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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 16, *Safety systems and impact testing*.

Road vehicles — Displacement Calibration Procedure — IR-TRACC Devices

Introduction

This document was written to address the need of the automotive crash testing community for a well-defined calibration method of non-linear telescopic displacement sensors know as IR-TRACC. Various aspects specific to this type of sensors are addressed in this procedure, among others linearization of the exponential voltage output and the sensitivity to tubes position of the telescopic devices.

1 Scope

This Technical Specification establishes a procedure to calibrate IR-TRACC displacement transducers (Infra-Red Telescoping for the Assessment of Chest Compression). This device is commonly used on crash dummies to measure the chest deflection as injury assessment parameter. Like all other sensors used on dummies, calibration is required. The calibration shall be carried out with the sensor disassembled from the dummy. The procedure is valid for sensors with analogue as well as digital output.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6487: 2015 "Road vehicles — Measurement techniques in impact tests — Instrumentation

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 IR-TRACC

An IR-TRACC (Infra-Red Telescoping for the Assessment of Chest Compression) is a non-ratiometric displacement transducer used to measure chest deflection in crash dummies. The technology of the transducer was described in a paper by Rouhana et al. [1998] [i]. The measurement principle is based on emission of infra-red light by an LED and a phototransistor sensitive to irradiance. The transducer is a non-linear device, as the irradiance and output voltage is proportional to the inverse square of the distance between the emitter and the phototransistor. The distance between the phototransistor and the LED is theoretically proportional to the inverse square root of the phototransistor output voltage: $d = C / \sqrt{U_{IR}}$. The inverse square root of the output voltage can also be written as the output voltage to the power of minus 0.5, therefore $d = C * U_{IR}^{-0.5}$.

3.2 Displacement Calibration

Displacement calibration is running according the classic compression method: the zero mm starting point is defined close to the extended range of the sensor. When the IR-TRACC overall length decreases (IR-TRACC compresses), its calibrated mm output increases. The IR-TRACC linearized output is negatively proportional to its length. During displacement calibration components are used to fix the transducer to a calibration fixture. These components do not necessarily belong to the final assembly of the sensor as used in the dummy. The displacement calibration therefore is not an absolute point to point (distance) calibration against a fixed reference. This is not necessary as the chest deflection of the dummy is calculated with respect to the IR-TRACC displacement at time zero. The IR-TRACC displacement output is associated with the ISO MME [ii] Code DS for Displacement.

3.3 Displacement Calibration Fixture

An example of a displacement calibration fixture is shown in Figure 1. The displacement calibration fixture shall have a fixed head to which the large diameter end of the IR-TRACC is attached through an interface, and a moveable cross head parallel to the sensitive axis of the IR-TRACC to which the small diameter end of the IR-TRACC is attached through another interface. The maximum allowable axis parallelism deviation is 1.5mm [1]. The minimum distance between the moveable and fixed head interface shall be less than the collapsed interface distance of the smallest sensor (currently 55mm) and the maximum shall exceed the fully extended interface distance of the largest displacement sensor (currently 201 mm). The interfaces shall have freedom of rotation about the two axis perpendicular to sensitive axis. The moveable head position shall be accurately adjustable by means of, for instance, a hand or motor operated screw; the moveable head shall be linked to a displacement measurement gage parallel to the sensitive axis with a resolution of at least 0.01mm. The moveable head shall be linked to the displacement gage without mechanical play. A lateral loading fixture shall be mounted about half way between the fixed and moving cross head to execute the forced lateral manipulation test.

[1] Generally a 1.5mm crosshead parallelism deviation causes less than 0.01mm displacement deviation.

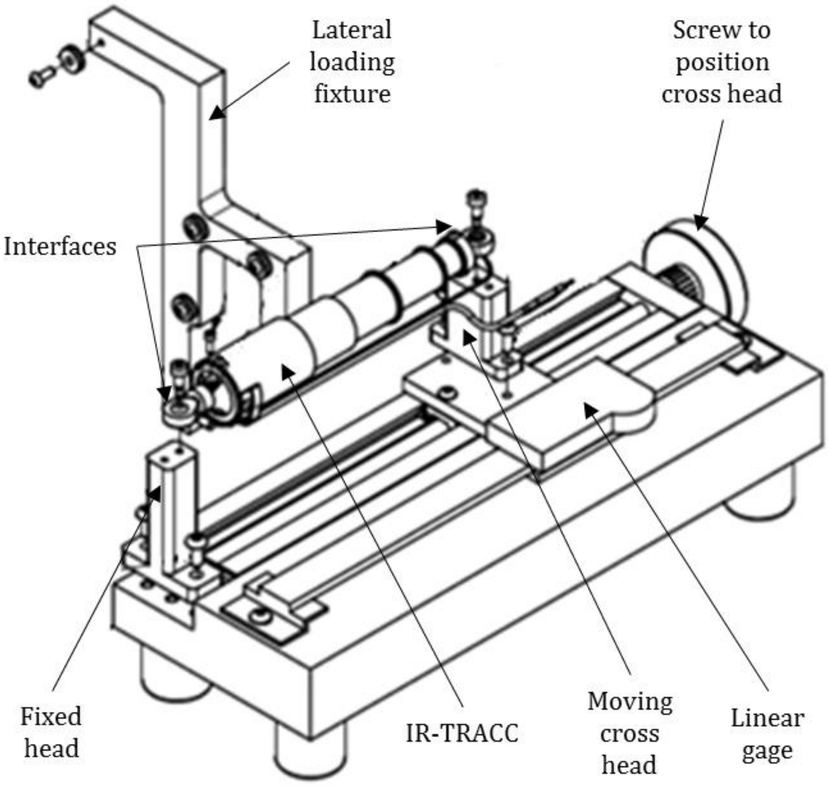

Figure 1 Example Displacement Calibration Fixture (exploded view)

3.4 Nominal Linearization Exponent

The theoretical parameter to linearize the phototransistor voltage output is an inverse square root function, or the voltage output U_{IR} to the power of -0.5, see paragraph 3.1. The theoretical linearization exponent is -0.5 [-]. During inception of the IR-TRACC it was found based on a certain quantity of examples or prototypes that in practise the exponent to linearize IR-TRACCs was not -0.5, but was close to -0.42857.

