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Upgraded RFTS Automation Script

Geoff Waldschmidt

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RFTS Conditioning Script

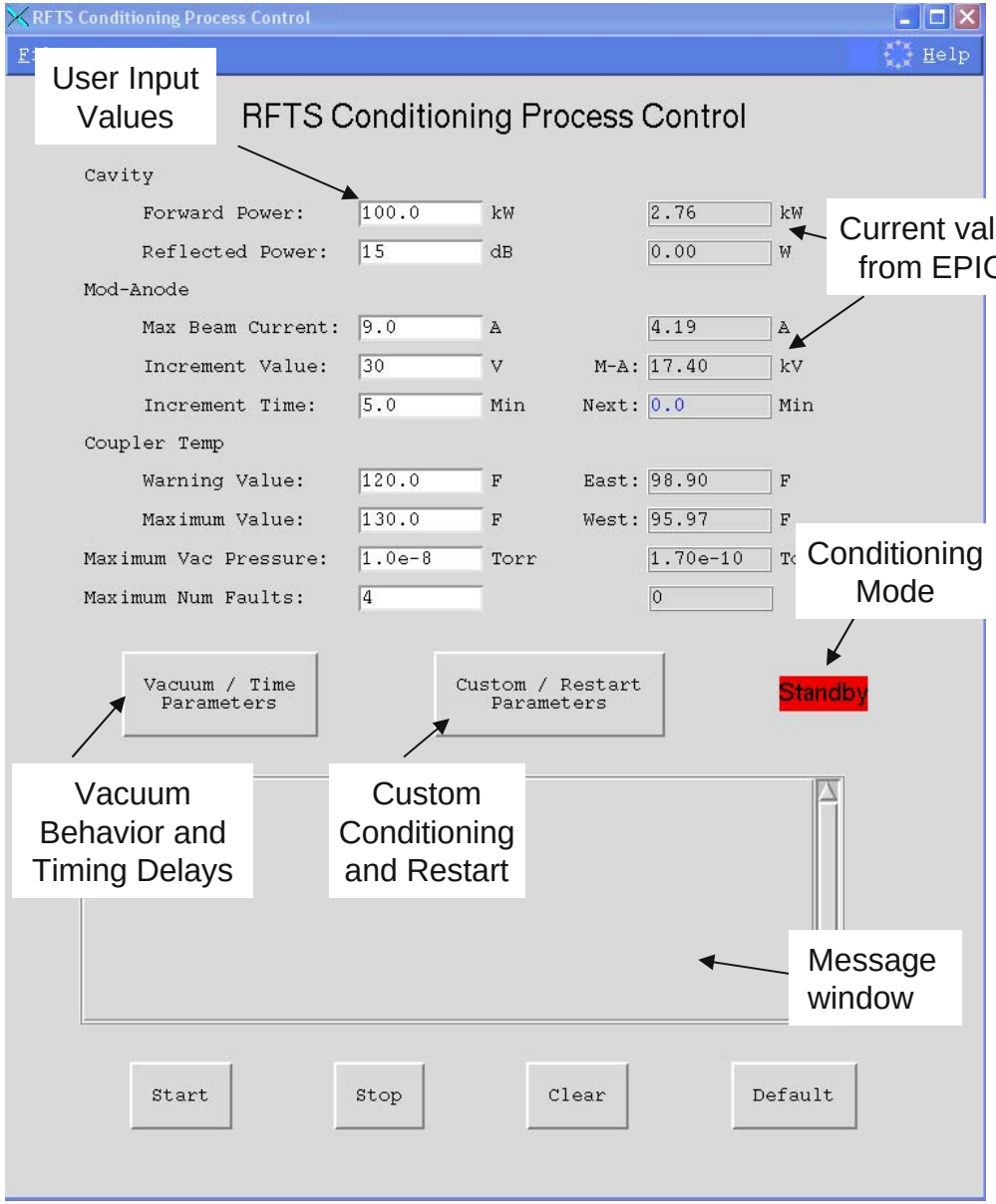
- Intended to eliminate the need for constant supervision of the test stand.
- Designed to be easy to use with few user inputs and limited oversight.
- Conditioning program can be activated after the cavity is setup, pumped down, and at least 5 kW of forward power is present in the cavity (automatic tuning).
- Eight conditioning modes are used to efficiently condition components.
- Program is designed primarily to ensure the safety of the test stand and components under test.
  - Secondary function of automation script is to condition components!
  - Hardware errors and communication errors are constantly evaluated.
  - RF parameters of the components in the RFTS are evaluated against user inputs and known limits.
- Programming method and protocols were modeled after existing APS scripts.
  - Tcl/Tk programming language
  - Communication with hardware is performed via channel access and EPICS
  - Communication errors with EPICS are “caught” and resolved before conditioning continues.

Conditioning Modes

- Eight conditioning modes are used to efficiently condition components.
- ‘Standby’: Conditioning script is not executing. This is the default mode when the GUI is first opened.
- ‘Running’: Conditioning script is executing. This is the nominal mode for typical conditioning process.
- ‘Restart’: Restarts the RFTS after specifically defined faults.
- ‘Recovery 1’: Allows rapid recovery from a restart. First stage of the recovery process. Cavity forward power is brought to a level that is within a range of the cavity power level prior to the fault. Power is increased more aggressively during the first stage.
- ‘Recovery 2’: Allows rapid recovery from a restart. Second stage of the recovery process. Cavity forward power is brought to a level that is within a range of the cavity power level prior to the fault. Power is increased more conservatively during the second stage.
- ‘Delay’: The delay mode delays the conditioning process by imposing a time delay before the mod-anode may be incremented again. This is similar to ‘cooking’ the coupler which is typically done during a difficult conditioning power range.
- ‘Custom’: Conditioning script is executed with a user-defined conditioning schedule. The conditioning schedule consists of user-defined voltage increments and timing information. Voltage increments as well as decrements may be defined to mimic ‘pulsing’ of the rf system.
- ‘Hold’: Conditioning is discontinued. ‘Hold’ is automatically activated when the maximum forward power or beam current is reached. If a fault occurs, the script will restart the RFTS and recover until ‘hold’ is again activated.

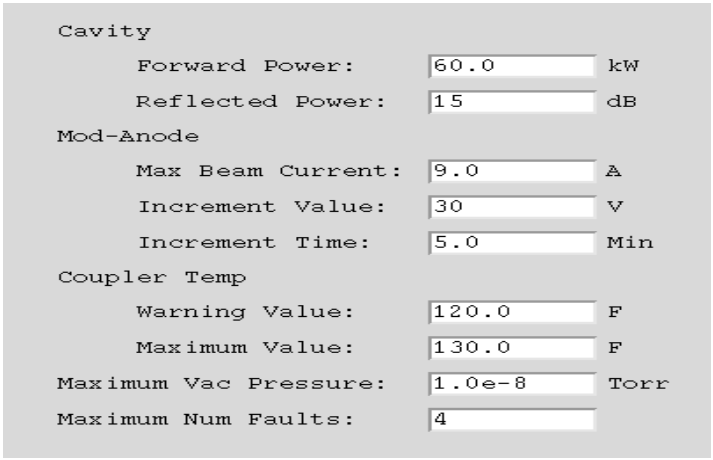
GUI Overview

- Left column of GUI has fields for user input.
- Right column shows values read from EPICS and from the conditioning program
- User inputs include cavity power, mod-anode increment values, coupler temperature, and maximum allowable vacuum pressure.
- Buttons perform following tasks:
  - “Start” the conditioning program
  - “Stop” the conditioning program
  - “Clear” the message window
  - Set the user inputs to their “Default” values.



Main Conditioning Window User Inputs

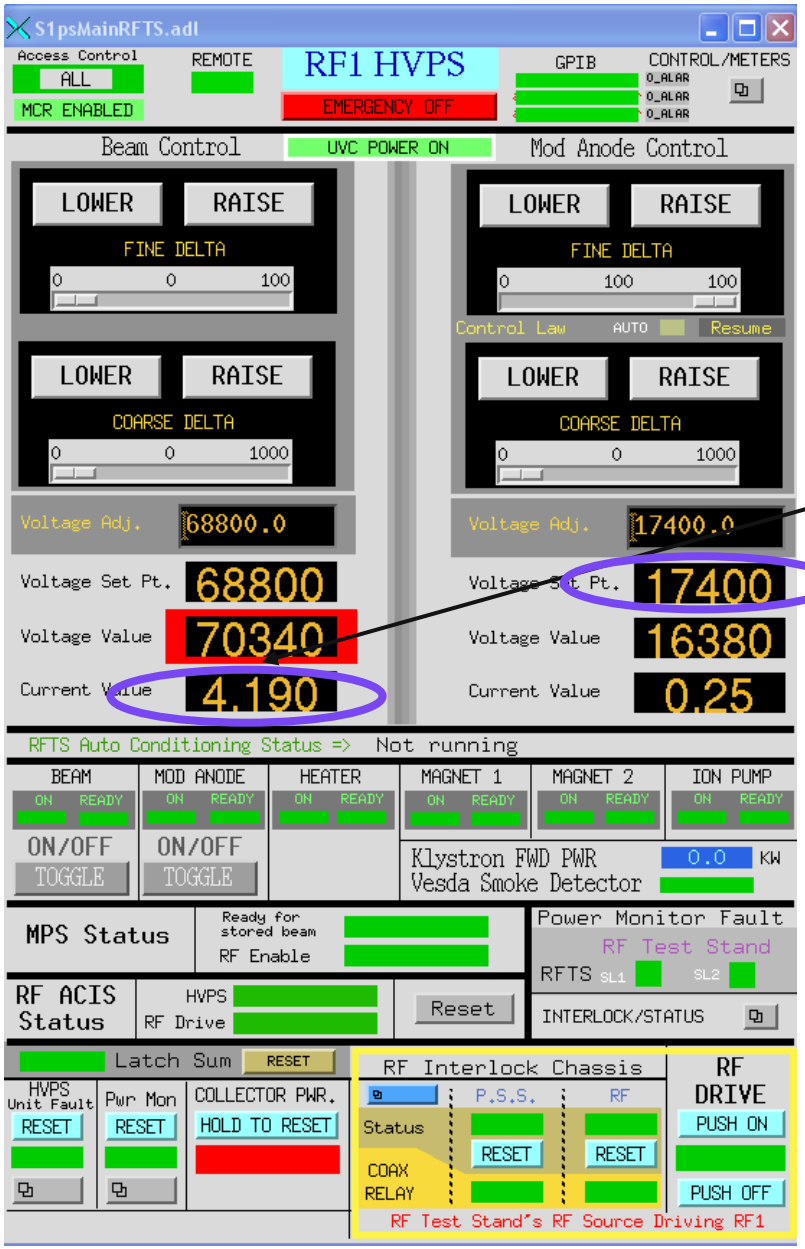
- ‘Cavity’ user inputs are associated with the maximum cavity forward power that is desired and the maximum permissible reflected power.
- The M-A is no longer incremented and conditioning ceases if the cavity reflected power or the maximum beam current is too large.
- ‘Mod-Anode’ inputs correspond to the rate of conditioning by specifying the M-A increment value and the time between increments.
- ‘Coupler Temp’ are inputs meant to protect the coupler from overheating. When the warning value is reached, conditioning is interrupted until it reduces below this value.
- An emergency situation is assumed if the maximum coupler temperature is reached. The script terminates and the rf drive is shutoff.
- While the cavity vacuum is greater than ‘maximum vac pressure’, conditioning is interrupted until it reduces below this value.
- If more than ‘maximum num faults’ occurs during normal conditioning, the script terminates.

