Closing the Loop: Using Feedback in EPICS

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- Many applications for feedback on APS beamlines
- Dedicated feedback controllers are expensive and relatively inflexible
- A new EPICS record for performing feedback
  - Enhanced Proportional Integral Derivative (EPID)
  - Flexible and fast feedback under EPICS

EPID record: Enhancements over the standard EPICS PID record

- Separation of device support from the record.
- Soft Record device support which uses EPICS database links
  - Very similar to the PID record
- EPID record can also be used with other device support
  - Communicate with faster feedback software
  - Hardware controllers.
  - Device support is provided in the Message Passing Facility for fast feedback (> 1 kHz) using an Acromag IP330 ADC and a Systran DAC128V DAC.
- Addition of many fields (OUTL, DRVH, DRVL) to simplify construction of databases

- The PID expression is computed as an absolute number, rather than a differential number to be added to the present output value.
  - Simplifies database construction, and also permits the record itself to perform limit checking on the output.
- Limits are placed on the magnitude of the integral term (I) which are lacking in the PID record.
- Monitors are posted for the CVAL field
  - Simplifies construction of user-interface tools, such as plotting.
- The CVL field has been renamed INP
  - This field can now be modified (a feature of EPICS R3.12 and higher)
  - A single EPID record can be used to control different processes at different times.
- Changed the time units of the KI and KD terms from minutes to seconds

PID Equation

The discrete from of the PID expression is as follows:

M(n) = P + I + D

P = KP * E(n)

I = KP * KI * SUMi (E(i) * dT(n))

D = KP * KD * ((E(n) - (E(n-1)) / dT(n))

Where

M(n) = value of manipulated variable at *n*th instant.

P = Proportional term

I = Integral term

D = Derivative term

KP = Proportional gain

KI = Integral gain

KD = Derivative gain

E(n) = Error at nth sampling instant

SUMi = Sum from i=0 to i=n

dT(n) = Time difference between n-1 instance and nth instance

Sanity checks on Integral Term

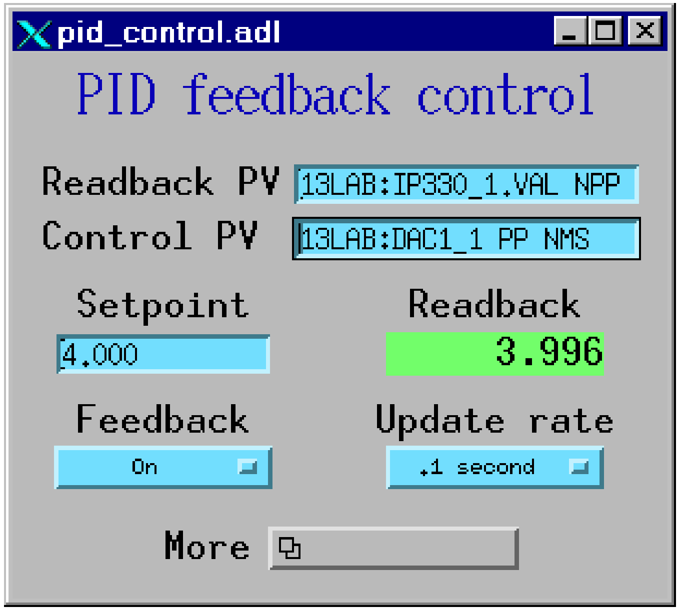
- Integral term is a sum from time=0 to the present time
- Can grow extremely large if not subject to some "sanity checks“
- The EPICS PID record does not perform any such checks, which is a serious limitation.