$d = C * U_{IR}^{-0.42857}$.

This number has been used for some time as a fixed exponent to linearize the voltage output, but due to minimal individual differences of IR-TRACC components, this fixed number did not give the smallest linearization error for each individual transducer. Up to this date this number is now applied a starting exponent for optimization of the exponent, see next paragraphs 3.5 and 3.6.

3.5 Optimized Linearization Exponent

The optimized exponent is a calibration parameter based on the actual calibration data (output voltage over calibration range) of one individual sensor, giving the least linearization error over the entire calibration range.

3.6 Exponent Optimization

The linearization exponent shall be optimized by applying data processing, for instance (but not limited to) numerical optimization. The method shall find the best linearization exponent that minimises the linearization errors over the entire calibration range. The result of the process is the optimized linearization exponent EXP and pertaining Calibration Factor C_{IR} and Displacement Intercept I_{DS} (and Displacement Intercept Voltage I_{DSV}). The optimization method is explained in paragraph 6.2.

3.7 Forced Lateral Manipulation Test

To ensure an IR-TRACC is not overly sensitive to bending of the tubes in a direction perpendicular to the axis of displacement measurement, a forced lateral manipulation test is implemented. The test is executed at the zero displacement point. A force of 4.45N ±0.15N is exerted to the IR-TRACC tube pulling perpendicular to the axis of compression about halfway between the fixed head and the moving cross head (the distance of the lateral loading point does not have to be exact, as the applied force is adequate to manipulate the tubes in bending extremes). The IR-TRACC lateral test output voltages ($U_{IR\text{-}LAT}$) are recorded pulling in four directions spaced 90 degrees.

3.8 Tubes In-Out Calibration Method

In any length of the IRTRACC displacement range (except fully extended / fully collapsed) the intermediate telescope tubes are free to move position. To ensure an IR-TRACC is not overly sensitive to the individual positions of the telescope tubes the calibration procedure takes two extreme tube position conditions into account at each calibration interval, the tubes-in and tubes-out position. Tubes-in: all free tubes shall be moved to the largest diameter end (to fixed cross head); Tubes-out: all free tubes shall be moved to the smallest diameter end (to moving cross head).

4 Symbols and Abbreviated Terms

A list of symbols, abbreviated terms, units and definitions is given in Table 1. The output of analogue sensors in V and the output of digital sensors in LSB (Least Significant Bit[2]) are handled in the same way, hence the same parameters and symbols apply to analogue and digital sensors throughout this document. The only difference is the amount of decimals used to express the values, as the analogue output are generally low values (0.0600 - 2.0000 V) and digital output are generally high values (1000.0 - 32000.0 LSB).

Table 1 List of symbols

Nr	Parameter	Symbol	Unit	Definition/Description
1	Zero displacement point	d_S	mm	Starting point of displacement calibration d=0 (fully compressed + calibration range + 2mm)
2	Calibration range	d_e	mm	End point of displacement calibration
3	Displacement	d	mm	Displacement from zero displacement point
4	Lateral manipulation displacement	d_{LAT} $d_{LAT\text{-}MAX}$ $d_{LAT\text{-}MIN}$	mm	Calculated displacement under forced lateral manipulation, maximum and minimum
5	IR-TRACC output	U_{IR}	V (LSB)	IR-TRACC output voltage (or digital output)
6	Tubes-IN voltage	$U_{IR\text{-}IN}$	V (LSB)	(Digital) output voltage at certain displacement with all floating tubes pushed IN

2 https://en.wikipedia.org/wiki/Least_significant_bit

7	Tubes-OUT voltage	$U_{IR\text{-}OUT}$	V (LSB)	(Digital) output voltage at certain displacement with all floating tubes pushed OUT
8	Average In-Out voltage	$U_{IR\text{-}AVE}$	V (LSB)	Average of Tubes-IN and Tubes-OUT (Digital) voltage
9	Forced lateral manipulation voltage	$U_{IR\text{-}LAT}$	V (LSB)	(Digital) output voltage at forced lateral manipulation
10	Nominal Linearization exponent	EXP_{NOM}	-	IR-TRACC Linearization optimization routine starting value: -0.42857 (fixed)
11	Optimized exponent	EXP	-	IR-TRACC linearization exponent resulting from optimization routine
12	Linearized voltage (or linearized digital output)	U_{LIN}	(V_{LIN}) (LSB_{LIN})	IR-TRACC output voltage (or digital output) to power of exponent (The linearized voltage (digital output) is a calculated parameter, not a physical quantity)
13	Calculated nominal displacement	d_{NOM}	mm	Displacement calculated using average In-Out voltage (or digital output)
14	Nominal linearity error	E_{NOM}	%	Error of calculated displacement using average in-out voltage w.r.t. calibration displacement
15	Calculated deviation-In	Δ_{IN}	mm	Deviation calibration displacement and calculated displacement using Tubes-In voltage
16	Calculated deviation-Out	Δ_{OUT}	mm	Deviation calibration displacement and calculated displacement using Tubes-Out voltage
17	Maximum variation	Δ_{MAX}	mm	Difference calculated deviation-In and calculated deviation-Out
18	Maximum Variation error	Var_{MAX}	%	Maximum variation divided by calibration range
19	Maximum Linearity error	E_{MAX}	%	Maximum error of calculated displacement using tubes-in voltage or tubes-out voltage (highest error from the two) w.r.t. calibration displacement
20	Maximum variance lateral displacement	Δ_{LAT}	mm	Maximum variance of lateral displacement: $\Delta_{LAT\text{-}MAX}$ minus $\Delta_{LAT\text{-}MIN}$
21	Maximum Lateral Variance Error	E_{LAT}	%	Maximum error of lateral variance w.r.t. calibration range
22	Calibration factor	C_{IR}	(mm/V_{LIN}) (mm/LSB_{LIN})	IR-TRACC mm displacement per linearized voltage (or linearized digital output) pertaining to optimized exponent
23	Sensitivity	S_{IR}	(V_{LIN} /mm) (LSB_{LIN} /mm)	IR-TRACC linearized voltage (or linearized digital output) per 1mm displacement pertaining to optimized exponent
24	Sensitivity	S_{NOM}	(V_{LIN} /mm) (LSB_{LIN} /mm)	IR-TRACC linearized voltage (or linearized digital output) per 1mm displacement pertaining to nominal exponent EXP_{NOM}
25	Displacement Intercept	I_{DS}	mm	Displacement at 0 V_{LIN} (or at 0 LSB_{LIN})
26	Displacement intercept	I_{DSV}	(V_{LIN}) (LSB_{LIN})	Linearized Voltage (or linearized digital output) at 0mm displacement

