Potential Application of Advance Control Algorithm for Fast Tuner Control

Shen Zhao
Low Level Radio Frequency Team Leader

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

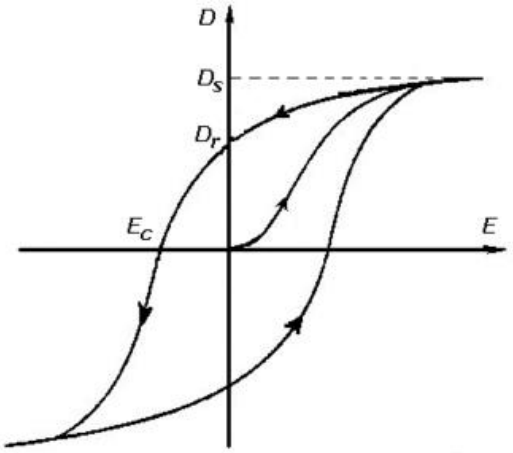
Outline

- Tuner Types
- Control Strategy
  - PID
  - Observer based control
- Simulation Study
  - Model
  - Results
  - Parameter tuning
- Summary

Slow Tuner vs. Fast Tuner

	Slow Tuner	Fast Tuner
Frequency Range	< 1 Hz	> 10 Hz
Tuner Types	Stepper Pneumatic Temperature	**Piezo** Variable reactance
Detuning Sources	Bath pressure variation	Microphonics Lorenz force detuning

- Piezo Tuner
  - Pros:
    - » Fast response
    - » Fine resolution
  - Cons
    - » **Hysteresis**
    - » Creep
    - » Nonlinear gain

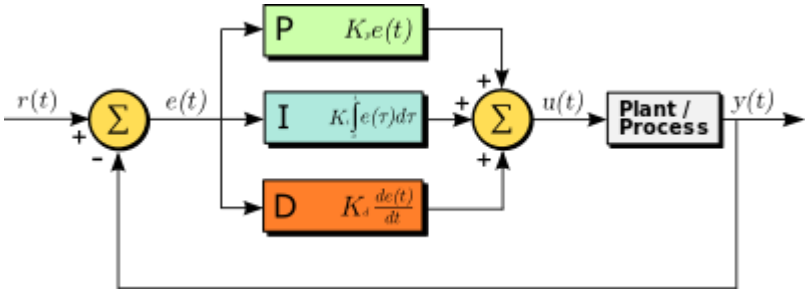


Control of Choice

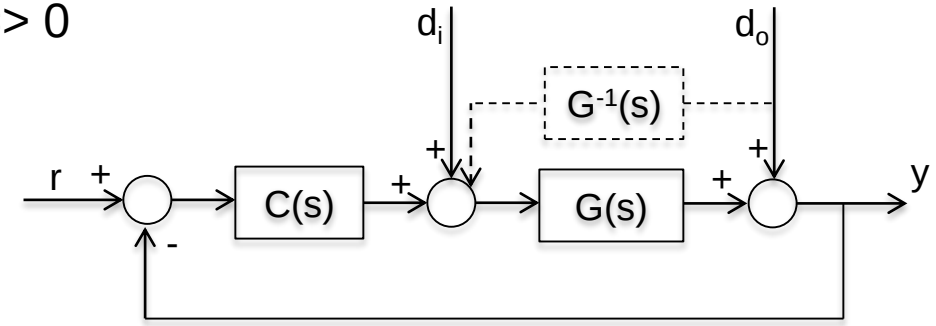
Category	Analysis Method	Method	Model Dependency	
Classical Control Theory	Frequency Domain (TF)	**PID** Lead-lag compensator Loop-shaping	**No** System TF System TF	
Modern Control Theory	Time Domain (SS)	State observer **Disturbance observer**	Yes **Yes / No**	Advanced control?
Other		Robust control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