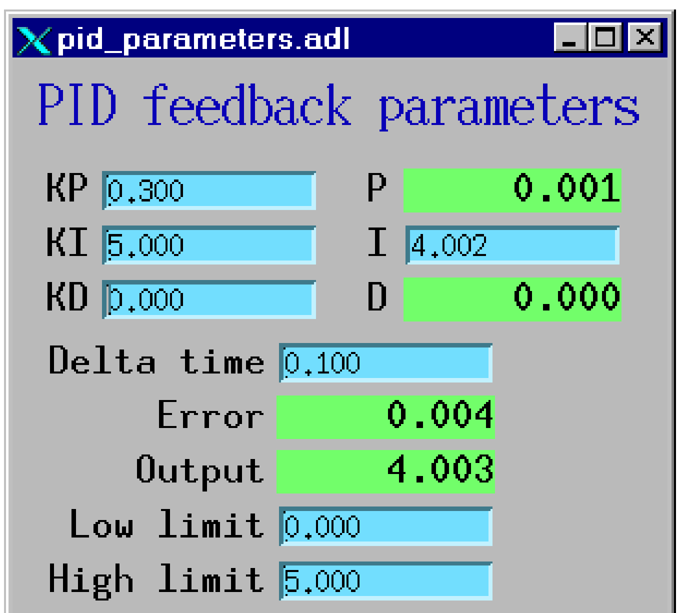
- The EPID record device support performs the following checks to prevent the integral term from growing too large:
  - I is not allowed to increase if the computed output, M(n), is at the high limit, DRVH.
  - I is not allowed to decrease if the computed output, M(n), is at the low limit, DRVL.
  - I is not allowed to be less than DRVL or greater than DRVH.
  - I can be modified from database access or channel access.
    - Allows the user to set I to a specific value to improve response time, rather than waiting for the normal time constant associated with this term.
  - If KI is 0. then set I to DRVL if KP is greater than 0, set I to DRVH is KP is less than 0.
  - If feedback is off don't change integral term.
  - When feedback is changed from OFF to ON set I to the current value of the output PV.