	voltage			
NOTE 1: to distinguish 0 (zero) and O (characters O,o) Consolas font is used in this table				

5 Displacement Calibration Procedure

This section describes the procedure for displacement calibration of IR-TRACCs. This calibration is running according the classic compression method: the zero mm starting point is defined at the extended range of the sensor: at full length the compression is close to zero mm and with increasing compression the IR-TRACC gets shorter until almost fully compressed (=highest mm output) the IR-TRACC is shortest.

The procedure shall be performed on a linear calibration fixture for example, but not limited to, Humanetics part# TE-3700-IRKIT. In this procedure calibration data shall be obtained in two conditions at each calibration interval: with IR-TRACC free intermediate tubes fully compressed in and fully extended out (Tubes In-Out). The calibration data shall be entered in data processing software, which shall calculate the optimized linearization exponent and linear sensitivity based on the input data, taking into account data from both tube conditions at each displacement interval. The software shall calculate the maximum linearity error per calibration interval and the maximum variation per calibration interval.

An example of the calibration software is available as template and is presented in Annex B of this standard. If users choose to apply other calibration fixtures or calibration software, some of these instructions may not directly apply. However, the manner in which the IR-TRACC is manipulated through the calibration increments should apply, as should the use of the calibration software.

The displacement calibration procedure is detailed in paragraphs 5.1 through paragraph 5.6; the calibration data processing procedure is detailed in section 6.

5.1 Preparations

- Start the calibration software (see also Annex B example calibration template (MS-Excel format)). Save the file to the appropriate location and naming convention specified in the user’s system. Enter the calibration date and all the necessary information specific to the sensor you are about to calibrate. As a minimum calibration date, sensor model number and serial number, operator name, current lab climate temperature and humidity, calibration range shall be recorded. Save the file again.

- Check IR-TRACC and the calibration fixture for any mechanical play, like loose screws, mechanical components, interfaces, etc., and fix as necessary.

5.2 Test equipment set up, power supply, voltmeter

- Conduct the calibration in a temperature controlled environment between 20°-25°C.

- Set up the linear calibration fixture on a stable workbench (see example Figure 1).

- Normally the transducers are equipped with specific connectors for the measurement system they are used in. For the purpose of defining this standard a generic method for connecting an IR-TRACC electrically is given, however this connection method is not mandatory. The transducers can be connected to measurement system in the normal way of operation.

- Connect the IR-TRACC to a stable DC power supply and a calibrated digital voltmeter with a resolution of 5 decimal places (Example: 5.12345V), see Table 3. Make sure to run a grounding cable from the calibration fixture casing to the grounding point of the voltmeter. Allow at least 120s warm-up time of the IRTRACC before taking calibration data.

- Set the voltmeter to display DC voltage reading in 4 decimal places, for example 5.1234V. Measure the excitation voltage, adjust the supply voltage according manufacturer specification of the sensor and enter the supply voltage in calibration sheet.

- Connect the voltmeter to measure the analogue IR-TRACC output, or connect the digital IR-TRACC to an appropriate digital measurement system.

5.3 Establish starting point

- Secure IR-TRACC to fixture as shown in **Figure 3**. Fasten until secure. Make sure the wire loop from the big end to the small end are facing the same side.

- Operate the cross head screw to collapse the IR-TRACC completely as shown in **Figure 3**. Make sure not to exert excessive force, as this will bend the heads of the fixture.

- Zero the linear displacement gage.

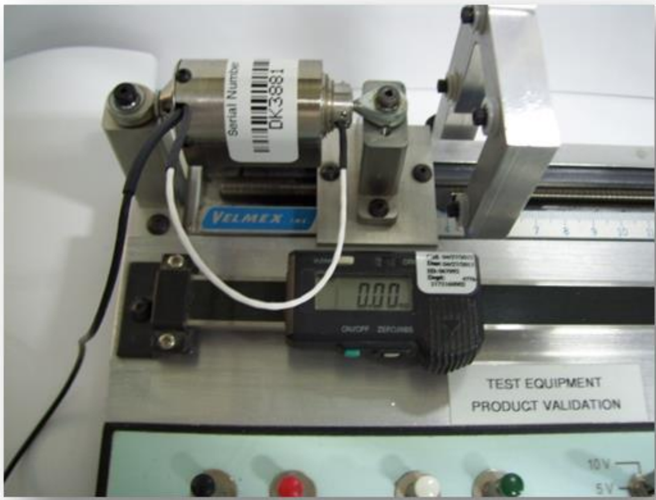

Figure 3 IR-TRACC fully collapsed. Note: wire loop from big end to small end is on the same side

- Establish the zero displacement point d_s of the IR-TRACC as follows, according values given in **Table 3** in Annex A:

Example (IF-367):

- From fully compressed, expand 85-86mm outward; see **Table 3**, column A

- To remove backlash, compress back to 82.00mm; see **Table 3** column B and **zero the displacement gage**. This is the zero displacement point d_s (calibration point d=0mm).

