Assessment of Performance of Single-Input-Single-Output Loops

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Layout of the presentation

- Minimum variance benchmarking;
- Case study at BP refineries;
- Control loop performance evaluation via spectra;
- Surveys.

Minimum variance benchmarking

- Aim: Reliable control with low maintenance
- Routine monitoring of every control loop
- Well tuned?
- Has it changed?
- Can performance be improved?
- Key academic advances:
  - Harris, T.J., Assessment of control loop performance, 1989

Minimum variance benchmarking

- Motivation:
  - Profitability;
  - Possible benchmarks:
    - Variance of the controlled variable, \( \sigma_y^2 \)
    - Minimum achievable variance, \( \sigma_{\text{mv}}^2 \)
    - Their ratio: \( \sigma_{\text{mv}}^2/\sigma_y^2 \) – the Harris index from 0 to 1

Minimum variance benchmarking

- Model the controller error signal
  - controller error, \( e \)
  - random noise, \( a \)

Minimum variance benchmarking

- Controller dependent term is zero in minimum variance control so \( \text{Var}(e) \) is \( \sigma_{\text{mv}}^2 \).
Desborough and Harris (1992) approach:

\[ y = \hat{y} + r \]

- controller dependent term (predictable component)
- residual (independent of controller)

Controller should have no d-step ahead predictable component (d is a prediction horizon)

\[ \eta = \frac{\text{mean of } (r^2)}{\text{mean of } (\text{controller error}^2)} \]

Predictable component method:

- \[ y = sp - pv - r = \hat{y} + r \]
- \( \hat{y} = \) predictable component (controller dependent term)
- \( \hat{y} = f(n(y_{1-d}, y_{2-d}, \ldots)) \) a d-step ahead prediction model
- \( r = \) random residual (controller invariant)

Find \( \text{Var}(r) \) and \( \eta = \frac{\text{Var}(r)}{\text{Var}(y)} \)

Advantage:

- Choose \( d \) to reflect engineering criteria.
- If \( d \) is the true time delay then the method is equivalent to FCOR.

Examples:

- Spectrum estimation:

\[ y = r + \hat{y} \]
- \( r = \) the controller invariant term (minimum variance component)
- \( \hat{y} = \) controller dependent term (predictable component)

If a control loop is oscillatory the spectrum of \( y \) has a peak at the frequency of oscillation.

The spectral signature is a good diagnostic (Harris, et al., 1996)
Case study - default settings

✧ Default settings from 40 refinery loops

<table>
<thead>
<tr>
<th>Loop type</th>
<th>Sample interval</th>
<th>Prediction horizon, d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid flow</td>
<td>10s</td>
<td>30s</td>
</tr>
<tr>
<td>Gas/steam flow</td>
<td>60s</td>
<td>300s</td>
</tr>
<tr>
<td>Pressure</td>
<td>20s</td>
<td>100s</td>
</tr>
<tr>
<td>Temperature</td>
<td>60-120s</td>
<td>360-600s</td>
</tr>
<tr>
<td>Level</td>
<td>20s</td>
<td>100s</td>
</tr>
<tr>
<td>Analyzer</td>
<td>60s</td>
<td>400s</td>
</tr>
</tbody>
</table>

Case study - default settings

✧ Prediction horizon, d

➢ choose the loop delay, if known.
➢ or choose a robust region where the index is flat

A flat region means the loop has behaviour predictable over a range of prediction horizons e.g. steady offset, persistent oscillation.

Case study - practical CLPA

✧ Tuning trials

<table>
<thead>
<tr>
<th>CLPA index</th>
<th>good</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>base case</td>
<td>trial 3</td>
</tr>
<tr>
<td>Trial 2</td>
<td>base case</td>
<td>base case</td>
</tr>
</tbody>
</table>

Conclusions:

➢ PID tuning influences performance index;
➢ Trial 1 had a steady offset (P-only control);
➢ Trial 4 used quantized data - its perfect index is not true;
➢ CLPA index is not unique because two settings gave the same index (trial 3 and base case).

