Introduction

Rolls-Royce

Nick Penfold
Bloodhound – World land speed record – 1000mph!
Company origin

- The first CMMs had a solid probe
- Operators captured points by pressing a foot pedal when the stylus was in contact with the feature to be measured.
Technology development

- Kinematic touch trigger probe
- Kinematic location Patented
- Revolutionised CMMs
RENISHAW worldwide presence

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
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<tbody>
<tr>
<td>USA</td>
<td>1981</td>
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<tr>
<td>Ireland</td>
<td>1981</td>
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<tr>
<td>Japan</td>
<td>1982</td>
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<tr>
<td>Germany</td>
<td>1986</td>
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<td>France</td>
<td>1988</td>
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<td>Italy</td>
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<td>Spain</td>
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<td>Switzerland</td>
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<td>Hong Kong</td>
<td>1993</td>
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<td>China</td>
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<td>Singapore</td>
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<td>Brazil</td>
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<td>South Korea</td>
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<tr>
<td>Taiwan</td>
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<tr>
<td>India</td>
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<td>Australia</td>
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<td>Netherlands</td>
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<td>Slovenia</td>
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<td>Czech Republic</td>
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<td>Poland</td>
<td>2002</td>
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<td>Russia</td>
<td>2002</td>
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<td>Hungary</td>
<td>2003</td>
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<td>Sweden</td>
<td>2003</td>
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<tr>
<td>Austria</td>
<td>2003</td>
</tr>
</tbody>
</table>

75 locations in 35 countries

+ 100 distributors in 50 countries
Our customers

- Aerospace
- Agriculture
- Automotive
- Consumer products
- Marine
- Construction
- Medical
- Power generation
- Quarrying and mining
- Oil and Gas
Renishaw’s global manufacturing

- Pre-production
  - New Mills, Glos, UK
  - Stonehouse, Glos, UK
  - Woodchester, Glos, UK

- Machining
  - Völklingen, Germany
  - Pune, India

- Sub-system and final assembly
  - Dublin, Ireland
Room to grow

• Expansion of assembly facilities in Pune, India

• Expansion of machining and additive manufacturing – Miskin (Wales)
Room for expansion

- 193 acres
- 42,828m²
- 25,000m² in use
- Machining
- SMD electronics
- Styli assembly
- Additive machine assembly
- Fabrication Development Centre
- Healthcare Excellence Clinic
Egypt - the great pyramid of Cheops – c.4000 years old

• 53,000sq metres
• Size: 230 x 230 x 146 metres
  – With a maximum height deviation across the corners is 13mm

• It is believed that it took one hundred thousand men, 20 – 30 years to build this pyramid, using 2,300,000 blocks of stone
Does size matter?

The pyramids are the first real indication we have of accurate measuring being used.

If we look at the actual measurements, there is only a maximum difference of 3.4cms!
With a maximum height deviation across the corners of 1.3cm

How did they achieve this accuracy?
How did they know where to place the stone blocks?
The cubit

The Cubit, is the “length of the forearm”, defined as: “from the elbow to the tip of the outstretched middle finger”

In the case of the Egyptian, or Royal cubit, it was the forearm of Pharaoh Amenhotep that was used, which equates to 524mm

The picture shows the wooden 'Cubit Rod' of Maya from the time of Tutankhamen. This 523mm rod is divided into 28 'digits', with lines at every fourth digit representing the 'palm'
So getting back to our site:

Using a cubit as their measuring tool, they would:

- Determine a reference point
- Mark out corners, sides and squares from reference point
- Divide sides into equal portions
Laying out the site

So getting back to our site:

Using a cubit as their measuring tool, they would:

- Determine a reference point
- Mark out corners, sides and squares from reference point
- Divide sides into equal portions
- Place the main, outer blocks, then fill in the rest!

• A maximum difference of 3.4cms!
What is a Micron?

- Microns (µm), how big are they?
  - Shortened term for micrometre
  - 1/1000 of a millimetre
  - Line 1000 up next to each other and they measure 1mm
  - Curly hair is oval in profile not round

1µm = 0.001mm
Our expertise – process control technology

- Co-ordinate measurement products
- Machine tool probe and tool setting systems
- Gauging
- Fixtures
- Calibration and performance testing products

Layered structure:
- Process foundation
- Process setting
- In-process control
- Post-process monitoring
Complex Prismatic component - example
# Manufacturing Economics

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities</td>
<td>22%</td>
</tr>
<tr>
<td>Labour</td>
<td>31%</td>
</tr>
<tr>
<td>Machinery &amp; Durables</td>
<td>27%</td>
</tr>
<tr>
<td>Materials</td>
<td>17%</td>
</tr>
<tr>
<td>Consumables</td>
<td>3%</td>
</tr>
</tbody>
</table>
To increase competitiveness a manufacturer could:

- Increase throughput
- Reduce labor cost
- Reduce quality costs

Alternatively:

- Make more with the same resources
- Make the same with fewer resources
- Make more with fewer resources

