PD ISO/TS 17242:2014

BSI Standards Publication

Quasi-static calibration procedure for belt force transducers

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee AUE/7, Automobile occupant restraint systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2014

ISBN 978 0 580 84335 8
ICS 43.040.80

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2014.

Amendments/corrigenda issued since publication

Date	Text affected

TECHNICAL SPECIFICATION

ISO/TS 17242

First edition
2014-05-01

Quasi-static calibration procedure for belt force transducers

Procédure d'étalonnage quasi-statique pour capteurs d'efforts pour ceintures

Reference number
ISO/TS 17242:2014(E)

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Foreword

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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems*.

Quasi-static calibration procedure for belt force transducers

1 Scope

The objective of this Technical Specification is to provide a procedure to calibrate seat belt force transducers with loading capacities up to 25 kN and consistent test specifications and sequences in order to improve comparability of measurement results between testing laboratories.

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 376, *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 5084, *Textiles — Determination of thickness of textiles and textile products*

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

ISO 13499, *Road vehicles — Multimedia data exchange format for impact tests*

ECE-R16, *Safety-belts, restraint systems, child restraint systems and ISOFIX child restraint systems for occupants of power-driven vehicles*

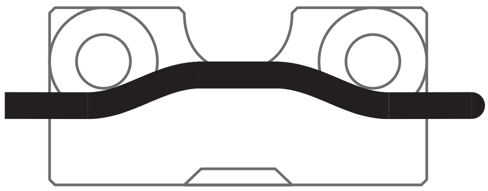
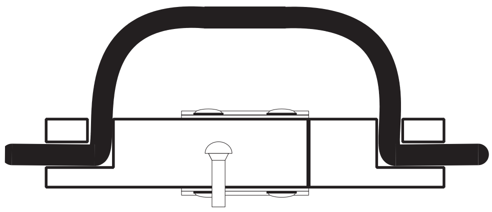
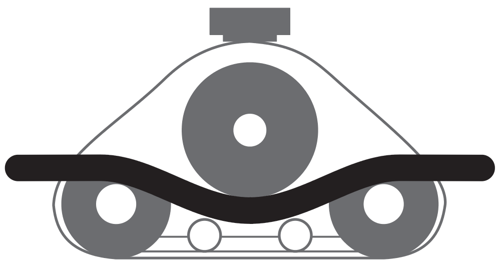
SAE-J2517, *Hybrid III Family Chest Potentiometer Calibration Procedure*

3 General specifications

3.1 General

The described measurement procedure refers to belt force transducers with the specifications according to Table 1 and a loading capacity of up to 25 kN.

Table 1 — Design categorization of belt force transducers

Type	Description	Belt Orientation
1	Baffle (test belt strap according to Annex 3)	
2	Loop (test belt strap according to customer requirement)	
3	Clamping (test belt strap according to customer requirement)	
4	3-Bolt (test belt strap according to customer requirement)	

3.2 Limitations or the application of the test belt strap

In general, the standardized calibration belt strap (see C.1) is only recommended for the calibration of belt force transducers which are to be utilized in tests that focuses on comparability between different laboratories (such as during development efforts). In case absolute values have to be obtained, the seat belt webbing designated for subsequent testing purposes is to be used for calibration.[1)]

Calibration using the standardized calibration belt strap shall be done for highly dynamically loaded transducers as shown in Type 1 (baffle). Consequently Types 2, 3, 4, and *Type 1 transducers for quasi-static loads and measurement ranges up to 500 N* (i.e. comfort measurements) are to be excluded.

NOTE If required (e.g. by the user or the test protocol), Type 1 transducers with measurement ranges beyond 500 N should be calibrated with a specimen of the seat belt webbing which is designated for subsequent testing purposes. For the calibration of Types 2, 3, 4, and Type 1 transducers for quasi-static loads and measurement ranges below 500 N, a specimen of the seat belt webbing which is designated for subsequent testing purposes will be necessary.

1) Measurement of absolute values shows significant variation for type 1 transducers. A different measurement principle is recommended.

The belt strap type used for calibration as well as the strap's average thickness (see Annex C) shall be identified in the calibration report.

If a non-standardized belt strap is supplied, it is also recommended to perform a calibration using the standardized belt strap for traceability.

4 Test conditions

The calibration test shall be performed under the conditions identified below.

4.1 Test method

A continuous loading up to the transducer's full scale range[2] shall be applied.

4.2 Clamping length

As shown in Annex A, the belt force transducer is tested on a belt strap specimen clamped into the universal tension machine. The free clamping length shall be within 375 mm ± 75 mm.

