Tackling process variation in manufacturing –
the benefits of modern process control techniques

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Intelligent application of *metrology* within manufacturing processes has beneficial effects far beyond the traditional aspects of dimensional QA…
Process control in manufacturing

The Productive Process Pyramid™

- **Informative** controls: applied after machining is complete
- **Active** controls: applied during metal cutting
- **Predictive** controls: applied just before production
- **Preventative** controls: applied in advance

**Post-process monitoring**
**In-process control**
**Process setting**
**Process foundation**
• Stable machining processes are a critical requirement for automated manufacturing.

• The Productive Process Pyramid was developed in our own machine shop.
Renishaw technology – enabling Automation
PREVENTATIVE

– Necessary activities required to provide stable conditions for machine operations
– Pro-active activities aimed at preventing sources of variation
– Forms the foundation of an advanced manufacturing facility
– Encompasses the manufacturing process beyond the machining process
PREVENTATIVE controls – Machine maintenance

Machine maintenance incorporates …

– performance assessment and optimisation of the machine tool to ensure it remains capable
– tracking of performance changes to ensure pro-active rather than reactive downtime

Benefits

– Enables planned downtime – minimised disruptions
– Gives more consistent throughput and reliable delivery performance
– Less machine to machine variation
PREVENTATIVE controls – Environmental and Input control

Control of process inputs involves …

- the use of tools to highlight and understand upstream factors that can affect machining process outcomes
- the use of techniques to systematically control these varying inputs
- managing variation inherent in the operating environment which cannot be eliminated
  - Thermal drift, Operator consistency, degradation of ‘best practice'

Benefits

- Stabilised processes demand less support
- Managed tool life ensures predictable process outcomes
- Managing sources of variation reduces process variation
## Sources of machining process variation

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### Probing
- Probe calibration method
- Stylus selection
- Probe repeatability
- Battery condition
- Tool setting probe associativity
- Probe calibration frequency
- Swarf on stylus
- Swarf on part
- Debris on tool

### CNC program
- Process control plan
- CAM vs CAD nominals
- Program issue control
- Use of work offsets
- Use of tool offsets
- Use of parametric programming
- Co-ordinate rotation
- Use of adaptive machining

### Tooling
- Tool wear
- Tool deflection
- Tool breakage
- Tool life
- Tool length
- Tool diameter
- Tool geometry
- Tool quality
- Tool condition
- Tool holding quality
- Tool holding condition
- Tool assembly process

### Environment
- Training
- Skill levels
- Alertness and attention
- Ambient temperature
- Pre-flight checks
- Work instructions
- Part temperature
- Machine temperature

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### Process variation

### Control measures
- Active
- Predictive
- Preventative
PREVENTATIVE controls – Process design & DfM

Process design incorporates …

– development of a comprehensive manufacturing strategy for components
– ensuring the process is optimised to maximise productivity
– standardisation of process inputs such as tooling, cutting parameters and CNC programming techniques
– Consistent process design to deliver predictable process capability

Benefits

– Components are manufactured using the most efficient processes
– Manufacturing uses optimised processes where failure modes are eliminated or understood
– Reduced time to market for new products
Process control in manufacturing

The Productive Process Pyramid™

- **Predictive controls**: Applied just before production
- **Active controls**: Applied during metal cutting
- **Informative controls**: Applied after machining is complete
- **Preventative controls**: Applied in advance

- **Process setting**
- **In-process control**
- **Post-process monitoring**
- **Process foundation**
**PREDICTIVE**

– Necessary on-machine activities prior to metal cutting
– Pro-active activities of ‘set-up’
– Gives a ‘good’ chance of the process being successful …
– … BUT is based on hope
  
  • It predicts that the process will be successful
  • But it cannot guarantee that the process will be successful
PREDICTIVE controls – Tool setting

Tool setting establishes …
- length from the spindle gauge-line
  - to establish a height offset
  - to check that length is within a specified tolerance
- diameter when spinning
  - to establish a tool size offset

Benefits
- Repeatable and robust measurement
- Eliminates variation caused by human error
- Rapid automated measurement avoids ‘waiting for operator’
PREDICTIVE controls – Part setting

Part setting establishes …

- position of a datum feature
  - to establish a work co-ordinate
  - Allows precision machining reference to existing surfaces regardless of thermal drift.
- orientation of a part relative to machine axes
  - to establish a co-ordinate rotation
- size of a billet / part
  - Compensate for input material variation

Benefits

- Reliable complex setting tasks associated with higher value work
- Repeatable and robust measurement
- Eliminates variation caused by human error
- Rapid automated measurement avoids ‘waiting for operator’
- Allow compensation for many sources of variation
PREDICTIVE controls – Machine setting

Machine setting establishes …

– alignment
  – Rotary axis or indexer
  – Fixturing elements to hold parts

– position
  – Indexer centre of rotation
  – Reference points on fixture elements

Benefits

– Allows machine-specific work offset calculation which reduces machine- to-machine variation (no dialling in)
– Repeatable measurement and calculation improves process accuracy
– Reduced setting times
ACTIVE

– Embedded within the metal-cutting process
– *Active* controls responding
  
  … to the actual part and conditions ‘on the day’
  
  … to unexpected events
– Gives *the best* chance of the process being successful
ACTIVE controls – Tool condition monitoring

Tool condition monitoring recognises ...

- presence of the tool
- position of the tool to ensure pull-out has not occurred

Benefits

- Rapid checks ensure non-value added processing is minimised

- Monitoring reduces scrap by identifying tooling problems

- Checks avoid ‘waiting for operator’, allowing processes to continue with sister tooling
On- and off-machine gauging enables ...

- **adapting** metal-cutting to variations in the machining process
  - Part distortion; tool deflection; thermal effects
- **updating** co-ordinate systems, parameters and offsets based on actual real-time conditions

**Benefits**

- Processes can respond to actual conditions in order to maintain accuracy
- Quicker predictable decision making about reject conditions increases value-added process time
- Reduced scrap and defects caused by inherent process variations
INFORMATIVE

- After the metal-cutting process and after the machining process
- Monitoring activities that provide information that can be used to change the next processed part or processing activity
- Unable to impact the actual ‘finished’ part but influences subsequent parts
On-machine part verification enables…

– inspection of critical features
  • in-situ with the same environmental conditions as the metal-cutting process
– rapid confidence in the stability of the machining process

Benefits

– Gives confidence in part conformance before unloading from machine
– Eliminate part re-setting time when re-machining is required
– Rapid highlighting of process problems resulting in reduced scrap and more value-adding metal-cutting
INFORMATIVE controls – Off-machine verification

Off-machine inspection enables …

- inspection of whole parts ensuring conformance to design intent
- full confidence in the dimensional conformance of the part
- point of manufacture QA on the shopfloor
- traceability of actual part dimensions using archiving utilities

Benefits

- Detection of scrap and defects before post machine processing / assembly or despatch
- Highlights process problems, enabling intervention in the machining process
- Enables feedback for process setting tasks
INFORMATIVE controls – Process logging

Process logging records …

- events that happen during the process route
- manual or automated changes to process parameters, offsets or co-ordinate systems
- interventions to the process which may have impacted on the outcome

Benefits

- Provides traceability of manufacturing processes and parts
- Special causes of failures can be traced and identified
- Enables reflection on and correction of the causes of process failure
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http://www.renishaw.com/processcontrol