PID Controller

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

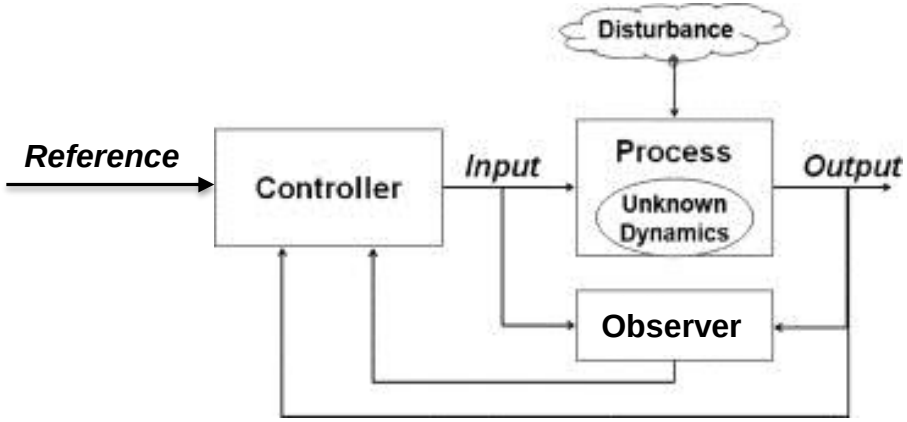


- Cons
  - One degree of freedom
    - » Tracking y(s) / r(s) => 1
    - » Disturbance rejection y(s) / d(s) => 0
  - Ignoring knowledge of system
  - Performance

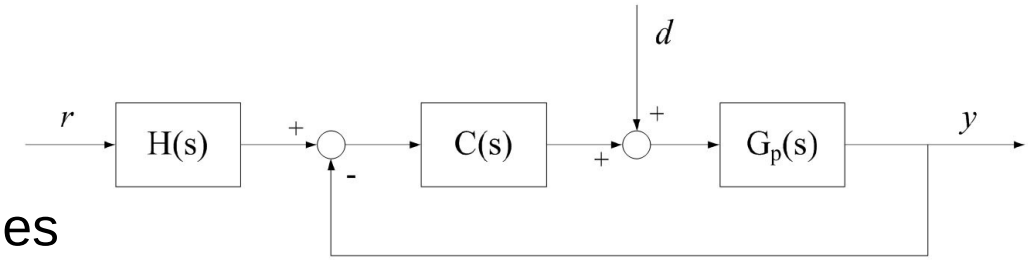


Observer based Control

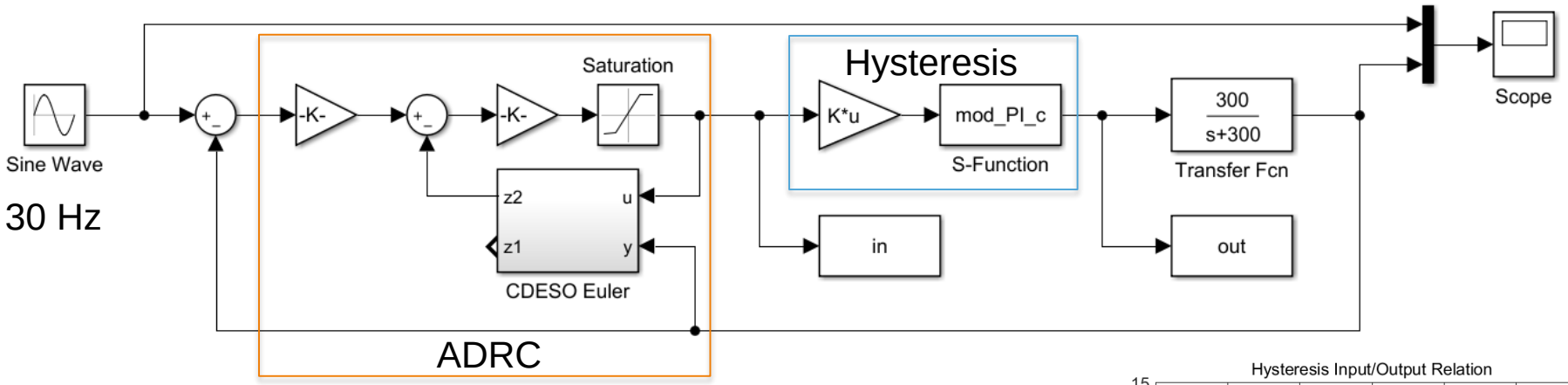
- Observers
  - Luenberger observer
    - » Estimate system states
  - Unknown input observer
    - » Estimate external disturbance
  - Extended state observer
    - » Estimate external disturbance and unknown dynamics



