Designation: F1469 – 11

Standard Guide for Conducting a Repeatability and Reproducibility Study on Test Equipment for Nondestructive Testing[1]

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1. Scope

1.1 This guide describes the steps required to conduct a complete repeatability and reproducibility (RR) study on nondestructive test equipment. This guide is a manual (use of calculator) method. Other methods may utilize the application of computer driven software.

1.2 This guide can be used to evaluate all test equipment that provides variable measuring data.

2. Terminology

2.1 *Definitions:*

2.1.1 *repeatability*—variation in the values of measurements obtained when one operator uses the same gage for measuring identical characteristics of the same parts.

2.1.2 *reproducibility*—variation in the average of measurements made by different operators using the same parts.

3. Significance and Use

3.1 This guide is recommended for the purpose of evaluating test equipment that may be utilized in statistical process control, testing laboratories, and for in-process control of manufacturing operations.

3.2 Ask the question: What effect does the operator have on the measurement process? If possible, the operators who normally use the test equipment should be included in the study. If operator calibration of the equipment is likely to be a significant cause of variation, then the operator should recalibrate the equipment prior to each group of readings.

3.3 The test equipment should provide direct readings in which the smallest digit is no larger than one tenth of the tolerance of the characteristic being evaluated.

3.4 It is recommended that a test equipment repeatability and reproducibility study be a mandatory part of all test equipment purchases and that acceptance criteria be <10 % for certification and statistical process control (SPC) use.

4. Equipment Certification

4.1 Test equipment shall be certified through use of certified standards as accurate to the manufacturer's/user's calibration systems with certified standards before a repeatability and reproducibility study is performed.

4.2 Certifications must be traceable to the National Institute of Standards and Technology (NIST), or recognized equivalent, and shall be current to the test equipment's calibration schedule.

5. Procedure

5.1 Although the number of operators, trials, and parts may be varied, the following guidelines represent the optimum conditions for conducting a study using the forms in Figs. 1 and 2.

5.2 Select three operators and identify them as Operators *A*, *B*, and *C*.

5.3 Calibrate the test equipment with a certified standard.

5.4 Select ten parts for measurements and number them from 1 to 10, such that the numbers, if possible, are not visible to the operator. Place a mark on each part to indicate the precise position at which the part shall be measured. This eliminates the variation within the part from the study results so that only the gage's performance and operator variation influences the study outcome.

5.5 Allow Operator *A* to inspect all ten parts in a sequential order by measuring each part at the designated location. Enter the results in the 1st trial column for Operator *A* of the Repeatability and Reproducibility Data Sheet (Fig. 1). Part identification and associated data entry shall be performed by an observer.

5.6 Repeat 5.5 with Operators *B* and *C* and enter the results in the corresponding 1st trial column for each operator.

5.7 Repeat 5.5 and 5.6 using a random selection of the ten parts. Enter data in the 2nd trial column for each operator. If three trials are needed, repeat the cycle and enter data in the corresponding 3rd trial column for each operator.

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Sample #	Operator A 1st Trial	Operator A 2nd Trial	Operator A 3rd Trial	Operator A Range	Operator B 1st Trial	Operator B 2nd Trial	Operator B 3rd Trial	Operator B Range	Operator C 1st Trial	Operator C 2nd Trial	Operator C 3rd Trial	Operator C Range
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
Totals												

Operator A	Operator B	Operator C
$= \bar{R}, A$	$= \bar{R}, B$	$= \bar{R}, C$
$\Sigma A =$	$\Sigma B =$	$\Sigma C =$
$\bar{X}, A =$	$\bar{X}, B =$	$\bar{X}, C =$

$\bar{R}$, A	
$\bar{R}$, B	
$\bar{R}$, C	
$\Sigma \bar{R}$ A, B, C	
$\bar{\bar{R}} =$	

$\bar{\bar{R}} =$		×	D-4	=	UCL-R*
		×			

# Trials		D - 4
2		3.27
3		2.58

Reference : The D-4 Constant is obtained from the table of Factors for X-Bar, R charts, page 12, Western Electric Statistical Quality Control Handbook.

$\bar{X}$, A	
$\bar{X}$, B	
$\bar{X}$, C	
Max $\bar{X}$	
Min $\bar{X}$	
$\bar{X}$ dif	

Notes :

FIG. 1 Gage Repeatability and Reproducibility Data Sheet

5.8 Steps 5.5, 5.6, and 5.7 may be changed to the following when large part size or simultaneous availability of parts is not possible:

5.8.1 Allow Operators *A*, *B*, and *C* to measure the first part and record their readings in the corresponding 1st trial columns for each operator.

