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Revision of
CGATS TR 016-2012

A Technical Report

Prepared by

Committee for Graphic Arts Technologies Standards (CGATS)

Graphic technology — Printing Tolerance and Conformity Assessment

SECRETARIAT
NPES THE ASSOCIATION FOR SUPPLIERS OF PRINTING, PUBLISHING AND CONVERTING TECHNOLOGIES

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AMERICAN NATIONAL STANDARDS INSTITUTE, INC.

1899 PRESTON WHITE DRIVE • RESTON, VIRGINIA 20191 • TEL: 703/264-7200 • FAX: 703/620-0994 • www.npes.org

TECHNICAL REPORT

Publication of this Technical Report, which has been registered with ANSI, has been approved by the Committee for Graphic Arts Technologies Standards (CGATS) in accordance with the CGATS Procedure for Development of a Technical Report. This document is not an American National Standard and the material contained herein is not normative in nature.

This Technical Report was developed in cooperation with Print Properties and Colorimetric Working Group of IDEAlliance.

Questions and comments regarding this Technical Report should be addressed to the CGATS Secretariat, NPES The Association for Suppliers of Printing, Publishing and Converting Technologies, 1899 Preston White Drive, Reston, Virginia 20191.

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Foreword

This CGATS Technical Report was prepared by the members of CGATS Subcommittee 3, Metrology & Process Control, in cooperation with the members of the GRACoL Working Group and the IDEAlliance Print Properties and Colorimetric Council. At the time of its approval, the following were the Participating Members and Observers of CGATS SC3.

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		QuadTech	Greg Wuenstel
		Specialty Graphic Imaging Association	Dutch Drehle
		Time, Inc.	Kin Wah Lam
		X-Rite	Kelly VandenBosch

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Chairman: Steve Smiley
Vice Chairman: Mike Rodriquez

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INK International Ink. Co.	Chuck LaFever	X-Rite, Incorporated	Raymond Cheydleur

Introduction

Printing standards are being developed by ANSI CGATS and ISO TC130, Graphic technology. The standards being developed are based on two different approaches. The traditional approach is to define the color of the solids, two-color solid overprints and tone-value increase (TVI). The newer approach is to use a reference characterization data set to define the printing aims, and the aims from process control are taken from characterization data.

Traditionally, specification of allowed tolerances on these aims take a one-size-fits-all approach. None of the standards provide any method by which individual normative requirement can be combined together to provide an overall evaluation of results. This makes evaluation of the conformance of a printing operation difficult and inconsistent among the various organizations providing certification schemas and conformity assessment.

The goal of this technical report is to provide a test method that is process agnostic, including standard test targets, sampling, measurement procedures, and tolerances, to evaluate deviation, within-sheet variation, and production variation of a variety of printing processes.

The first edition of the CGATS TR016 was published in January 2012. TR016 was revised based on two years of field experiences. The test method in the TR016 (2014) emphasizes that colorimetric measurements are to be made according to ISO 13655 using the measurement condition and backing associated with the reference color characterization data. In addition, substrate correction is to be applied to process control aims for printing process control and to dataset for printing conformity assessment.

The TR016 (2012) edition specifies a 3-level tolerance (A, B, C) and justifies the varying tolerance thresholds based on limited databases. The TR016 (2014) edition, based on the acceptability criteria, simplifies the tolerance thresholds while increases the tolerance range with a 4-level tolerance.

There are many normative requirements in the deviation assessment and production variation assessment. The assessments are likely resulted in different tolerance levels among these requirements. This technical report provides a scoring method to derive a single tolerance level.

TR016 enables conformity assessment and certification activities. But, it does not specify the scope of a print production workflow nor specific conformity testing conditions for pass/fail decision. Annex A suggests a scoring method, including weighting functions and passing scores, that certification schema owners may utilize as guidelines. Organizations involved in buying and accomplishing printing can specify the appropriate tolerance schema to evaluate the conformance of a printing operation to the reference color characterization data used as the intended printing aim.

Graphic technology — Printing Tolerance and Conformity Assessment

1 Scope

This technical report defines a process that can be used in evaluating the conformance of printed material to a set of reference color characterization data, which are used as the intended printing aim. It also provides a conformance assessment procedure which includes evaluation of deviation, within-sheet variation, and production variation as well as a four-level tolerance schema for the combination of the weighted results into a single score.