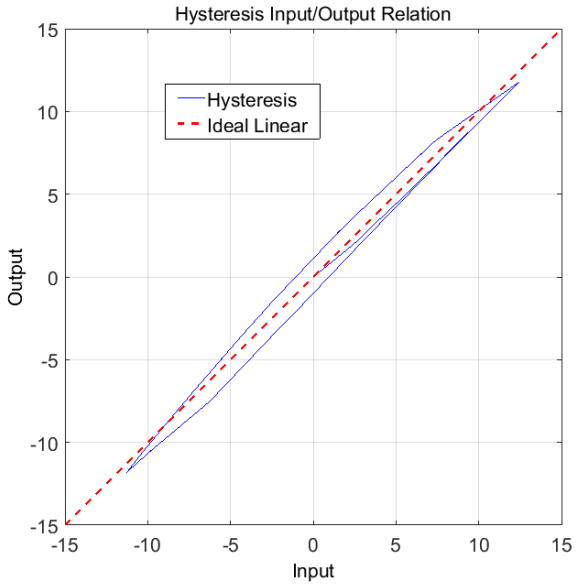
- Equivalent Transfer Function Representation
  - Two degree of freedom
  - Observer performance determines disturbance rejection performance
  - Controller performance determines tracking performance



Simulation Model

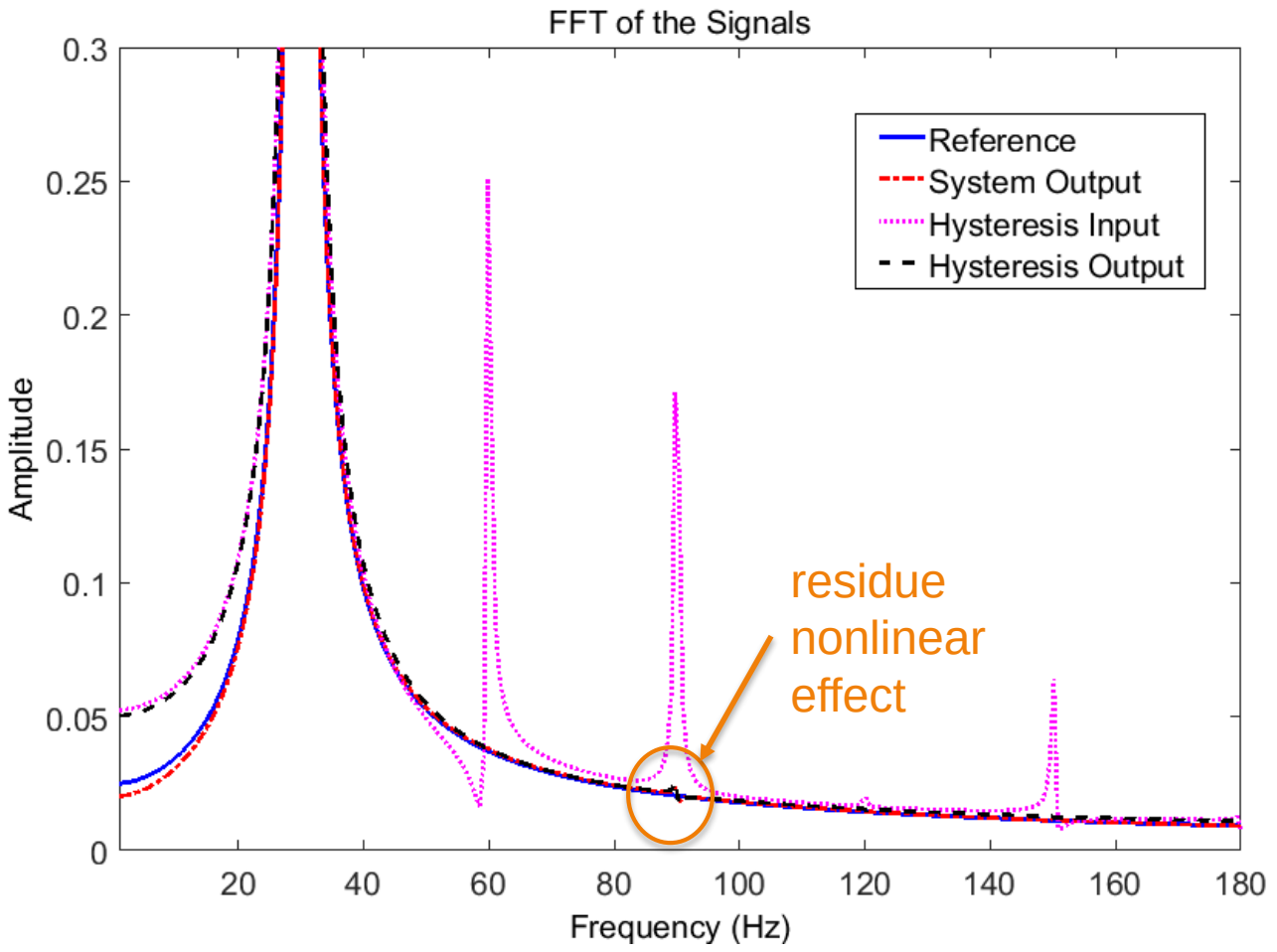


- Notes
  - Hysteresis is treated as disturbance and its effect is estimated by the ESO (z_2) and then cancelled in the controller