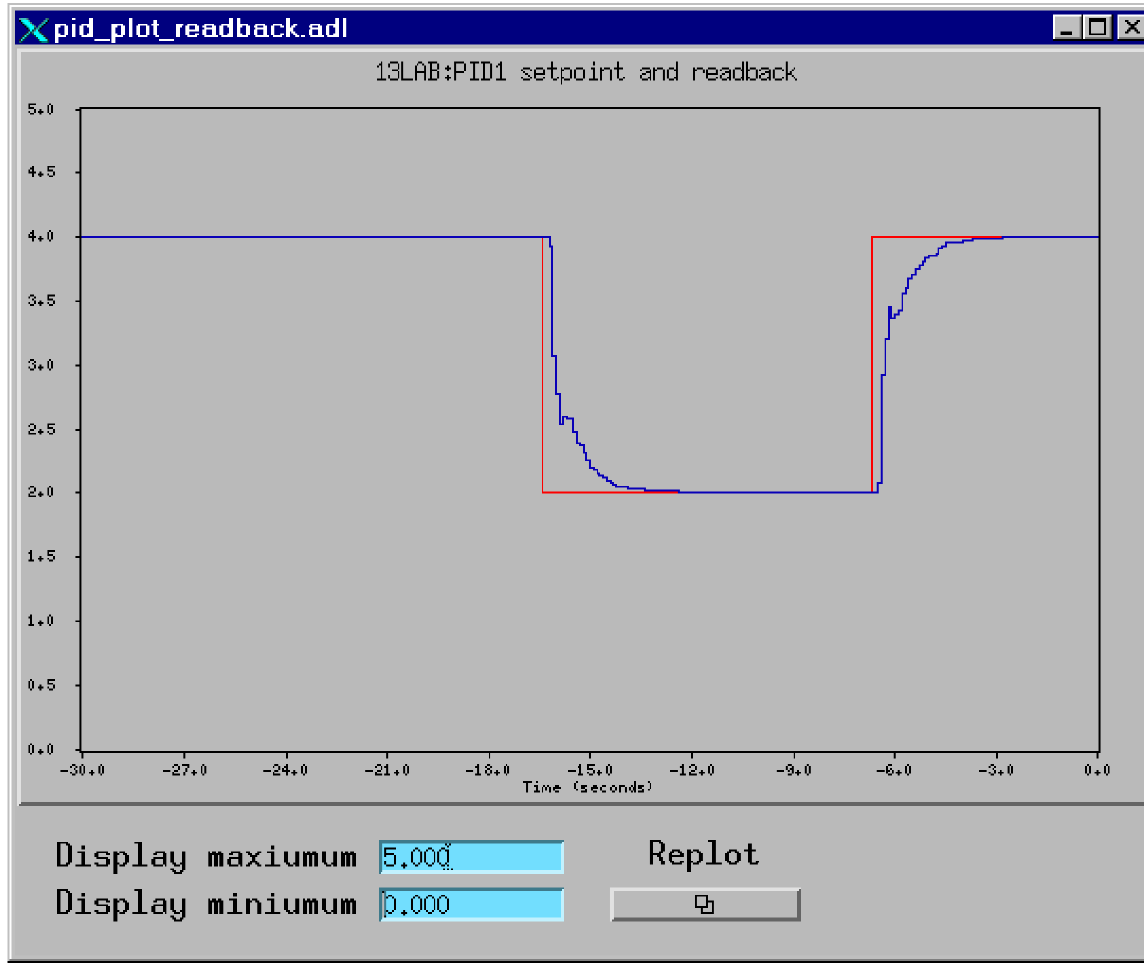
“Slow” Feedback

- The EPID record has two kinds of device support.
- “Soft” device support allows the readback input and control output to be any EPICS process variables.
  - Very flexible
  - Any type of device can be used for input (analog to digital converter, RS-232, GPIB, scaler, etc.)
  - Any type of device can be used for output (digital to analog converter, RS-232, GPIB, etc.)
  - Can be reconfigured on the fly, changing the input and outut process variables, feedback coefficients, etc.
  - Limited to standard EPICS scan rates, typically 10 Hz maximum
  - Sufficient for many applications