4.3 Test velocity

The speed of displacement of the tension machine for the continuous loading shall be within 170 mm/min ± 30 mm/min.

4.4 Belt strap

A standardized belt strap specimen as defined in Annex C should be utilized.[3]

4.5 Load relieving

The hysteresis is not verified.

4.6 Data acquisition

In case of polynomial regression, the zero offset shall not be corrected prior to the test. So the amplifier offset should be considered for the error of measurement of the whole measurement channel. The filter settings shall comply with the ISO 6487 specifications.

4.7 Data evaluation

For the evaluation, the first loading sequence[4] recorded with a minimum sampling rate of 100 Hz[5] shall be considered in a range from 2 % to 100 % of the transducer's calibration range (e.g. 0,32 kN – 16 kN @ 16 kN sensor range)[6]. The nonlinearity is displayed as a percentage in % of the calibration range.

2) See transducer data sheet.

3) Other belt strap types have to be identified in the calibration report.

4) No preloading procedures.

5) To reach appropriate accuracy.

6) Ensure the comparison standard is traceable (e.g. ISO 376).

4.8 Sensor excitation

The sensor excitation voltage, as well as the sensor connection, shall be in accordance to the customer requirements and shall be recorded.[7)]

4.9 Environmental conditions

The calibration test shall be performed under monitored environmental conditions within a temperature range of 19 °C to 23 °C and a Relative Humidity of 10 % to 70 %. For acclimatization purposes, the transducers as well as the belt strap specimen should be kept in this environment for a period of 8 h prior to the calibration.

5 Calibration procedure

Proceed with the following steps to perform the calibration test.

5.1 Conditioning

An adequate warm-up time for the data acquisition system, test and reference transducer should be allowed to reach thermal equilibrium.

5.2 Test preparation

The sensor offset should be measured under no load condition. A new belt strap shall be inserted and centred in the fixations[8)]. The test transducer shall be mounted centred and perpendicular in accordance to the sensor user's manual. The belt strap preload shall not exceed 0,2 % of the calibration range (while holding the transducer in place).

5.3 Calibration test

In case of linear regression, prior to the test the sensor's zero offset shall be corrected. In case of polynomial regression, the zero offset shall not be corrected prior to the test[9)]. Only one loading sequence with one belt strap per test transducer up to a force level of 101 % of the transducer's calibration range shall be performed within the given velocity range. The calibration data shall be acquired continuously. There are no requirements for the load relieving sequence.

5.4 Data storage

The data storage format is optional[10)].

5.5 Data evaluation

A Linear Equation following B.1 or a Third Degree Polynomial without any offset correction as defined in B.2[11)] should be determined from the recorded data points.

---

7) Excitation voltage as well as pin assignment and if excitation sensing was utilized shall be stated in calibration report.

8) Fixation by clamp or loop (ECE-R16 conform).

9) Use of the calibration coefficient as defined in SAE-J2517: Prior to a crash test, the original zero offset level should be preserved by either not zeroing the transducer or the amount that was zeroed should be added during post-processing.

10) ISO 13499 recommends: incl. time channel, output test sensor, output reference sensor, and travel distance.

11) If the calibrated transducer is used in tests, the hardware offset shall not be corrected.

5.6 Documentation

The test report shall include the following:

- temperature;
- humidity;
- belt strap type;
- strap thickness;[12)]
- sensitivity in kN/mV/V and mV/kN/V (for linear regression) or a third degree polynomial equation in the form *F* = AS^3+BS^2+CS+M;[13)]
- the polynomial coefficients in kN/mV/V (polynomial coefficient's significant digits: 3rd degree: 9 (e.g. 0,001 234 567 89), 2nd degree: 6 (e.g. 1,234 56), 1st degree: 3 (e.g. 12,3);
- measured sensor offset in unloaded condition in mV/V;[14)]
- nonlinearity as a percentage in % of the transducer's calibration range.

12) See page 13 "Measurement of Test Belt Strap Thickness".

13) See page 11 ″Polynomial Regression".

14) To check the offset magnitude of the data acquisition system.