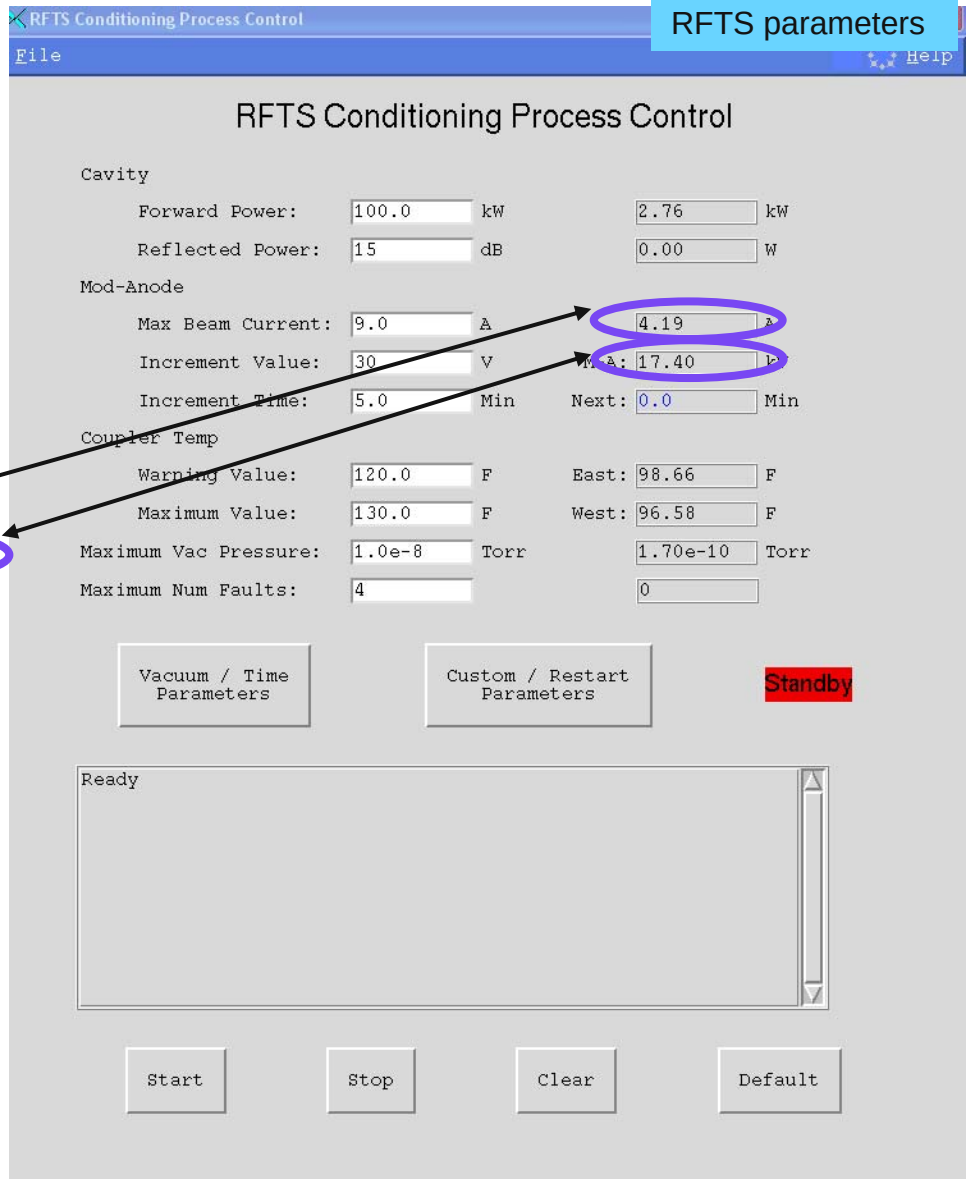


- The conditioning defined above would continue until the forward power into the cavity reached 60 kW.
- If the reflected power exceeded -15dB or if the beam current exceeded 9.0A, the script would terminate.
- After the appropriate time has expired, the M-A is incremented by 30V where the nominal increment time is 5.0min.
- If either the west or east coupler temperatures exceeded 120.0^{o}F, the M-A would not be incremented until the temperature was reduced. If the temperature exceeded 130^{o}F, the script would terminate and rf would be shutoff.
- The M-A would not incremented until the vacuum pressure was below 1e-8.
- If more than 4 faults occurs, the script terminates.

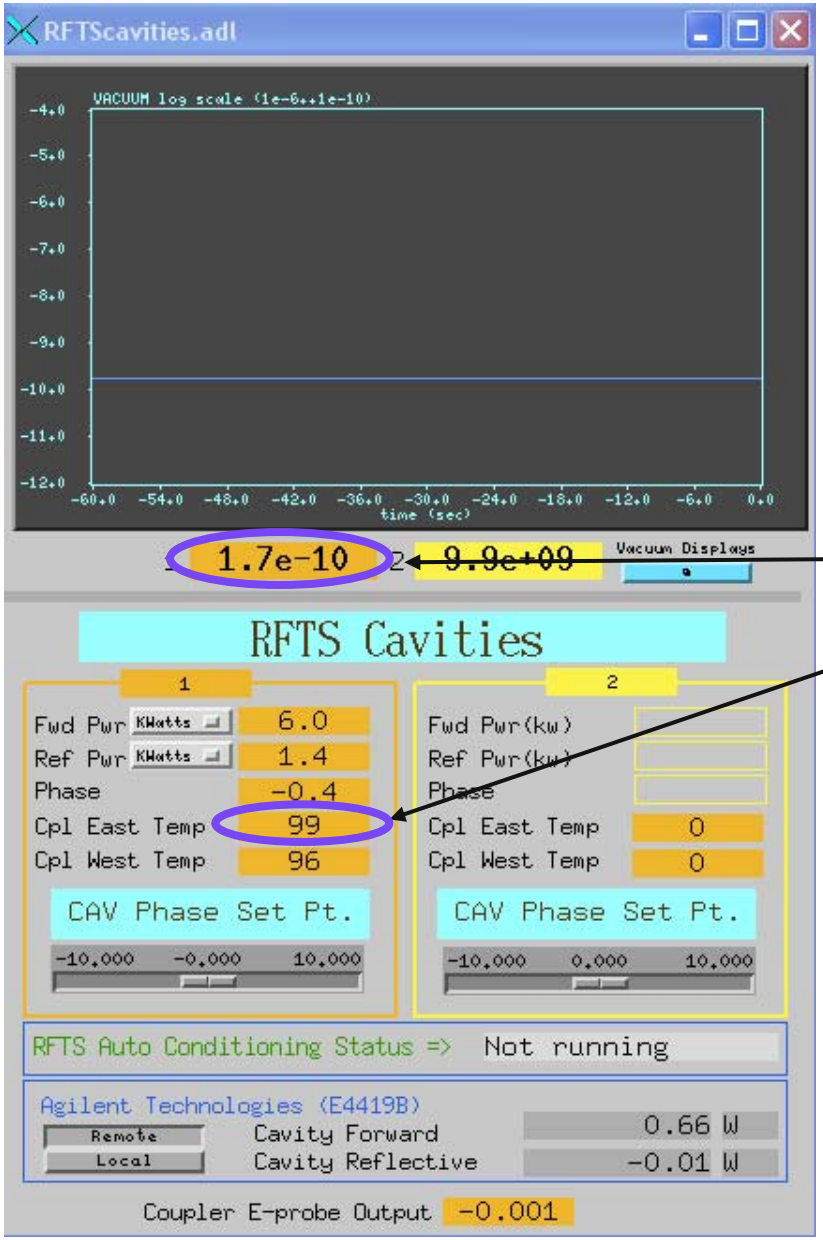
Main Conditioning Windows Epics Interface: High Power