Slow feedback - D/A connected to A/D



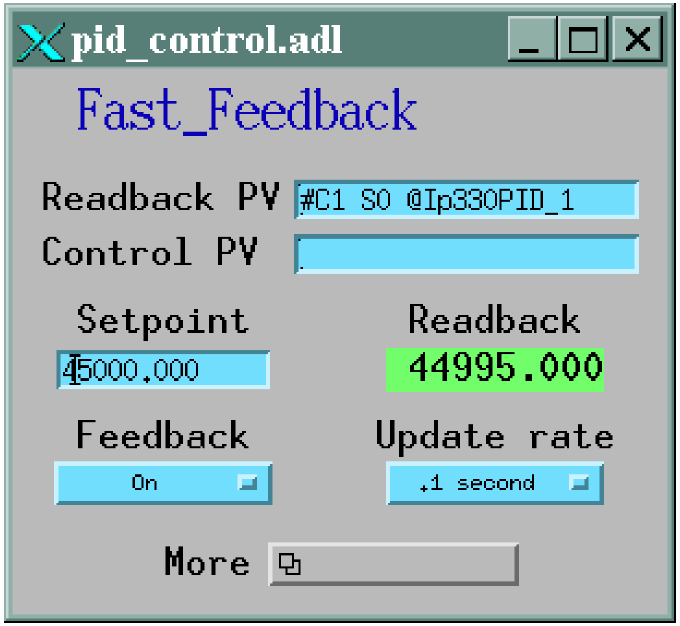


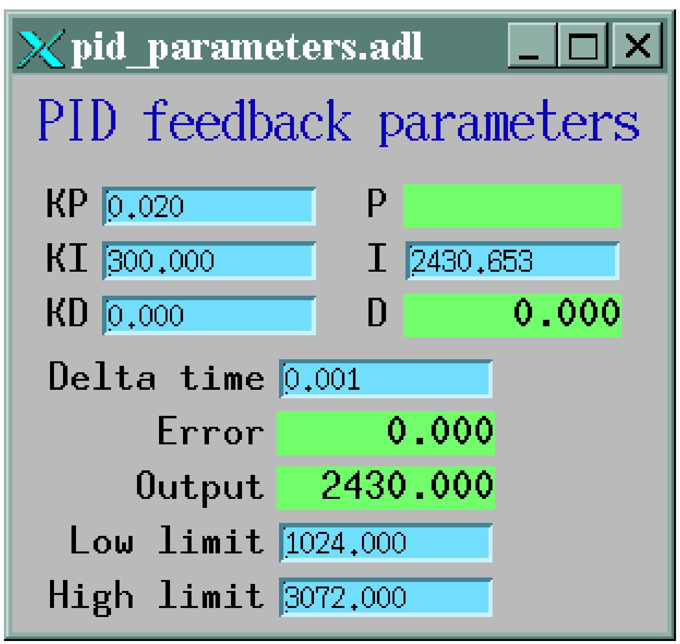


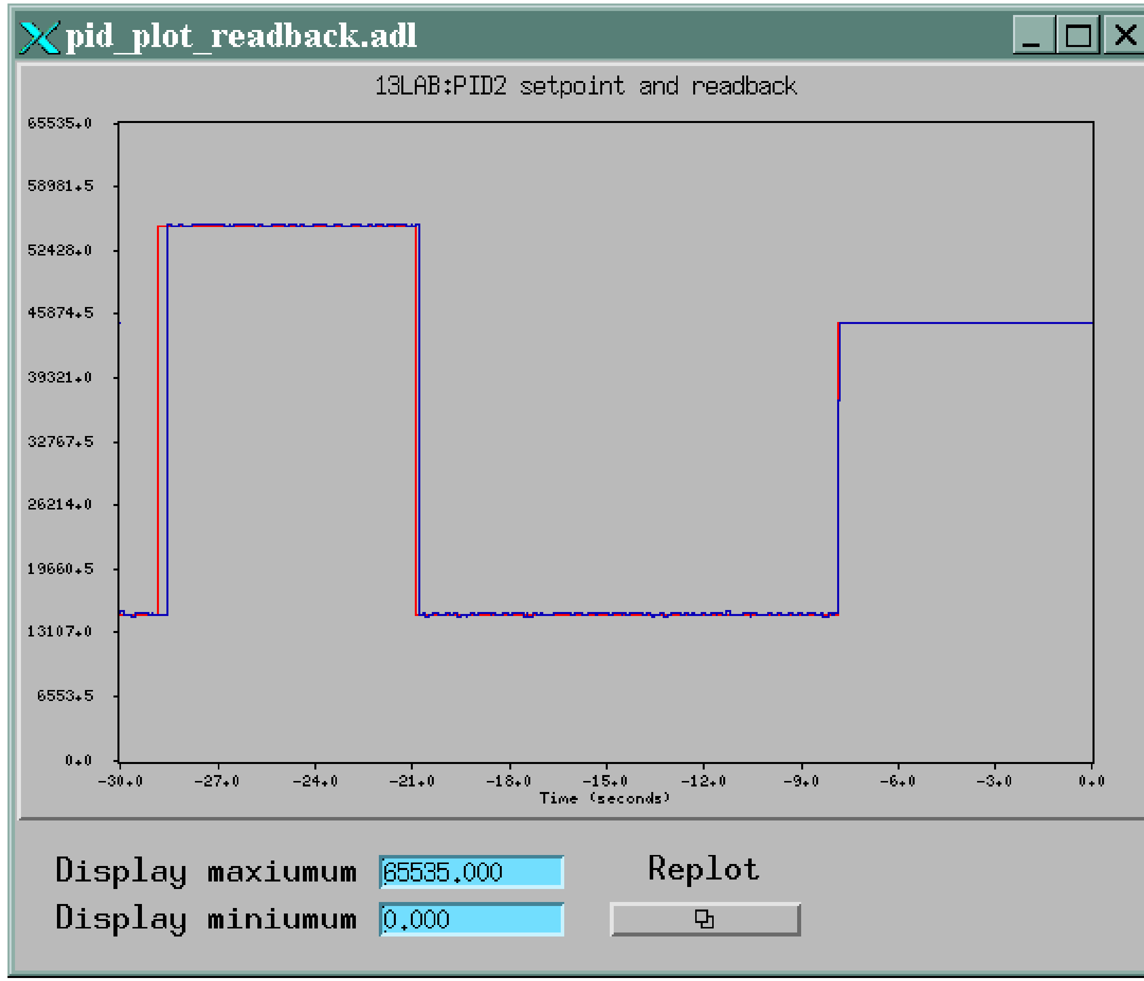
“Fast” Feedback

- “Hardware” device support is presently limited to using the Acromag IP-330 A/D converter for the input and the Systran DAC-128V digital to analog converter for the output
- Inexpensive Industry Pack modules
  - ADC is about $1000 for 16 channels
  - DAC is about $300 for 8 channels
- Very fast
  - Up to 10 kHz feedback rate
- Feedback coefficients and feedback rate be reconfigured on the fly
- Uses the Message Passing Facility to communicate with EPICS
  - The feedback loop can be running on a dedicated inexpensive CPU, such as a MVME162 with only 1 MB of memory

Fast feedback - D/A connected to A/D







GSECARS applications

- Monochromator second crystal feedback on both BM and ID beamlines
- Furnace temperature control in the large-volume press
- Temperature stabilization via laser power control in the laser-heated diamond-anvil cell.

