Where are we?

Define	Measure	Analyse	Improve	Control
✓ Introduction	❑ Measurement & Variation	☐ Root Cause	☐ PDCA	☐ Auditing
✓ Y=(f)x	❑ Data Collection	☐ Regression	☐ Risk Management	☐ Lessons Learnt
✓ SIPOC	❑ Collection Plan	☐ Hypothesis Testing	☐ FMEA	☐ SOPs
✓ Cause & Effect	❑ MSA	☐ t-tests	☐ Value Stream Mapping	
✓ 5 Whys	☐ SPC	☐ ANOVA	☐ Solution Selection Matrix	
✓ Is it? Is it not?	☐ Process Capability	☐ DoE	☐ Five S	
✓ Project Charter	☐ Charting	☐ Cost Benefit Analysis	☐ Benchmarking	
✓ VoC & QFD	☐ Industry 4.0 technologies		☐ Control Plans	
✓ Critical to Quality (CTQ)			☐ Pilot Studies	
✓ Team Working				





Level 5 – Continuous Improvement with Industry 4.0

Measure 1 - Measurement and Variation

Measure Phase

- Identify measurement and variation
- Determine data type
- Develop data collection plan
- Measurement Systems Analysis
- Perform data collection
- Perform capability analysis

- **What are we trying to achieve?**
- **Why measure? What to measure? How to measure?**

- Measurement allows us to;
  - Establish baseline process performance
  - Isolate sources of variation
  - Identify areas where improvements can be made.

Data Collection Plan

Help us ensure successful analysis of the problem by ensuring the data we collect is useful.



Measure - Data Collection Plan

1. What data will be collected?
2. Why is it needed?
3. Who is responsible?
4. How will it be collected?
5. When will it be collected?
6. Where will it be collected?



What data will be collected?

Will you be measuring inputs (x) to a process or outputs (y)

	Y	X1	X2	X3
Existing data				
New Data				

Data Collection Sheets – why?

- Standardize the data collection process
- Organises the data into an acceptable format (by product, operator, time, dept etc)
- Allows team to collect any additional comments during the process

Data Collection Sheets – why?

- Consider all the characteristics you want to collect (different inputs and outputs)
- Talk to people who are collecting the data (if not you) to explain the reason for this
- Test the form before you implement

Data Collection Sheets – example continuous data

date	operator	product	machine	Size off MC	comments
10/3/21	DJ	ABC123	Press 5	253.25	No issues

Data Collection Sheets – example attribute data

date	operator	product	machine	Scratch Y/N	Coating OK Y/N	comments
10/3/21	DJ	ABC123	Press 5	Y	N	No issues

Measure - Data Collection Plan

A well-prepared collection plan will help to ensure successful analysis of the problem by ensuring useful data has been captured

“In God we trust, everybody else bring data”

Attribute

Pass / Fail, Yes / No or Stop / Go

Hot/Cold (Attribute - Binary data)

Strongly agree/Agree/Disagree

(Attribute - Ordinal data)

Variable

Can be measured? Examples?

Ask yourself some questions…

- What knowledge is desired about the process?
- What are the potential sources of variation in the process?
- Are there cycles in the process?
- How much time is needed to collect data to capture a true picture?
- Who will be collecting the data?
- How will the measurement system be tested?

