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Road vehicles — Displacement calibration method of IR-TRACC devices

Véhicules routiers — Méthode d'étalonnage de déplacement des dispositifs IR-TRACC

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Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 36, *Anthropomorphic test devices*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 known as IR-TRACC. This device is commonly used on crash dummies to measure the chest deflection as injury an assessment parameter. 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.

Road vehicles — Displacement calibration method of IR-TRACC devices

1 Scope

This document establishes a procedure to calibrate IR-TRACC displacement transducers. Like all other sensors used on dummies, calibration is required. The calibration is 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 are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
IR-TRACC
Infra-Red Telescoping Rod for the Assessment of Chest Compression
non-ratiometric displacement transducer used to measure chest deflection in crash dummies

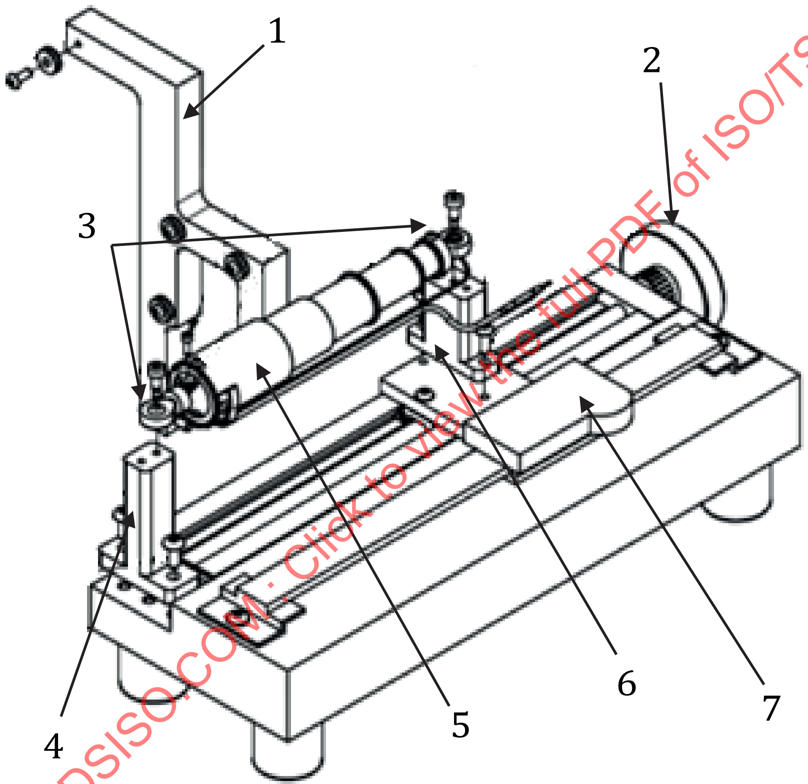
Note 1 to entry: The technology of the transducer was described in a paper by Rouhana et al. [1998][1]. The measurement principle is based on emission of infra-red light by an LED and a phototransistor sensitive to irradiance. The transducer is a non-linear device, as the irradiance and output voltage 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 $d = C \times U_{IR}^{-0,5}$

3.2
Displacement Calibration
classic compression method where the zero mm starting point is defined close to the extended range of the sensor

Note 1 to entry: 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[2] Code DS for Displacement.

3.3
Displacement Calibration Fixture
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

Note 1 to entry: An example of a displacement calibration fixture is shown in Figure 1. The maximum allowable axis parallelism deviation is 1,5 mm[1)]. The minimum distance between the moveable and fixed head interface is less than the collapsed interface distance of the smallest sensor (currently 55 mm) and the maximum exceeds the fully extended interface distance of the largest displacement sensor (currently 201 mm). The interfaces have freedom of rotation about the two axis perpendicular to sensitive axis. The moveable head position is accurately adjustable by means of, for instance, a hand or motor operated screw; the moveable head is linked to a displacement measurement gage parallel to the sensitive axis with a resolution of at least 0,01 mm. The moveable head is linked to the displacement gage without mechanical play. A lateral loading fixture is mounted about half way between the fixed and moving cross head to execute the forced lateral manipulation test.



Key

1 Lateral loading fixture
2 Screw to position cross head
3 Interfaces
4 Fixed head
5 IR-TRACC
6 Moving cross head
7 Linear gauge

Figure 1 — Example Displacement Calibration Fixture (exploded view)

1) Generally a 1,5 mm crosshead parallelism deviation causes less than 0,01 mm displacement deviation.