Case study - default settings

✧ Data ensemble length

Case study - default settings

✧ Data sampling intervals

➢ Look for well defined impulse response and spectrum

Example of steam flow loop:
- 20s was over-sampled because the full response was not captured;
- 1 min was okay;
- 3 min was under-sampled because the graph was mostly random variation.
**Case study - practical CLPA**

- **controller error (o)** prediction (red).
- **estimated impulse response.**
- **spectra:** controller error (red), minimum variance (black).

**Conclusion:** Trial 3 had the same performance index as the base case because the predictable response had the same magnitude, even though the frequency was different.

**Case study - practical CLPA**

- **controller error (o)** prediction (red).
- **estimated impulse response.**
- **spectra:** controller error (red), minimum variance (black).

**Conclusion:** Trial 4 had a spurious performance index (too high) because quantization removed predictability. Use pv-filtering if the DCS supplies it.

**Case study - practical CLPA**

- Compression is common in data historians.
- *e.g.* “Swinging door” compression on tag (a), slide 6.
- Compression changes the predictability of the trend and changes the performance index. *e.g.* “Swinging door” (blue circles), “Box car backward slope” (pink squares).

**Conclusion:** Avoid use of compressed data from the data historian.

**Layout of the presentation**

- Minimum variance benchmarking;
- Case study at BP Amoco refineries;

**Spectral peaks - origins**

- Spectral peaks mean the time trend is oscillating;
- Process variability is bad for profits;
- **Oscillation detection:**
  - Visual inspection - look for spectral peaks or oscillatory autocovariance functions;
  - Integrated average error (IAE) method of Hägglund (1995);
  - Regularity of zero crossings and magnitudes of IAE (Thornhill and Hägglund, 1997; Forsman and Stattin, 1998);
  - Examination of peaks and valleys of autocovariance function (Seborg and Miao (1999);

**Conclusion:** A loop with oscillatory tuning has a periodic component at that frequency in its data from normal running. The reason is that the loop resonates in response to random noise.
Oscillation due to disturbance

- The step response of the re-tuned loop had some overshoot but no oscillation.
- Normal operation had an oscillation at 40 samples per cycle and a spectral peak at 0.025 s⁻¹.
- Conclusion: The oscillation was not due to tuning. Is a disturbance present?

Oscillation due to limit cycles

- Example from a liquid flow loop in a level-flow cascade
- Limit cycles arise when loop has non-linearity e.g. valve deadband.
- Limit cycles are sustained non-sinusoidal oscillations. Often slow compared to expected time scales.

Oscillation due to limit cycles

- Different non-linearities show different sp-pv patterns. This loop has a valve deadband. (see Thornhill and Hägglund, 1997, for more examples)
- Limit cycles have harmonics in the spectrum at integer multiples of the fundamental.
- Oscillation frequency of 6.10⁻⁴ s⁻¹ has a period of 1667s or 27.8 min.

Limit cycle oscillation can propagate

- There is a need for methods that detect plant-wide oscillations and determine root causes.
- The topic will be pursued this afternoon.
Layout of the presentation

- Case study at BP Amoco refineries;
- Control loop performance evaluation via spectra;
- Surveys:
  - literature cited - next slide;
  - key academic groups and experts;
  - commercial products and services.

Literature cited


Surveys - groups and experts

- Literature survey - see the workshop booklet
- See the "groups and experts" tables in the workshop booklet for contact details.

Surveys - products and services

- ABB: Loop Optimizer
  - http://www.abb.com/ (search for loop optimizer or loop auditor)
- Aspentech: Aspen Watch
  - http://www.aspentech.com/
- ControlArts: CAT I, III, and V
  - http://www.controlartsinc.com/
- Entech/Emerson Process Management
  - http://www.emersonprocess.com/entechcontrol/Services/
  - http://www.emersonprocess.com/home/services/
- Honeywell: Loop Scout
  - http://192.5.100.78/loopscout/home.asp
- Invensys/Foxboro: Performance Watch
  - http://206.32.221.67/lifetime/performance/
- Invensys/SimSci: ARPM (equipment monitoring)
  - http://www.simsci.com/homepage.stm
- Invensys/Walsh Automation: Performance Management
  - http://www.walshautomation.com/anglais/chemical/1_1_2_4.htm
- Matrikon: ProcessDoctor
- Top Control/Expertune: Plant Triage

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