Ask yourself some questions…

- **Existing versus New?**
- **Have data or Need more data?**

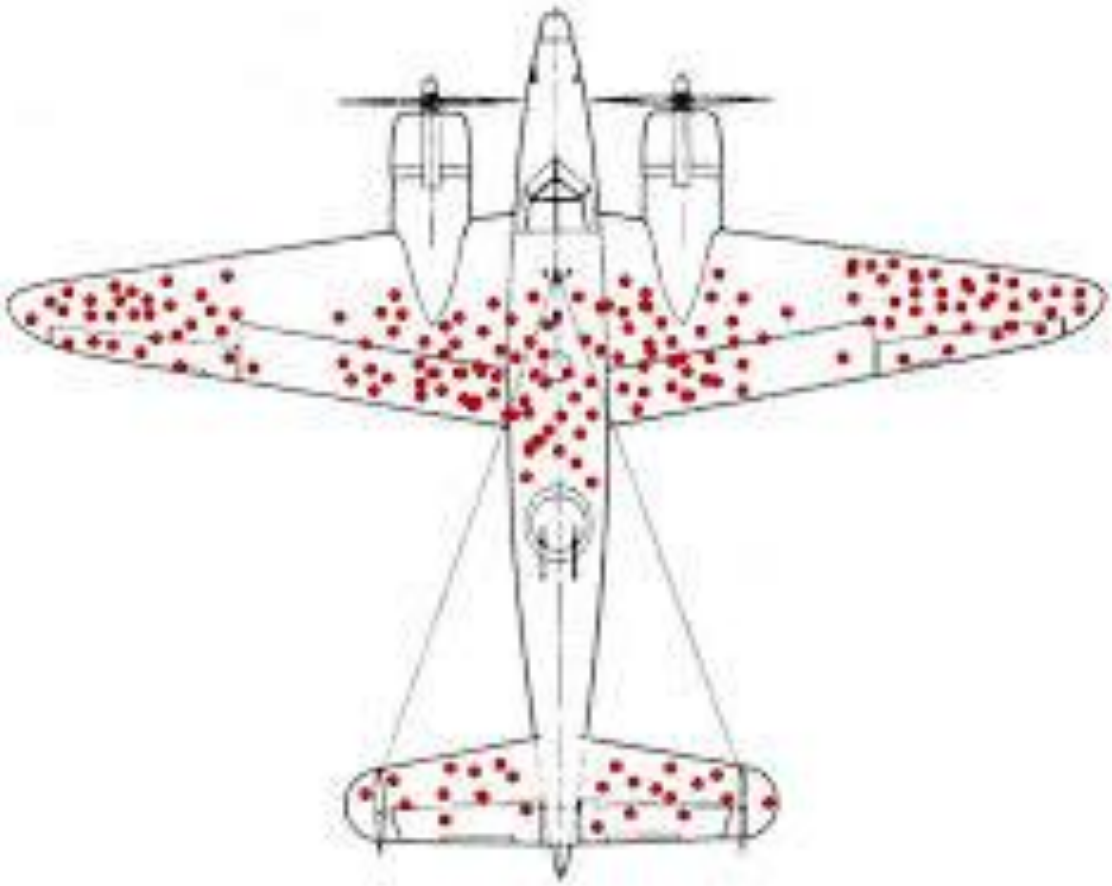
- Perhaps you have data already available? If not, what is the collection plan?

- Are your own organisation's definitions for measurement sufficiently detailed?

- Where could data collection errors occur? How will data collection errors be handled?

- How will the data be displayed?

The Pattern seems clear



Many of the airplanes were riddled with gunfire all over the wings and fuselage.

But they were not being hit in the cockpit or tail.

Syed, Matthew. 2015. Black Box Thinking. New York: Penguin Random House. pp 33-37



How do we know our Measurement System is giving us a true view of what is occurring?

Measurement Systems Analysis (MSA)

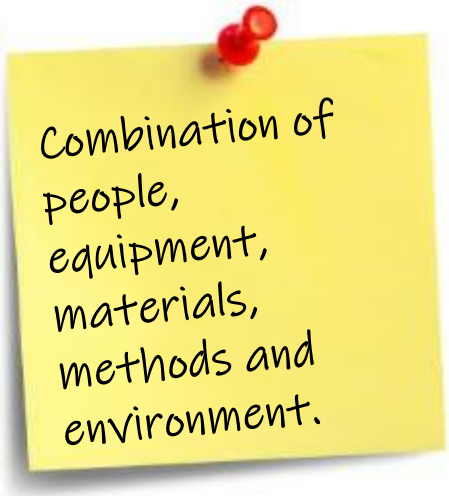
- How do we know our Measurement System is giving us a true view of what is occurring?