Feedback Tuning: Quick guide to selecting the optimal values for KP, KI and KD.

- Turn off feedback (FBON=0).
- Set KI and KD to zero initially in order to first determine the optimum value for KP.
- If possible calculate theoretically or empirically the "correct" value of KP, e.g. the required change in OVAL to produce a unit change in CVAL.
  - For example if controlling a heater power supply with a DAC which has 10 Watt/volt response, and the heater response is 10 degrees/Watt, then KP=.01 volts/degree.

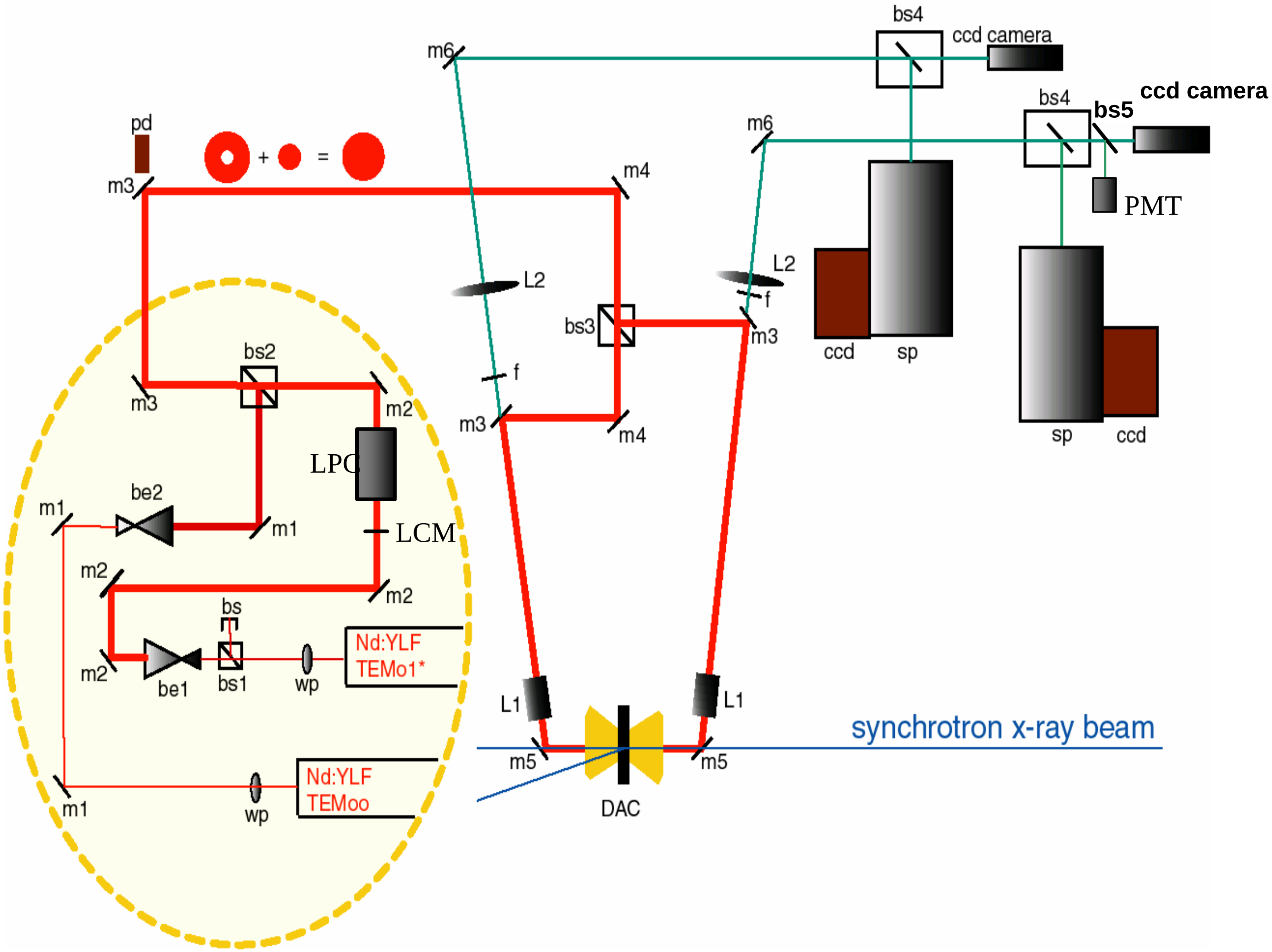
- Set KP to about 10%-25% of the "correct" value computed above.
- Turn on feedback (FBON=1) and make changes in the setpoint (VAL) and observe the system response.
  - Don't worry about system droop (CVAL != VAL), since this is unavoidable when KI=0.
  - Rather look for oscillations and instability.
  - Gradually increase KP while making changes in the setpoint.
  - When KP is too large the system will begin to oscillate.
  - Decrease KP until the oscillations just disappear.