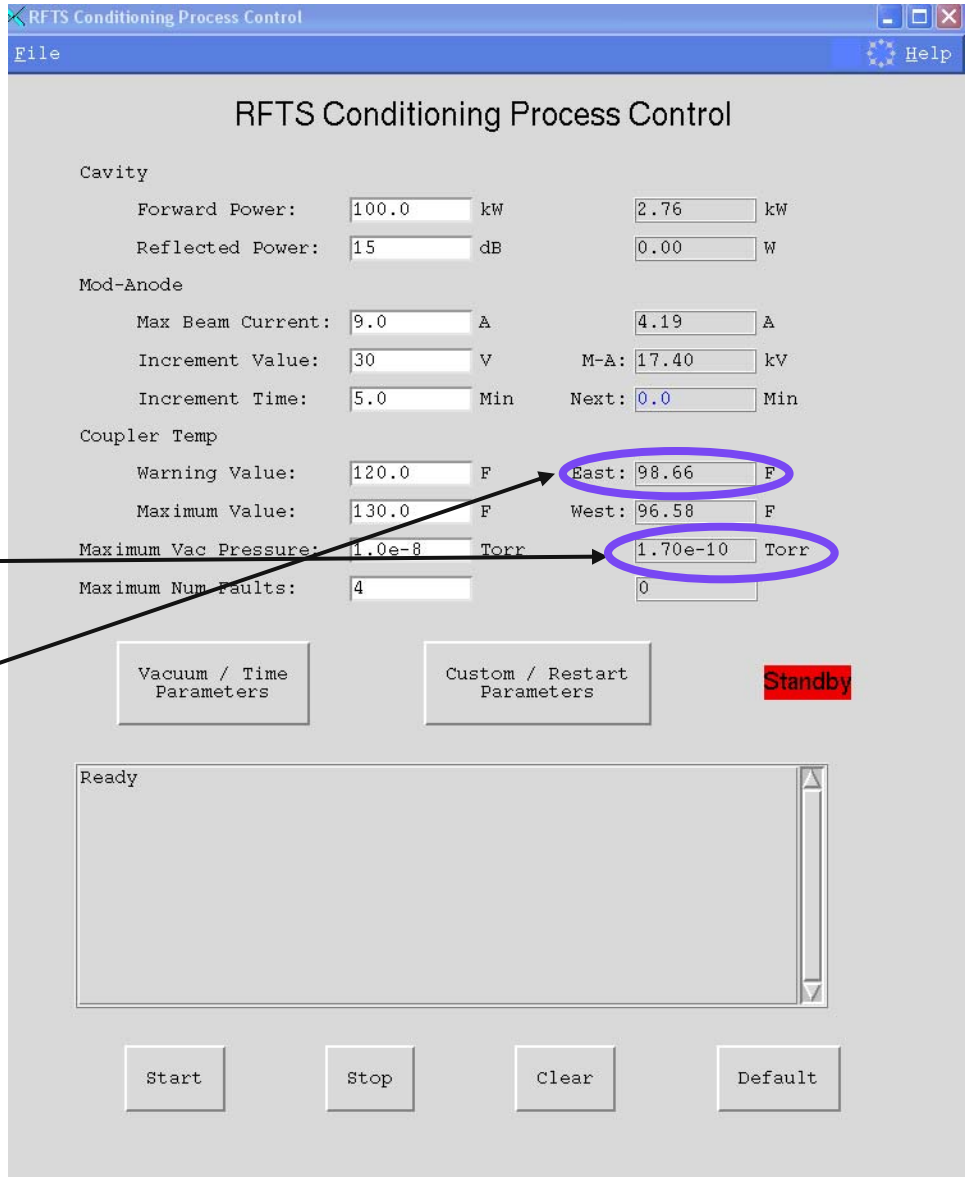
GUI displays current values of RFTS parameters





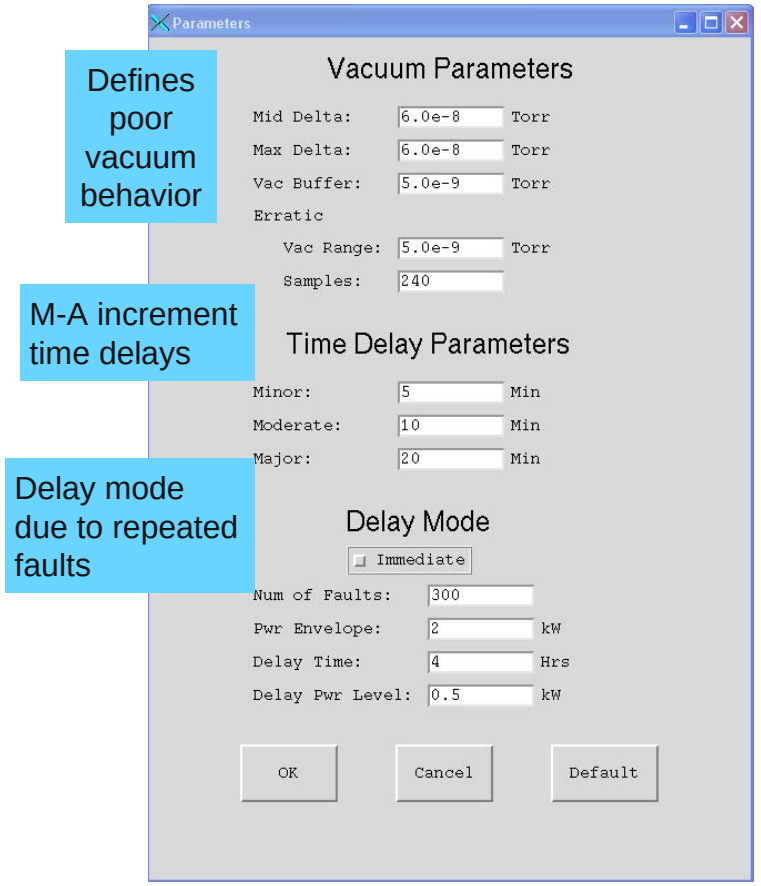
Main Conditioning Windows Epics Interface: Cavity





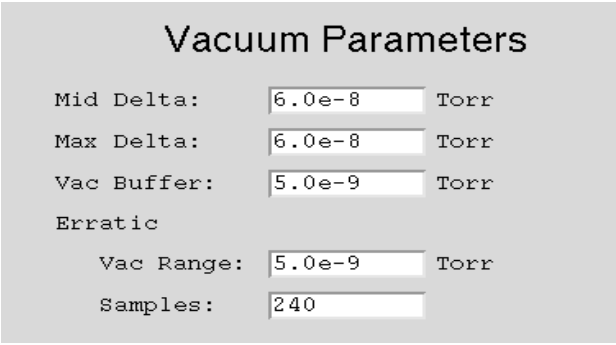
Vacuum / Time Parameters GUI

- Vacuum parameters set the values used for vacuum behavior monitoring.
- Poor vacuum is typically defined as erratic or improperly settling between M-A voltage increments.
- Time delays are used when conditions are not suitable for the mod-anode to be incremented such as poor vacuum and coupler temperature.
- Time delays have varying severity depending on the circumstances.
- Delay mode is used to slow the conditioning process and acts as a specialized time delay.
- If repeated faults occur, delay mode prevents the M-A from incrementing for an extended period of time.
- Delay mode mimics leaving the test stand at a given power level to slowly condition rough conditioning zones.
- Once delay mode has completed, normal conditioning resumes.



Vacuum Parameters

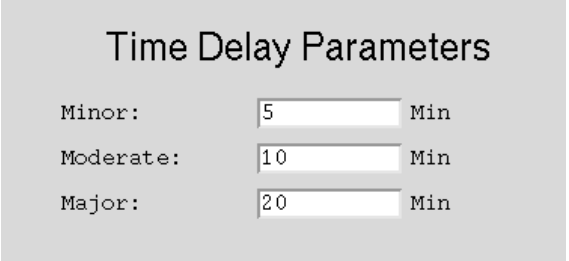
- Vacuum parameters categorizes poor vacuum behavior.
- 'Erratic' vacuum refers to relatively rapidly varying vacuum values. It is defined using the difference between vacuum samples.
  - The number of 'samples' is a user input that specifies how many vacuum samples will be compared with the most recent sample acquired from EPICS.
  - A poor vacuum condition is determined if the difference between the vacuum samples is greater than 'vac range'.
- 'Vac buffer' monitors the difference between the vacuum level prior to a M-A increment to just before the next increment.
  - If the difference is greater than 'vac buffer', the vacuum is not settling sufficiently.
  - 'Vac buffer' is tested only just prior to a M-A increment. If 'vac buffer' is exceeded, the M-A increment is postponed.
- 'Mid/Max Delta' compares two sequential vacuum samples. If the difference exceeds the user input value, poor vacuum is defined. It is rarely used since 'erratic' vacuum is more flexible.
- When poor vacuum is determined, a time delay is charged which postpones the next possible increment of the M-A.
- Vacuum behavior is not evaluated immediately after the M-A is incremented in order to let the vacuum settle. This delay ranges for a number of seconds following the increment.
- Time delays are defined in the 'Vacuum / Time' GUI.



- From the above parameters, if the difference between successive vacuum values is > 6.0e-8, a 'mid / max delta' condition is defined. ('Mid / max delta' is effectively disabled by the large user-input value.)
- When it is time to increment the M-A, if the current value of the vacuum is at least 5.0e-9 higher than the value of the vacuum before the last M-A increment, a 'vac buffer' condition is defined.
- If the current vacuum sample is 5.0e-9 ('vac range') larger than any of the previous 240 'samples', then an 'erratic' vacuum condition is defined.
- Time delays are assigned to the conditioning based on the vacuum condition that has been determined.

Time Parameters

- Time delays are used when conditions are not suitable for the mod-anode to be incremented.
- Time delays are assigned due to poor vacuum or reaching warning levels for the coupler temperature.
- Time delays are also assigned to high vacuum which is defined in the main GUI as ‘maximum vac pressure’.
- Time delays are characterized from minor to major depending on the specific vacuum condition.
- Time delay lengths are user-defined.
- If a time delay is imposed, the current ‘mode’ of the script is not changed.
- Time delay values may not be preempted. They are in effect during the ‘running’, ‘recovery’, and ‘custom’ modes of operation.
- The main GUI message window prints a description of any time delay.

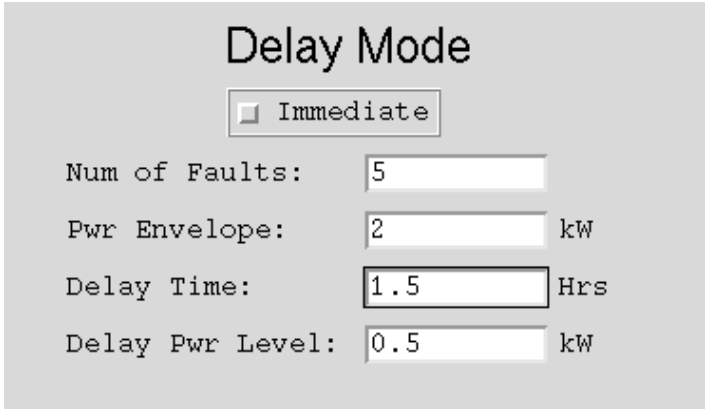


Warning	Time Delay
Mid Delta	Moderate
Max Delta	Major
Vac Buffer	Minor
Erratic Vacuum	Moderate
High Vacuum	Major
Coupler Temp Warning	Major

Time delay levels associated with various circumstances in the test stand during the conditioning process.

