TS-05 Compare RS TS-01 (X)_6	TS-05 Compare RS TS-01 (X)_7
TS-10	TS-10 Compare RS TS-06 (Z)_5	TS-10 Compare RS TS-06 (Z)_6	TS-10 Compare RS TS-06 (Z)_7

3.1 Incoming inspection

No relevant observations were made during the Visual Incoming Inspection.

3.2 Test Conditions

The temperature and relative humidity was measured during the test period. The following table presents the extreme of temperature and relative humidity:

Table 10 Extreme of temperature and relative humidity

Date	Temperature		Relative humidity	
	Minimum	Maximum	Minimum	Maximum
August 5th, 2009	21.7 °C	25.2 °C	30 %	46 %
August 6th, 2009	22.8 °C	24.6 °C	31 %	39 %

The following graph presents the measured values of temperature.

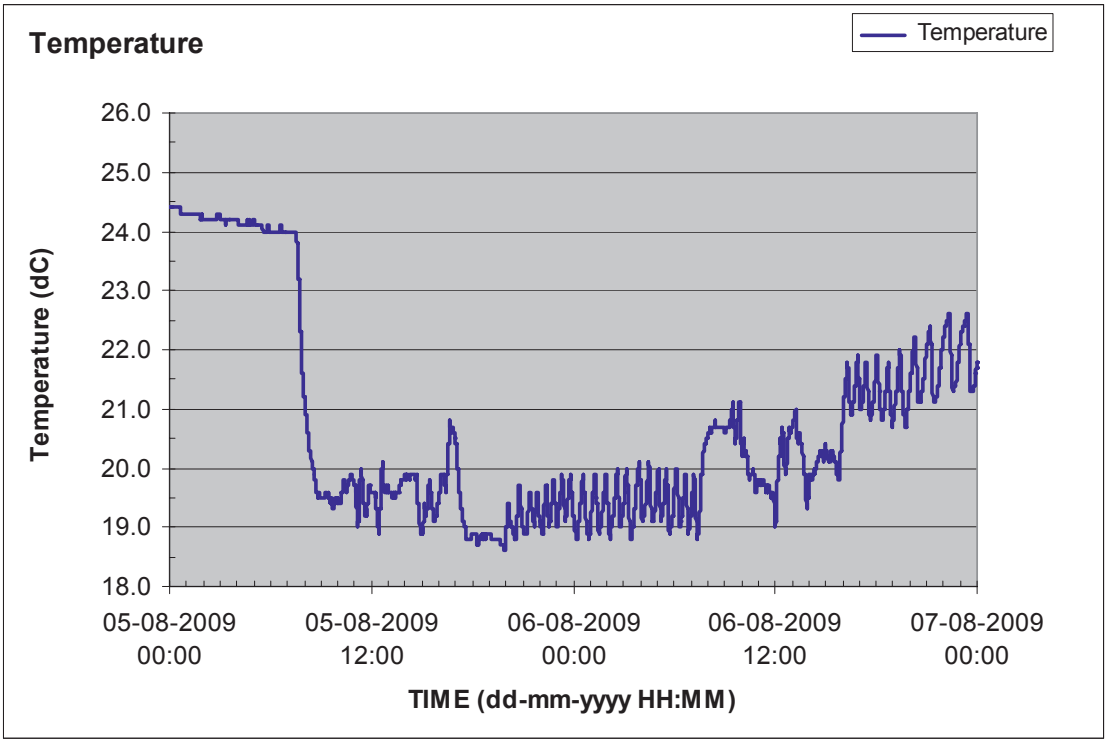

Fig. 4 Measured temperature during the test period

The following graph presents the measured value of the relative humidity.