Annex A
(normative)

Test setup

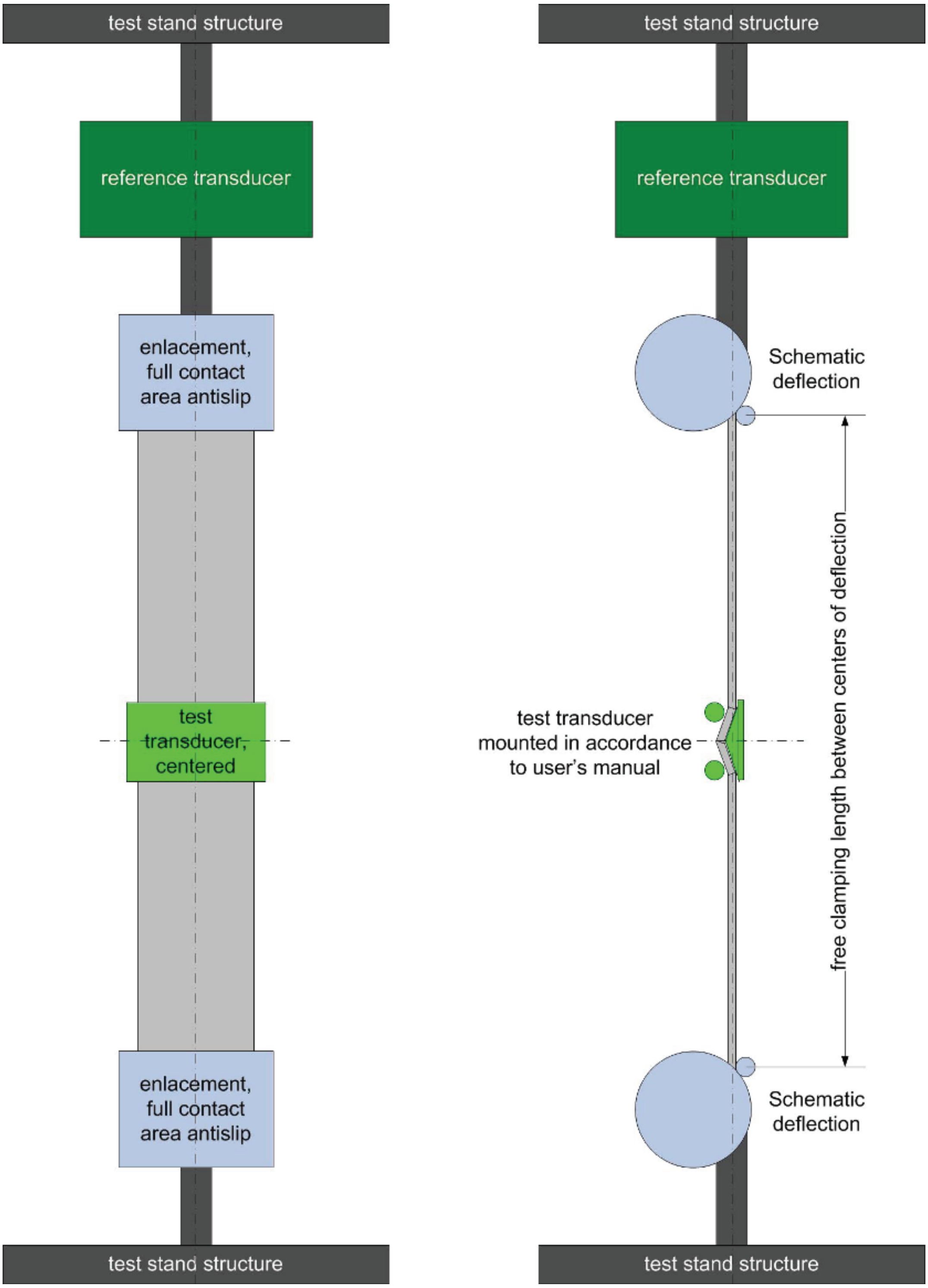


Figure A.1 — Schematic calibration test setup

Annex B
(normative)

Evaluation method

B.1 Linear regression

For the software linearization a least-squares fit method applied through the point of origin is used:

The starting point of the linearized line is identical with the starting point of the measurement. This point is set to zero (point of origin). This measurement is independent of the defined evaluation interval (see 4.7). The resulting linear equation is

$$F_i = b\,(S_i - S_0) + D \tag{B.1}$$

where

$S_0 = 0$;

$D = 0$.

For the linearization, the square sum of the difference between measured value and linearized value must be minimal:

$$\sigma = \sum_{i=1}^{n} [F_i - (b\,(S_i - S_0) + D)]^2 \tag{B.2}$$

The differentiation is equated to zero:

$S_i, F_i = \textit{measured}$

From this will follow:

$$b = \frac{\sum_{i=1}^{n} (F_i - D)}{\sum_{i=1}^{n} (S_i - S_0)} \tag{B.3}$$

$$a = \frac{1}{b}$$

Key

F is the actual force in kN

S is the sensor output reading in mV/V

D is the calculated offset in kN (linear regression)

a is the sensitivity in mV/kN/V

b is the inverse sensitivity in kN/mV/V

σ is the deviation

B.2 Polynomial regression

For the polynomial approximation, a least-squares fit method shall be utilized to determine the polynomial coefficients A, B, C, and M.