Delay Mode

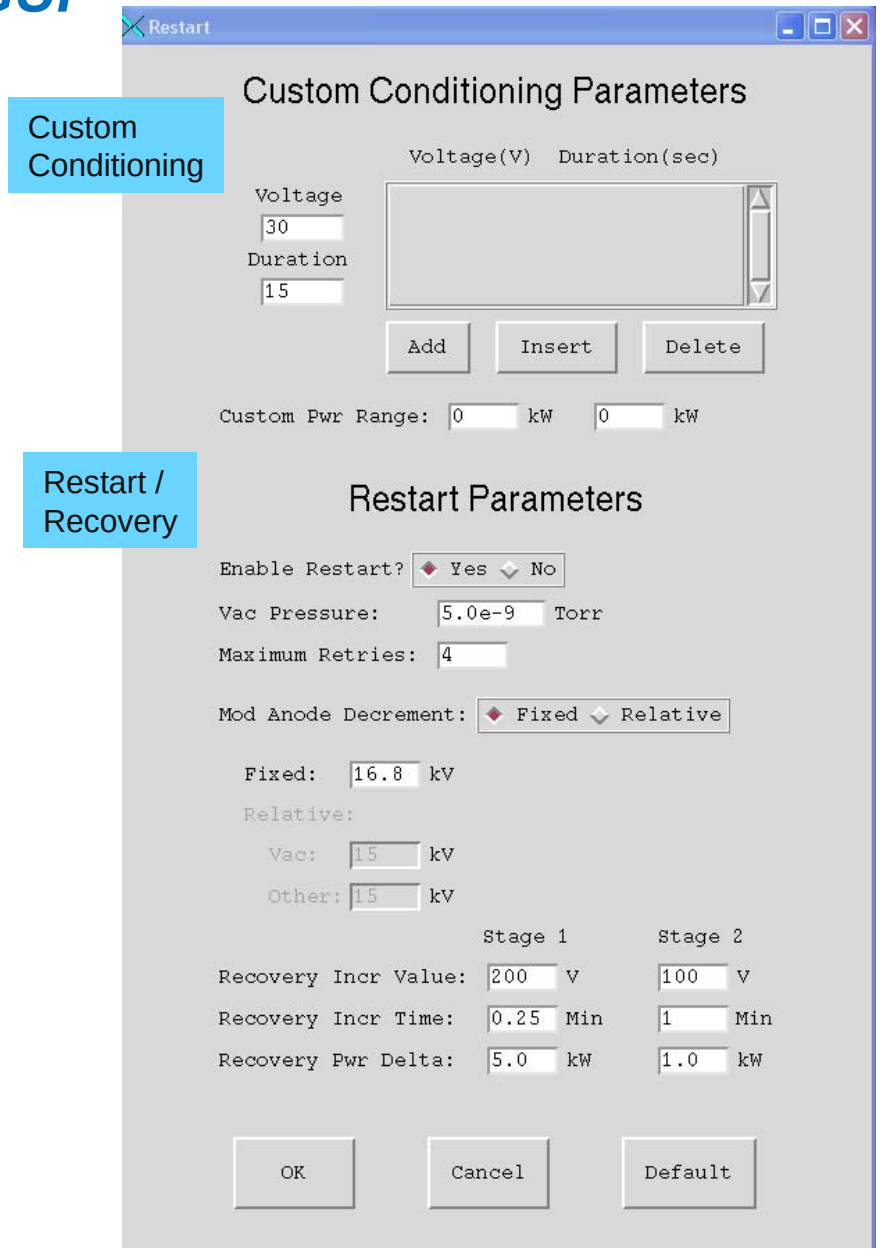
- Delay mode delays the conditioning process, but does not terminate the script.
- It's motivation is to slow down the rate of conditioning in case of repeated faults determined by 'num of faults'.
- Imposes a long delay defined by 'delay time' which suspends any further M-A increments.
- If 'num of faults' faults occurs during conditioning where the faults occur within a certain power range defined by 'pwr envelope', the delay mode will be initiated after the system is restarted and the cavity is brought to a power level that is 'delay pwr level' below the minimum power level of the last 'num of faults' faults.
- Delay mode will abort the recovery modes which are part of the restart process.
- Delay mode will interrupt custom conditioning, but will not abort it. Custom conditioning will resume following the completion of the delay mode.
- Delay mode will not interrupt custom conditioning midway through a schedule. The custom conditioning schedule must be fully completed. The custom conditioning schedule consists of all the steps listed in the text box in the 'custom / restart parameters' GUI.
- 'Immediate' activation of delay mode can be initiated through the radio button. This is used if the user does not wish to wait for a prescribed number of faults before initiating delay mode upon script startup.



- The delay mode as defined in the above window may begin after 5 faults have occurred.
- The cavity power level of the 5 faults must be within 2 kW of each other.
- If the above conditions are true, the delay mode will be activated when the cavity power level reaches 0.5 kW below the minimum power level of the 5 faults after the system has been recovered after a fault.
- If the delay mode is activated, a time delay of 1.5 hours will be imposed before the M-A will increment again.
- After 1.5 hours, the script will return to normal operation pending another fault.

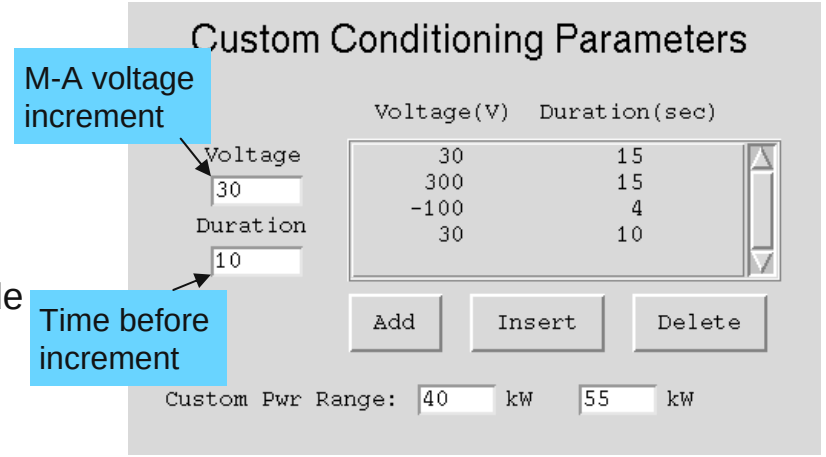
Custom / Restart Parameters GUI

- Custom / Restart GUI allows the user to tailor the conditioning process.
- A custom conditioning schedule can be uniquely defined for troublesome conditioning regions.
- Conditioning schedule supports an arbitrary number of conditioning steps.
- Restart capability can be enabled or disabled for a conditioning run.
- If enabled, a restart only occurs for specific faults such as vacuum trips and certain types of arcing.
- Restart permits ramping of the forward power in two stages to facilitate quicker recoveries from a fault.
- A restart is initiated by resetting the mod anode voltage to a user defined fixed or relative value.



Custom Conditioning

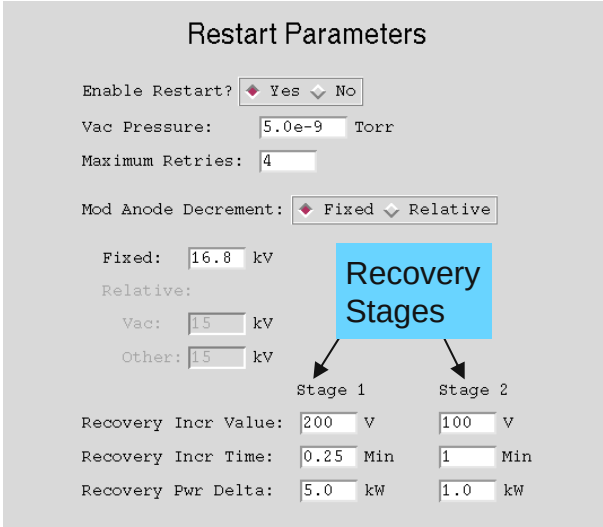
- Custom conditioning allows a user-defined conditioning schedule.
- A text box lists each of the steps comprising the conditioning schedule. The schedule may be easily tailored using the GUI buttons.
- The schedule defines the incremental mod anode voltage and the duration before that voltage increment will be implemented.
- Positive and negative increments are permitted.
- The custom power range defines when the custom scheduling will be activated.
- The custom conditioning schedule executes the entire schedule unless a hardware limit or maximum user-defined power is reached (defined in the main GUI window) or an interlock trips.
- If poor vacuum behavior or a warning coupler temp occurs, a time delay will be imposed as defined in the Vacuum / Time Parameters GUI. However, the schedule will continue with only a temporarily modified time delay.
- Safety limits are imposed on the upper limit of the user-input voltage increment and decrement as well as the timing duration.
- The script does not allow the beam current to drop below 4A. If this occurs, the current is increased and the script is terminated.



- Schedule defined above would begin when the cavity power reached 40 kW and would continue until it reached 55 kW.
- The schedule would execute as follows:
  a. Wait 15s and increase M-A voltage by 30V.
  b. Wait 15s and increase M-A by 300V.
  c. Wait 4s and decrease M-A by 100V.
  d. Wait 10s and increase M-A by 30V.
- Once an iteration of the schedule is complete, schedule execution will continue if the custom mode is still active.
- Delay mode supersedes custom conditioning, but it does not terminate it.

