# Nuclear Advanced Manufacturing Research Centre


Supported by the Regional Growth Fund

CATAPULT High Value Manufacturing

EUROPEAN UNION
Investing in Your Future
European Regional Development Fund 2007-13

MANCHESTER 1824
The University of Manchester

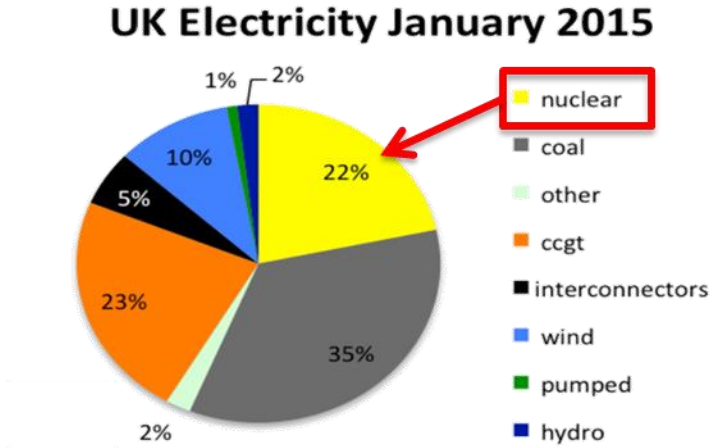
The University Of Sheffield.

# The Nuclear Advanced Manufacturing Research Centre

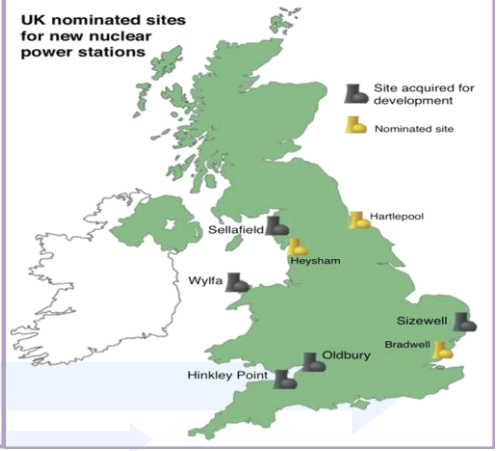
- Opened in September 2011
- 6,000m$^2$ shop floor
- Two 50 tonne cranes
- State-of-art, industrial capability.

# UK Nuclear Power

- About 22% of UK generating capacity will close over the next decade.
- Nuclear ticks the box for:
  - Security of supply ✓
  - Low $CO_2$ ✓
  - Base load ✓




## New Built




- Government has authorised **8 sites** for **new nuclear power stations**.
- If all stations go ahead they will provide 16GWe and an **investment of £40 billion**.
- **Huge opportunity for Nuclear manufacturing supply chain.**

# The Nuclear AMRC Partnership

A joint initiative between the Universities of Sheffield and Manchester, industrial partners from across the nuclear manufacturing supply chain.

The University Of Sheffield.

MANCHESTER 1824
The University of Manchester

**FOUNDER MEMBERS:**

AREVA

Westinghouse

Rolls-Royce

SHEFFIELD FORGEMASTERS INTERNATIONAL

TATA STEEL

**SUPPORTED BY:**

EDF ENERGY

HM Government

NIA Nuclear Industry Association


AREVA


ITW WELDING PRODUCTS


SHEFFIELD FORGEMASTERS
INTERNATIONAL


Böhler Welding
GROUP
A voestalpine company


NEWBURGH
PRECISION


AVURE


Mazak


starrag
Starrag Group


edgecam


NIKKEN


DASSAULT
SYSTEMES


NDA
Nuclear
Decommissioning
Authority


TATA STEEL


HOUGHTON


OUTOKUMPU


IFA
Independent Forgings & Alloys


POLYSOUDE
THE ART OF WELDING


Delcam


Sellafield Ltd


Westinghouse


IMS
SOFTWARE


Red-D-Arc
Weld Automation
reddarc.com


DMG
MORI SEIKI


NES
ENGINEERING
INNOVATION


AMI
ARC MACHINES, INC.