With mesh points (S_i; F_i) the third degree polynomial will acquire the general form:

$$F_i = A \cdot S_i^a + B \cdot S_i^2 + C \cdot S_i + M \tag{B.4}$$

The function values F_i are complemented by residues r_i (corrections)

$$F_i + r_i = A \cdot S_i^a + B \cdot S_i^2 + C \cdot S_i + M \tag{B.5}$$

Applied on the mesh points the observation formulae follow:

$$r_1 = A \cdot S_1^a + B \cdot S_1^2 + C \cdot S_1 + M - F_1 \tag{B.6}$$

↓

$$r_1 = A \cdot S_i^a + B \cdot S_i^2 + C \cdot S_i + M - F_i$$

The observation equations are squared and then pooled.

$$\begin{aligned}\sum r_i^2 = \sum A^2 \cdot S_i^6 \\ &+2\sum AB \cdot S_i^5 + 2\sum AC \cdot S_i^4 + 2\sum AM \cdot S_i^a \\ &-2\sum A \cdot F_i \cdot S_i^a \\ &+2\sum B^2 \cdot S_i^4 \\ &+2\sum BC \cdot S_i^a + 2\sum BM \cdot S_i^2 \\ &-2\sum B \cdot F_i \cdot S_i^2 + \sum C2 \cdot S_i^2 + 2\sum CM \cdot S_i - 2\sum C \cdot F_i \cdot S_i + M^2 - 2M \cdot F_i + F_i^2\end{aligned}$$

To determine the minimum of the residues r_i, the observation formula's sum of squares are differentiated and equated to zero.

$$\frac{d(\sum r_i^2)}{dA} = 2\sum A \cdot S_i^6 + \sum B \cdot S_i^5 + \sum C \cdot S_i^4 + \sum M \cdot S_i^a - \sum F_i \cdot S_i^a = 0$$

$$\frac{d(\sum r_i^2)}{dB} = \sum A \cdot S_i^5 + 2\sum B \cdot S_i^4 + \sum C \cdot S_i^a + \sum M \cdot S_i^2 - \sum F_i \cdot S_i^2 = 0$$

$$\frac{d(\sum r_i^2)}{dC} = \sum A \cdot S_i^4 + \sum B \cdot S_i^a + 2\sum C \cdot S_i^2 + \sum M \cdot S_i - \sum F_i \cdot S_i = 0$$

$$\frac{d(\sum r_i^2)}{dM} = \sum A \cdot S_i^a + \sum B \cdot S_i^2 + \sum C \cdot S_i + 2\sum M - \sum F_i = 0$$

A linear system of equations results from putting in the mesh points (x_i; y_i). Coefficients A, B, C, and M and therefore the equalization polynomial through the point of origin can be calculated.

Key

F	is the actual force in kN
S	is the sensor output reading in mV/V
M	is the physical offset prior to the test in kN (polynomial regression)
A, B, and C	are the calibration coefficients

Annex C
(informative)

Belt strap characteristics

C.1 Specifications for the standardized calibration belt strap

For the calibration of the belt force transducers, a test belt strap with the specifications shown below should be utilized

C.1.1 Construction

Normal band equal on both sides, bonding K2/2, doubleshot.

C.1.2 Width

47 mm to 49 mm

C.1.3 Thickness

1,25 mm to 1,35 mm

C.1.4 Weight

64 g/m to 68 g/m

C.1.5 Minimum breaking load

≥30 kN

C.1.6 Strain

14 % to 16 % at 10 kN

C.1.7 Colouring/Finishing

Spin dying

C.1.8 Number of chaining threads

300 ± 10

C.1.9 Number of filling threads

66 ± 5 (1/100 mm)

The belt strap shall be stored in a packed condition. Furthermore it should be protected from sunlight.

NOTE The test belt strap as defined above is only permitted to be used for highly dynamically loaded transducers according to Type 1 (baffle). For other transducers, the test belt strap which is in accordance with customer requirements should be chosen.

C.2 Measurement of test belt strap thickness

For verification of significant belt strap characteristics, and to ensure traceability, the average thickness of the utilized belt strap lot should be identified. The average and the classification of the belt strap shall be noted in the calibration report. Measurements of the test belt strap thickness are taken as follows[15]:

The test gauge should have a resolution of 0,01 mm and a maximum indication error of 3 %. The belt strap shall be measured between a planar rigid underlay and a flat transceiver with a surface area of 20 cm^2 (caliber of ca. 50,46 mm) within a test load from 1 kPa. The averaged belt strap thickness is calculated by three measurements on different points in the medium range of the belt strap. The minimum distance between these points should be 25 % of the overall tested belt strap length. If a belt strap charge is longer than 10m, the average belt strap thickness should be identified once per each 10 m section.