3.4
Nominal Linearization Exponent
theoretical parameter to linearize the phototransistor voltage output as an inverse square root function, or the voltage output U_{IR} to the power of −0,5

Note 1 to entry: See 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 −0,428 57.

Note 2 to entry: $d = C * U_{IR}^{-0,428\,57}$

Note 3 to entry: This value 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 value did not give the smallest linearization error for each individual transducer. Up to this date this value is now applied as a starting exponent for optimization of the exponent (see 3.5 and 3.6).

3.5
Optimized Linearization Exponent
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
optimization of the Linearization Exponent by applying data processing, for instance (but not limited to) numerical optimization

Note 1 to entry: The method finds 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, Calibration Factor C_{IR}, Displacement Intercept I_{DS}, Sensitivity S_{IR} and Displacement Intercept Voltage I_{DSV}. The optimization method is explained in 6.3.

3.7
Forced Lateral Manipulation Test
test implemented to ensure an IR-TRACC is not overly sensitive to bending of the tubes in a direction perpendicular to the axis of displacement measurement

Note 1 to entry: The test is executed at the zero displacement point. A force of 4,45 N ± 0,15 N 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
calibration procedure that takes two extreme tube position conditions into account at each calibration interval (tubes-in and tubes-out position) to ensure an IR-TRACC is not overly sensitive to the individual positions of the telescope tubes

Note 1 to entry: Tubes-in: all free tubes are moved to the largest diameter end (to fixed cross head); Tubes-out: all free tubes are moved to the smallest diameter end (to moving cross head).

Note 2 to entry: In any length of the IR-TRACC displacement range (except fully extended/fully collapsed) the intermediate telescope tubes are free to move position.

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) 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 (0,060 0 - 2,000 0 V) and digital output are generally high values (1 000,0 - 32 000,0 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 + 2 mm)
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} $d_{LAT-MAX}$ $d_{LAT-MIN}$	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-IN}	V (LSB)	(Digital) output voltage at certain displacement with all floating tubes pushed IN
7	Tubes-OUT voltage	U_{IR-OUT}	V (LSB)	(Digital) output voltage at certain displacement with all floating tubes pushed OUT
8	Average In-Out voltage	U_{IR-AVE}	V (LSB)	Average of Tubes-IN and Tubes-OUT (Digital) voltage
9	Forced lateral manipulation voltage	U_{IR-LAT}	V (LSB)	(Digital) output voltage at forced lateral manipulation
10	Nominal Linearization exponent	EXP_{NOM}	—	IR-TRACC Linearization optimization routine starting value: -0,428 57 (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
The measurement techniques applied in this procedure shall be in accordance with ISO 6487.				

Table 1 *(continued)*

Nr	Parameter	Symbol	Unit	Definition/Description
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 1 mm displacement pertaining to nominal exponent EXP_{NOM}
25	Displacement Intercept	I_{DS}	mm	Calculated displacement at $U_{LIN} = 0$
26	Displacement intercept voltage	I_{DSV}	(V_{LIN}) (LSB_{LIN})	Linearized Voltage (or linearized digital output) at 0 mm displacement
The measurement techniques applied in this procedure shall be in accordance with ISO 6487.				

5 Displacement Calibration Procedure

This clause describes the procedure for displacement calibration of IR-TRACCs. This calibration is run according to 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, see example in Figure 1. 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. 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 shall apply, as shall the use of the calibration software.

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

5.1 Preparations

— Start the calibration software [see also Annex B example calibration template (MS-Excel format[2])]. 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 °C to 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 a method in this document, a generic method for connecting an IR-TRACC electrically is given, however this connection method is not mandatory. The transducers can be connected to the 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: 5,123 45 V). Make sure to run a grounding cable from the calibration fixture casing to the grounding point of the voltmeter. Allow at least 120 s warm-up time of the IR-TRACC before taking calibration data.

— Set the voltmeter to display DC voltage reading in 4 decimal places, for example 5,123 4 V. 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 2. 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 2. Make sure not to exert excessive force, as this will bend the heads of the fixture.

— Zero the linear displacement gage.