- We know we have process variation, what about appraiser (measurement device) variation?

Measurement Systems Analysis (MSA) is used to ensure that the information collected is a true representation of what is occurring in the process.

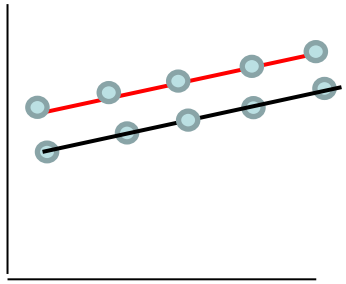
Measurement Systems Analysis (MSA)

- Measurement System Analysis (usually referred to as MSA) is a structured procedure which we use to assess the ability of a measurement system to provide good quality data.



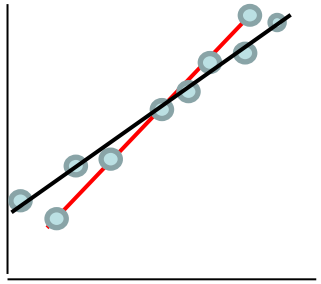
- Is the measurement system capable for this study?
- How big is the measurement error?
- How much uncertainty should be attached to a measurement when interpreting it?
- Are the measurements being made with measurement units that are small enough to properly reflect the variation present?

Measurement Systems Analysis (MSA)



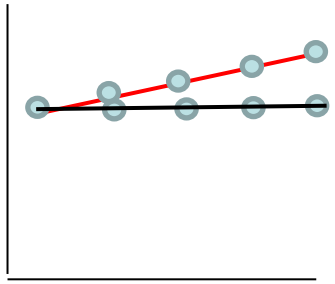
Bias Error – difference between actual and measured consistent e.g. weighing scales out by 10Kg (the offset is constant)

Measurement Systems Analysis (MSA)



Linearity Error – difference between actual and measured changes (the offset changes)

Measurement Systems Analysis (MSA)



Stability Error – differ to the other two as they manifest over time – same part measured but value changes (might be temperature, gauge wear?)

MSA Examples…

Time taken from receipt of an invoice until payment
Measurement System: a piece of computer software which measures the time from start to finish, or possibly someone measuring the time using a stopwatch or a clock

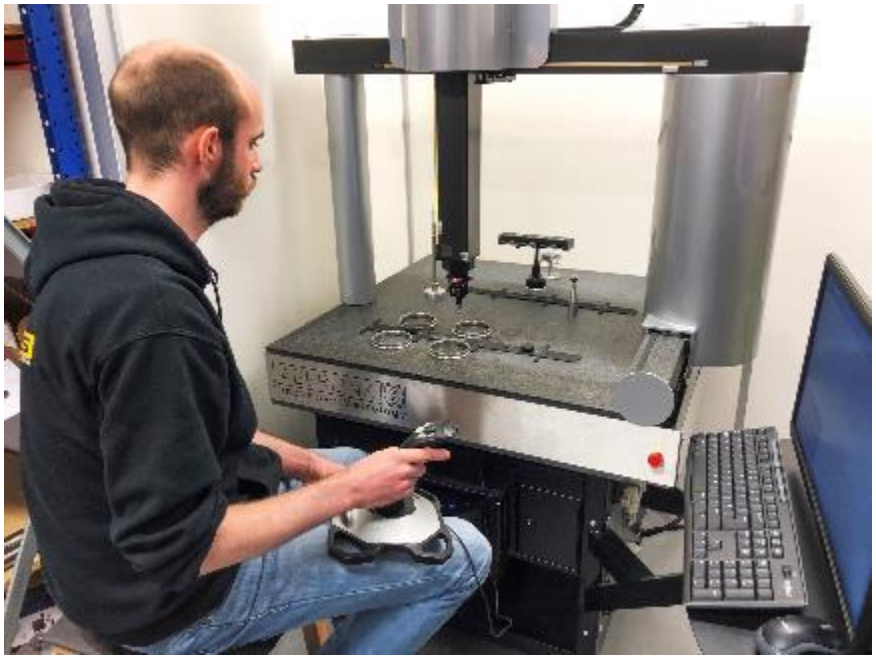
Dimensions of a machined part
Measurement System: a vernier calliper, a coordinate measurement machine (CMM) or a Go/No Go gauge in combination with the person operating the piece of equipment, the procedures they are following and environmental conditions such as the temperature or vibration level in the working environment.