JOHNSON
ALLEN
NDT


SolidCAM
The Leaders in Integrated CAM


HERMLE


Rolls-Royce


Institution of
MECHANICAL
ENGINEERS


TBT
TIEFBOHRTECHNIK


Argyll-Ruane Ltd
Learning & Development


MAHER


TÜVRheinland®
Precisely Right.
Precisely Rig


HEXAGON
METROLOGY

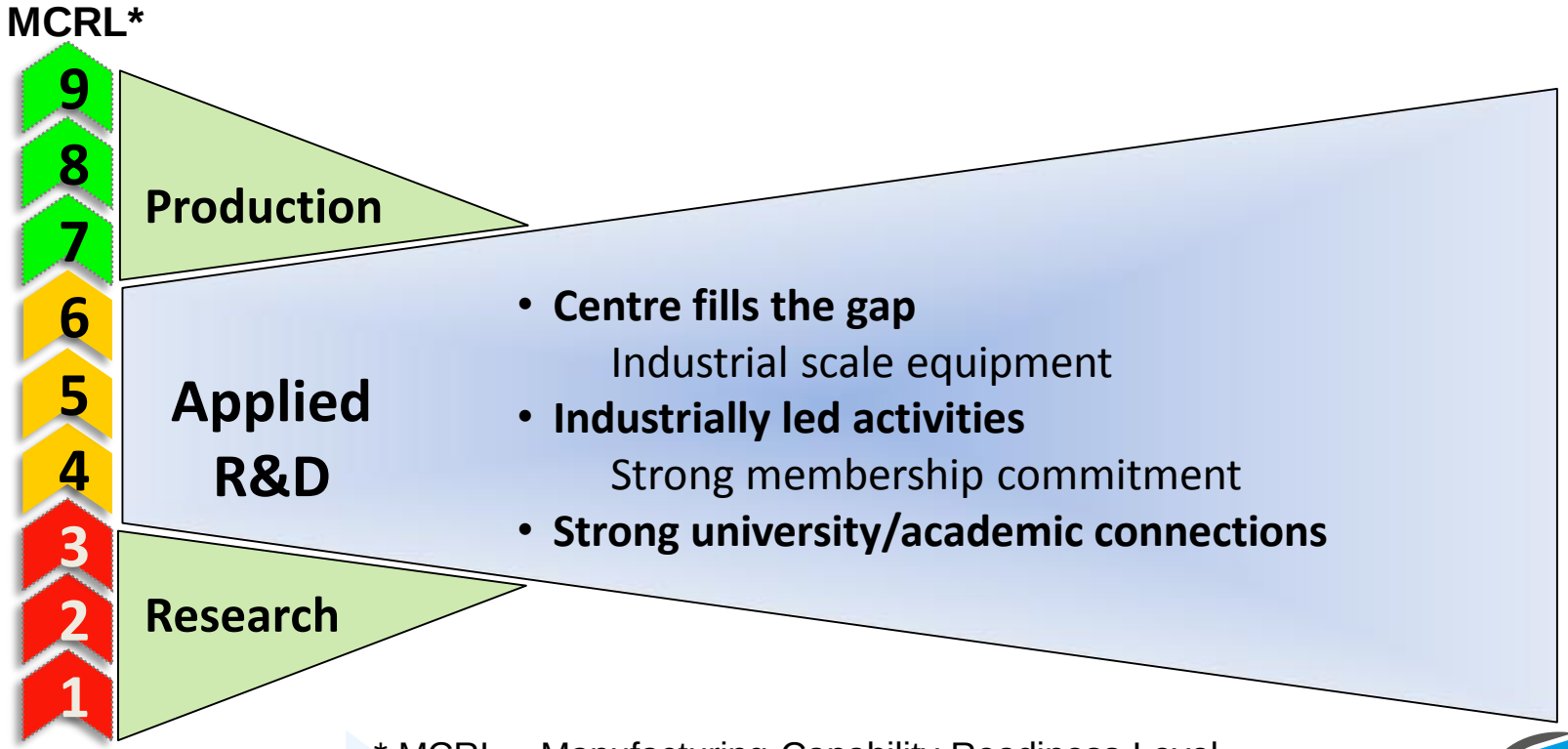

SANDVIK
Coromant


BOC
A Member of The Linde Group


WEHR

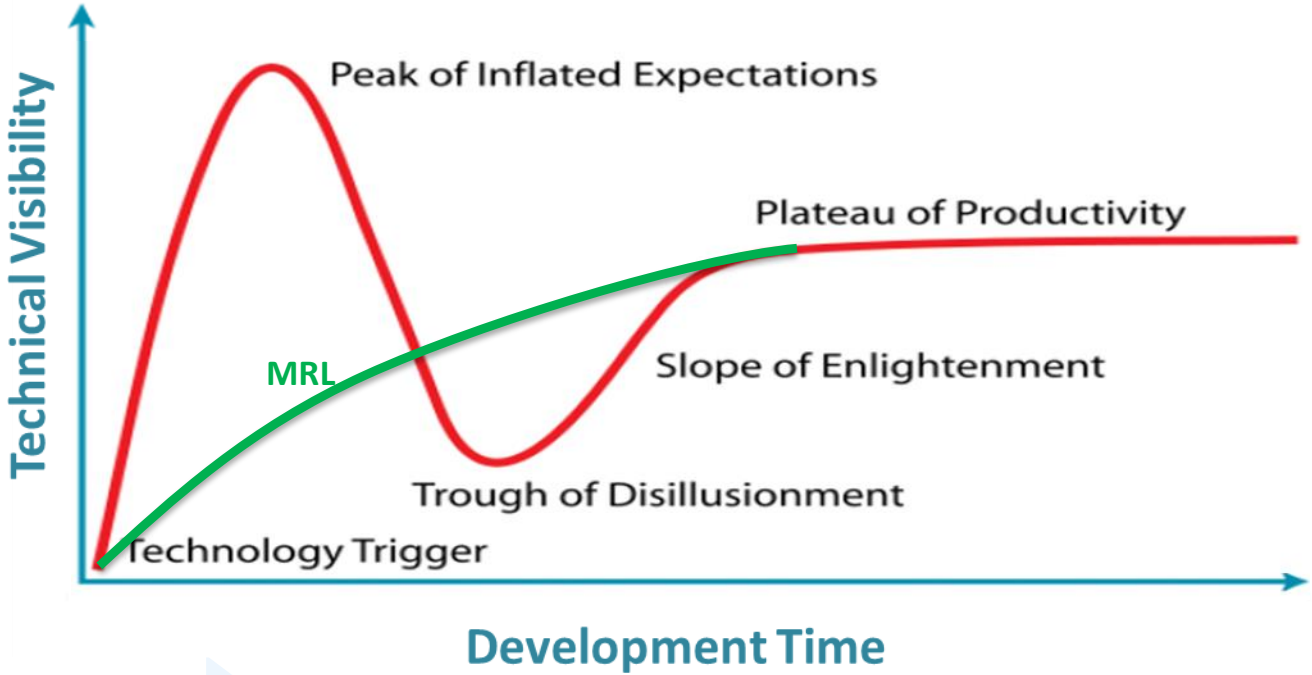

VIRTALIS

# Manufacturing Capability Readiness Levels



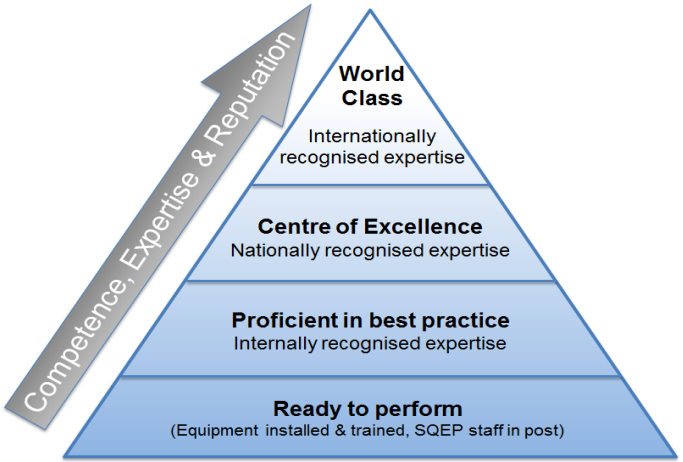

* MCRL – Manufacturing Capability Readiness Level

# Hype Cycle


Technical Visibility
Peak of Inflated Expectations
Plateau of Productivity
MRL
Slope of Enlightenment
Trough of Disillusionment
Technology Trigger
Development Time

