Potential Application of Advance Control Algorithm for Fast Tuner Control

Shen Zhao
Low Level Radio Frequency Team Leader
Outline

- Tuner Types
- Control Strategy
  - PID
  - Observer based control
- Simulation Study
  - Model
  - Results
  - Parameter tuning
- Summary
### Slow Tuner vs. Fast Tuner

<table>
<thead>
<tr>
<th></th>
<th>Slow Tuner</th>
<th>Fast Tuner</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency Range</strong></td>
<td>&lt; 1 Hz</td>
<td>&gt; 10 Hz</td>
</tr>
<tr>
<td><strong>Tuner Types</strong></td>
<td>Stepper, Pneumatic Temperature</td>
<td><strong>Piezo</strong> Variable reactance</td>
</tr>
<tr>
<td><strong>Detuning Sources</strong></td>
<td>Bath pressure variation</td>
<td>Microphonics Lorenz force detuning</td>
</tr>
</tbody>
</table>

#### Piezo Tuner
- **Pros:**
  - Fast response
  - Fine resolution

- **Cons:**
  - Hysteresis
  - Creep
  - Nonlinear gain
## Control of Choice

<table>
<thead>
<tr>
<th>Category</th>
<th>Analysis Method</th>
<th>Method</th>
<th>Model Dependency</th>
<th>Advanced control?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical Control Theory</td>
<td>Frequency Domain (TF)</td>
<td>PID</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lead-lag compensator Loop-shaping</td>
<td>System TF</td>
<td></td>
</tr>
<tr>
<td>Modern Control Theory</td>
<td>Time Domain (SS)</td>
<td>State observer</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disturbance observer</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>Robust control</td>
<td>Yes</td>
<td>Advanced control?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaptive control</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fuzzy logic</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neural network</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>…</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
PID Controller

**Pros**
- Simple structure
- System can be treated as black box
- Only three parameters to tune
- Transfer function analysis

**Cons**
- One degree of freedom
  - Tracking \( \frac{y(s)}{r(s)} \Rightarrow 1 \)
  - Disturbance rejection \( \frac{y(s)}{d(s)} \Rightarrow 0 \)
- Ignoring knowledge of system
- Performance
### Observers
- **Luenberger observer**
  - Estimate system states
- **Unknown input observer**
  - Estimate external disturbance
- **Extended state observer**
  - Estimate external disturbance and unknown dynamics

### Equivalent Transfer Function Representation
- **Two degree of freedom**
- Observer performance determines disturbance rejection performance
- Controller performance determines tracking performance
Simulation Model

- **Notes**
  - Hysteresis is treated as disturbance and its effect is estimated by the ESO ($z_2$) and then cancelled in the controller.
  - The ESO does not include any model information of the hysteresis; the estimation performance is mainly determined by the observer bandwidth, which is limited by sampling rate and noise level.
The nonlinear effect of the hysteresis will distort the perfect sinusoidal input and create higher order harmonic components in the system output.

With feedback control, the third harmonic in the system output signal is greatly suppressed.
## Parameter Tuning

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Case #1</th>
<th>Case #2</th>
<th>Case #3</th>
<th>Case #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sine Wave Frequency (Hz)</td>
<td>30</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Controller Bandwidth (rad/s)</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
<td>4000</td>
</tr>
<tr>
<td>Observer Bandwidth (rad/s)</td>
<td>10000</td>
<td>10000</td>
<td>20000</td>
<td>10000</td>
</tr>
<tr>
<td>Tracking Error (%)</td>
<td>10</td>
<td>20</td>
<td>19</td>
<td>10</td>
</tr>
</tbody>
</table>

![Graph showing the comparison of reference, response, and error signals for different cases.](graph.png)
Summary

- Traditional PID controller is still dominant, but performance may be limited for challenging problems.

- The disturbance observer based control design may be an effective solution to deal with the hysteresis effect in the piezo fast tuner.

- Looking for collaborations if interested.