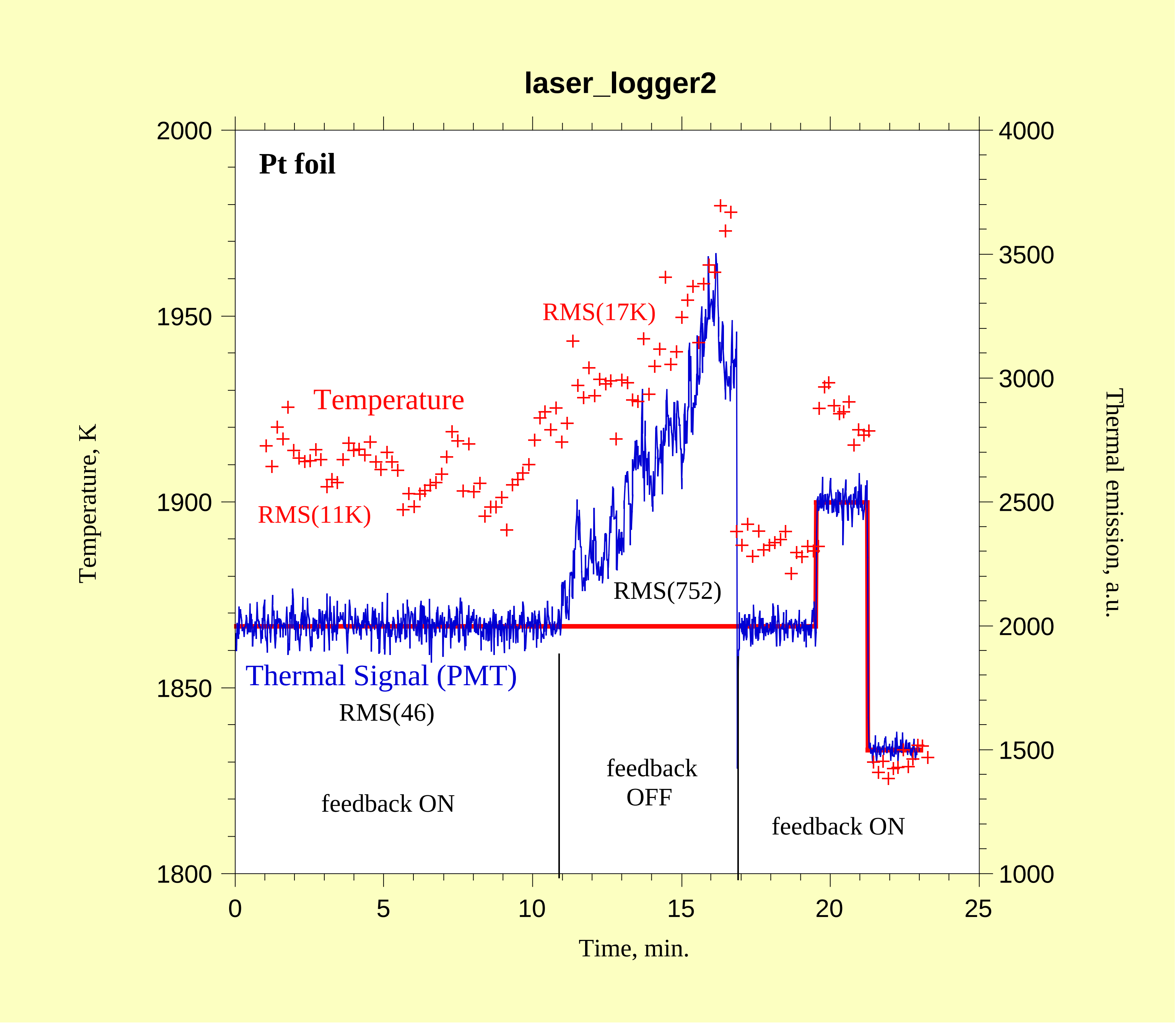
- Increase KI (units of Hz) to eliminate the system droop.
  - The optimum value of KI depends upon the time constant of the system and the update rate of the feedback loop.
  - Increase KI until the system responds as rapidly as possible to changes in the setpoint without overshoot or oscillation.
- For systems with no significant inertia KD should be left at zero.
  - For systems with large inertia increase KD (units of seconds) to minimize overshoot.