# Nuclear AMRC Core Technology Themes

- Intelligent Machining
- Bulk additive Manufacturing
- Electron Beam Manufacturing
- Hot Isostatic Pressing
- Integrated Manufacturing
- Large Volume Metrology
- Laser Beam Manufacturing
- Mechanised Arc Welding
- Surface Engineering
- Virtual & Augmented Reality



# Nuclear AMRC Core Technology Themes

Intelligent Machining

Bulk additive Manufacturing

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Laser Beam Manufacturing

Mechanised Arc Welding

Surface Engineering

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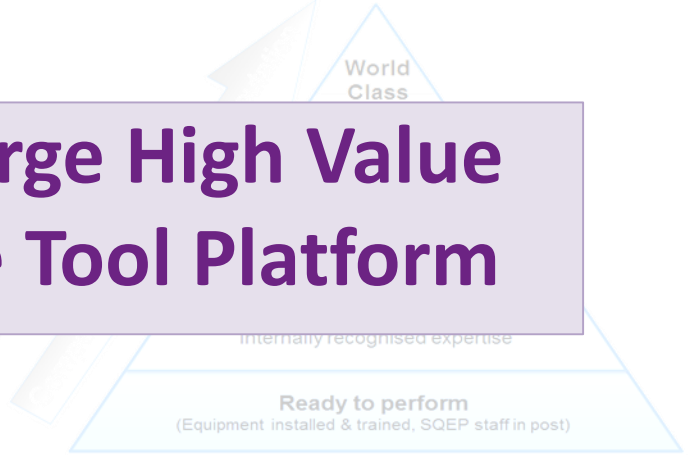
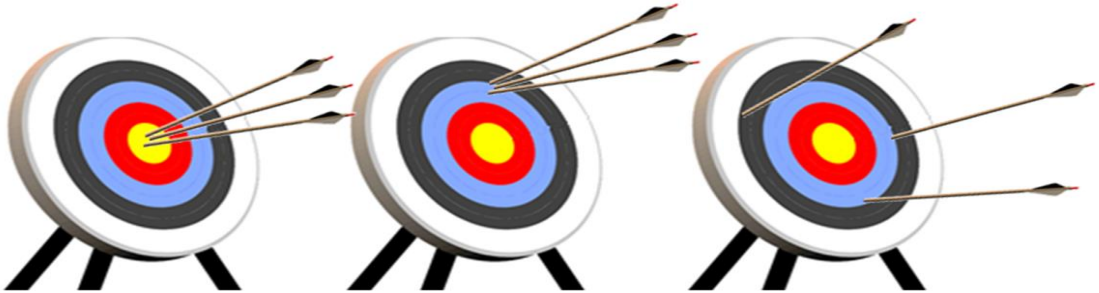



## In-Process Inspection of Large High Value Components on a Machine Tool Platform

# What is Metrology?

- The Science of Measurement.
- Understanding of measurement of the quality and quantity.
- Evidence of traceability and accuracy.
- Repeatability, reproducibility, reliability.
- Understanding the uncertainty.

# Accuracy and Precision



**Accurate** and **Precise**

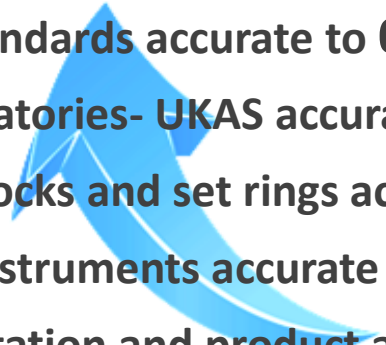
**Precise** but **Not Accurate**

**Not Precise** and **Not Accurate**

**Accurate** measurement system has **small systematic error**, **precise** measurement system has **small random error**.

# Traceability

- Prove a traceable and unbroken route to the national standards body.
- Uncertainty of a measured value is determined by the unbroken chain.
- NPL in the UK (PTB  in Germany)



**National Standards accurate to 0.001%**

**Calibration Laboratories- UKAS accurate to 0.01%**

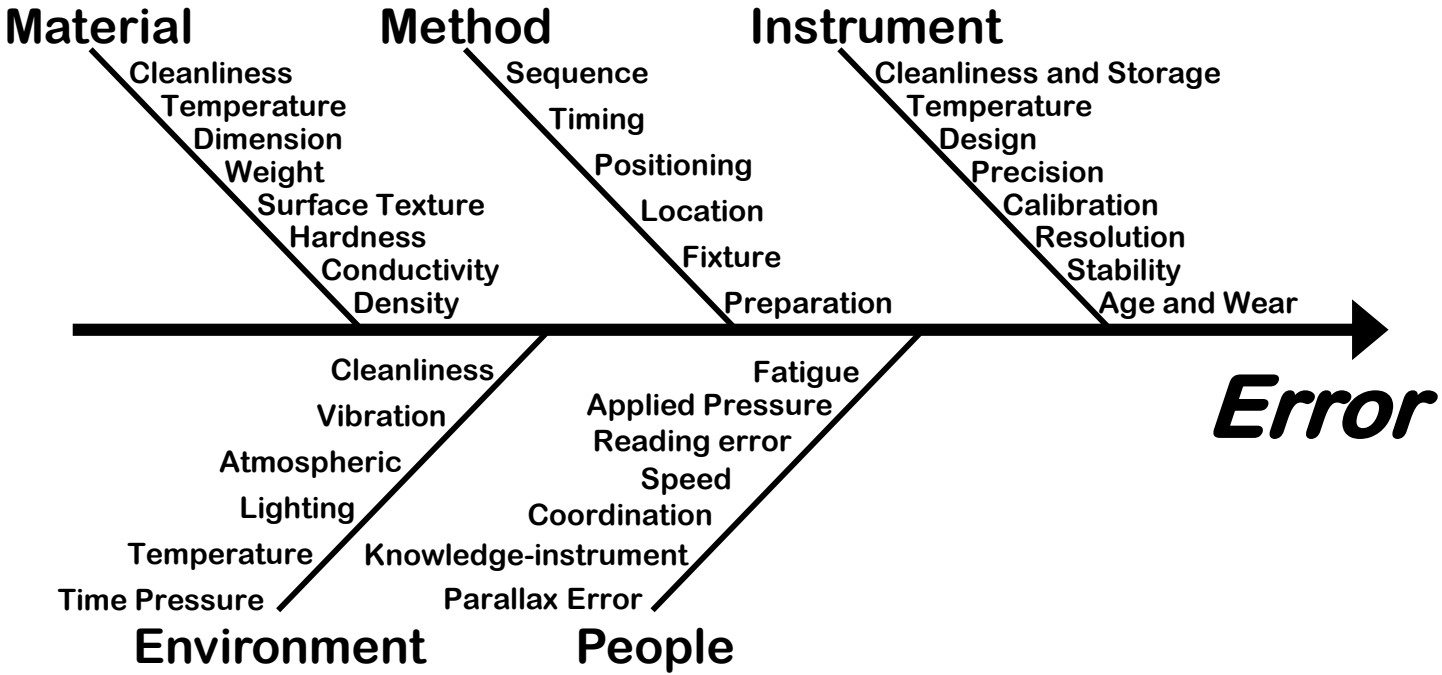
**Standards – gauge blocks and set rings accurate to 0.05%**