- Save the file again.

5.4 Forced Lateral Manipulation Test

- At the starting point d_s (calibration point 0mm) from paragraph 5.3, run the forced lateral manipulation test with a ballast of 0.44 – 0.47kg (~1 lbs.) as follows.

- Load the IR-TRACC in a plane perpendicular to the sensitive axis in four directions spaced 90 degrees as shown in Figure 4. Move all IR-TRACC tubes fully out, see **Figure 6**-right. The user’s fixture may be different than the set-up shown in **Figure 4**. The intent is to take four readings 90 degrees apart with the ballast pulling in each direction.

- *Note: Wire loop around IR-TRACC should be in line with fixture pulleys.

- Observe the 120s sensor warm-up time. Enter the four voltage (or digital output) readings (4 decimals analogue, 1 decimal digital) in the calibration software.

- Remove the ballast

- Save the file.

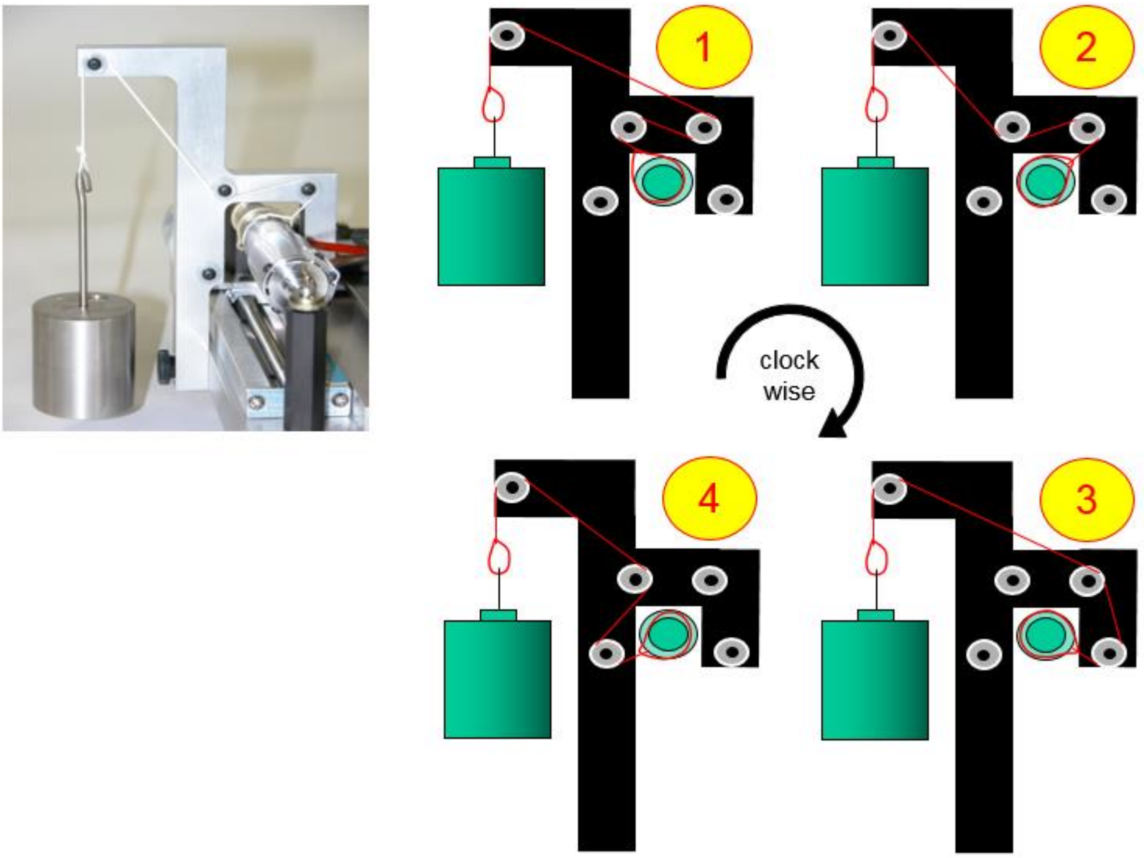

Figure 4: IR-TRACC forced lateral manipulation setup

5.5 Displacement Calibration Data Collection

- In this step data is taken of the tubes-in and tubes-out condition. It is mandatory to obtain data of tubes-in at each displacement interval first, then go back beyond the zero displacement point (d= -1 or -2) and repeat all displacement intervals tubes-out.

NOTE: Do not manipulate the tubes from **IN** to **OUT** position to record both in- and out- voltages at the same step. Even though it would save positioning each interval twice, this is not recommended as it has two major disadvantages. 1) While manipulating the tubes IN to OUT one could inadvertently push the IR-TRACC small end out of position, thereby invalidating the calibration position; 2) When the IR-TRACC is one or two steps from fully compressed and tubes are IN, it is nearly impossible to get the tubes to the OUT position. It is far easier to keep the tubes in the OUT position during collapse from fully extended, when positioning the moveable head in the consecutive calibration points.

- Make sure the cross head is at 0.00mm displacement
- Slide all floating IR-TRACC tubes-IN to the big end (to the left in **Figure 6**)
- Enter voltage reading [V] at 0mm in the calibration software.
- Subsequently collapse IR-TRACC in 5.00mm increments, pushing all tubes to the IN position and take voltage readings at each calibration point

Important: only take data in one direction pushing the moving head left to the next calibration interval. If 5mm movement is accidentally exceeded, bring moveable head back about 1mm beyond the target point and reposition the head to the target calibration point.