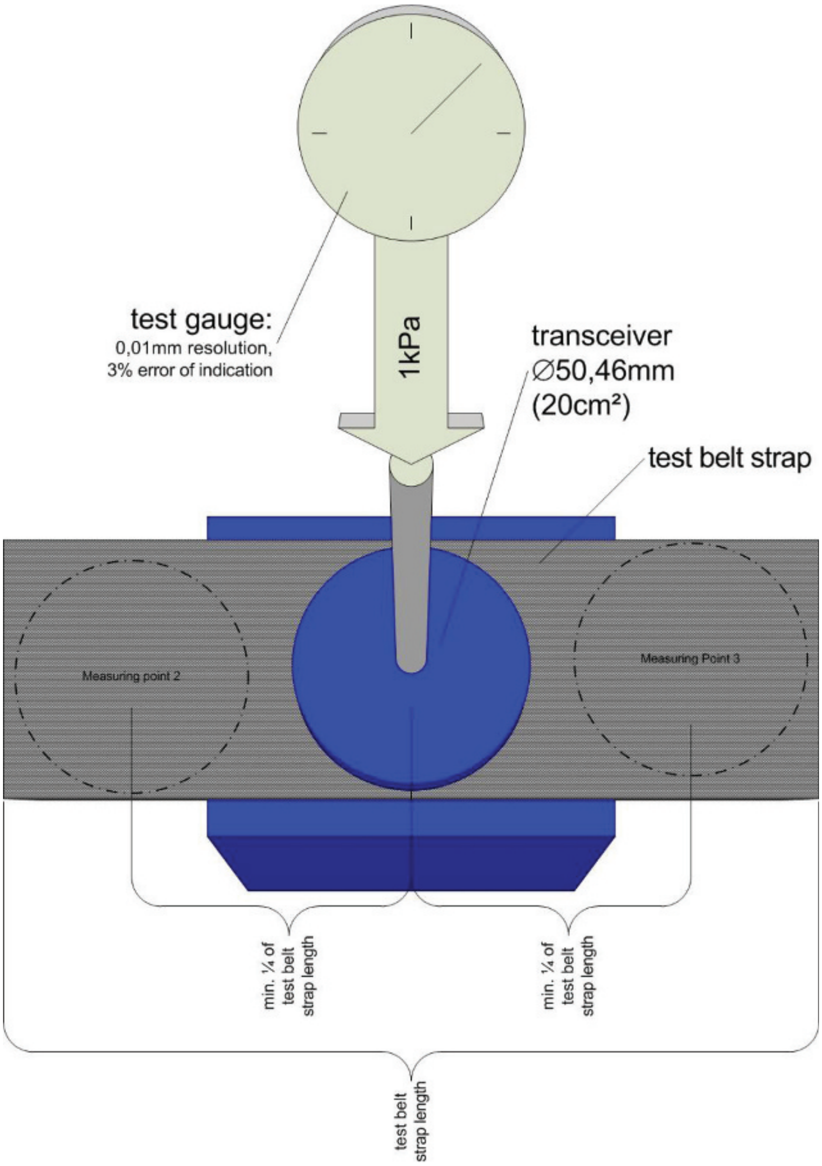


Figure C.2 — Schematic measurement setup for the belt strap thickness

15) Following EN ISO 5084.

Annex D
(informative)

Applications notes

D.1 Application of the polynomial scaling

By means of electronic linearization, the nonlinearity of belt force transducers can be reduced to less than 1 %. In that case the higher accuracy of a polynomial regression fitting the calibration curve has no significant effect on the measurement results considering the error of measurement in the calibration institutes and in the crash test laboratories applying the polynomial scaling.

Therefore for process simplification the polynomial scaling is only recommended for belt force transducers without linearization electronics.

D.2 Application of unified measurement ranges

To achieve higher accuracy with the linear regression over a certain measurement range below the transducer's full range, a limitation of the calibrated range can be effective. The sensor's nonlinearity leads to different transducer sensitivities over different measurement ranges. This has to be considered for proper comparability of the measurement results between laboratories on sensors calibrated in different ranges. The recommended separation of measurement ranges of highly dynamically loaded belt force transducers is 6 kN, 10 kN, 16 kN, and 25 kN.

To improve comparability, laboratories should agree to utilize transducers of the same measurement range in the same test scenarios.

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