**Inspection instruments accurate to 0.1%**

**Process instrumentation and product accurate to 1%**

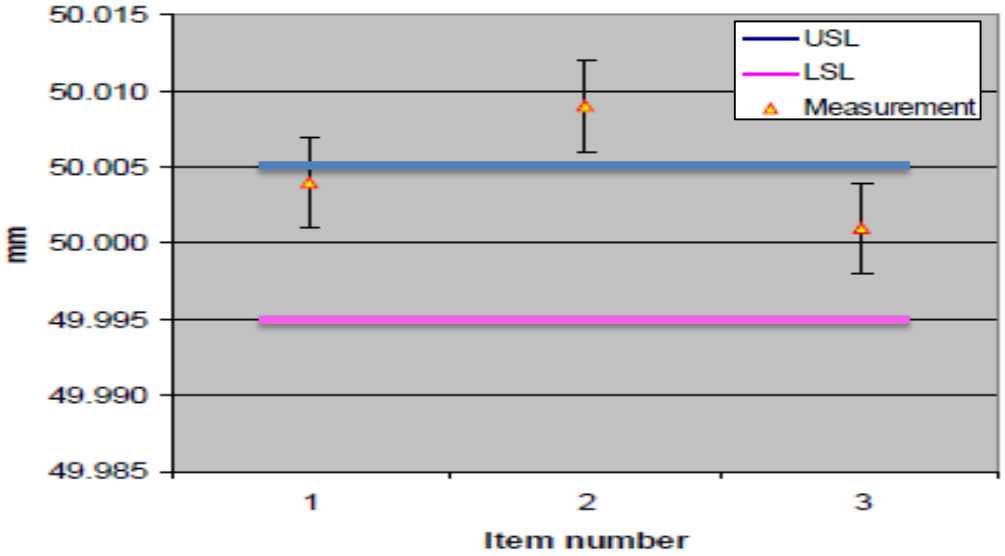
*…with each step towards the National measurement standards bodies, we look for an artefact that has a* ***precision*** *of at least* ***10 times greater accuracy***