  - The ESO does not include any model information of the hysteresis; the estimation performance is mainly determined by the observer bandwidth, which is limited by sampling rate and noise level.



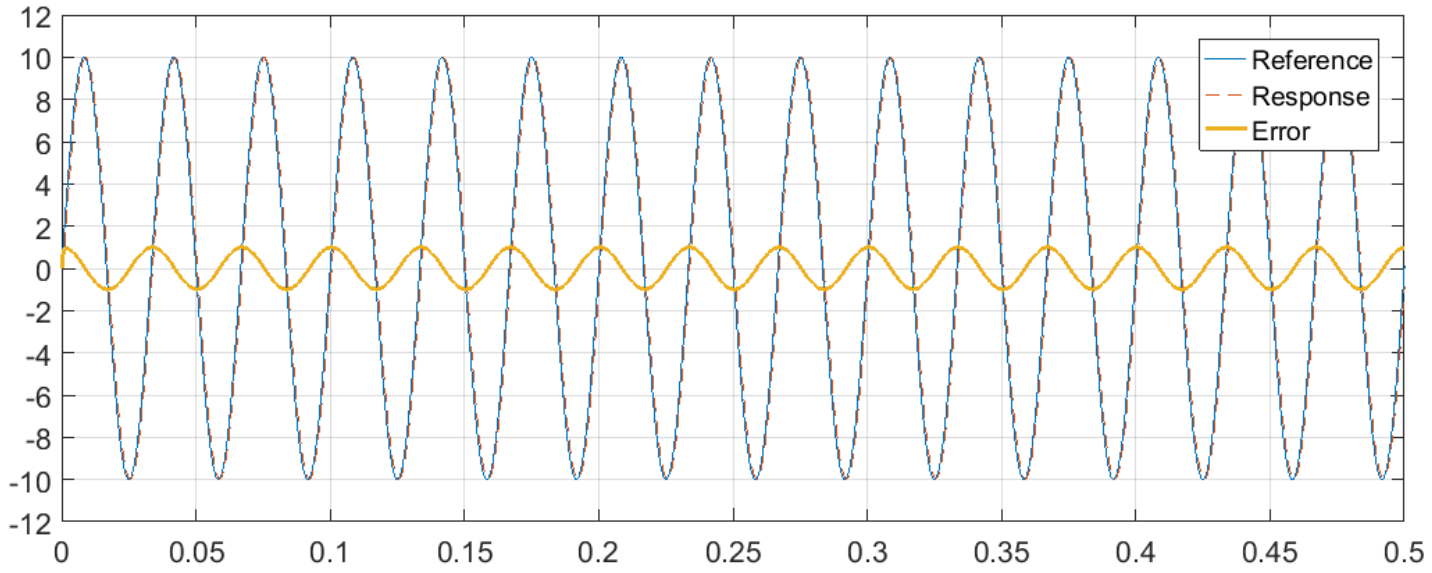
Simulation Results

- 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

Parameters	Case #1	Case #2	Case #3	Case #4
Sine Wave Frequency (Hz)	30	60	60	60
Controller Bandwidth (rad/s)	2000	2000	2000	4000
Observer Bandwidth (rad/s)	10000	10000	20000	10000
Tracking Error (%)	10	20	19	10



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