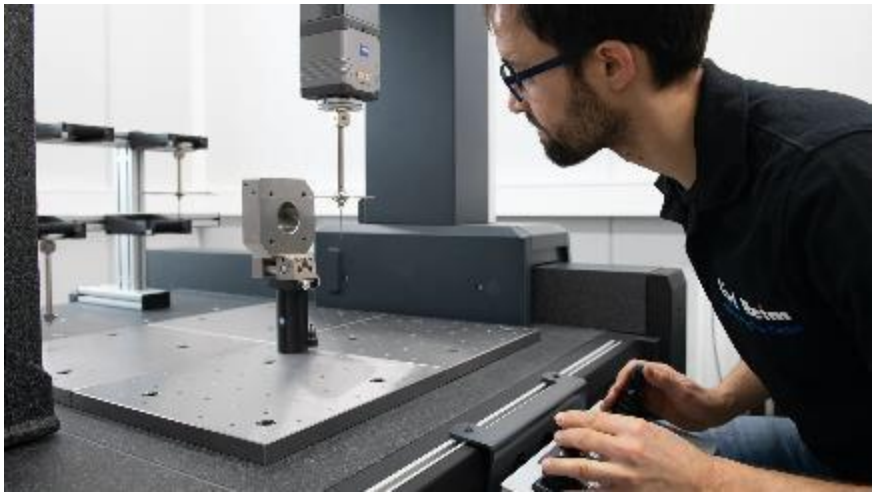
Number of errors on an engineering drawing
Measurement System: a person checking each drawing and counting the number of errors in combination with the assessment standards, procedures being used and environment conditions such as changes in the natural light conditions.

MSA Potential Pitfall

Where the measurement system is a device such as a vernier calliper or CMM and you have multiple devices it is important to recognise that each device is a separate system, and each must separately be analysed.

For example just because one CMM machine is a good or bad system does not mean that other ‘identical’ machines will have the same characteristics.





How does it work?

If the same person or piece of equipment measures the same item over and over again, do we consistently get the same data?

For example if the same person measures the weight of a parcel 3 times would they record the same weight each time?



If a person or a piece of equipment is not able to consistently measure the same item, then clearly this would result in unreliable data.

Repeatability assesses whether each person can measure the same item multiple times with the same measurement device and get the same value when measuring continuous data.

How does it work?

If <u>different</u> people or piece of equipment measures the same item over and over again, do we consistently get the same data?

For example if three different people weighed the same parcel multiple times would they each record the same weight?



Problems such as 'no fault found' parts are often a result of a lack of agreement between two different measurement systems. Any disagreement indicates a problem with the reliability of data collected from such a system

Reproducibility assesses whether different people can measure the same item multiple times with the same measurement device and get the same average value



Repeatability is asking the question 'do the appraisers agree with themselves when asked to do the same assessment a number of times?'

Reproducibility is asking the question 'do the appraisers agree with each other when asked to do the same assessments?'