2) Microsoft Excel ™ is the trademark of a product supplied by Microsoft. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

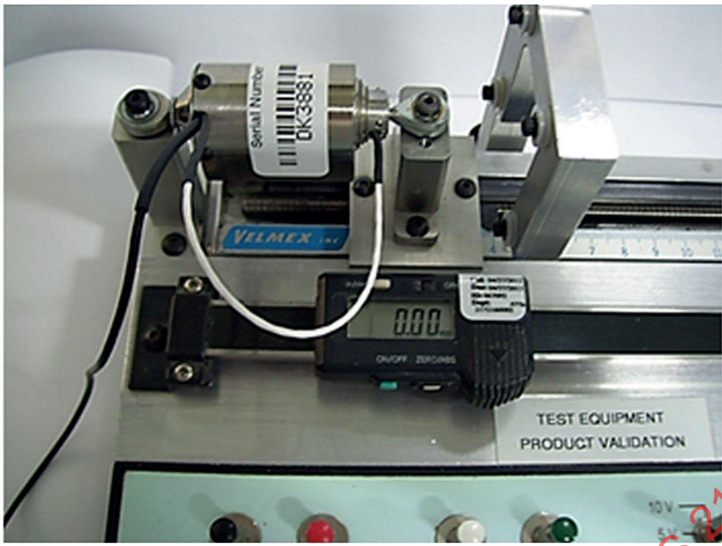


Figure 2 — IR-TRACC fully collapsed

NOTE In Figure 2, the 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 A.1:

Example (IF-367):

— From fully compressed, expand 85 mm to 86 mm outward; see Table A.1, column A

— To remove backlash, compress back to 82,00 mm; see Table A.1 column B and **zero the displacement gage**. This is the zero displacement point d_S (calibration point d = 0 mm).

— Save the file again.

5.4 Forced Lateral Manipulation Test

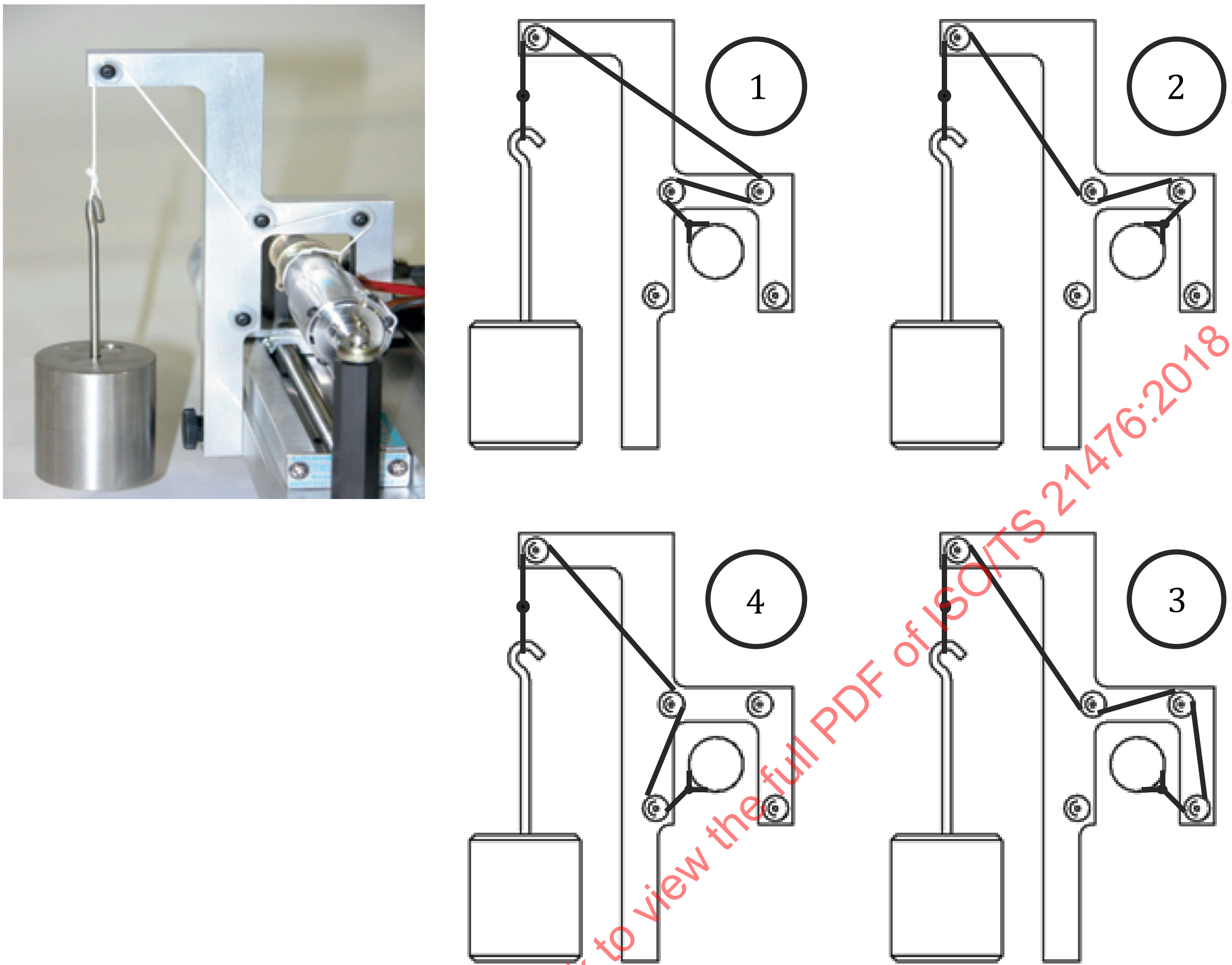
— At the starting point d_S (calibration point 0 mm) from 5.3, run the forced lateral manipulation test with a ballast of 0,44 kg to 0,47 kg (~1 lbs.) as follows.