# Factors that influence measurement



# Knowing the Uncertainty is Important

*Extracts from.. NPL Good Practice in Dimensional Metrology*

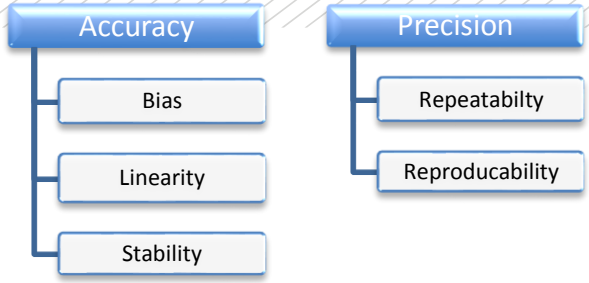


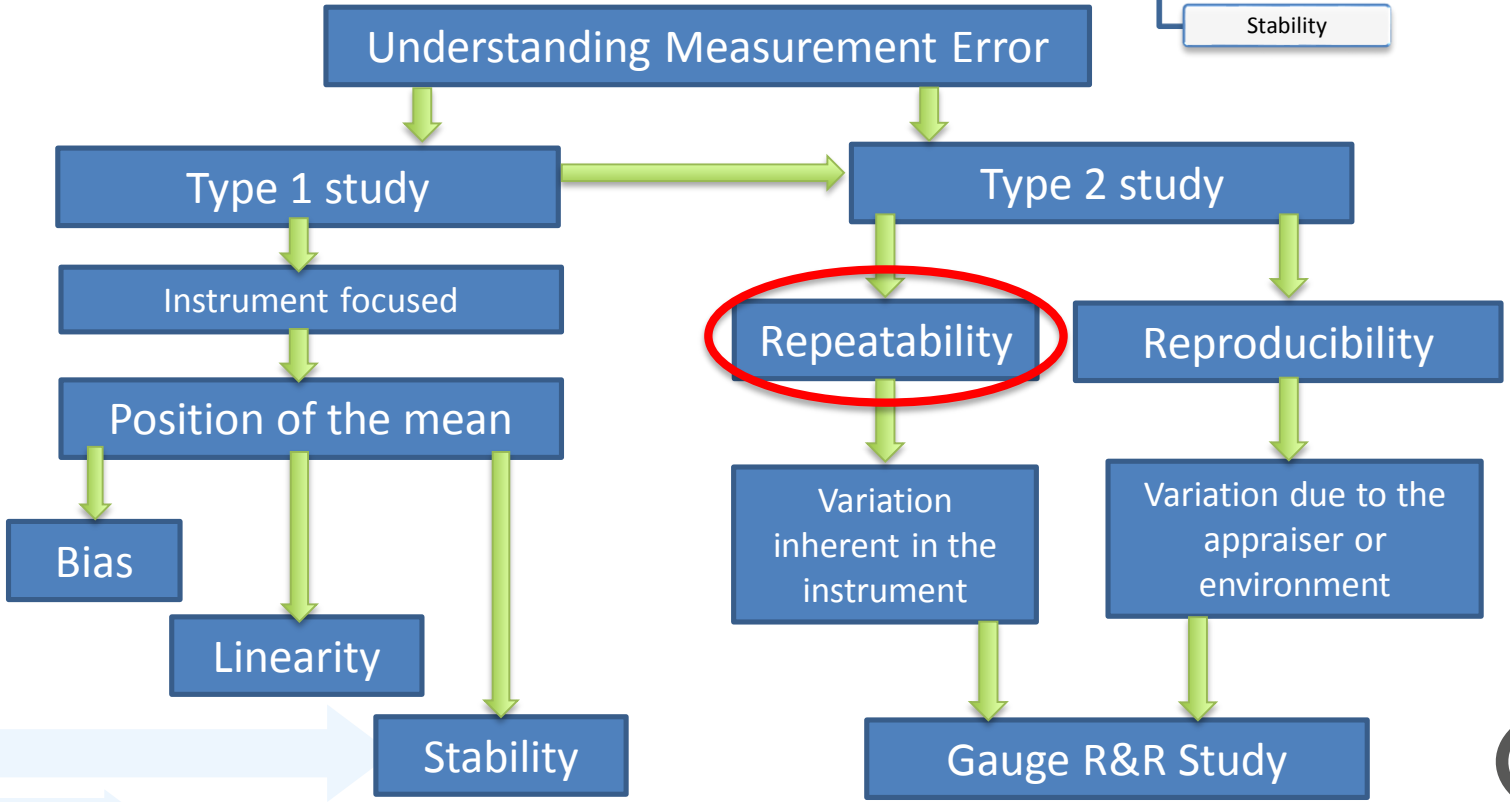

*Conformance with a specification can only be proven when the **result of a measurement (complete with a statement on uncertainty)** falls within tolerance zone*

***Possible outcomes** - measurement of 3 items:*

1. *Neither conformance nor non-conformance with a specification can be proven*
2. *Non-conformance is proven*
3. *Conformance is proven*

# Measurement System Analysis



# What is the Difference Between On-Machine Inspection and On-Machine Verification?

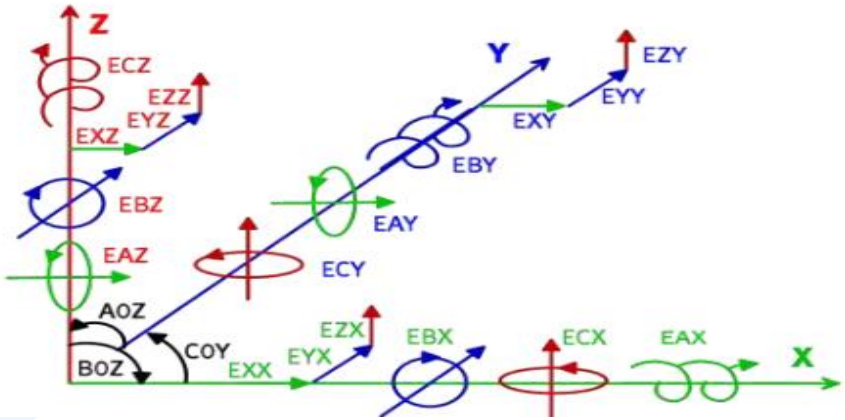
The majority of **modern machine** tools are supplied with or can be **equipped with touch probes** that can be employed in the dimensional measurement of component features.

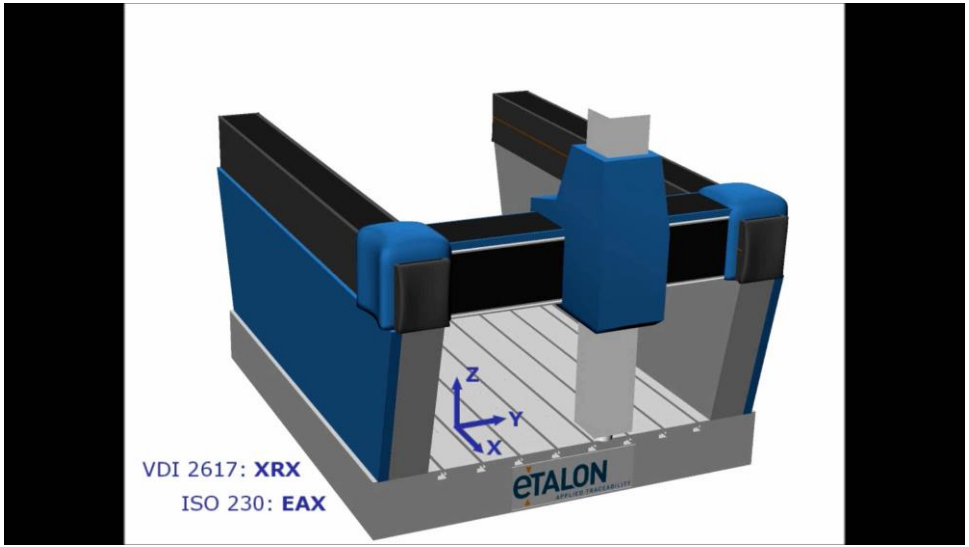
Equipping a **machine tool with a probe** effectively **turns** it **into** a **coordinate measuring machine**.

- A Primary and significant limitation of on-machine probing is that the **same axes of motion** used to machine the form will be **used to record the measured values**.
- Any errors in the axes of motion will therefore contribute and reside in the measured data and will not be evident in the recorded values.
- **Thermal expansion** of the machine will not be detectable in the values recorded.

# Technical Challenge

- Monitoring the 21 Possible Errors
  - Scale and Straightness
  - Roll Pitch and Yaw
  - Square




Images referenced from Etalon

# Points to consider

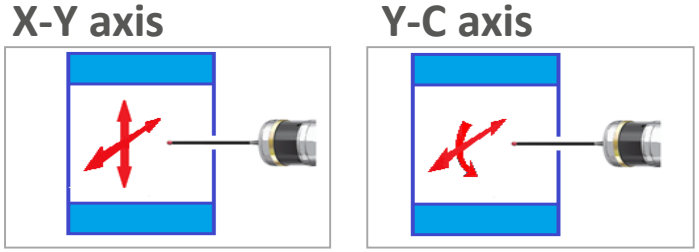
- How to validate a machine tool to be a measurement instrument traceable to international standards.
- Error mapping technologies.
- Temperature and monitoring.
- Compensation methods.
- Robust and traceable processes.