Measure Phase – Dynamic and Static tests

Exercise to see methodology for undertaking review of a measuring system

Measure Phase – Dynamic and Static tests

Part Description :
Engineering Drawing No :
Detail Drawing No :
Op Description :
Characteristics Matrix :
Cmm Program :
TI No :
Part Serial No :
Gauge Study Owner :
Date :

Measurement System Analysis Approval

Approvals:	Name	Date
Supplier / Company		
Rolls-Royce ME		
Rolls-Royce Design (If applicable)		

Complete the white cells

Acceptance Key:	
	Results are unacceptable and should be improved
	Results are outside of normal acceptance limits but maybe agreeable with Design
	Results are acceptable

Feature Type (1)	Drg Sheet (2)	Feature Num (3)	Engineering Drg Ref (4)	Engineering Toln			Dimension Description (5)	Feature Code	Feature ID	Description Text	DYNAMIC (5 runs)					STATIC (5 Runs)					Dynamic Run Averages & Ranges		Static Run Averages & Ranges		Total Averages & Ranges		STATIC INDEPENDENT				Acceptance 10%		Comment
				Dim (6)	Tol (-) (7)	Tol (+) (8)					R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	Average of 5 Dynamic Runs	Range of 5 Dynamic Runs	Average of 5 Static Runs	Range of 5 Static Runs	Average of 10 Runs	Range of 10 Runs	Independent run (if needed)	BIAS	Total Toln.	Repeatability (DYNAMIC)	Repeatability (STATIC)	Overall Repeatability	Bias / Correlation	
				0	0	0.03	Flatness		DATUM A	Flatness 0.03	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.001	0.030	0.000	0.030	0.001	0.032	0.002	0.030	3.3%	0.0%	3.3%	7.0%	
				48.545	-0.025	0.025	Diameter		Datum B	Diameter 48.545 +-0.025	48.549	48.55	48.55	48.55	48.55	48.549	48.549	48.55	48.549	48.549	48.550	0.001	48.549	0.001	48.550	0.001	48.54	0.009	0.050	2.0%	2.0%	2.0%	19.0%	
																					#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	
																					#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	
																					#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	
																					#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	
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																					#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	
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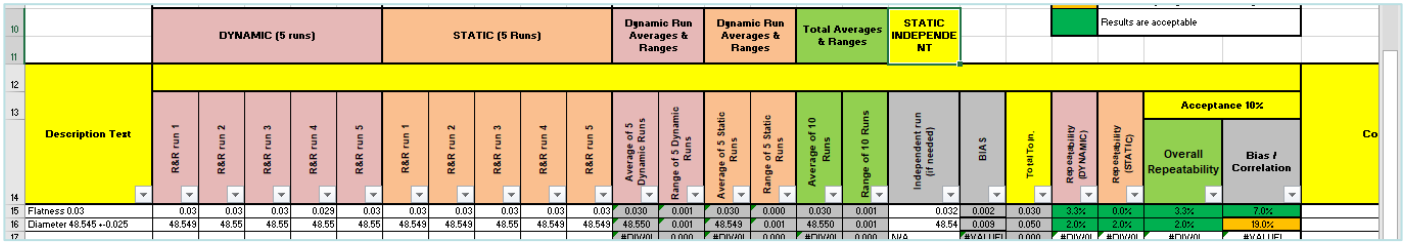
Measure Phase – Static and Dynamic tests

Explanation of the CMM Spreadsheet Calculations

Static Test = Leave part in fixture (5 times)

Dynamic test = Take part off the fixture and replace each time measured (5 times)

Independent Static = Static test performed with separate programme (5 times)



	Description Test	DYNAMIC (5 runs)					STATIC (5 Runs)					Dynamic Run Averages & Ranges		Dynamic Run Averages & Ranges		Total Averages & Ranges		STATIC INDEPENDENT					Acceptance 10%		Co
		R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	Average of 5 Dynamic Runs	Range of 5 Dynamic Runs	Average of 5 Static Runs	Range of 5 Static Runs	Average of 10 Runs	Range of 10 Runs	Independent run (if needed)	BIAS	Total Tol.	Repeatability (DYNAMIC)	Repeatability (STATIC)	Overall Repeatability	Bias / Correlation	
15	Flatness 0.03	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.001	0.030	0.000	0.030	0.001	0.032	0.002	0.030	3.3%	0.0%	3.3%	7.0%	
16	Diameter 48.545 +-0.025	48.549	48.55	48.55	48.55	48.55	48.549	48.549	48.55	48.549	48.549	48.550	0.001	48.549	0.001	48.550	0.001	48.54	0.009	0.050	2.0%	2.0%	2.0%	19.0%	
17												#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	