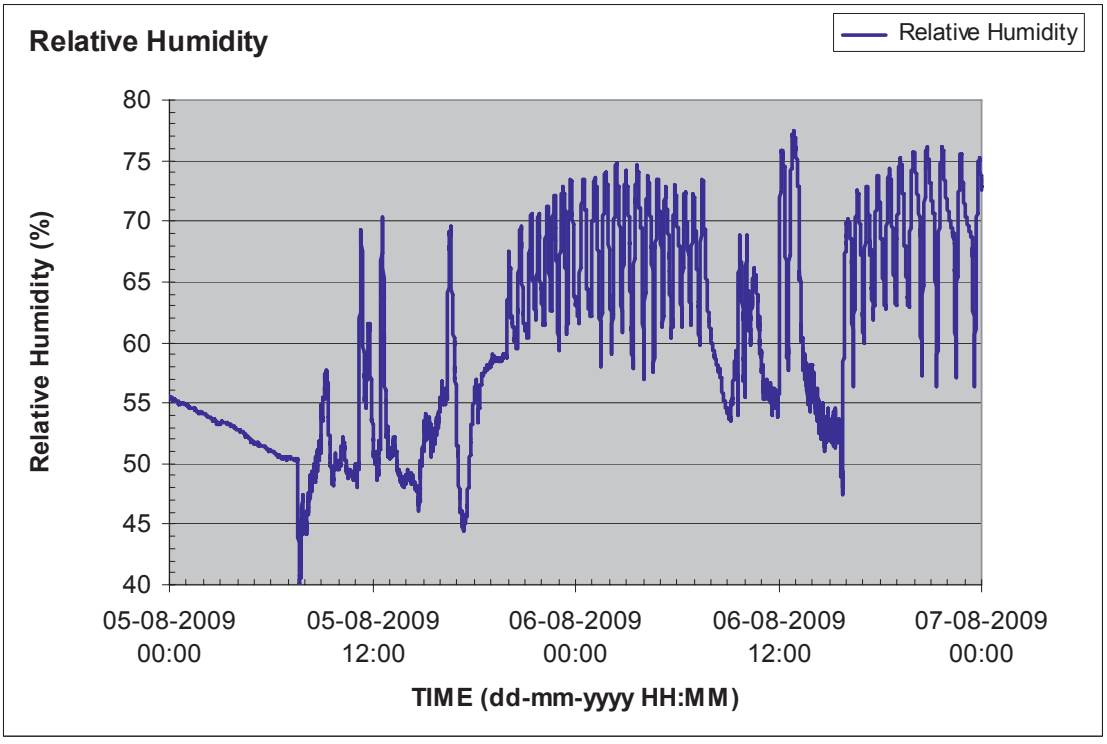

Fig. 5 Measured relative humidity during the test period

The barometric pressure was measured during the test period. The following table presents the extreme of barometric pressure:

Table 11 Extreme of barometric pressure

Date	Pressure	
	Minimum	Maximum
August 5th, 2009	1026.6	1028.3
August 6th, 2009	1025.1	1027.7

The following graph presents the measured value of the barometric pressure.

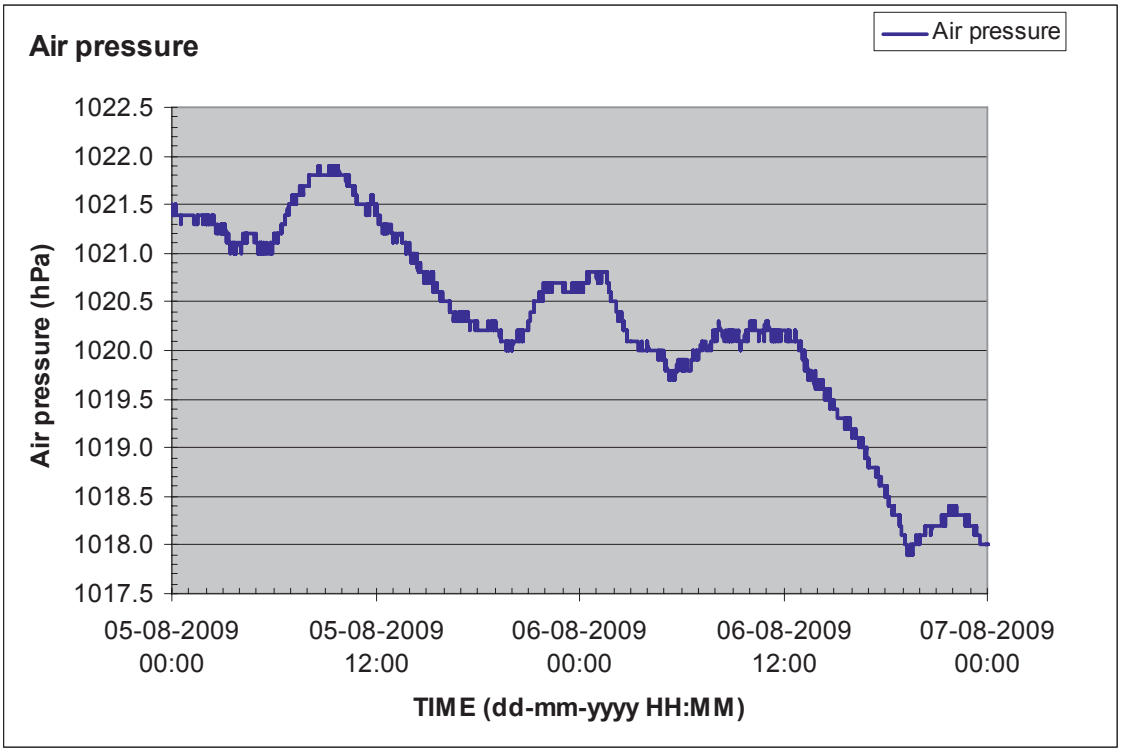

Fig. 6 Measured barometric pressure during the test period

3.3 Resonance Survey test

The test sample was successfully subjected to a Resonance Survey in all orientations, both before and after the qualification level tests.