- We can sell these
- We can’t sell these
- Non-conforming, but still acceptable
- Concessions
- Scrap
OEE – Overall Equipment Effectiveness

OEE = Availability x Performance x Quality
Process Pyramid

**INFORMATIVE**
applied *after* machining is complete

**ACTIVE**
applied *during* metal cutting

**PREDICTIVE**
applied *just before* cutting starts

**PREVENTATIVE**
applied in *advance*

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**Post-process monitoring**
Verification of the process and the part

**In-process control**
Active response to inherent variation

**Process setting**
Establish location and size of all machining system elements

**Process foundation**
Maximise stability of process, environment and machine
Why measure your machine?
Why measure your machine?
Machine Geometric and Dynamic Errors

- Controllers
- Scale Errors
  - Backlash
  - Stick slip
- Servo mismatch
- Feedrate
- Reversal spikes
- Rotary
- Cyclic error
- Linear
- Cutting speed
- Feedrate
- Vibration
- Cutting forces
- Dynamic
- Contamination
- Straightness
  - Peaks
  - Flatness
  - Troughs
- Foundation
- Geometry
- Lateral play
- Squareness
- Rigidity
- Build quality
- Mass
- Structural stiffness
- Environment
- Lighting
- Local heat
- Temperature
- Humidity
- Thermal radiation
Machine Verification and Calibration

- Scale Errors
- Rotary Linear Controllers
- Backlash
- Stick slip
- Servo mismatch
- Feedrate
- Reversal spikes
- Environment
  - Local heat
  - Temperature
  - Humidity
  - Thermal radiation
  - Contamination
  - Vibration
  - Foundation
  - Lighting
- Machine dynamic characteristics
- Geometry
  - Cutting forces
  - Lateral play
  - Squareness
  - Straightness
  - Flatness
  - Peaks
  - Troughs
  - Rigidity
  - Build quality
  - Mass
  - Structural stiffness
- M/C Errors
  - Linear accuracy and repeatability of an axis
  - Dynamic cutting speed
  - Cyclic error
  - Angular pitch and yaw of an axis
  - Straightness of an axis
  - Squareness between axes
- QC20 ballbar
- Run 1
- Run 2
- XL80 LASER
- Dynamic reversal spikes
QC20-W wireless ballbar system
Check the performance of your machine and diagnose problems
Process Pyramid

- **INFORMATIVE**: applied after machining is complete
- **ACTIVE**: applied during metal cutting
- **PREDICTIVE**: applied just before cutting starts
- **PREVENTATIVE**: applied in advance

**Post-process monitoring**
Verification of the process and the part

**In-process control**
Active response to inherent variation

**Process setting**
Establish location and size of all machining system elements

**Process foundation**
Maximise stability of process, environment and machine
Probing

• Work piece measurement systems
  • probe and help to control parts being machined
  • typically used on lathes, milling machines, 5 axis machines, grinding machines, and laser cutting machines

• Tool setting systems
  • probe the lengths and diameters of tools
  • check condition of tools
  • help to control tools and therefore the parts they produce
Probing fundamentals
Machine tool probes

- Vertical CNC machining centres
- Horizontal CNC machining centres
- CNC mill/turn centres
- CNC lathes
Product portfolio – PC Software

- Easy to Use visual programming.
- Comprehensive set of software for advanced use.
- Removes human error
Process Setting – Tool setting

Tool setting

RENISHAW.®
apply innovation™
Non-Contact Tool Setting

NC4

non-contact tool setter
Component Alignment

Workpiece set-up
Process Pyramid

INFORMATIVE
applied after machining is complete

ACTIVE
applied during metal cutting

PREDICTIVE
applied just before cutting starts

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applied in advance

Post-process monitoring
Verification of the process and the part

In-process control
Active response to inherent variation

Process setting
Establish location and size of all machining system elements

Process foundation
Maximise stability of process, environment and machine
Workpiece probe solutions for Lathes
CAD based software solutions

RENISHAW
apply innovation™

Productivity+™
Process Pyramid

**INFORMATIVE**
applied after machining is complete

**ACTIVE**
applied *during* metal cutting

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applied in *advance*

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**In-process control**
Active response to inherent variation

**Process setting**
Establish location and size of all machining system elements

**Process foundation**
Maximise stability of process, environment and machine

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**Post-process monitoring**
Verification of the process and the part
Final Inspection on the CNC Machine Tool
Post Process Monitoring
Post Process Monitoring

high accuracy machine probe
Post Process Monitoring – Generate Inspection Paths

- Measure feature
- Report on feature
- Track feature over time

Productivity+™
Active Editor Pro

![Graph showing measurement data with control limits and Cpk value]
Gauging - Introducing Equator
The high-speed, in-process measurement system

Introducing Equator
Equator - the versatile gauging system

Automated cells and process updates
Improved simple machining process …

We can sell these non-conforming, but still acceptable concessions.
**How much could you save with Renishaw?**