- Enter voltage reading in the calibration software
- When the last IN data point is entered at full calibration range, save the file
- Return the calibration head beyond d=0mm (between -1, -2mm); slide all floating IR-TRACC tubes-OUT to the small end (to the right in **Figure 6**);
- Move calibration cross head back to d=0.00mm
- Enter voltage reading at 0mm in the calibration software for tubes-OUT
- Subsequently collapse IR-TRACC in 5mm increments, keeping all tubes to the OUT position and take voltage readings at each calibration point
- Repeat until the full calibration range is reached.
- Save the file.

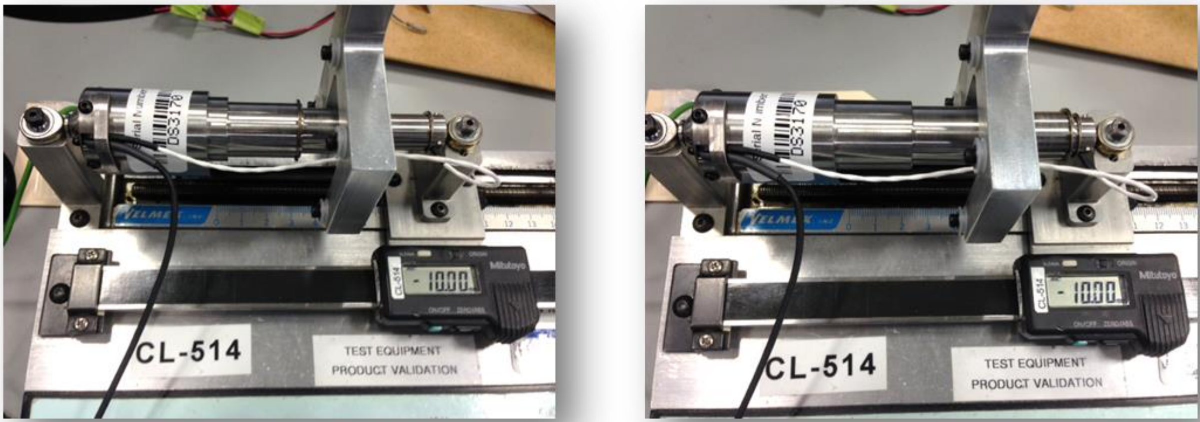

Figure 6 IR-TRACC tubes-in shown left and tubes-out shown right

5.6 Parameter optimization and data review

- After all data points are entered, run the optimization process and produce pass/fail results.

- Review the data to check if the IR-TRACC passes calibration criteria for nominal and maximum linearity error, maximum variation and forced lateral displacement.

- The Displacement Calibration is now completed. Save the file. Print calibration sheet on paper or PDF, according the user's preference.

6 Displacement Calibration Data Processing

This paragraph describes calibration data processing steps to calculate calibration results. These steps are implemented in the example calibration template.

6.1 Linearization over calibration range with nominal exponent

Per each calibration increment calculate the IR-TRACC Average In-Out voltage:

$$U_{IR\text{-}AVE} = (U_{IR\text{-}IN} + U_{IR\text{-}OUT})/2 \ [V] \qquad (1)$$

Per each calibration increment calculate the nominal linearized voltage starting with the nominal Exponent, (EXP_{NOM}, -0.42857):

$$U_{LIN} = U_{IR\text{-}AVE}^{(-0.42857)} \ [V_{LIN}] \qquad (2)$$

(the average In-Out voltage to the power of nominal exponent).

Over the entire calibration range calculate the nominal sensitivity S_{NOM} [V_{LIN}/mm] (slope), and nominal displacement intercept voltage I_{DSV} [V_{LIN}] of the displacement range and the linearized voltage range by means of a best fit/ least error routine.

With Nominal Sensitivity and Displacement Intercept Voltage found in (1) and (2), calculate the 'calculated nominal displacement' d_{NOM} per each calibration increment:

$$d_{NOM} = (U_{LIN} - I_{DSV})/S_{NOM} \ [mm] \qquad (3)$$

and the nominal linearity error E_{NOM} (in percent of calibration range):

$$E_{NOM} = (d_{NOM} - d)/ d_e * 100 \ [\%]. \qquad (4)$$

At this point the IRTRACC output voltage data is averaged, linearized using the Nominal Exponent and at each increment, the errors with respect to the calibration point is known for each calibration increment of the calibration range.

6.2 Linearization optimization

In this step the linearization exponent is optimized by applying a numerical optimization routine. The method updates and optimizes the linearization exponent in an iteration loop until the linearization errors over the entire calibration range are minimised. The calculations (2), (3), and (4) in paragraph 6.1 are repeated with an incrementally changing exponent until the optimum is found, or until the minimum exponent of -0.5 is reached.

The result is the optimized linearization exponent EXP and pertaining calibration factor C_{IR} and displacement intercept I_{DS} (and Sensitivity S_{IR} and Displacement Intercept Voltage I_{DSV}). In section 6.4 an example data set is provided, to allow checking various optimization methods. An example calibration template is introduced in Annex B. The optimization results of the example template are given in **Figure 10** for comparison.

6.3 Data analysis and pass criteria calculations

6.3.1 Optimized Nominal Linearity Error

Calculate the Maximum Nominal Linearity Error of each calibration interval by applying the optimized linearization exponent. The formulas are the same as in paragraph 6.1, but applying optimized exponent EXP instead of nominal exponent.

$U_{LIN} = U_{IR\text{-}AVE}{}^{EXP}$ $[V_{LIN}]$ (5)

(the average In-Out voltage to the power of optimized exponent).

$d_{NOM} = (U_{LIN} - I_{DSV})/S_{IR}$ [mm] (6)

per each calibration step, followed by repeating (4) Nominal Linearity Error calculated from (6)

$E_{NOM} = (d_{NOM} – d)/ d_e * 100$ [%]. (4)

The Maximum Nominal Linearity Error is the maximum absolute nominal error over the entire calibration range.