Restart Parameters

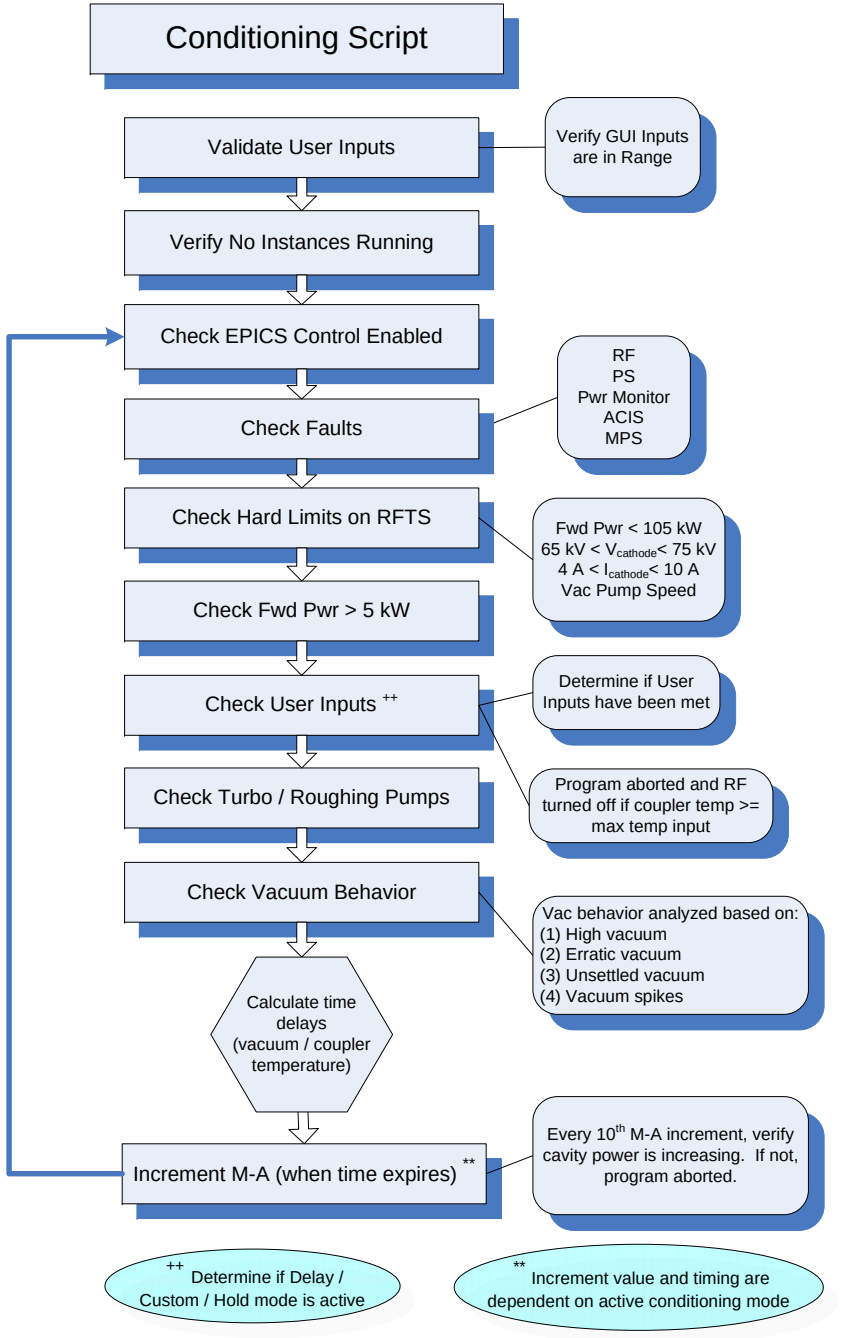
- Conditioning program can automatically restart after certain types of faults.
- Program can recover from a klystron arc, circulator internal / load / out arc, and vacuum faults
- Restart is activated by selecting the “Yes” radio button in the “Automatic Restart” GUI frame.
- Restart is initiated when the conditioning program determines that a fault is recoverable and automatic restart is enabled
- During a restart, the program reduces the mod anode voltage by a user specified amount or it is set to a ‘fixed’ value.
- If a restart is successful, the recovery mode is initiated.
- Recovery enables the conditioning process to quickly return to a level close to the level prior to the fault.
- Recovery has two stages whose active ranges are defined by the ‘recovery pwr delta’ which is defined relative to the power level just prior to the fault.
- Multiple recovery stages allows rapid recovery through well-conditioned power levels, and more conservative recovery through more recently conditioned power levels.



- Stage 1 recovery input defines a 200V M-A voltage increment every 0.25 minutes.
- Stage 1 is to remain active until the cavity power is within 5kW of the power prior to the fault.
- Upon completion of Stage 1, Stage 2 is activated with 100V increments every 1 minute until the power is within 1kW of the pre-fault power level.
- Typical running mode resumes after recovery.

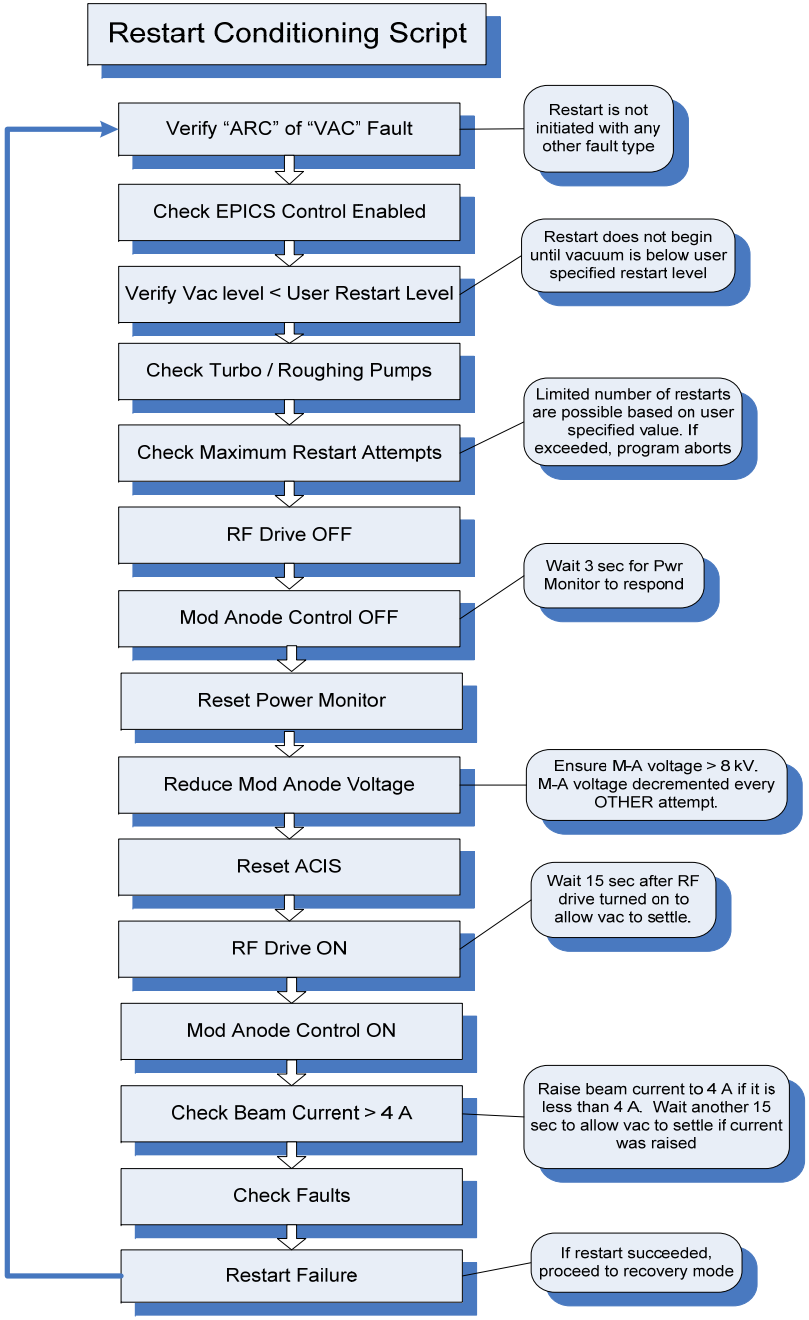
Conditioning Logic Flow

- Conditioning script is activated when the “Start” button is selected.
- Conditioning can be aborted by selecting “Stop”, by terminating the GUI, or turning off EPICS “Program Control”.
- Nominal operation of conditioning script is the ‘Running’ mode.
- ‘Delay’ / ‘Custom’ / ‘Hold’ modes may be activated based on user-input and hardware imposed values.
  - Various modes may be activated by user / hardware specifications and fault history.
  - ‘Delay’ mode will increase the M-A increment time.
  - ‘Custom’ mode will create a user defined schedule consisting of M-A increment values and timing.
  - ‘Hold’ mode will prevent further conditioning but will enable recovery from a fault.
- RFTS system is constantly evaluated for faults, poor vacuum behavior, user inputs and hardware limits.



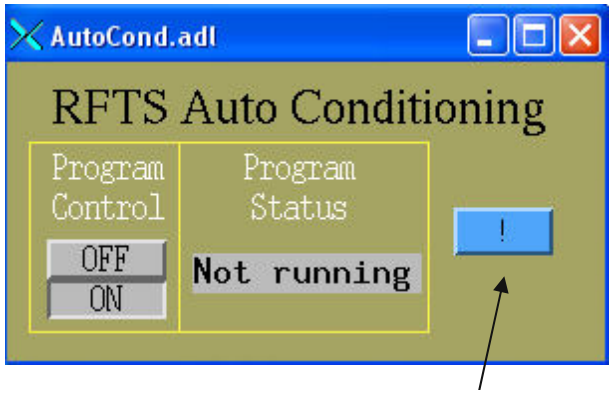
Restart Logic Flow

- Restart is initiated when a recoverable fault occurs and automatic restart is enabled.
- If power supply is off due to the fault or if the fault is not recognized, restart is aborted and the conditioning program is terminated.
- RFTS is restarted by using the mod-anode control during the restart process.
- Mod-anode is not permitted to be lowered below 8 kV.
- If beam current drops below 4 A, the current is increased until > 4 A. No further mod-anode decrements are permitted.
- If necessary, restart is retried up to the user input retries specified in Custom / Restart GUI.
- After a successful restart, stage 1 of the recovery mode is initiated.
- ‘Recovery’ modes 1 and 2 transition to the ‘Running’ mode when the specified power level is achieved.
- The delay or custom modes may interrupt the completion of the ‘recovery’ modes.