Table 12 presents the measured values of the main resonance frequencies.

Table 12 Resonance frequencies

Measurement	1st Resonance frequency			
	X-Axis		Z-Axis	
	TS-01	TS-05	TS-06	TS-10
transformer	47.15 Hz	43.7 Hz	76.8 Hz	57.8 Hz

During TS-06, the pre resonance survey test in the X-direction, the abort band was increased between 70 and 110 Hz due to the resonance of the test object.

No further relevant observations were made during the Resonance Survey tests.

3.4 Sine vibration

The transformer was successfully subjected to the sine vibration test in all applicable orientations.

During the TS-07, the sine test in the Z-direction, the test stopped at 52 Hz due to an overload at the 'Top_Z' channel. The test was continued in a new run to complete the test for a total of 10 up and down sweeps.

No further relevant observations were made during the sine vibration tests.

3.5 Random vibration test

The transformer was subjected to 120 minutes of random vibration in each of the applicable directions specified. The actual PSD value was within 5% of the nominal level.

During the TS-08 the test stopped a number of times due to an 'over travel detection' on the shaker. This is due to the test specification. The test specification compromises a maximum displacement of 32.4 mm (o-pk) which exceeds the shaker system capability of 25.4 mm (0-pk). The Gaussian random distribution of the test specification was adapted from 5 σ to 3.9 σ which resulted in a maximum displacement of 25.3 mm (0-pk). The MIL-STD 810G allows to adapt the test specification to the shaker system capability. The test was continued in a new run to complete the test for a total 120 minutes test time.

No further relevant observations were made during the random vibration tests.

3.6 Shock test

The test sample was subjected to three 15 g / 11 ms shocks in each of the applicable orthogonal directions in both the negative and positive senses.

The time base of 11 ms of the shock test resulted in a difficult to control test. A test object with a main resonance frequency of 73 Hz will be maximal excited by a half sine shock with pulse duration of 11 ms. The following relation is applicable:

$f_n = 0.8 / D$ where D is the duration of the half sine pulse

The transformer has a main resonance frequency between 50 and 75 Hz.
The **Base_{X,Y,Z}** sensor was used as control sensor. Note that the polarity of the **Extender_A** and **Extender_B** sensor is reversed due to the mounting position.

No further relevant observations were made during the Shock tests.

3.7 Concluding functional testing

After completing all tests, the Current transformer set was tested in its full functional configuration at the ELEQ Steenwijk B.V. premises. According to ELEQ Steenwijk B.V. the transformer showed full compliance with the applicable performance standards. Appendix C contains a summary of the electrical measurement test results. The full test results can be found in the directory '*10) Characterization measurement data)*' on the accompanying DVD. No significant change was indicated during these measurements. The measured values were within the normal expected distribution.

The Current transformer set was dismantled and visually inspected. Pictures of the dismantled Current transformer set can be found in the directory '*5) Pictures\3) After test inspection*' on the accompanying DVD. No damage or abnormal wear could be found.

4 Conclusions

The transformer completed the vibration and shock tests according to IEC 60068-2-6, IEC-60068-2-27 and MIL-STD-810G.

No significant change in electrical behaviour could be found after the vibration and shock tests.

After completing all tests, the Current transformer set was tested in its full functional configuration at the ELEQ Steenwijk B.V. premises. According to ELEQ Steenwijk B.V. the transformer showed full compliance with the applicable performance standards. The Current transformer set was dismantled and visualy inspected. No damage or abnormal wear could be found.

The Current Transformer Set is a typical example of a transformer configuration, consisting of a set of three transformers stacked on top of each other. The tests comprised the following standards: IEC 68-2-6, IEC-68-2-27, and MIL-STD-810G. The test in accordance with MIL-STD-810G represented a vibration profile corresponding to 500 miles transportation in a composite wheeled vehicle.
The unit under test successfully passed the referenced vibration and shock tests, without measurable or visible loss of functional or physical characteristics.

References

1. IEC 60068-2-6:2007, Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal), Edition 7.0 date: 2007-12.
2. IEC-60068-2-27:2008, Environmental testing – Part 2-27: Tests –Test Ea and guidance: Shock, Edition 4.0 date 2008-02
3. MIL-STD 801G, Test method standard, Environmental engineering considerations and laboratory tests, date 31-october-2008.