Max E_{NOM} = Maximum of $|(d_{NOM} – d)|/ d_e * 100$ [%] between d_s and d_e . (7)

6.3.2 Tubes In-Out Variation

In the next step the IR-TRACC voltage outputs from tubes-In and -Out are applied to calculate deviations from the calibration displacement. Pass- fail tests are applied to the deviations.

With the optimized exponent EXP, calibration factor S_{IR} and displacement voltage intercept I_{DSV}, calculate the 'tubes-in deviation' and 'tubes-out deviation' per each calibration increment.

$\Delta_{IN} = (U_{IR\text{-}IN}{}^{EXP} – I_{DSV}) / S_{IR} – d$ [mm] (8)

$\Delta_{OUT} = (U_{IR\text{-}OUT}{}^{EXP} – I_{DSV}) / S_{IR} – d$ [mm] (9)

Calculate the Maximum variation Δ_{MAX} in mm per each calibration step from (8) and (9): the difference between tubes-In deviation Δ_{IN} and tubes-Out deviation Δ_{OUT} in mm per each calibration increment.

$\Delta_{MAX} = \Delta_{IN} - \Delta_{OUT}$ [mm], (10)

Calculate the Maximum linearity error: the maximum (absolute) deviation from either tubes–in or tubes-out in % of calibration range per each calibration increment.

E_{MAX} = Maximum absolute value of $\Delta_{IN} / d_e * 100$ and $\Delta_{OUT} / d_e * 100$ [%] (11)

6.3.3 Pass – fail tests and limits

Calculate the Maximum variation error over the entire calibration range.

$Var_{Max} = \Delta_{MAX} / d_e * 100$ [%] (12) Max absolute variation error between d_s and d_e. (12)

Three pass requirements are implemented with pass limit over the entire calibration range. The IR-TRACC shall pass the calibration if Nominal Linearity Error, Maximum Variation Error and Maximum Linearity Error do not exceed ±1% over the entire calibration range.

6.3.4 Forced Lateral Manipulation variation

Calculate the Lateral Manipulation variation from all four measurements with the Lateral displacement voltage.

$$d_{LAT} = ((U_{IR\text{-}LAT}{}^{EXP}) - I_{DSV}) * C_{IR} \quad (13)$$

Calculate the maximum variance of lateral displacement by subtraction of minimum and maximum lateral manipulation displacement.

$$\Delta_{LAT} = d_{LAT\text{-}MAX} - d_{LAT\text{-}MIN} \quad (14)$$

Calculate maximum lateral variance error and apply pass criteria.

$$E_{LAT} = \Delta_{LAT} / d_e * 100\ [\%] \quad (15)$$

The IR-TRACC shall pass the forced lateral manipulation test if the Lateral Variance is less than ±3%.

6.4 Example Data

An example data set given in **Table 2** below can be used to check data processing software. The results processed with the example calibration template (see Annex B) are given in **Figure 10**.

Table 2: Example data set

d **Calibration displacement [mm]**	**$U_{IR\text{-}IN}$** **Sensor output tubes-In [V]**	**$U_{IR\text{-}OUT}$** **Sensor output tubes-Out [V]**
0	0.0709	0.0707
5	0.0784	0.0782
10	0.0869	0.0869
15	0.0977	0.0969
20	0.1094	0.1090
25	0.1238	0.1234
30	0.1414	0.1406
35	0.1620	0.1616
40	0.1882	0.1877
45	0.2208	0.2206
50	0.2624	0.2615
55	0.3162	0.3160

60	0.3875	0.3874
65	0.4860	0.4852
70	0.6232	0.6234
75	0.8225	0.8248
80	1.1292	1.1283

Annex A

(Informative) Starting point, zero displacement point and calibration range per model number

Table 3 Starting point, zero displacement point and calibration range per model number

	Column A	**Column B** Zero displacement point d_s	**Column C** Calibration range d_e
Base Model Number	**Expand outwards from fully compressed…[mm]**	**Compress to … [mm] and zero gage**	**Compress in 5mm intervals to …[mm]**
6110 8830	92.5-93	92.00	90.00
IF-362 IF-363 IF-364 IF-366 IF-375 472-3550/-3560 472-3570/-3580 476-3550/-3560 476-3570/-3580	90-91	87.00	85.00
IF-367 IF-368 IF-372	85-86	82.00	80.00
IF-369 IF-371 IH-11400 IH-11620	70-71	67.00	65.00
6510 9810	63-64	62.00	60.00
10180	Fully extend	25.50	25.00

Annex B Example Calibration Template

(Informative)

An example Displacement Calibration Template in MS-EXCEL is made available. Annex B gives instructions how to use the example template. The use of the example template is not mandatory.

The example calibration template applies the Solver Add-in in MS Excel[iii] [3], but there may be other optimization software available that can be applied. The example data set provided in **Table 2** can be used to compare optimization methods, see data in **Figure 10**.

3 Search internet with key words Excel Solver. See for example: http://www.excel-easy.com/data-analysis/solver.html

The example calibration template distinguishes orange cells, which are meant for data entry. In the top section of the template the specifics of the current calibration shall be entered: calibration date, sensor model number and serial number, operator name, current lab climate temperature and humidity, calibration range.

The date shall be entered in cell I11 (Tip: click [ctrl;] to get current date). The technician's names working in the lab can be stored in cells O10- O18. All the entered names are then available in the drop down list (cell I13), to avoid typing names over and over again.

The example calibration template can be used for analog sensors, as well as digital sensors. The default template is set up for analog data. When using it for digital data, adjust the amount of decimals of the cells per column to show 5 significant numbers.

Enter IR-TRACC specific calibration range on the certification template "Cal. Range [mm]" (cell B14) at the top of the certification sheet, see **Annex A, Table 3,** column C, press Enter. This will set the calibration range of the template and removes lines that are not used.