Component 48.545 +/- 0.025mm

Measure Phase – Static and Dynamic tests

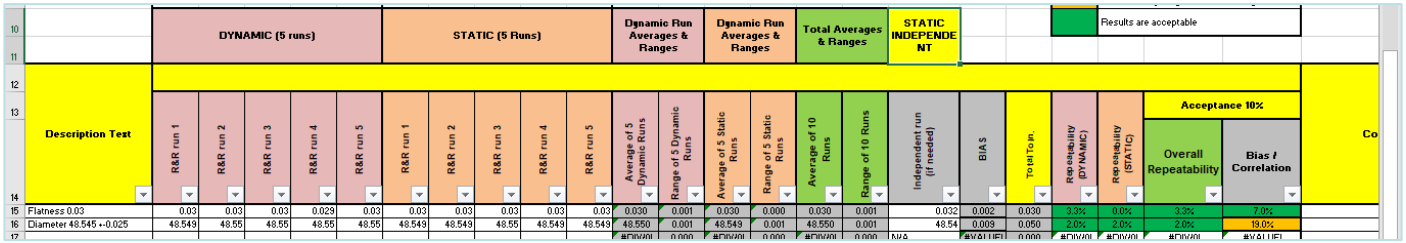
Static Test (Leave part and measure 5 times)

Average of the 5 runs = 48.549 + 48.549 + 48.55 + 48.549 + 48.549 / 5 = 48.549

Range of 5 static runs (repeatability) = 48.55 – 48.549 = 0.001
Tolerance = 0.05mm

Range 0.001 / 0.05 = 0.02 = 2%

AS13003 "Review the data from the static runs by finding the largest and smallest measurement result for each measured feature. The range of measurement should be far less than that seen in the dynamic runs. If any feature exceeds 10% of feature tolerance – it is likely that there is a programming, mechanism, fixture or datum system problem that needs to be fixed"



		DYNAMIC (5 runs)					STATIC (5 Runs)					Dynamic Run Averages & Ranges		Dynamic Run Averages & Ranges		Total Averages & Ranges		STATIC INDEPENDENT								
																								Acceptance 10%		
	Description Text	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	Average of 5 Dynamic Runs	Range of 5 Dynamic Runs	Average of 5 Static Runs	Range of 5 Static Runs	Average of 10 Runs	Range of 10 Runs	Independent run (if needed)	BIAS	T-test To zero	Repeatability (DYNAMIC)	Repeatability (STATIC)	Overall Repeatability	Bias & Correlation	Co
15	Flatness 0.03	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.001	0.030	0.000	0.030	0.001	0.032	0.002	0.030	3.3%	0.0%	3.3%	7.0%	
16	Diameter 48.545 +-0.025	48.549	48.55	48.55	48.55	48.55	48.549	48.549	48.55	48.549	48.549	48.550	0.001	48.549	0.001	48.550	0.001	48.54	0.009	0.050	2.0%	2.0%	2.0%	19.0%	
17												#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	

Results are acceptable

Measure Phase – Static and Dynamic tests

Dynamic Test (remove and replace part after each Measurement)