Appendix B Figures

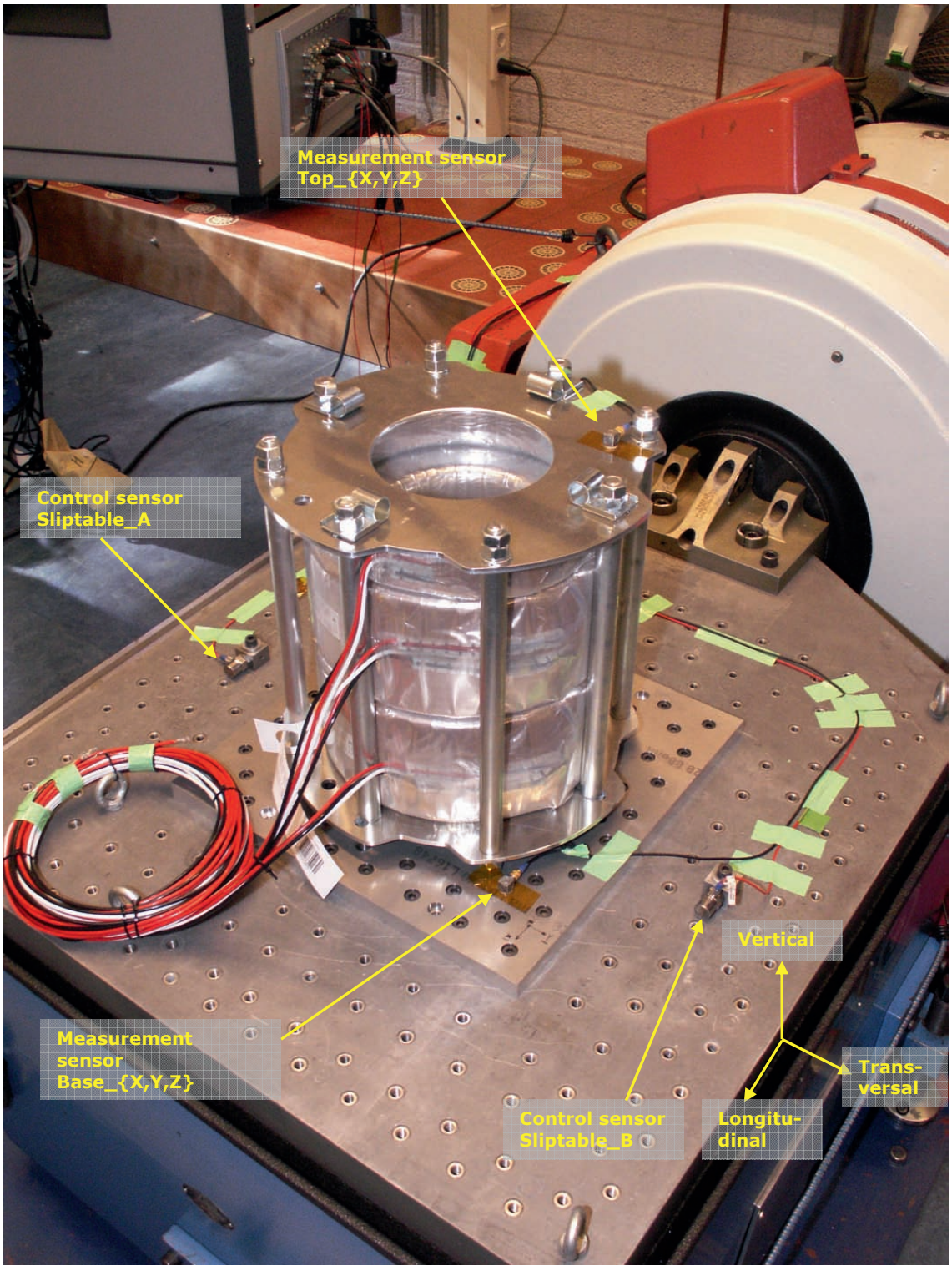

Fig. B.1 Transformer on Slip table in X-direction (Longitudinal)