2. Normative references

ISO 12642-2, *Graphic technology -- Input data for characterization of 4-colour process printing -- Part 2: Expanded data set*

ISO 13655, *Graphic technology -- Spectral measurement and colorimetric computation for graphic arts images*

3. Terms and definitions

For the purposes of this technical report the following terms and definitions apply:

3.1
color characterization
relationship between input data values, typically CMYK, and color measured on the printed sheet, typically CIEAB data

3.2
conformity assessment
demonstration that specified requirements relating to a product or process are fulfilled

3.3
deviation
measure of a system's ability to achieve specified requirements; the color difference between the calibration samples and the reference characterization data set

3.4
printing process
method by which images are transferred to a substrate such as paper, including but not limited to offset, gravure, letterpress, flexography, electrophotography, ink-jet, etc.

3.5
production variation
measure of a system's ability to maintain consistency between the same color patches printed in the same locations of the sheet over the press run; variation is the difference between "production samples" and the aims

3.6
substrate-corrected colorimetric aims (SCCA)
color characterization data that are corrected for the colorimetric difference between production and the reference substrate

3.7
calibration samples
production prints singled out to represent the system capability; containing ISO 12642-2 target and is used to evaluate deviation and within-sheet variation

NOTE: Calibration sample was called OK sheet or First sheet, used to verify if the printing operation is calibrated based on the ISO 12642-2 CMYK target. For measurement purposes, sequential sheets are often selected and their measurements averaged to minimize the effect of artifact and measurement variation.

3.8
tolerance
permissive or allowed quantitative differences

3.9
within-sheet variation
color variation of the same color patches, based on the ISO 12642-2 CMYK target, printed in different locations on the calibration sample

4 Overview

The conformity assessment approach described in this Technical Report is applicable to any printing process for which the printing aims are defined through reference to color characterization data, and for which the characterization process can be appropriately modeled using a 4-channel CMYK target. While such data are usually defined by standards, technical reports, or other formal documentation, a characterization data set may also be privately defined by agreement between the parties involved in the printing contract.

A default assumption is that the color characterization data are based on the ISO 12642-2 CMYK target and measurements of printed samples are made in accordance with ISO 13655. It is further required that where color characterization data are to be used with a substrate whose color differs from that contained in the color characterization data set, the substrate correction methodology defined in Annex A of ISO 13655 is applied to produce substrate-corrected colorimetric aims (SCCA). These data are used for the printing aims, process control aims, and conformity assessment.

Three specific aspects of printing conformance are included in this technical report. These are:

1. The ability of a printing system to be successfully calibrated as demonstrated by the color difference between the calibration sample and the reference characterization data set, including the selected color patches that define the reference color gamut. Called herein “deviation.”
2. The within-sheet or spatial uniformity of the printing process as demonstrated by the color variation of the same color patches printed in different locations on a single press sheet. Called herein “within-sheet variation.”
3. The ability of a printing system to maintain accuracy and consistency between the selected color patches that define the reference color gamut printed in the same locations on the sheet and the aim over the press run. Called herein “production variation.”

In evaluating each of these aspects of conformity assessment it is important to identify the following requirements:

a. The test target elements, i.e., color patches with known device CMYK values, to be measured
b. The reference characterization data set and the substrate correction to be used
c. Any necessary processing of the measurement data, including CIEDE2000 (ΔE_{00}) computation
d. The allowed tolerance or tolerances
e. A scoring method to determine the tolerance level achieved.

Although measurements of printed samples are made in accordance with ISO 13655, inter-instrument agreement (e.g., one instrument has been used to calibrate the printing system and the other to perform conformity assessment) will be treated as a part of the deviation tolerance. Annex B provides a procedure to test and report inter-instrument agreement. If the inter-instrument difference is large enough to impact the conformity at any level, stakeholders should be informed to address such discrepancies with corrective action.

Because this conformity assessment approach is intended to apply to different printing processes and cover a wide range of printing applications a four-level tolerance table has been included. The four levels are identified as Level I tolerance for the most color critical applications, e.g., proofing; Level II tolerance for color critical applications, e.g., commercial printing; Level III tolerance for normal process color printing , and Level IV for pleasing color.

All colorimetric measurements are to be made according to ISO 13655 using the measurement condition and backing associated with the reference color characterization data being used.

The tolerances in this procedure are based on the use of CIEDE2000 with weighting factors of 1:1:1 as defined in ISO 13655.

The specifics of the elements to be measured, measurement references, data handling and specified tolerances for each of the three aspects of printing conformity are described in Clause 5.