— Load the IR-TRACC in a plane perpendicular to the sensitive axis in four directions spaced 90 degrees as shown in Figure 3. Move all IR-TRACC tubes fully out, see Figure 4-right. The user's fixture may be different than the set-up shown in Figure 3. The intent is to take four readings 90 degrees apart with the ballast pulling in each direction. Wire loop around IR-TRACC should be in line with fixture pulleys.

— Observe the 120 s 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.



Key

1 quadrant 1 (pull far-up)

2 quadrant 2 (pull near-up)

3 quadrant 3 (pull near-down)

4 quadrant 4 (pull far-down)

Figure 3 — 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.

IMPORTANT — 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 0,00 mm displacement.

— Slide all floating IR-TRACC tubes-IN to the big end (to the left in Figure 4).

— Enter voltage reading [V] at 0 mm in the calibration software.

— Subsequently collapse IR-TRACC in 5,00 mm 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 in compression direction (left) to the next calibration interval. If 5 mm movement is accidentally exceeded, bring the moveable head back beyond the target calibration point and reposition the head to the target calibration point in compression direction (example: target calibration point is 10,00 mm, but exceed at 10,20 mm: move the head back to ~9 mm and approach 10,00 mm target calibration point again in compression direction).

— 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 back beyond d = 0 mm (between −1 mm to −2 mm); slide all floating IR-TRACC tubes-OUT to the small end (to the right in Figure 4).

— Move calibration cross head to d = 0,00 mm.

— Enter voltage reading at 0 mm in the calibration software for tubes-OUT.

— Subsequently collapse IR-TRACC in 5 mm 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.

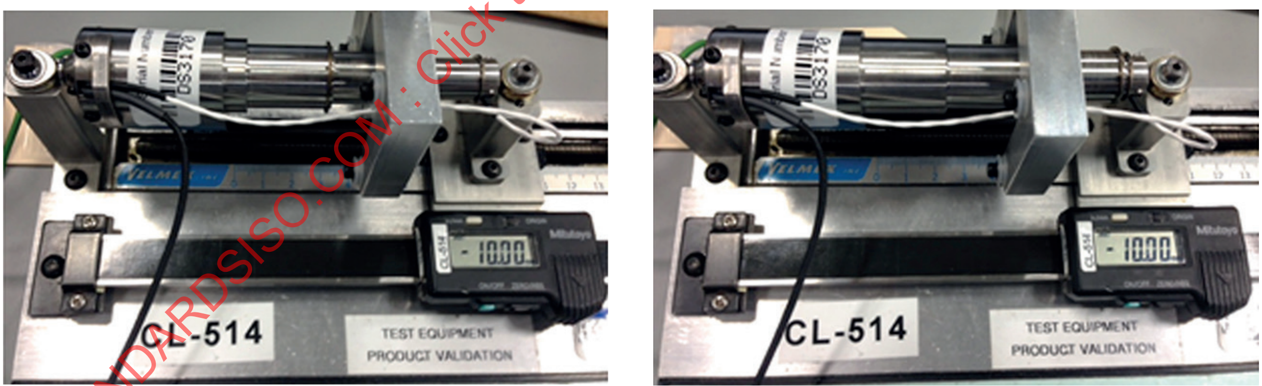


Figure 4 — IR-TRACC tubes-in shown left and tubes-out shown right

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

6.1 General

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

6.2 Linearization over calibration range with nominal exponent

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

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

Per each calibration increment calculate the nominal linearized voltage starting with the nominal Exponent, (EXP_{NOM}, −0,428 57):

$$U_{\text{LIN}} = U_{\text{IR-AVE}}^{(-0{,}428\,57)} \left[\text{V}_{\text{LIN}}\right] \tag{2}$$