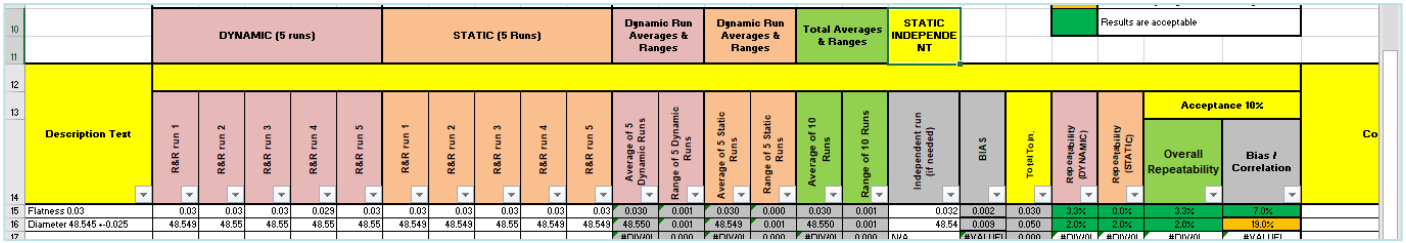
Average of the 5 runs = 48.549 + 48.547+ 48.55 + 48.55 + 48.55 / 5 = 48.549

Range of 5 dynamic runs (reproduceability) = 48.55 – 48.547 = 0.003

Tolerance = 0.05mm

Range 0.003 / 0.05 = 0.06 = 6%

AS13003 "Review the data from the dynamic runs by finding the largest and smallest measurement result for each measured feature. If the range of measurement is less than 10% of the feature tolerances continue. If any measurement result range is greater than 10% of the component tolerance, analysis of the program and CMS mechanism is required to understand the root cause of repeatability issue"



		DYNAMIC (5 runs)					STATIC (5 Runs)					Dynamic Run Averages & Ranges		Dynamic Run Averages & Ranges		Total Averages & Ranges		STATIC INDEPENDENT									
																									Acceptance 10%		
	Description Text	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	Average of 5 Dynamic Runs	Range of 5 Dynamic Runs	Average of 5 Static Runs	Range of 5 Static Runs	Average of 10 Runs	Range of 10 Runs	Independent run (if needed)	BIAS	Total To pr.	Repeatability (DYNAMIC)	Repeatability (STATIC)	Overall Repeatability	Bias / Correlation	Co
15	Flatness 0.03	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.001	0.030	0.000	0.030	0.001	0.032	0.002	0.030	3.3%	0.0%	3.3%	7.0%	
16	Diameter 48.545 +-0.025	48.549	48.55	48.55	48.55	48.55	48.549	48.549	48.55	48.549	48.549	48.550	0.001	48.549	0.001	48.550	0.001	48.54	0.009	0.050	2.0%	2.0%	2.0%	19.0%	
17												#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	

Results are acceptable

Measure Phase – Static and Dynamic tests

Dynamic Test (remove and replace part after each Measurement)

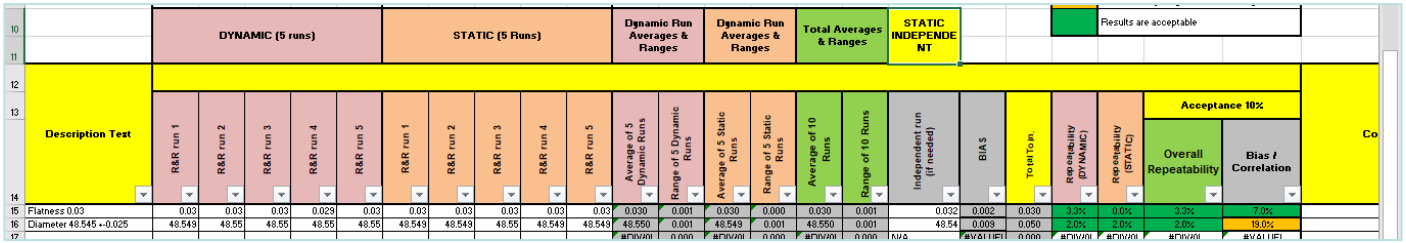
Average of all 10 runs = 48.549 + 48.547+ 48.55 + 48.55 + 48.55 48.549 + 48.547 + 48.55 + 48.549 + 48.549 / 10 = 48.549