Annex A provides a scoring method, including weighting functions and the passing score, that combine the individual aspects of printing conformity into a single score.

5 Tolerances and conformity levels

5.1 Tolerance for deviation

In conventional printing, deviation and within-sheet conformity assessment are based on measurement of calibration samples which represents the system capability. In digital printing, the first few color-managed production samples are used.

Two metrics are required for the evaluation of deviation. These are (1) the color differences of all of the patches of the printed ISO 12642-2 target from the aim values, including any substrate correction, and (2) the differences of selected key solids and tints of the printed ISO 12642-2 target, from the substrate-corrected aim values.

The cumulative probability of the differences of all patches (95th percentile) is used as the evaluation tool for the full data set. The individual patches to be evaluated are listed in Table 1. Table 1 also shows the CIEDE2000 (ΔE_{00}) tolerances assigned to each parameter for each conformance level.

Table 1 —Deviation tolerances and conformity levels

Target description		Deviation tolerance (CIEDE2000)			
		Level I	Level II	Level III	Level IV
All patches of ISO 12642-2 at the 95th percentile		2.0	3.0	4.5	6.0
Solid	100C	2.0	3.0	4.5	6.0
	100M				
	100Y				
	100K				
50% input tint	50C				
	50M				
	50Y				
	50K				
Near-neutral	50C40M40Y				

Note: There are two measurements of C, M, Y, and K solids from the ISO 12642-2 target. Deviation of these solids should be assessed by taking the average of two CIELAB measurements and, then, computing the ΔE_{00} between the average and the aim, including substrate correction.

If any one of the 10 deviation requirements exceeds Level IV tolerance, the job automatically fails the conformity.

To derive a single score from the 10 normative requirements in the deviation assessment, (1) no deviation exceeds Level IV tolerance, (2) compute the weighted average whereby the ΔE_{00} from the ISO 12642-2 dataset counts as one-half of the weight, and the average ΔE_{00} from the 9 color patches counts as the other one-half of the weight; (3) assign the single level according to Table 1, and (4) convert the single level to single score (Level I = 4, Level II = 3, Level III = 2, Level IV = 1).

5.2 Tolerance for within-sheet variation

There are many ways to estimate the within-sheet variation. The results depend on the number of redundant patches, their respective locations in the printed area, and their tonal values. In order to provide a common baseline for within-sheet variation assessment, the ISO 12642-2 target, containing 29 sets of CMYK values that appear twice within the target, is used.

The cumulative probability of the color differences between the measured values of these redundant patches are used to determine within-sheet variation. Table 2 lists the CMYK values and patch IDs of the redundant patches. Table 3 lists the allowed CIEDE2000 values for the 95th percentile for each conformance level.

Table 2 — Duplicate patches in IT8.7/4 target

#	C	M	Y	K	ID 1	ID 2		#	C	M	Y	K	ID 1	ID 2
1	0	0	0	0	1	1367		**16**	10	0	0	0	10	1302
2	0	0	10	0	82	1342		**17**	20	0	0	0	19	1300
3	0	0	20	0	163	1340		**18**	30	0	0	0	28	1298
4	0	0	30	0	244	1338		**19**	40	0	0	0	37	1297
5	0	0	40	0	325	1337		**20**	70	0	0	0	55	1294
6	0	0	70	0	487	1334		**21**	85	0	0	0	64	1291
7	0	0	85	0	568	1331		**22**	100	0	0	0	73	1287
8	0	0	100	0	649	1327		**23**	100	85	85	0	647	1368
9	0	10	0	0	2	1322		**24**	0	0	0	10	1362	1486
10	0	20	0	0	3	1320		**25**	0	0	0	20	730	1360
11	0	30	0	0	4	1318		**26**	0	0	0	40	946	1357
12	0	40	0	0	5	1317		**27**	0	0	0	60	1071	1355
13	0	70	0	0	7	1314		**28**	0	0	0	80	1196	1352
14	0	85	0	0	8	1311		**29**	0	0	0	100	1260	1347
15	0	100	0	0	9	1307								

Table 3 — Within-sheet tolerances and conformity levels

Target description	Within-sheet variation tolerance (CIEDE2000)			
95th percentile of redundant patches	Level I	Level II	Level III	Level IV
	1.0	1.5	3.0	4.5

For within-sheet variation assessment, identify the 29 redundant CIELAB values from Table 2, compute ΔE_{00} between the two redundant CIELAB values, sort ΔE_{00} in ascending order, and find the 95th percentile.
If the within-sheet variation exceeds Level IV tolerance, the job automatically fails the conformity.