- **Free online benefits calculator**

**Machine details**

<table>
<thead>
<tr>
<th>Details</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Hours worked per week</td>
<td>65</td>
</tr>
<tr>
<td>Working weeks per year</td>
<td>50</td>
</tr>
<tr>
<td>Jobs per week</td>
<td>20</td>
</tr>
<tr>
<td>Hourly machine rate (£)</td>
<td>80</td>
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<tr>
<td>Downtime for maintenance etc. (% of gross hours)</td>
<td>10</td>
</tr>
<tr>
<td>Scrap rate due to setting errors without probing (%)</td>
<td>4</td>
</tr>
</tbody>
</table>

**Tool / part setting**

<table>
<thead>
<tr>
<th>Details</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tools per job</td>
<td>5</td>
</tr>
<tr>
<td>Time to load/set one tool without probe (mins)</td>
<td>5</td>
</tr>
<tr>
<td>Time to set parts per job without probe (mins)</td>
<td>10</td>
</tr>
</tbody>
</table>

[Calculate]
Additive Manufacturing

- Rapid Prototyping of highly complex parts
- Layer thickness of 20 – 100 μm
- Materials include:
  - Stainless steel 316L and 17-4PH
  - H13 tool steel
  - Aluminium Al-Si-12 and Al-Si-10
  - Titanium CP, Ti-6Al-4V and Ti-6Al-7Nb
  - Cobalt-chrome (ASTM75)
  - inconel 718 and 625
Additive Manufacturing
Additive Manufacturing
Metal 3D printing pushes the boundaries in Moto2™ through defiant innovation

Case study

In the high-stakes world of MotoGP™ motorcycle racing, technical advancements can have a big impact. Race
serving BMS-Metal team Trans fortunes is using cutting-edge additive manufacturing metal 3D printing technology into its
unconventional front suspension system to gain a significant competitive advantage.

Background

Motorcycle rider in the Moto2™ World Championship are renowned feeds
the general public can’t buy them and they can’t be used on a public road. As prototypes racing bikes they are
custom tailored to create their rider and maximize performance on the track.

Moto2, the second of the three MotoGP classes, was created
in 2016. Its official engine is a 600cc four-stroke production
engine, currently supplied by Honda. The French MotoGP team
Trans fortunes, based in Peugeot, South West France, is innovating from suspension design in order to stay ahead of the pack.

Trans fortunes is led by former 250cc World Championship
rider Christian Boudinot, and the team’s unconventional
suspension system was inspired by the seminal work of the
legendary French motorcycle designer Claude For.

Bouchart’s former hand and mentor, For, recognized the
gains to be made from developing the front suspension from
denting forces. Resolving flaws of Faster shifts, the design enables
an easier feeling into a corner and faster acceleration out.

The weight reduction from metal 3D printing has allowed the team to design a
unconventional front suspension component that has enabled an on
bypassing traditional weight transfer phenomenon and the problems associated with that. Besides the
weight, it’s allowed us to design a part that is not only lighter, but far more rigid at the same time.

Trans fortunes (France)

Instead of the more traditional telescopic front fork
suspension, the Trans fortunes motorcycle employs a rigid front fork suspension system separated from the chassis
using two wishbones.

To further advance the development of its innovative design, Trans fortunes approached 3D Concept, a world-class expert in metal additive design and manufacturing techniques.
Additive Manufacturing
Additive Manufacturing

Case study

Renishaw produces a prototype nose tip for the BLOODHOUND Supersonic Car SSC

Challenge
To be the first land vehicle to exceed 1000 miles per hour (1600 km/h) - at this speed it will be traveling the length of 4.5 football pitches every second.

Background
BLOODHOUND and Renishaw have collaborated to produce a prototype for a critical component of the Supersonic Car. BLOODHOUND's aim is not only to break the sound barrier but also to be the first land vehicle to exceed 1000 miles per hour (1600 km/h). At this speed it will be traveling the length of 4.5 football pitches every second.

The nose tip is manufactured from carbon fiber-reinforced plastic. During the recent attempt, the car will experience more than 2900 kg of air drag. However, as the nose tip is in the 'leading edge', it will experience a greater proportion of the load up to 1290 kg.

Extremely good accuracy of complex surfaces
Although the outer surfaces of the production appearance must be flat, there are 3D surfaces which contribute to the overall shape of the nose tip. The achieved accuracy was 30 micro meters per part for an accuracy of ±30 μm over the 230 mm test, enabling the geometry in the CAD model.

Hollow taper
The hollow sector depth is 130 mm, and tapers if the nose tip is to be machined, as a deeper cut is made, a hollow cutter is required to maintain stiffness and to determine the shape that can be made. With additive manufacturing, although some design rules apply, there is much more scope to manufacture novel shapes with ease.

Titanium alloy, minimal waste
Titanium alloy, Ti6Al4V, is easily processed using additive manufacturing, and can be built up in an additional potentially 50% lighter than traditional methods, and, as only the material required is consumed, it may be more cost-effective than expected. The honeycomb-like structure is more complex than a uniform wall and uses less material as necessary to manufacture.
Additive Manufacturing
Thank you for Listening
Thank you for Listening