Range of 10 runs = 48.55 – 48.547 = 0.003

Tolerance = 0.05mm

Range 0.003 / 0.05 = 0.06 = 6% Overall Repeatability

AS13003 "Review the data from the dynamic runs by finding the largest and smallest measurement result for each measured feature. If the range of measurement is less than 10% of the feature tolerances continue. If any measurement result range is greater than 10% of the component tolerance, analysis of the program and CMS mechanism is required to understand the root cause of repeatability issue"



		DYNAMIC (5 runs)					STATIC (5 Runs)					Dynamic Run Averages & Ranges		Dynamic Run Averages & Ranges		Total Averages & Ranges		STATIC INDEPENDENT						Results are acceptable			
	Description Text	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	Average of 5 Dynamic Runs	Range of 5 Dynamic Runs	Average of 5 Static Runs	Range of 5 Static Runs	Average of 10 Runs	Range of 10 Runs	Independent run (if needed)	BIAS	T-test Tp.	Repeatability (DYNAMIC)	Repeatability (STATIC)	Acceptance 10% Overall Repeatability	Acceptance 10% Bias / Correlation	Co
15	Flatness 0.03	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.001	0.030	0.000	0.030	0.001	0.032	0.002	0.030	3.3%	0.0%	3.3%	7.0%	
16	Diameter 48.545 +-0.025	48.549	48.55	48.55	48.55	48.55	48.549	48.549	48.55	48.549	48.549	48.550	0.001	48.549	0.001	48.550	0.001	48.54	0.009	0.050	2.0%	2.0%	2.0%	19.0%	
17												#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	

Measure Phase – Bias tests

Independent Static Test (Separate programme, machine)

Average of 5 runs = 48.54

Bias = average of 10 runs – average of independent test = 48.549 – 48.54 = 0.009

Tolerance = 0.05mm

Range 0.009 / 0.05 = 0.18 = 18 % Bias

AS13003 "In order to test if the figures from the CMS mechanism are accurate, it is expected that an alternative method of measurement shall be used to check the measured result achieved. The equipment that is used to verify the measured result must be at least as accurate as the measurement system under test. This normally means that an alternative method of CMS inspection is required.

It is expected that the maximum bias result between the average measurements taken on two measurement systems will be less than 10% of the feature tolerance.

	DYNAMIC (5 runs)					STATIC (5 Runs)					Dynamic Run Averages & Ranges		Dynamic Run Averages & Ranges		Total Averages & Ranges		STATIC INDEPENDENT					Acceptance 10%		
Description Text	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	R&R run 1	R&R run 2	R&R run 3	R&R run 4	R&R run 5	Average of 5 Dynamic Runs	Range of 5 Dynamic Runs	Average of 5 Static Runs	Range of 5 Static Runs	Average of 10 Runs	Range of 10 Runs	Independent run (if needed)	BIAS	Total Tol'n.	Repeatability (DYNAMIC)	Repeatability (STATIC)	Overall Repeatability	Bias / Correlation	Co
Flatness 0.03	0.03	0.03	0.03	0.029	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.001	0.030	0.000	0.030	0.001	0.032	0.002	0.030	3.3%	0.0%	3.3%	7.0%	
Diameter 48.545 +-0.025	48.549	48.55	48.55	48.55	48.55	48.549	48.549	48.55	48.549	48.549	48.550	0.001	48.549	0.001	48.550	0.001	48.54	0.009	0.050	2.0%	2.0%	2.0%	18.0%	
											#DIV/0!	0.000	#DIV/0!	0.000	#DIV/0!	0.000	N/A	#VALUE!	0.000	#DIV/0!	#DIV/0!	#DIV/0!	#VALUE!	

Results are acceptable

Measure Phase

- [ ] Equipment to be used is calibrated
- [ ] Equipment used has sufficient measurement resolution.
- [ ] That the measurement system is suitable for a range of measurements.
- [ ] Equipment used is stable
- [ ] That there are clear operational definitions in place.
- [ ] Observe a few measurements being made.