ISO/NP TS 21476 IR-TRACC - CALIBRATION SHEET

Tubes In-Out Calibration Procedure

Calibration No.	101614DS3170	Date	16-Oct-14	
Model No.	IF-367-R2S7	Last Calibrated		
Serial No.	DS3170	Technician	Jan Janssen	
Cal. Range [mm]	80	Temp (C)	23.8	
Diffuser?	Yes	Hum. (%)	47.5	
Customer		Calibration Standard	DTC-CLP029	
Order		Excitation	5	Volt

Figure 5 Calibration Identification fields (part of example calibration template in MS-EXCEL)

Forced Lateral Manipulation Test

Run the Forced Lateral Manipulation Test (5.4). Enter the four voltage (or digital output) readings (4 decimals analogue, 1 decimal digital) in the example calibration template in the orange fields "Forced Lateral Manipulation Test" (**Figure 6**, $U_{IR\text{-}LAT}$)).

Forced Lateral Manipulation Test			
Lateral direction	$U_{IR\text{-}LAT}$ Measured Output (V)	U_{LIN} Linearized Output [V_{LIN}]	d_{LAT} Lat. Displ. [mm]
1	0.0691	3.341	-1.16
2	0.0724	3.271	1.19
3	0.0715	3.290	0.57
4	0.0700	3.322	-0.50
Maximum variance lateral displacement Δ_{LAT} [mm]			2.36
Maximum Lateral Variance Error E_{LAT} [%]			2.95% Pass

Figure 6 Lateral manipulation input fields in orange (example calibration template)

Displacement Calibration Data Collection

- Enter the Tubes In voltage reading [V] in the example calibration template orange column tubes-IN (**Figure 7** $U_{IR\text{-}IN}$))

- Save the file.

- Enter Tubes Out voltage reading in the example calibration template for tubes-OUT (**Figure 7** $U_{IR\text{-}OUT}$)

- Save the file.

Displacement	Sensor Output			Optimized Exponent			Calculated Variation Tubes In-Out			
d Calibration displacement [mm]	$U_{IR\text{-}IN}$ [V]	$U_{IR\text{-}OUT}$ [V]	$U_{IR\text{-}AVE}$ Average Tube In-Out [V]	U_{LIN} Linearized voltage [V_{LIN}]	d_{NOM} Calculated Displacement [mm]	E_{NOM} Nominal Linearity Error [%]	Δ_{IN} Deviation IN [mm]	Δ_{OUT} Deviation OUT [mm]	Δ_{MAX} Maximum Variation [mm]	E_{MAX} Maximum Linearity Error [%]
0	0.0709	0.0707	0.0708	3.3046	0.07	0.09%	0.14	0.00	0.14	0.18%
5	0.0784	0.0782	0.0783	3.1578	5.04	0.06%	0.11	-0.02	0.12	0.13%
10	0.0869	0.0869	0.0869	3.0127	9.96	-0.05%	-0.04	-0.04	0.00	0.05%
15	0.0977	0.0969	0.0973	2.8628	15.03	0.04%	0.21	-0.15	0.36	0.27%
20	0.1094	0.1090	0.1092	2.7175	19.95	-0.06%	0.03	-0.12	0.15	0.15%
25	0.1238	0.1234	0.1236	2.5697	24.96	-0.05%	0.02	-0.10	0.13	0.13%
30	0.1414	0.1406	0.1410	2.4214	29.98	-0.02%	0.09	-0.12	0.21	0.15%
35	0.1620	0.1616	0.1618	2.2755	34.92	-0.10%	-0.03	-0.12	0.09	0.15%
40	0.1882	0.1877	0.1880	2.1267	39.96	-0.05%	0.00	-0.08	0.09	0.10%
45	0.2208	0.2206	0.2207	1.9780	45.00	0.00%	0.01	-0.01	0.03	0.02%
50	0.2624	0.2615	0.2620	1.8307	49.99	-0.02%	0.03	-0.06	0.10	0.08%
55	0.3162	0.3160	0.3161	1.6819	55.03	0.03%	0.04	0.02	0.02	0.05%
60	0.3875	0.3874	0.3875	1.5342	60.03	0.03%	0.03	0.02	0.01	0.04%
65	0.4860	0.4852	0.4856	1.3855	65.06	0.08%	0.08	0.05	0.03	0.10%
70	0.6232	0.6234	0.6233	1.2379	70.06	0.08%	0.06	0.07	-0.01	0.08%
75	0.8225	0.8248	0.8237	1.0915	75.02	0.03%	0.00	0.04	-0.05	0.05%
80	1.1292	1.1283	1.1288	0.9468	79.92	-0.10%	-0.07	-0.08	0.01	0.10%

Figure 7 Example calibration template: orange columns to enter calibration data tubes-in and tubes-out.

- After all data points are entered, run the optimization process in the example calibration template by clicking the “Solve it” button, see **Figure 8** and **Figure 9**.).

- Review the data to check if the IR-TRACC passes calibration criteria for nominal and maximum linearity error, maximum variation and forced lateral displacement. See example calibration template in **Figure 10**.

Optimized Exponent (Max Error 0.51%)			
Calibration Factor C	[mm/V_{LIN}]	**-36.9859**	
Linearization exponent EXP	[-]	**-0.42857**	
Displacement Intercept I_D	mm	**-115.45**	
**Calculate displacement using the formula: mm = (Vsensor ^ -0.4286) * -36.9859 + -115.45*			!Solve It!
**Calculate displacement using the formula: mm = (Vsensor ^ -0.4286 - 3.1216) / -0.02704*			Click !Solve It!
Sensitivity S	[V_{LIN}/mm]	**-0.02704**	
Displacement Intercept Voltage I_{DV}	[V_{LIN}]	**3.1216**	