5.3 Tolerance for production variation

As far as a single job is concerned, production variation between sample measurements and their averages is of importance. If jobs are printed in multiple locations, at different times, or by different printing processes, both production variation between sample measurements and their averages, and production variation between sample averages and the substrate-corrected process control aims, are important. This technical standard specifies production variation in terms of color difference between production samples and the substrate-corrected process control aims.

Production variation is the assessment of color consistency of the same color patches printed in the same locations of the sheet over the press run. Because this test is generally performed on live work, the ISO 12642-2 target is too large in size to be useful. Therefore color control bars or run bar targets need to be used.

The printing run should be sampled randomly over the length of the run and a minimum of 20 samples collected. The metric for production variation is the 70th percentile of the distribution of the color difference between production samples and the substrate-corrected process control aims. Table 4 provides the CIEDE2000 tolerances assigned to the 9 control patches for each conformance level.

Table 4 — Production variation tolerances and conformity levels

<table>
<tr><th colspan="2" rowspan="2">Target description</th><th colspan="4">Production variation tolerance at the 70th percentile (CIEDE2000)</th></tr>
<tr><th>Level I</th><th>Level II</th><th>Level III</th><th>Level IV</th></tr>
<tr><td rowspan="4">Solid</td><td>100C</td><td rowspan="9">2.0</td><td rowspan="9">3.0</td><td rowspan="9">4.5</td><td rowspan="9">6.0</td></tr>
<tr><td>100M</td></tr>
<tr><td>100Y</td></tr>
<tr><td>100K</td></tr>
<tr><td rowspan="4">50% input tint</td><td>50C</td></tr>
<tr><td>50M</td></tr>
<tr><td>50Y</td></tr>
<tr><td>50K</td></tr>
<tr><td>Near-neutral</td><td>50C40M40Y</td></tr>
</table>

If any one of the 9 variation requirements exceeds Level IV tolerance, the job automatically fails the conformity.

To derive a single score from the 9 normative requirements in the production variation assessment, (1) no variation exceeds Level IV tolerance, (2) compute the average ΔE_{00} from the 9 color patches; (3) assign the single level according to Table 4, and (4) convert the single level to single score (Level I = 4, Level II = 3, Level III = 2, and Level IV = 1).

Annex A

(Informative)

Sample scoring methods

Introduction

This Technical Report specifies printing tolerances to complement printing standards that use reference characterization datasets are printing aims. This Technical Report does not specify how printing tolerances are used to determine the pass/fail requirements in conformity assessment.

Certification is an impartial third-party attestation that specified requirements has been demonstrated and fulfilled. Clause 5 specifies tolerances and tolerance levels for assessing deviation, within-sheet variation, and production variation.

For conformity assessment purposes, there is a need to combine all aspects of the assessment results into a single value ranking system for pass/fail decision. One such approach is described below that certification schema owners may utilize for conformity assessment decision. It is the responsibility of the buyer and producer of a printed product to agree on how conformity assessment should be scored.

To assess a printing system, this Technical Report specifies four levels of tolerance for deviation, within-sheet, and production variation (Table A.1). The assessment fails if any one of the 20 normative requirements exceeds Level 4 tolerance.

Table A.1 Four levels of tolerance for deviation, within-sheet, and production variation

	Deviation	Within-sheet	Production Variation
Normative requirements	10	1	9
Test targets	ISO 12642-2; 9 patches	ISO 12642-2 (29)	4 solids, 4 tints, 1 gray
Level I	Equal or less than 2.0	Equal or less than 1.0	Equal or less than 2.0
Level II	Equal or less than 3.0	Equal or less than 1.5	Equal or less than 3.0
Level III	Equal or less than 4.5	Equal or less than 3.0	Equal or less than 4.5
Level IV	Equal or less than 6.0	Equal or less than 4.5	Equal or less than 6.0

When there is no ‘F’ score, the next step is to assign a single Level for each category, i.e., deviation, within-sheet, and production variation. To derive a single Level for deviation assessment, the ΔE_{00} from the ISO 12642-2 dataset counts one-half of the score and the average ΔE_{00} from the 9 color patches counts as the other one-half. For production variation, the single Level is based on the ΔE_{00} from the average of the 9 color patches. Within-sheet variation is a single Level to begin with. Table A.1 is used to convert the ΔE_{00} value into letter scores (I, II, III, IV).