(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:

$$d_{\text{NOM}} = \left(U_{\text{LIN}} - I_{\text{DSV}}\right)/S_{\text{NOM}} \quad [\text{mm}] \tag{3}$$

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

$$E_{\text{NOM}} = \left(d_{\text{NOM}} - d\right)/d_{\text{e}} \times 100 \, [\%] \tag{4}$$

At this point the IR-TRACC 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.

6.3 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 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 optimization shall be executed up to the 5th decimal of the exponent as minimum. The result is the optimized linearization exponent EXP, Calibration Factor C_{IR}, Displacement Intercept I_{DS}, Sensitivity S_{IR} and Displacement Intercept Voltage I_{DSV}. In 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 processed with the example template are given in Figure B.6 for comparison.

6.4 Data analysis and pass criteria calculations

6.4.1 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 6.1, but applying optimized exponent EXP instead of nominal exponent:

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

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

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

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

$$E_{NOM} = \left(d_{NOM} - d \right) / d_e \times 100 \left[\% \right]$$

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

$$\text{Max } E_{NOM} = \text{Maximum of} \left| \left(d_{NOM} - d \right) \right| / \mathrm{d_e} \times 100 \left[\% \right] \text{ between } d_s \text{ and } d_e \quad (7)$$

6.4.2 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.

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

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

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

$$\Delta_{MAX} = \Delta_{IN} - \Delta_{OUT} \left[\mathrm{mm} \right] \quad (10)$$

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

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

6.4.3 Pass–fail tests and limits

Calculate the Maximum variation error over the entire calibration range.

$$\mathrm{Var}_{\mathrm{Max}} = \Delta_{\mathrm{MAX}} / d_e \times 100 \left[\% \right] (12) \text{ Max absolute variation error between } d_s \text{ and } d_e \quad (12)$$

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.

6.4.4 Forced Lateral Manipulation variation

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

$$d_{\mathrm{LAT}} = \left[\left(U_{\mathrm{IR\text{-}LAT}}{}^{\mathrm{EXP}} \right) - I_{\mathrm{DSV}} \right] \times C_{\mathrm{IR}} \quad (13)$$

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

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

Calculate maximum lateral variance error and apply pass criteria.

$$E_{\mathrm{LAT}} = \Delta_{\mathrm{LAT}} / d_{\mathrm{e}} \times 100 \left[\% \right] \quad (15)$$

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

6.5 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 B.6.

Table 2 — Example data set

d Calibration displacement [mm]	$U_{\mathrm{IR\text{-}IN}}$ Sensor output tubes-In [V]	$U_{\mathrm{IR\text{-}OUT}}$ Sensor output tubes-Out [V]
0	0,070 9	0,070 7
5	0,078 4	0,078 2
10	0,086 9	0,086 9
15	0,097 7	0,096 9
20	0,109 4	0,109 0
25	0,123 8	0,123 4
30	0,141 4	0,140 6
35	0,162 0	0,161 6
40	0,188 2	0,187 7
45	0,220 8	0,220 6
50	0,262 4	0,261 5
55	0,316 2	0,316 0
60	0,387 5	0,387 4
65	0,486 0	0,485 2

Table 2 *(continued)*

d **Calibration displacement** [mm]	$U_{IR\text{-}IN}$ **Sensor output tubes-In** [V]	$U_{IR\text{-}OUT}$ **Sensor output tubes-Out** [V]
70	0,623 2	0,623 4
75	0,822 5	0,824 8
80	1,129 2	1,128 3

Annex A
(informative)

Sensor Model Numbers

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

Table A.1 — 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 5 mm intervals to** ...[mm]
6110 8830	92,5 to 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 to 91	87,00	85,00
IF-367 IF-368 IF-372	85 to 86	82,00	80,00
IF-369 IF-371 IH-11400 IH-11620	70 to 71	67,00	65,00
6510 9810	63 to 64	62,00	60,00
10180	Fully extend	25,50	25,00