Figure 8 Example calibration template pre-solved: click the ‘Solve It’ button

Optimized Exponent (Max Error 0.1%)			
Calibration Factor C	[mm/V_{LIN}]	**-33.8666**	
Linearization exponent EXP	[-]	**-0.45142**	
Displacement Intercept I_D	mm	**-111.99**	
**Calculate displacement using the formula: mm = (Vsensor ^ -0.4514) * -33.8666 + -111.99*			!Solve It!
**Calculate displacement using the formula: mm = (Vsensor ^ -0.4514 - 3.3067) / -0.02953*			Solved
Sensitivity S	[V_{LIN}/mm]	**-0.02953**	
Displacement Intercept Voltage I_{DV}	[V_{LIN}]	**3.3067**	

Figure 9 Example calibration template solved

Calibration range 80 mm

Displacement	Sensor Output			Optimized Exponent			Calculated Variation Tubes In-Out			
d Calibration displacement [mm]	V_{IRT-IN} [V]	$V_{IRT-OUT}$ [V]	$V_{IRT-AVE}$ Average Tube In-Out [V]	U Linearized voltage [V_{linear}]	d_{NOM} Calculated Displacement [mm]	E_{NOM} Nominal Linearity Error [%]	Δ_{IN} Deviation IN [mm]	Δ_{OUT} Deviation OUT [mm]	Δ_{MAX} Maximum Variation [mm]	E_{MAX} Maximum Linearity Error [%]
0	0,0709	0,0707	0,0708	3,3046	0,07	0,09%	0,14	0,00	0,14	0,18%
5	0,0784	0,0782	0,0783	3,1578	5,04	0,06%	0,11	-0,02	0,12	0,13%
10	0,0869	0,0869	0,0869	3,0127	9,96	-0,05%	-0,04	-0,04	0,00	0,05%
15	0,0977	0,0969	0,0973	2,8628	15,03	0,04%	0,21	-0,15	0,36	0,27%
20	0,1094	0,1090	0,1092	2,7175	19,95	-0,06%	0,03	-0,12	0,15	0,15%
25	0,1238	0,1234	0,1236	2,5697	24,96	-0,05%	0,02	-0,10	0,13	0,13%
30	0,1414	0,1406	0,1410	2,4214	29,98	-0,02%	0,09	-0,12	0,21	0,15%
35	0,1620	0,1616	0,1618	2,2755	34,92	-0,10%	-0,03	-0,12	0,09	0,15%
40	0,1882	0,1877	0,1880	2,1267	39,96	-0,05%	0,00	-0,08	0,09	0,10%
45	0,2208	0,2206	0,2207	1,9780	45,00	0,00%	0,01	-0,01	0,03	0,02%
50	0,2624	0,2615	0,2620	1,8307	49,99	-0,02%	0,03	-0,06	0,10	0,08%
55	0,3162	0,3160	0,3161	1,6819	55,03	0,03%	0,04	0,02	0,02	0,05%
60	0,3875	0,3874	0,3875	1,5342	60,03	0,03%	0,03	0,02	0,01	0,04%
65	0,4860	0,4852	0,4856	1,3855	65,06	0,08%	0,08	0,05	0,03	0,10%
70	0,6232	0,6234	0,6233	1,2379	70,06	0,08%	0,06	0,07	-0,01	0,08%
75	0,8225	0,8248	0,8237	1,0915	75,02	0,03%	0,00	0,04	-0,05	0,05%
80	1,1292	1,1283	1,1288	0,9468	79,92	-0,10%	-0,07	-0,08	0,01	0,10%
						0,10%	**0,21**	**0,15**	**0,45%**	**0,27%**
						Max E_{NOM}			**Var_{MAX}**	**E_{MAX}**
						Pass			Pass	Pass
						Nominal Linearity Error <2% Calibration Range			**Maximum variation <2% Calibration Range**	**Maximum Linearity error <2% Calibration Range**

Optimized Exponent (Max Error 0.1%)		
Calibration Factor C_{IR}	[mm/V_{LIN}]	**-33,8666**
Linearization exponent EXP	[-]	**-0,45142**
Displacement Intercept I_{DS}	mm	**111,99**
Calculate displacement using the formula: *mm = (Vsensor ^ -0.4514) * -33.8666 + 111.99*		
Calculate displacement using the formula: *mm = Vsensor ^ -0.4514 -3.3067 / -0.02953*		
Sensitivity S_{IR}	[V_{LIN}/mm]	**-0,02953**
Displacement Intercept Voltage I_{DSV}	[V_{LIN}]	**3,3067**

Solved

Lateral Displacement Measurement			
Lateral direction	**$V_{IRT-LAT}$ Measured Output (V)**	**U Linearized Output [V_{LIN}]**	**d_{LAT} Lat. Displ. [mm]**
1	0,0691	3,341	-1,16
2	0,0724	3,271	1,19
3	0,0715	3,290	0,57
4	0,0700	3,322	-0,50
Maximum variance lateral displacement Δ_{LAT} [mm]			2,36
Maximum Lateral Variance Error E_{LAT} [%]			**2,95%** Pass

Figure 10 Example calibration template: Completed Tubes In-Out calibration data

Bibliography

[i] Rouhana, S.W., Elhagediab A.M., Chapp, J.J. 'A High-Speed Sensor for Measuring Chest Deflection In Crash Dummies, PROCEEDINGS 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Windsor, Ontario, Canada, May 31- June 4, 1998, Paper Number 98-S9-O-15. http://www-nrd.nhtsa.dot.gov/departments/esv/16th

[ii] ISO/TS 13499 Road vehicles - Multimedia data exchange format for impact tests, RED B Channel Codes, ISO/TC 22/SC 12/WG 3.

[iii] MS EXCEL Solver Add-in. Perform an internet search with 'MS EXCEL Solver Add-in' for links to download the code and further information, examples and tutorials. For instance: http://www.addictivetips.com/windows-tips/microsoft-office-excel-2010-solver-add-in/ . The GRG Nonlinear solver is applied. GRG stands for Generalised Reduced Gradient algorithm, developed by Lasdon, Fox and Ratner.
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