5.8.2 Allow Operators *A*, *B*, and *C* to remeasure the first part and record their readings in the corresponding 2nd trial columns for each operator. If three trials are to be used, repeat the cycle and enter the results in the corresponding 3rd trial columns for each operator.

5.9 If the operators are not available at the same time, the following method may be used. Allow Operator *A* to measure all ten parts at once and enter the results in the 1st trial column for Operator *A*. Repeat the measurements in a different order and enter the results in the corresponding 2nd and 3rd trial columns for Operator *A*. Do the same with Operators *B* and *C*, as soon as they are available entering their data in their corresponding 1st, 2nd, and 3rd trial columns.

5.10 Make all necessary calculations on the Repeatability and Reproducibility Data Sheet (Fig. 1) and Repeatability and Reproducibility Report (Fig. 3). For clarity, Fig. 2 and Fig. 4 are provided as examples.

6. Analysis of Results

6.1 Evaluate the data following the steps on the data sheets to determine if the test equipment is acceptable for its intended application. The criteria for acceptability is dependent upon the percentage of part tolerance that is consumed by the test equipment error. Acceptability is based upon the following criteria:

6.1.1 Test equipment with a repeatability and reproducibility percentage of 10 % or less is fully capable and may be used for certification testing.

6.1.2 Test equipment with a repeatability and reproducibility percentage between 10 and 30 % shall be reviewed by a qualified technician. If possible, the testing system should be improved or replaced; however, the system may continue to be used as is until an improvement is found.

6.1.3 Test equipment with a repeatability and reproducibility percentage greater than 30 % is unacceptable. Take immediate corrective action to replace or improve the testing system.

7. Keywords

7.1 repeatability; reproducibility; statistical process control; test equipment

Part Name :	1/2 - 13 x 4 A490	**Gage Name :**	Rockwell Tester	**Date :**	03/11/92
Part Number :	A490 - 15	**Gage No. :**	XYZ	**Performed By:**	
Characteristic:	Hardness	**Specification :**	HRC 33 - 38	**File Name :**	

From Date Sheet : $\bar{\bar{R}}$ = 0.113333 $\bar{X}$ dif = 0.095 **Tolerance :** 5

Measurement Unit Analysis

Repeatability - Equipment Variation (E.V.)

E.V. = $(\bar{\bar{R}}) \times (K-1)$

= (0.113333) × (4.56)

= 0.5168

Trials#	**2**	**3**
K – 1	4.56	3.05

Reproductibility - Appraiser Variation (A.V.)

A.V. = $\sqrt{[[(\bar{X}\text{ dif}) \times (K-2)]^2 - [(E.V.)^2 / (n \times r)]]}$

= $\sqrt{[[(0.095) \times (2.7)]^2 - [(0.5168)^2 / (10 \times 2)]]}$

= 0.228994

Operator#	**2**	**3**
K – 2 =	3.65	2.7

n = # parts r = # trials

Repeatability and Reproducibility (R & R)

R & R = $\sqrt{((E.V.)^2 + (A.V.)^2)}$

= $\sqrt{((0.5168)^2 + (0.228994)^2)}$

= 0.565261

* Guidelines for acceptance are referenced in "Measurement System Analysis" by A.I.A.G., 1990, page 46. All calculations are based upon predicting 5.15 sigma (99.0% of the area under the normal distribution curve). A.V. – if a negative value is calculated under the square root sign, the appraiser variation (A.V.) defaults to Zero (0).

% Tolerance Analysis

% E.V. = 100[(E.V.) / (Tol)]

= **100[(0.5168) / (5)]**

= **10.34**

% A.V. = 100[(A.V.) / (Tol)]

= **100 [(0.2289938) / (5)]**

= **4.58**

% R&R

= $\sqrt{[(\%\ E.V.^2 + (\%\ A.V.^2)]}$

= $\sqrt{[(106.8329) + (20.97526)]}$

= **11.3 %**

*** Guidelines for acceptance are:**

Under 10% error - gage system O.K.

10% – 30% error - may be acceptable based on importance of application, cost of gage, cost of repairs, etc.

Over 30% error - Gage system needs improvement. Make every effort to identify the problems and have them corrected.