Example Application: Laser power stabilization

- Laser-heated diamond anvil cell apparatus
- YLF lasers are used to heat the sample in the diamond anvil cell
- Temperature is measured from the blackbody radiation with an optical spectrometer
- Important to maintain the sample at a constant temperature during the diffraction measurement.
- Read thermal radiation with a photomultiplier
- Control polarization (transmission) of an optical element
- Do not feed back directly on temperature, because this takes several seconds to measure
- Temperature is stable if the thermal radiation is stable.
- Currently using the Acromag A/D converter to directly measure the photomultiplier output, with “fast” feedback.

Double Sided Laser Heating System
at the GSECARS (Sector 13, APS)




laser_logger2
Pt foil
Temperature
RMS(11K)
RMS(17K)
RMS(752)
Thermal Signal (PMT)
RMS(46)
feedback ON
feedback
OFF
feedback ON
Temperature, K
Thermal emission, a.u.
Time, min.
2000
1950
1900
1850
1800
4000
3500
3000
2500
2000
1500
1000
0
5
10
15
20
25

Example Application: Monochromator Second Crystal Stabilization

- In testing used Newport LAE-500 laser autocollimator to measure the angular deviation of the second crystal.
  - The LAE-500 is RS-232, connected to the EPICS crate via the Generic Serial Record
  - Readings decoded with the sCalcOut record.
  - A angle of the second crystal changed via a Queesgate piezo drive.
  - The piezo was controlled by an EPICS D/A output
- In actual operation we feedback the monochromator crystal using the intensity of an ion chamber on the experimental table, using slow feedback at 10 Hz
  - EPID record works very well for this application