EPICS Master Control

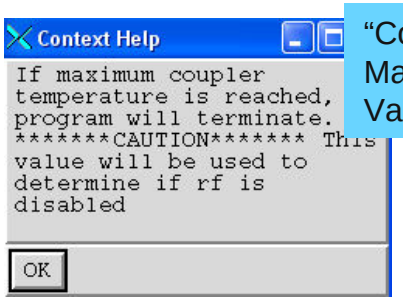
- Conditioning GUI is started from EPICS screen (“!”)
- “Program Status” shows whether a conditioning script is executing.
- When the “Start” button is pressed in the GUI, the “Program Status” changes to “Running”
- If “Program Status” is “Running”, then no other conditioning scripts are permitted to execute. However, there is no limit to the number of GUI’s that may be opened.
- “Program Control” controls whether ANY conditioning script can be running.
  - Deny program execution
  - Abort any instance of conditioning script
- If “Program Control” is “OFF”, then no script can run. In fact, any running scripts are terminated.
- EPICS master control enables the user to regain control of the script if it is running elsewhere or in an undetermined location.



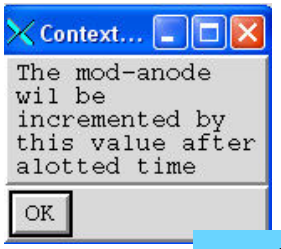
Opens the latest version of the auto-conditioning GUI

GUI Help and Message Window

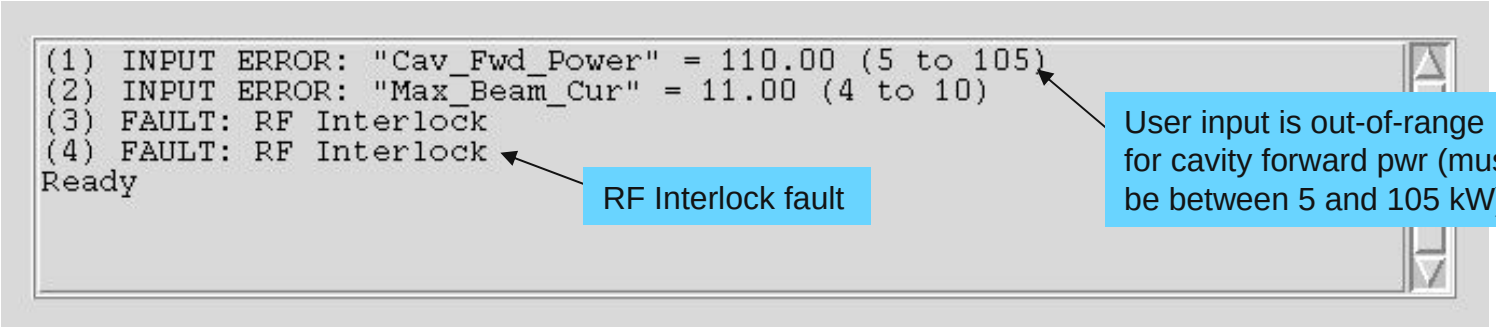
- Help messages are available by dbl clicking the right mouse button over the field in the GUI.
- Comprehensive help messages are available for all user inputs.
- Help messages are intended to give general information and tips for entering values.
- Message window is a text box at the bottom of the main GUI window.
- Message window displays errors and warnings related to user inputs, hardware limits, interlocks, etc and time stamps the message.
- Messages that are relevant to the conditioning process are displayed such as unusual vacuum behavior, coupler temperature, restart status, etc.
- Message window is meant to inform the user of the status of the conditioning script and the hardware.