FIG. 2 Gage Repeatability and Reproducibility Data Sheet

	Operator A				Operator B				Operator C			
Sample #	1st Trial	2nd Trial	3rd Trial	Range	1st Trial	2nd Trial	3rd Trial	Range	1st Trial	2st Trial	3rd Trial	Range
1	35.6	35.7		0.1	36.3	36.1		0.2	35.7	35.8		0.1
2	35.5	35.5		0	35.8	35.7		0.1	35.9	36.0		0.1
3	36.1	35.9		0.2	35.9	36.1		0.2	36.1	35.9		0.2
4	36.3	36.2		0.1	36.0	35.8		0.2	35.8	35.5		0.3
5	36.2	36.2		0	36.3	36.2		0.1	36.3	36.3		0
6	35.9	36.0		0.1	35.6	35.5		0.1	36.2	36.0		0.2
7	36.2	36.1		0.1	35.7	35.7		0	35.5	35.7		0.2
8	35.8	35.7		0.1	36.4	36.3		0.1	35.8	36.0		0.2
9	35.8	35.8		0	36.2	36.3		0.1	36.0	36.1		0.1
10	35.9	36.1		0.2	36.0	36.0		0	35.7	35.7		0
Totals	359.3	359.2	0	0.9	360.2	359.7	0	1.1	359	359	0	1.4

	Operator A	Operator B	Operator C
1st Trial total	359.3	360.2	359
3rd Trial total	0	0	0
Range total / 10	0.09 = $\bar{R}$, A	0.11 = $\bar{R}$, B	0.14 = $\bar{R}$, C
Σ	Σ A = 718.5	Σ B = 719.9	Σ C = 718
$\bar{X}$	$\bar{X}$, A = 35.925	$\bar{X}$, B = 35.995	$\bar{X}$, C = 35.9

$\bar{R}$, A	0.09
$\bar{R}$, B	0.11
$\bar{R}$, C	0.14
Σ $\bar{R}$, A, B, C	0.34
$\bar{\bar{R}}$ =	0.113333

$\bar{\bar{R}}$	×	D-4	=	UCL-R*
0.113333	×	3.27	=	0.3706

# Trials	D-4
2	3.27
3	2.58

$\bar{X}$, A	35.925
$\bar{X}$, B	35.995
$\bar{X}$, C	35.9
Max $\bar{X}$	35.995
Min $\bar{X}$	35.9
$\bar{X}$ dif	0.095

Reference: The D-4 Constant is obtained from the table of Factors for X-Bar, R charts, page 12, Western Electric Statistical Quality Control Handbook.

Notes:

FIG. 3 Gage Repeatability and Reproducibility Data Sheet

Part Name :	______	Gage Name :	______	Date :	______		
Part Number :	______	Gage No. :	______	Performed By:	______		
Characteristic:	______	Specification :	______	File Name :	______		

From Date Sheet: $\bar{\bar{R}}$ = [ ] $\bar{X}$ dif = [ ] Tolerance : [ ]

Measurement Unit Analysis

Repeatability - Equipmnt Variation (E.V.)

E.V. = ($\bar{\bar{R}}$) × (K – 1)
= ( ) × ( )
= [ ]

Trials#	2	3
K - 1	4.56	3.05

Reproductibility - Appraiser Variation (A.V.)

A.V. = $\sqrt{[[(\bar{X}dif) \times (K-2)]^2 - [(E.V.)^2 / (n \times r)]]}$
= $\sqrt{[[() \times ()]^2 - [()^2 / (10 \times ()]]}$
= [ ]

Operator#	2	3
K • 2 =	3.65	2.7

n = # parts r = # trials

Repeatability and Reproductibility (R & R)

R & R. = $\sqrt{((E.V.)^2 + (A.V.)^2)}$
= $\sqrt{(()^2 + ()^2)}$
= [ ]

* Guidelines for acceptance are referenced in "Measurement System Analysis" by A.I.A.G., 1990, page 46. All calculations are based upon predicting 5.15 sigma (99.0% of the area under the normal distribution curve). A.V. – if a negative value is calculated under the square root sign, the appraiser variation (A.V.) defaults to Zero (0).

% Tolerance Analysis

% E.V. = 100[(E.V.) / (Tol)]
= 100[( ) / ( )]
= [ ]

% A.V.= 100[(A.V.) / (Tol)]
= 100[( ) / ( )]
= [ ]

% R&R
= $\sqrt{[(\% E.V.^2) + (\%A.V.^2)]}$
= $\sqrt{[() + ()]}$
= [ ]

*** Guidelines for acceptance are:**
Under 10% error - gage system O.K.
10% – 30% error - may be acceptable based on importance of application, cost of gage, cost of repairs, etc.
Over 30% error - Gage system needs improvement. Make every effort to identify the problems and have them corrected.

FIG. 4 Gage Repeatability and Reproducibility Data Sheet