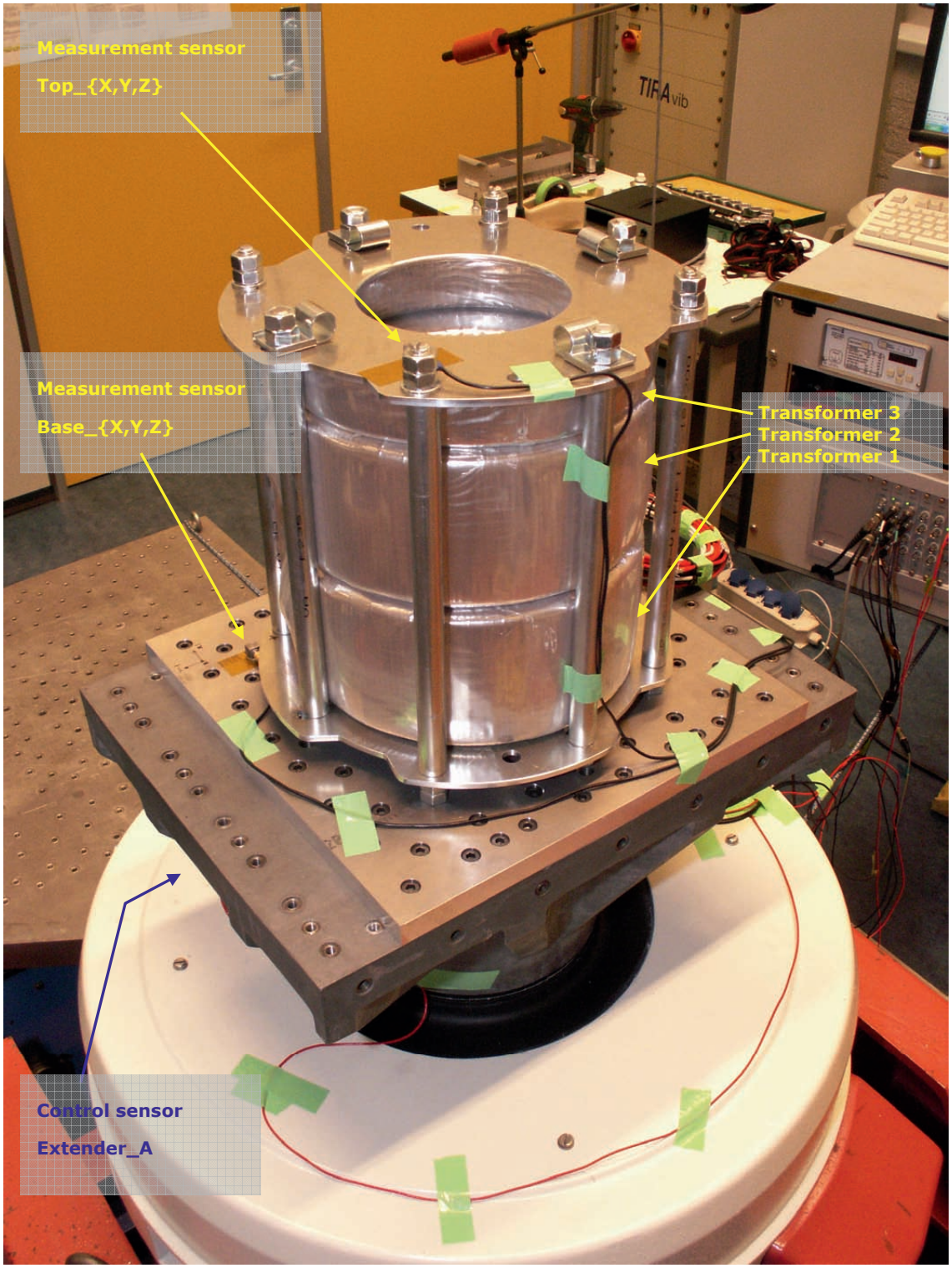

Fig. B.2 Transformer on shaker in Z-direction (vertical)

ELEQ mastering electricity worldwide

ELEQ designs and manufactures smart electrotechnical applications for protecting, measuring and connecting electrical energy and works worldwide for renowned power companies, system builders and installers. Together with our clients we anticipate on the future and on required innovations.

ELEQ is a true producer and partner of clients and relations who are professionally involved in energy and public lighting systems and who rely on continuous precision and high services.

ELEQ delivers all its products and applications in accordance to the high Dutch and German quality standards and serves markets in Europe and beyond from its locations in the Netherlands (Steenwijk) and Germany (Kerpen).

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ELEQ b.v.
P.O. Box 12, 8330 AA Steenwijk
Tukseweg 130, 8331 LH Steenwijk
The Netherlands
T +31 (0) 521 533 333
E info@eleq.com
I www.eleq.com

Karl-Ferdinand-Braun-Straße 1
50170 Kerpen (Sindorf)
Germany
T +49 (0) 22 73 / 988 70
E info@eleq.com
I www.eleq.com

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