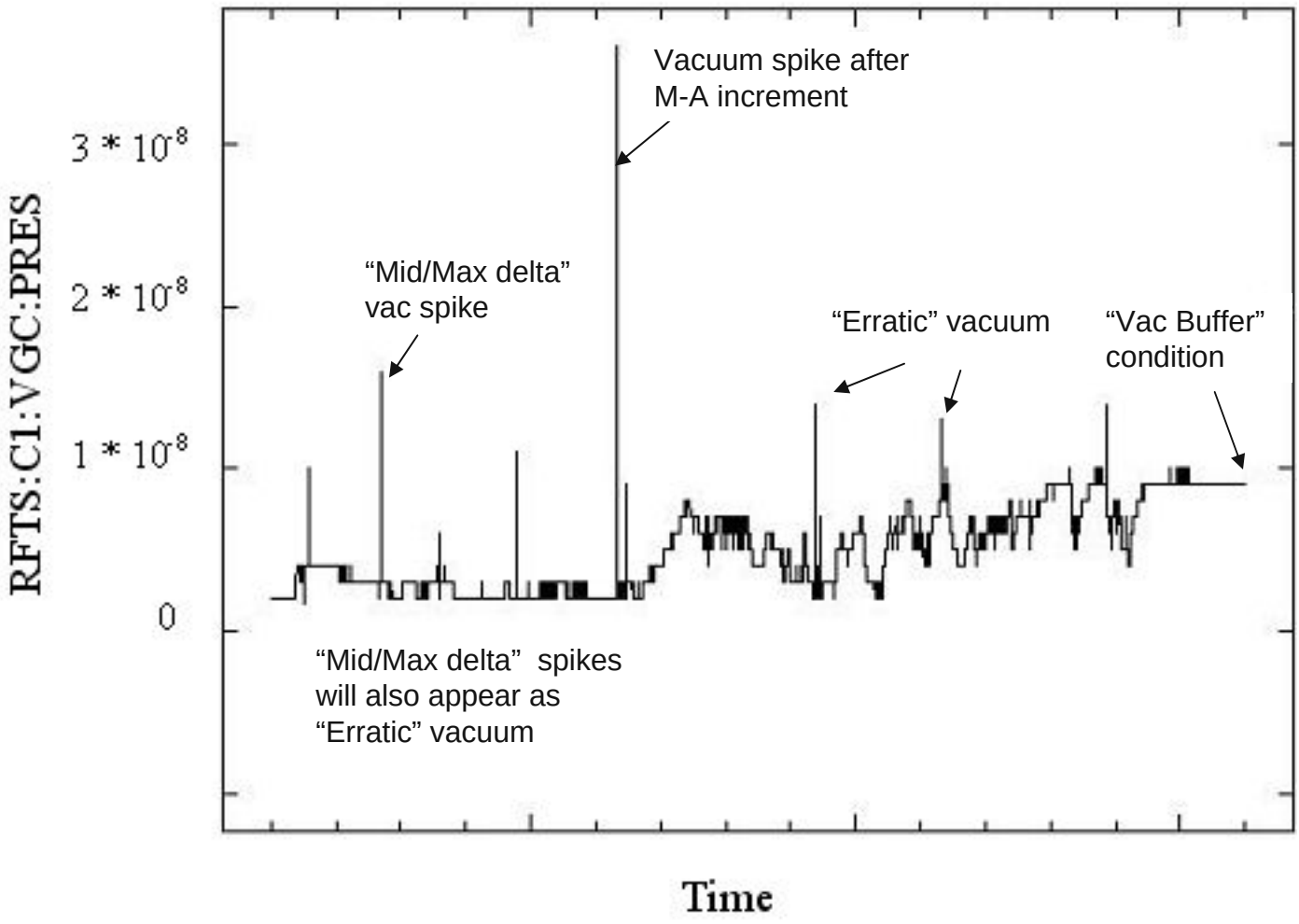
"Coupler Temp Maximum Value" help text



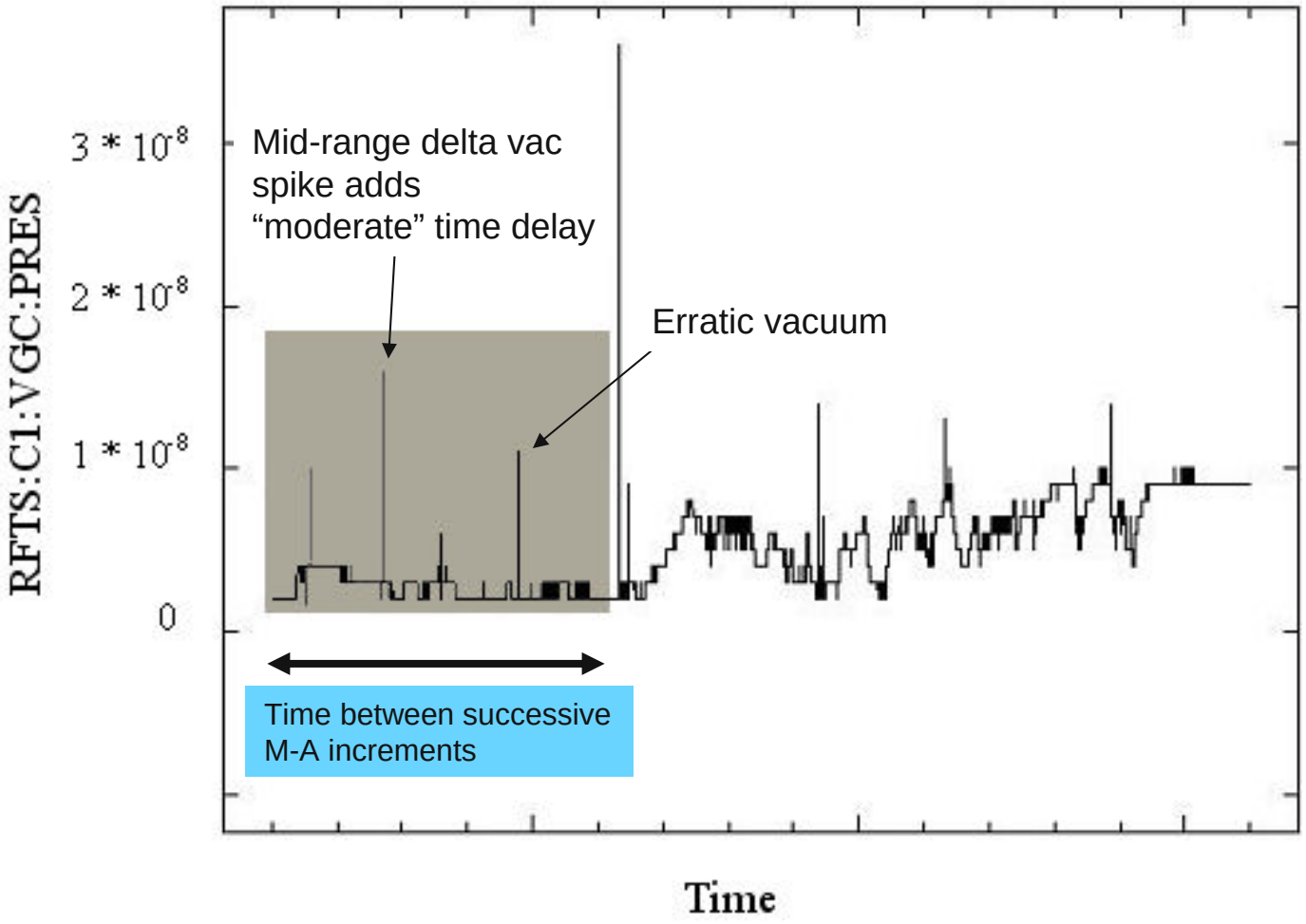
"Mod-Anode Increment Value" help text



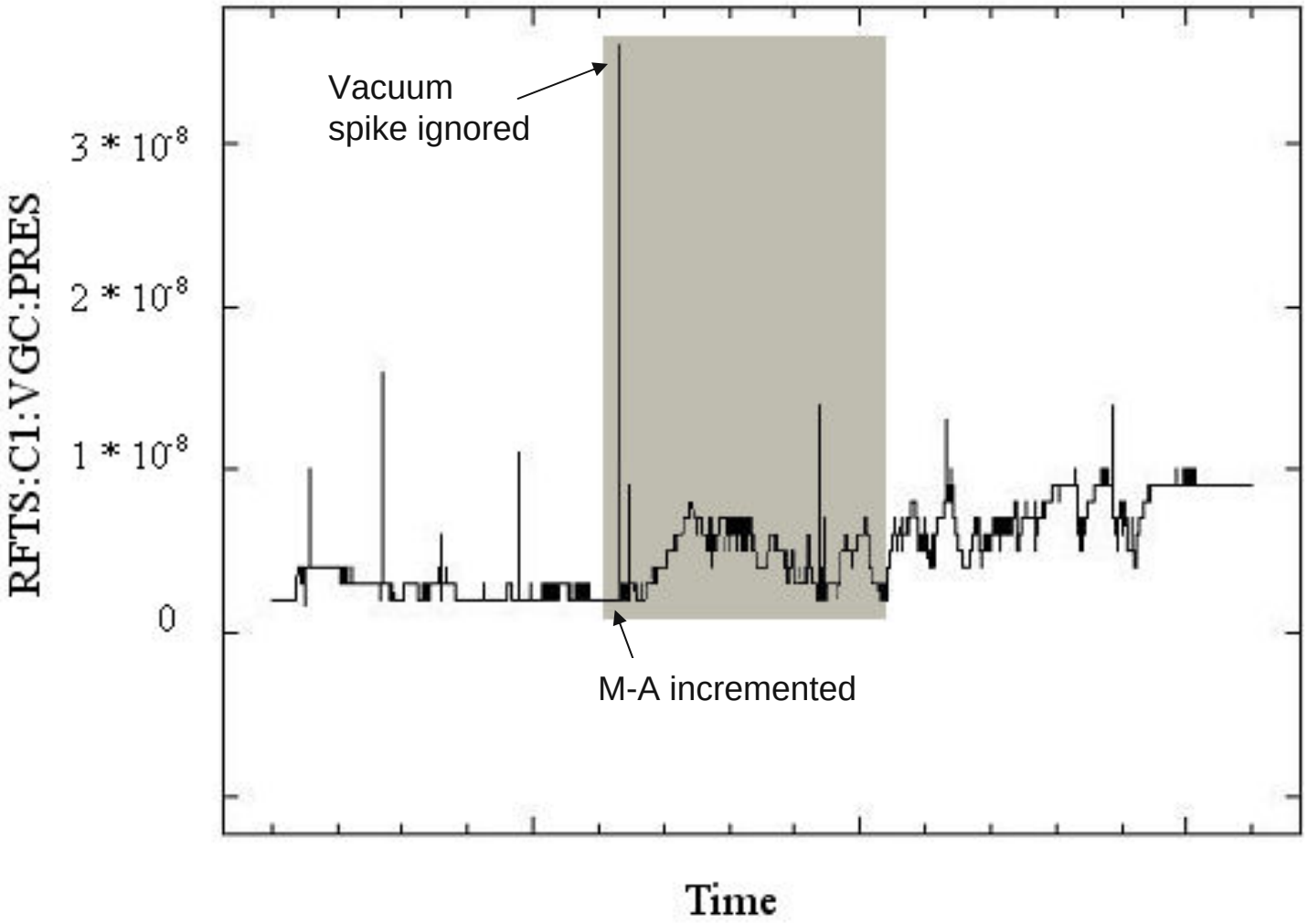
Vacuum Behavior Overview



Time-Frame I: 'Mid / Max Delta' and 'Erratic' Condition

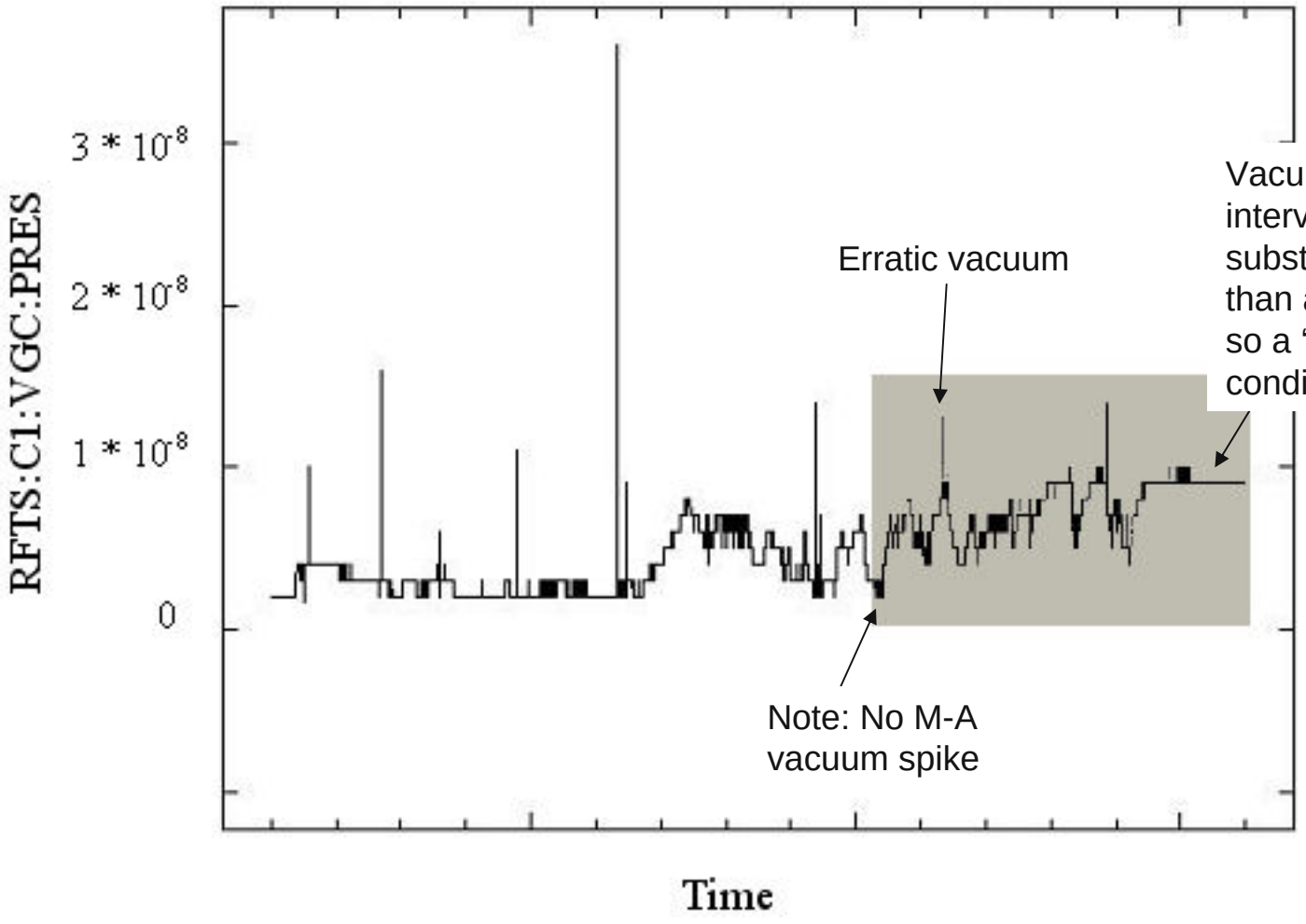


Time-Frame II: M-A Vacuum Spike

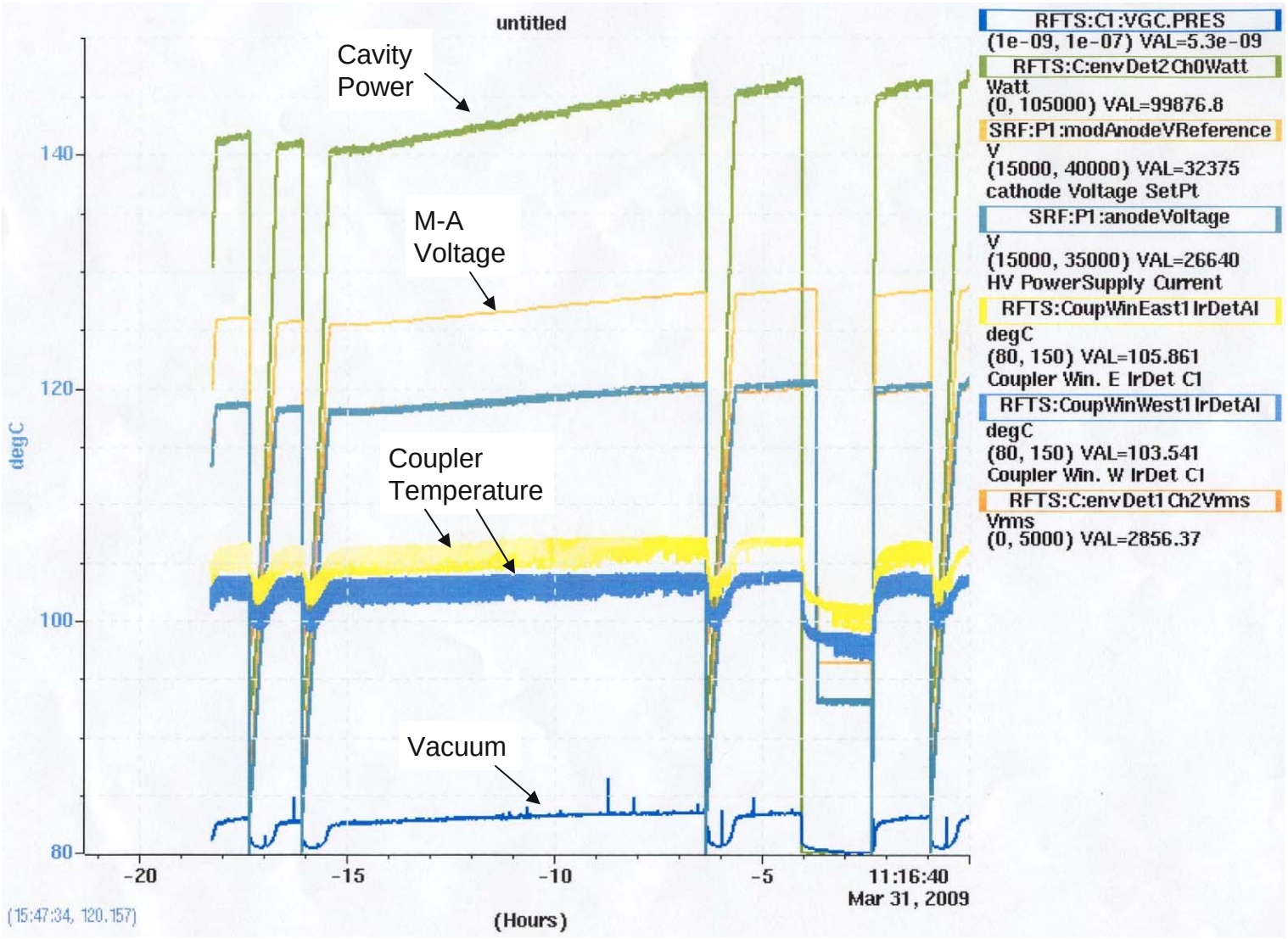