Pass/Fail criteria and sample scoring methods

In certification activities, it is the responsibility of the schema owner to specify and communicate with printing companies on how conformity assessment, including weighting functions and the passing score, are conducted.

To combine the three tolerance levels in deviation, within-sheet, and production variation into a single score for pass/fail decision, the first step is to convert level scores into numerical scores as shown below:

Level I	4
Level II	3
Level III	2
Level IV	1

Because deviation, within-sheet variation, and production variation are not necessarily equally important in conformity assessment, the next step is to apply weighting functions to each category. As an example, the weighting functions for the three categories in conventional printing are shown below:

Deviation	3
Within-sheet variation	1
Production variation	6

Different weighting functions are associated with applications and printing processes. Similar to conventional printing, the above example places more emphasis on production variation over deviation and within-sheet variation. For short-run digital printing, different weighting functions and passing score may apply.

The single score is the sum of the products of individual scores times the weighting functions for the aspects. As shown in Table A.2, if a printing system achieves Level II in deviation, and Level I in within-sheet and production variation, the combined score would be 37 (3x3 + 4x1 + 4x6).

Table A.2 An example of conformity assessment score

Tolerance	Average	Level	Score	Weighting Factor	Combined Score	Passing Score
Deviation	2.1	II	3	3	37	30
Within-sheet	0.8	I	4	1		
Variation	1.3	I	4	6		

The passing score is the minimum score required to pass the conformity assessment. If Level II is the passing score, the numerical score for passing is 30 (3x3 + 3x1 + 3x6).

Different weighting factors, due to different printing processes and customer requirements, are allowed if prior agreement is obtained between all parties involved before copy preparation work is started.

Where this conformity assessment technique is used for single sheets, such as proofs or validation prints, only the deviation and within-sheet variation aspects are used to create the single score.

Annex B
(Informative)

Assessing instrument repeatability and inter-instrument agreement

Introduction

Although measurements of printed samples are made in accordance with ISO 13655, inter-instrument agreement will be treated as a part of the deviation tolerance. If two instruments are used in the same conformity assessment, e.g., one instrument is used to calibrate the press, and another instrument is used to measure production samples, we need to know the magnitude of potential color differences between the two spectrophotometers in order to avoid nonconformity. This annex provides a test method and data reporting for instrument repeatability and inter-instrument agreement.

Resources needed

1) Spectrophotometers being used
2) A printed control strip using the same inks and substrate as the intended measured sheet.

Test method

1) Turn the instrument on and allow it to warm up for one-half hour. Samples of control strips should be stored in ambient temperature.
2) Calibrate the spectrophotometer per manufacturer's procedure.
3) Measure 10 color patches from the control strip (4 CMYK solids, 4 CMYK 50% tints, C50M40Y40, and paper).
4) Repeat the measurement process in Step 3 four times.
5) Calculate the average color difference from the mean (ACDM), on a patch-by-patch basis, using ΔE_{00} metric as shown below. This step results in 10 ACDM values.

$$\boldsymbol{ACDM = \frac{1}{4}\sum_{i=1}^{4} \Delta E_{00}(\{L^*a^*b^*\}_{ave}\,,\{L^*a^*b^*\}_{i})}$$

6) To depict the repeatability of an instrument, generate a CRF (cumulative relative frequency) from the 10 ACDM values.
7) Repeat Step 1-6 for the next spectrophotometer's repeatability.
8) To depict the inter-instrument agreement, calculate ΔE_{00} between the average CIELAB values of two instruments for each color patch. This results in 10 ΔE_{00} values.

$$\Delta E_{inter-instrument} = \Delta E_{00}(\{L^*a^*b^*\}_{ave\#1}\,,\{L^*a^*b^*\}_{ave\#2})$$

9) Generate a CRF (cumulative relative frequency) of ΔE_{00} from step 8.

Reporting

Table B.1 shows an example of repeatability and the inter-instrument agreement between Instrument #1 and Instrument #2. In this case, the variation in the instrument repeatability is small in comparison with the variation due to inter-instrument agreement.