# Knowledge Development

- Understanding of machine tool expansion and dynamic characteristics.
- Efficient and robust processes.
- Thermal monitoring, control and compensation in differing modes of operation.
- In process machine health check.
- Artefact comparison technologies.
- How to establish the un-certainty of a machine.

» Extensive papers on all these subjects.

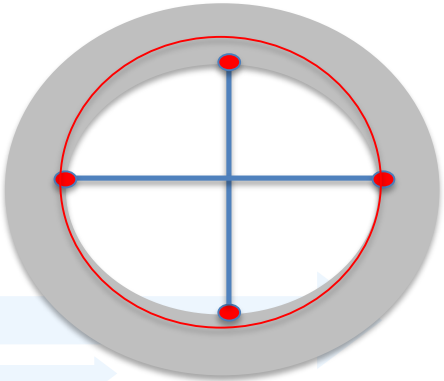
# Probing Cycle

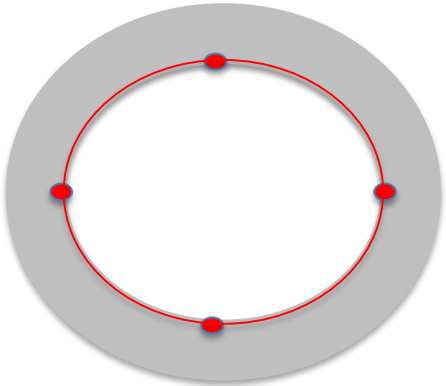



Two cycles were studied and measured a setting ring of diameter 90.003mm

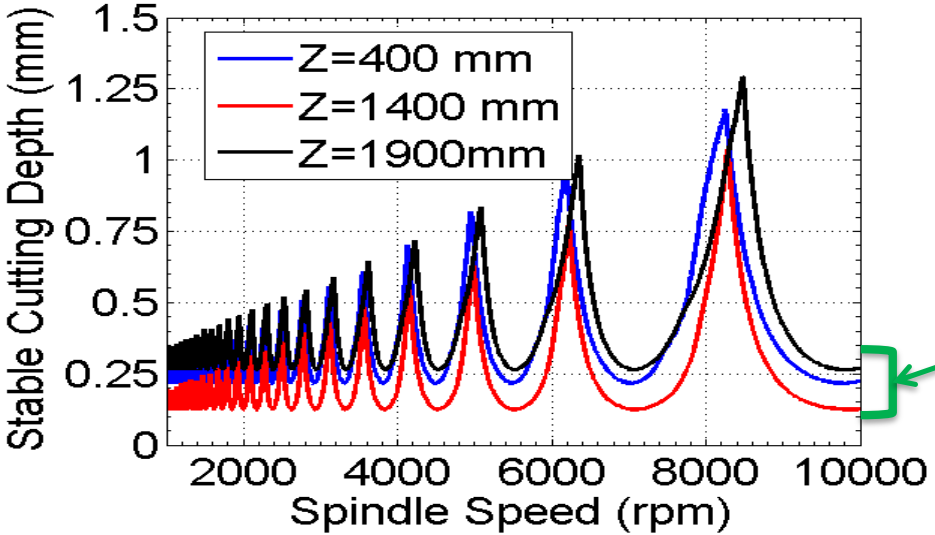
- Probe using **X-Y axis**
  - $Ø_{XY1}$ = 89.996mm → -0.007 mm
  - $Ø_{XY1}$ = 89.996mm → -0.007 mm
- Probe using **Y-C axis**
  - $Ø_{YC1}$ = 90.005mm → 0.002 mm
  - $Ø_{YC2}$ = 90.003mm → 0.000 mm

# Algorithm selection





# Thermal issues



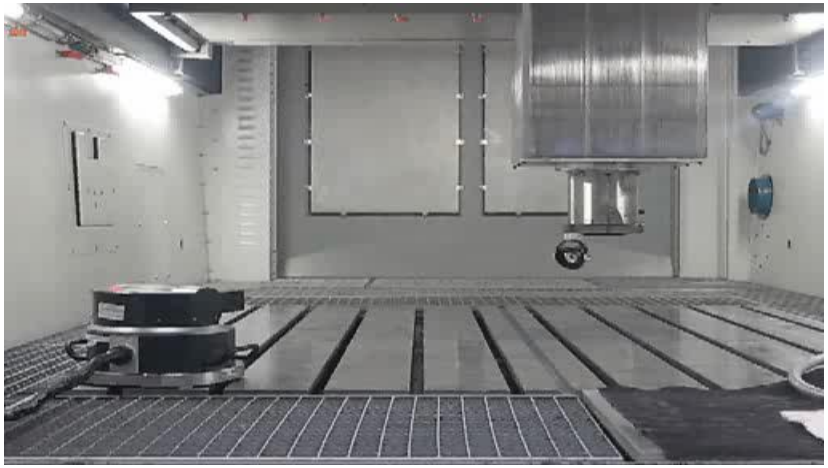

- After a short warm up cycle the recorded values increased by **10µm**

# Current Practice

- On machine measurement of tight tolerances is achievable with process control.
- Calibrate with an artefact of similar size (probe used as a comparator).
- Calibrate at a machine temperature that is comparable to the temperature during the measurement.
- Position the calibration artefact close to the area that the measurements will be taken.
- Probing cycle selection, limit the axis travel.

# Alignment Technology

- Images referenced from Renishaw Etalon and API



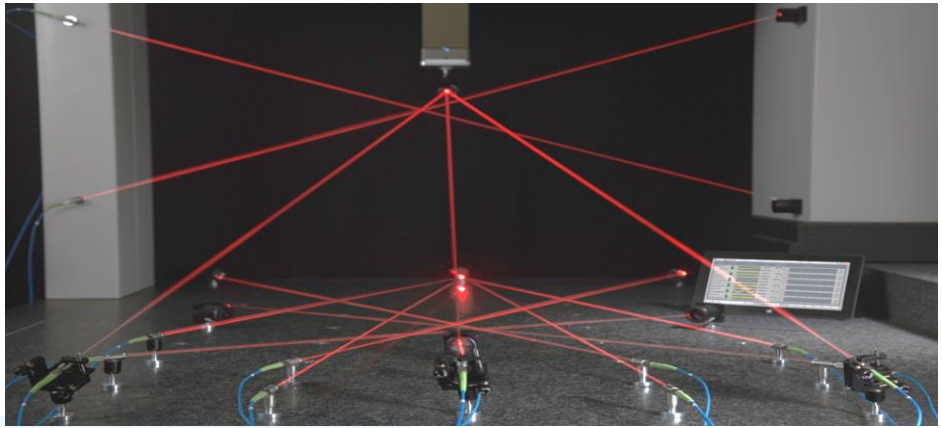
Video reference Etalon

- Review existing ISO and international standards.
- CNC machine Tool geometry accuracy checks ISO230.
- CMM  acceptance and reverification tests ISO 10360.