Conditioning script waits for a number of seconds (currently 5s) before it evaluates the vacuum behavior. As a result, the M-A vacuum spike does NOT introduce a time delay (assuming the spike duration < 5s)

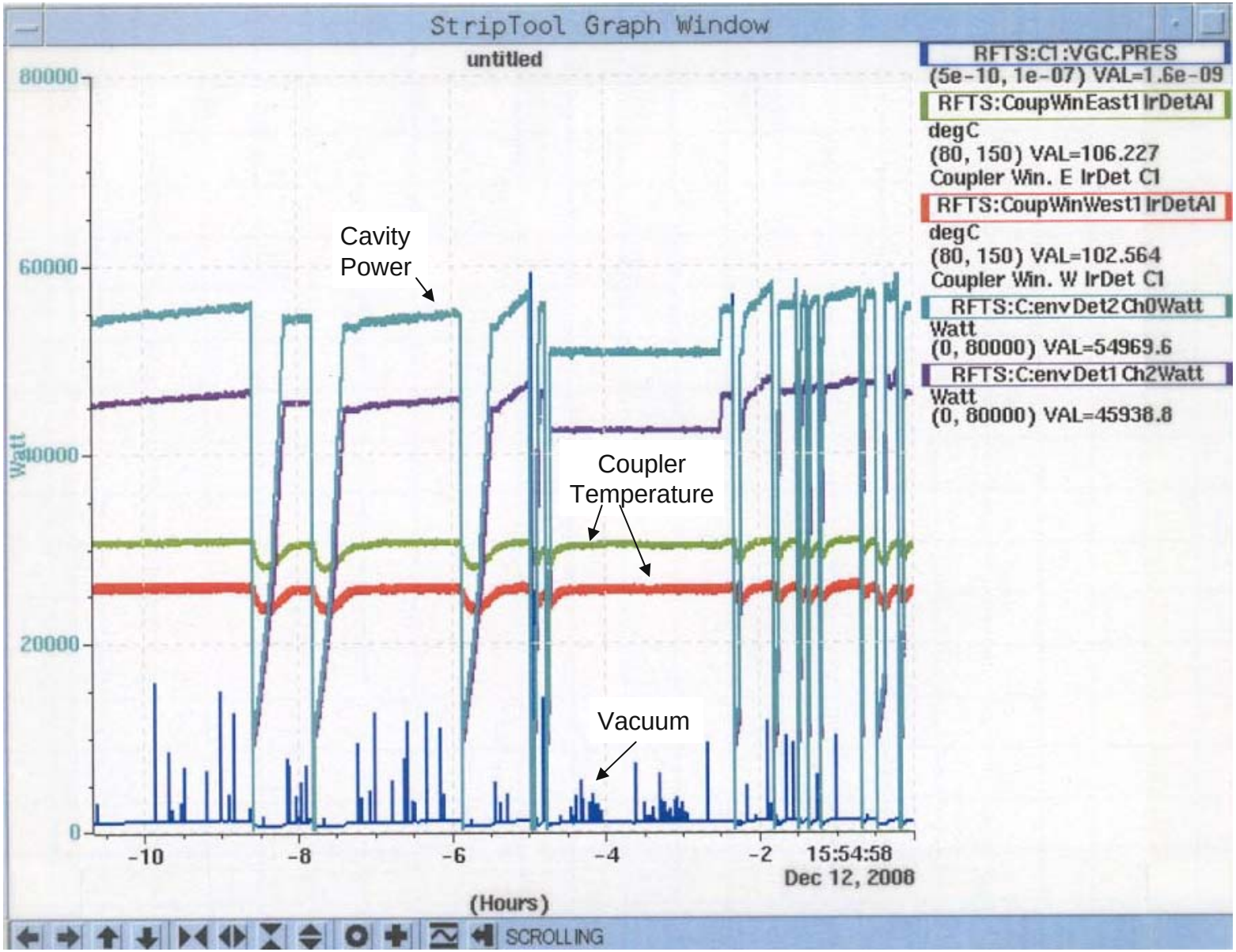
Time-Frame III: 'Vac Buffer' and 'Erratic' Condition



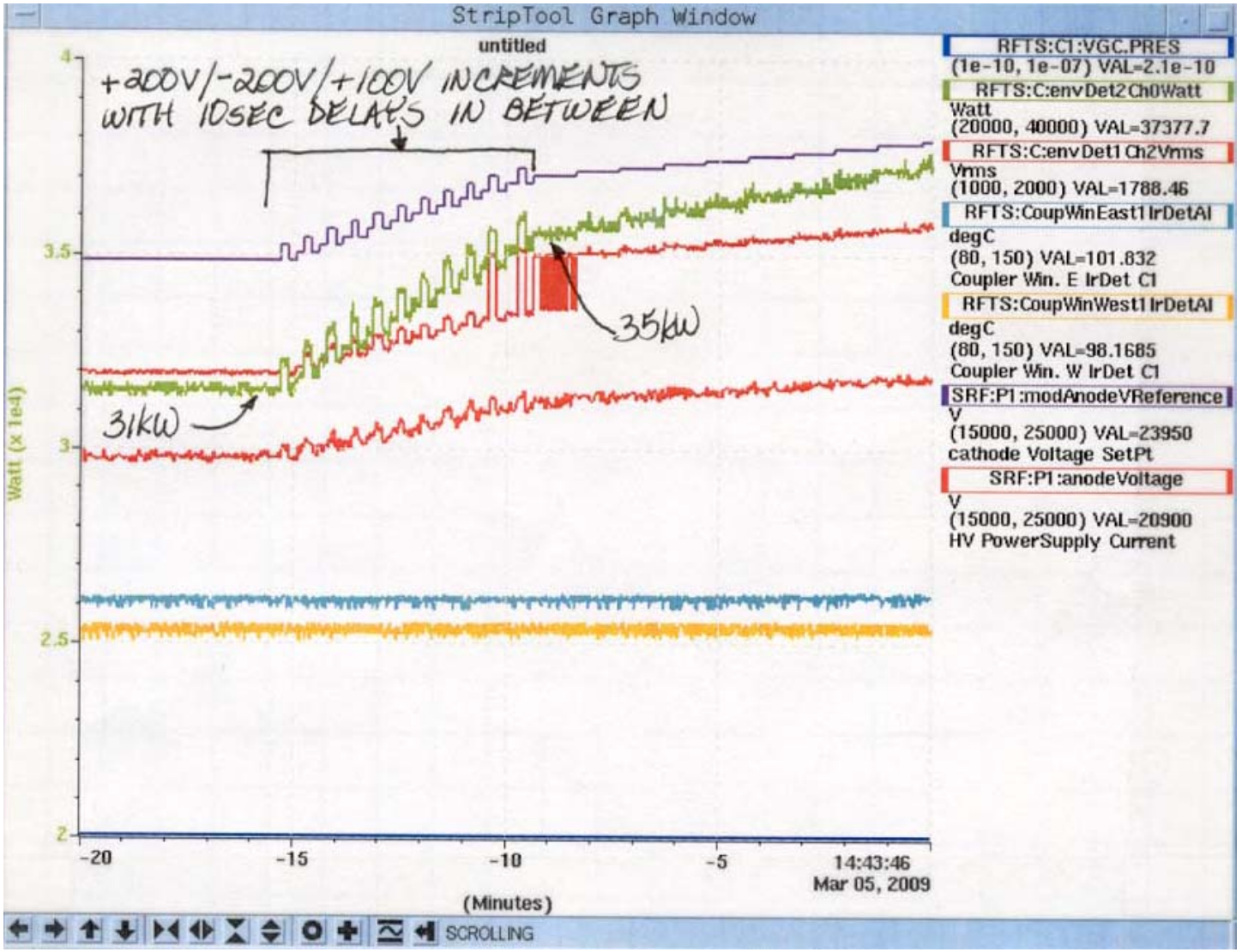
Typical Conditioning



Difficult Vacuum Zones



Conditioning Difficult Vacuum Zones (I)



Conditioning Difficult Vacuum Zones (II)