Table B.1. An example of instrument repeatability and the inter-instrument agreement

Color patches	Instrument #1				Instrument #2				ΔE00 (#1_#2)	ΔE00_sort	Count	CRF
	L*ave	a*ave	b*ave	ACDM	L*ave	a*ave	b*ave	ACDM		0.00	0	0.00
Paper	93.21	-0.12	-3.25	0.03	93.80	0.13	-3.98	0.07	0.81	0.22	1	0.10
C100	57.56	-40.40	-48.37	0.03	57.93	-39.70	-49.34	0.03	0.57	0.46	2	0.20
M100	49.20	74.71	-9.29	0.02	49.54	75.13	-10.65	0.14	0.61	0.55	3	0.30
Y100	87.76	-6.24	90.73	0.03	88.48	-6.11	90.90	0.02	0.46	0.57	4	0.40
K100	16.70	0.45	-0.68	0.08	16.78	0.52	-0.88	0.11	0.22	0.61	5	0.50
C50	74.62	-17.26	-26.78	0.03	75.20	-16.82	-28.04	0.03	0.78	0.64	6	0.60
M50	70.57	33.26	-8.88	0.03	71.25	33.86	-9.66	0.03	0.69	0.69	7	0.70
Y50	89.83	-3.44	37.89	0.06	90.55	-3.31	37.06	0.04	0.55	0.72	8	0.80
K50	60.95	-0.54	-4.86	0.11	61.34	-0.27	-5.47	0.13	0.72	0.78	9	0.90
C50MY40	59.43	-0.18	-3.84	0.08	59.80	0.03	-4.40	0.11	0.64	0.81	10	1.00

Figure B.1 illustrates repeatability and the inter-instrument agreement between Instrument #1and Instrument #2 graphically. While instrument repeatability impacts the within-sheet variation, the effect is generally small. On the other hand, inter-instrument agreement may impact deviation and production deviation greatly.

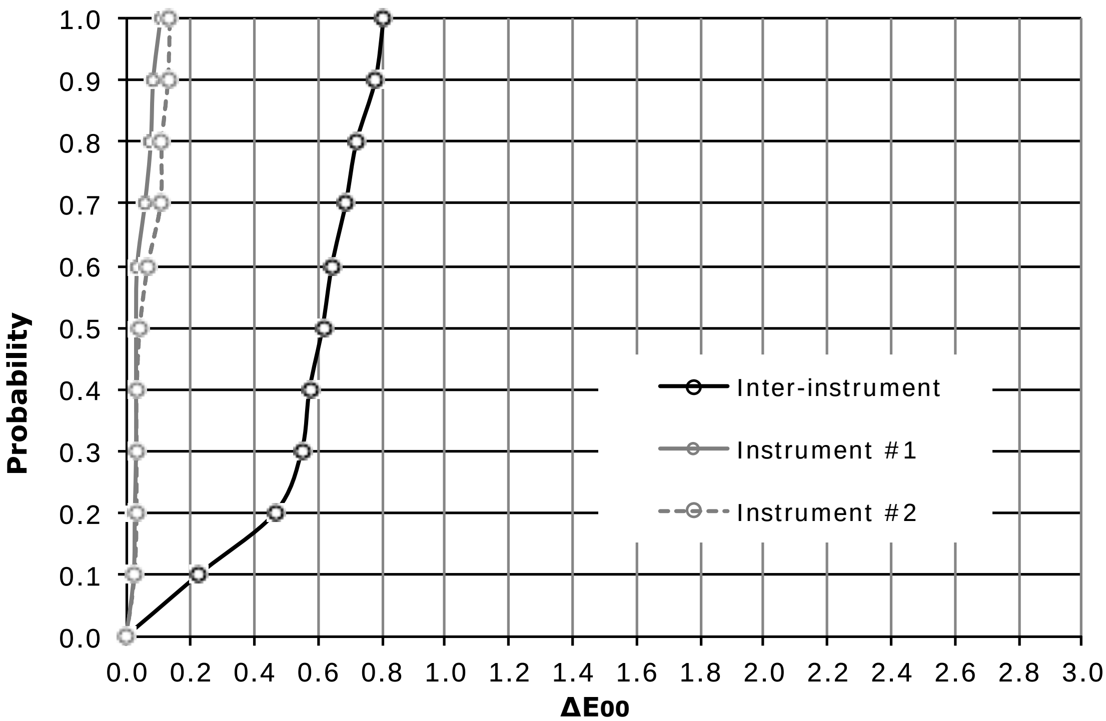

Figure B.1 Repeatability and the inter-instrument agreement between Instrument #1and Instrument #2

As mentioned before, if the inter-instrument difference is large enough to impact the conformity at any level, stakeholders should be informed to address such discrepancies with corrective action.

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