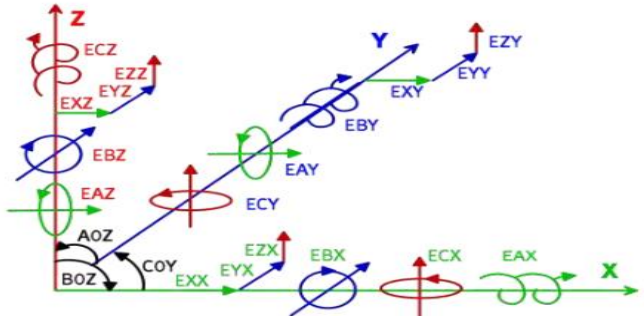
# Etalon Multiline

Integration into a machine tool allows :

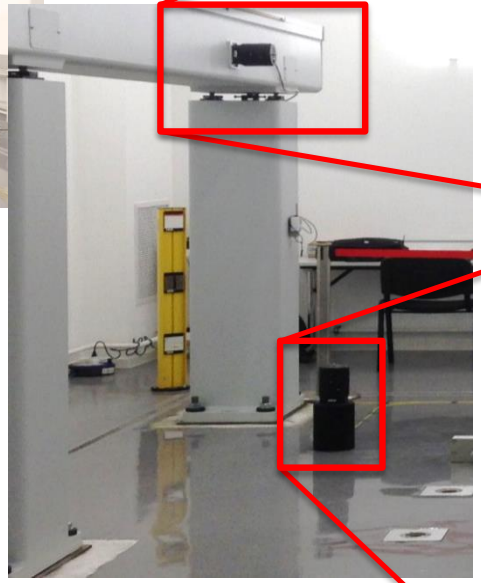
- efficient and **regular monitoring** of the machine **geometry**
- has potential to **dynamically update the error map** of the machine
- **ensure** the **dimensional accuracy** of the manufactured component.



Reference Etalon



# Validation Plattform



Hexagon
DEA Delta Slant CMM

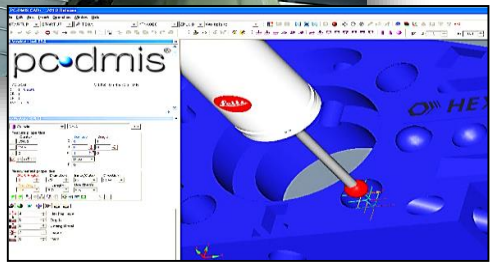
Capable of taking parts up to
**6 x 3 x 2 metres**

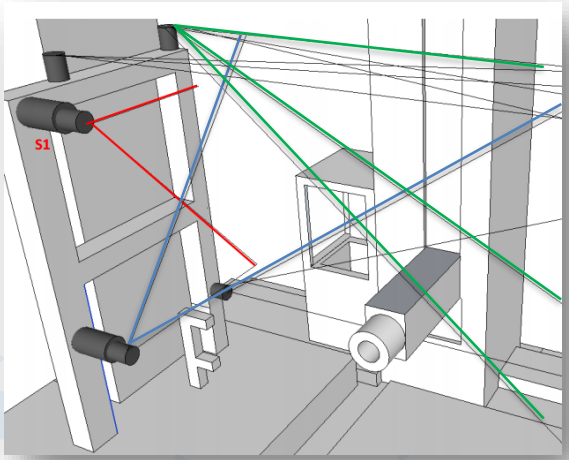
# Experimental Facilities

Capability:

- Multi-axis machining platform
- Renishaw RMP60 and RMP600 probes
- Renishaw Sprint
- Blum Roughness Texture probe
- PC-DMIS Software interfaced
- Etalon Multiline interferometer






Soraluce FX1200 Working Volume Area of 300 m³

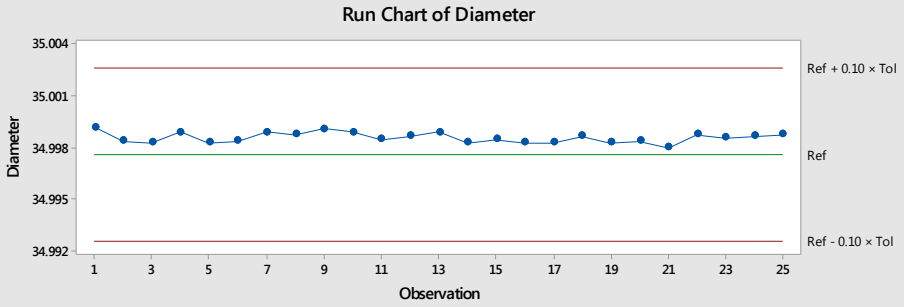
X 12.000mm, Y 5.300mm, Z 1.900mm, W 2000mm

# Experimental Procedures

## Type 1 Gage Study for Diameter

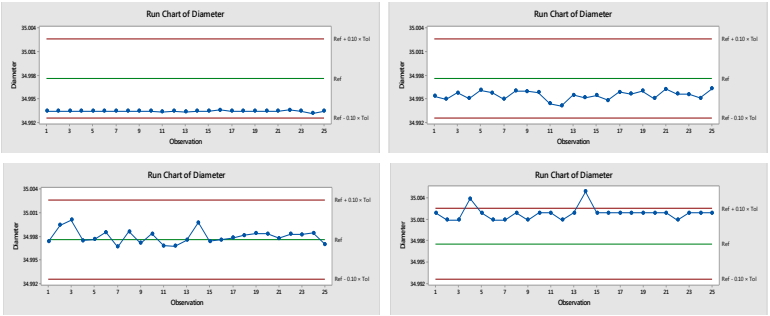
Gage name: Sprint probe- 4 points
Date of study: 02/08/2016

Tolerance: 0.05




| Basic Statistics | | Bias | | Capability | |
|---|---|---|---|---|---|
| Reference | 34.9976 | Bias | 0.001000 | Cg | 5.56 |
| Mean | 34.998600 | T | 16.6666667 | Cgk | 4.44 |
| StDev | 0.0003000 | PValue | 0.000 | | |
| 6 × StDev (SV) | 0.0018000 | (Test Bias = 0) | | | |
| Tolerance (Tol) | 0.05 | | | | |

| | |
|---|---|
| %Var(Repeatability) | 3.60% |
| %Var(Repeatability and Bias) | 4.50% |

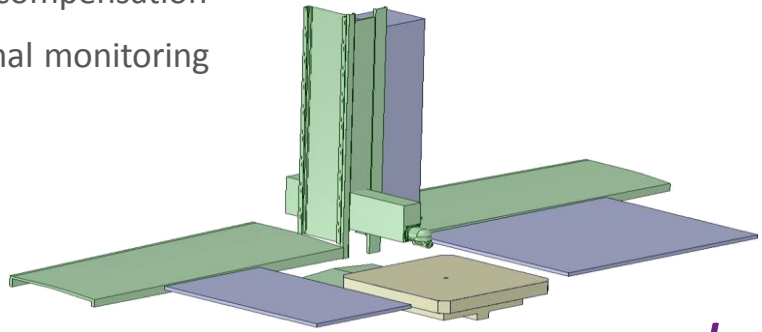


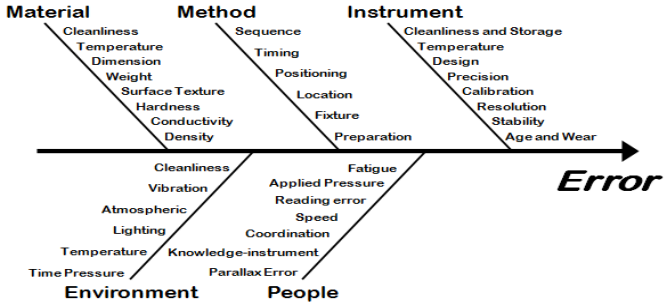

- Type 1 Study: Software, hardware, methods
- Gauge R&R Study: best performing combination
- Validation
- Multiple features size
- Complex geometries
- Full working envelop

# Investigation of Structural Variations in Large Scale Machine Tools

Research required:

- Structural analysis and modelling of machine tools.
- Successful application of process models to estimate machining mechanics and dynamics.
- How to develop geometrical models of machine tool components.
- Utilising laser interferometer as displacement sensor
- Error compensation
- Thermal monitoring

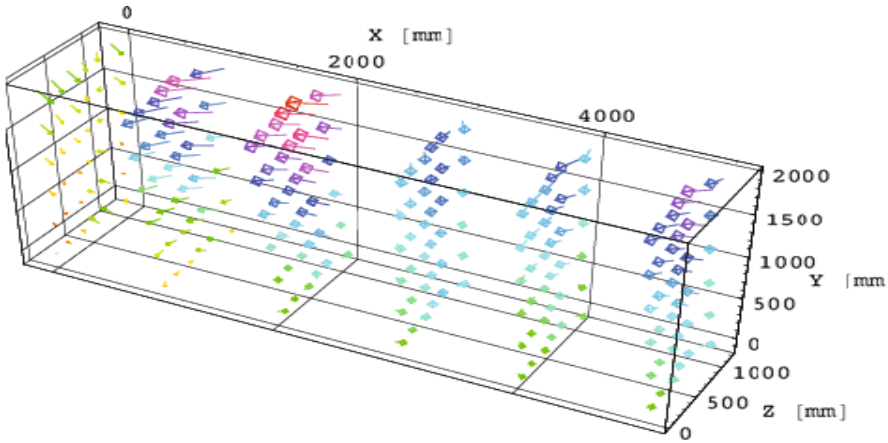





*Important but why!*

# Machine Tool Condition Monitoring

1. Monitoring of the machine tool provides knowledge of the current condition.
2. Active update of error map will increase accuracy and precision.
3. Apply compensations.
4. Resulting in increased product conformity.
5. Closed loop process, should be our goal.
6. Traceable measurements to a recognised international standard.



# *An idea without a plan is just a dream!* *Katherine Paterson*

| Stream | Current Scenario | Quarter 2 2016 | Quarter 3 2016 | Quarter 1 2017 | Quarter 3 2017 | Goals |
|---|---|---|---|---|---|---|
| On Machine Inspection Technology | Three readily available probing system and Three control software. | Literature Review, Measurement System Evaluation and Selection of best combination of probe and software | Use of different geometrical features to identify the best probing system for the application | Use of Advanced Calibration and Alignment Techniques to improve process efficiency | Experiments for Process Optimisation | **Optimised Process** Best Application of a given probe Sprint or Strain |
| | No current Error valuation system | Installation of Etalon multiline traceability technology to improve volumetric compensation : In Process health checks | Data Analysis to understand the effect of temperature variation on machine tool platform | Estimation on error compensation, uncertainty of recorded measurements in an ambient environment | | **Traceable** Measurement with Known Uncertainty **Active Error Mapping** and Temperature **Compensation** |
| | Manufacturing Readiness Level 3 | Operator Training; Creating and updating relevant standard manufacturing documents; Confidence in understanding of process and documented requirements | MRL 4 Review; Identify Key Process Variables and Process Sensitivity; Use of Artefact to duplicate production environment; Investigate Process Capability, Stability and potential cost driver | MRL 5 Review; Implement Process Controls; Process Optimisation; Experiments to inspect full range of features | MRL 6 Review | Achieve manufacturing readiness level **(MRL) 6.** |
| | No standard Passed | | Understanding the requirements to achieve ISO 10360 for a machine tool | Tests to review the process against ISO 10360 for machine tool | | Achieve **ISO 10360** standard for machine tool |

***Appropriately applied metrology*** *can deliver significant benefits in quality and cost to manufacturing. Metrology is at the heart of every project at the Nuclear AMRC.*

## *Thank you*

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