High Performance Pad Conditioning Arm for Improved CMP Process Monitoring and Control

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External Use

Outline

- Motivation
- New High Performance Pad Conditioner (HPPC)
  - Hardware overview
- Pad thickness measurement
  - Pad installation issues
  - Pad life monitoring
  - Closed-loop control of pad wear profile
- Conditioning torque measurement
  - Disk installation issues
  - Disk life monitoring
  - Closed-loop control of conditioning down force
- Conclusions

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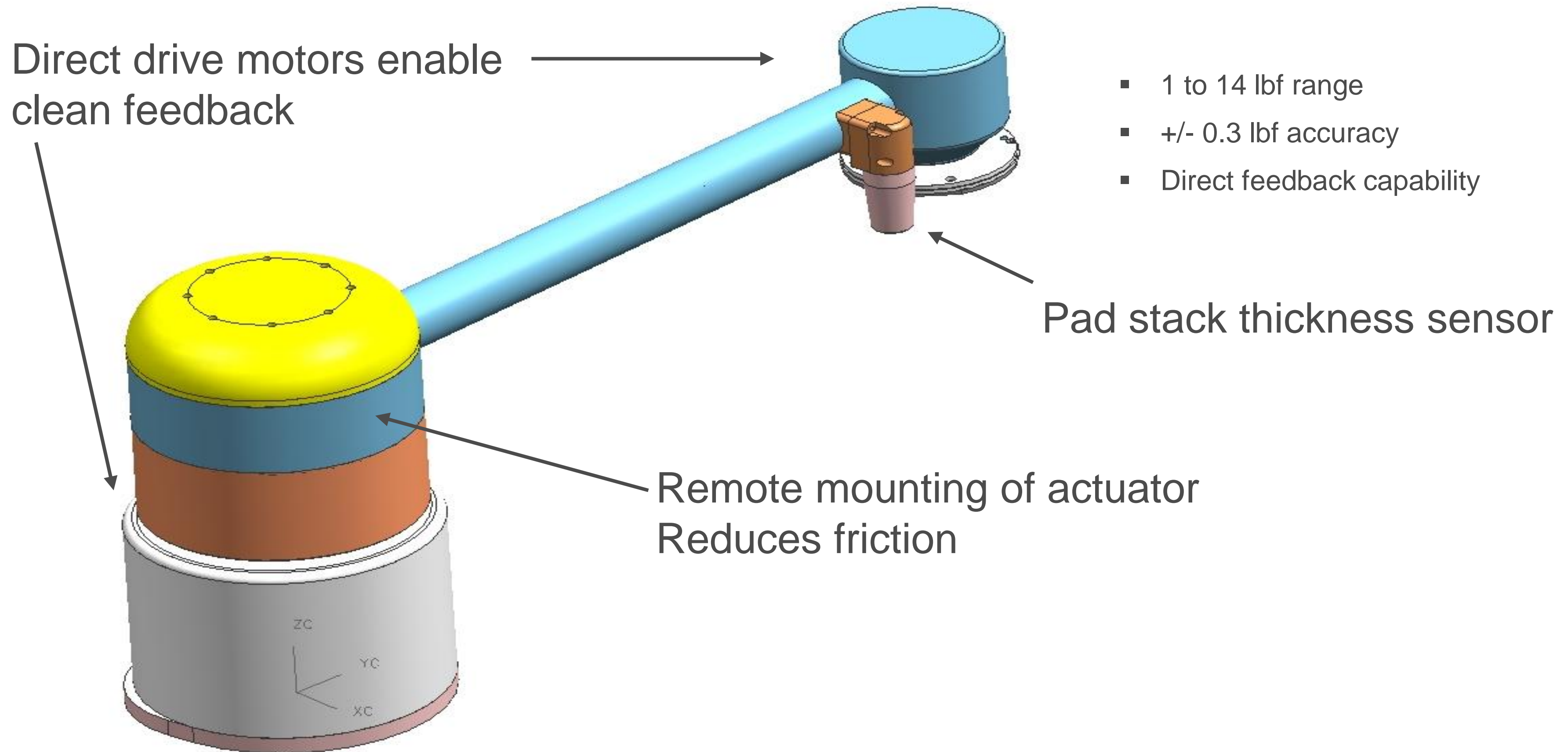
Motivation

- Provide a solution to industry requirements for
  - Wide range of down forces for pad conditioning & increased accuracy
  - Detecting installation issues
  - System health monitoring
  - Extend pad lifetimes by enabling uniform pad wear
  - Provide consistent conditioning performance over lifetime of consumables

High Performance Pad Conditioner

- New pad conditioning arm design:
  - Improved accuracy at lower down forces
  - Integrated pad stack thickness sensor / non-contact
  - Clean conditioning torque feedback signal
- Smarter pad conditioner for detecting poor installation
  - Wrong pad / disk
  - Incorrect installation of the pad or disk
  - Presence of bubbles or foreign objects that degrade polish performance
- Smarter pad conditioner for health monitoring
  - Monitor conditioning performance throughout consumables lifetimes
  - Provides indicator for consumables change
  - Can be used with closed-loop control to achieve extended lifetimes

High Performance Pad Conditioner



- 1 to 14 lbf range
- +/- 0.3 lbf accuracy
- Direct feedback capability

Pad Conditioner Enables both Accurate Low Down Force Process and Feedback

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Pad Stack Thickness Measurement

- Integrated pad stack thickness sensor can be used to
  - Flag installation issues
    - Trapped air or “bubbles” between pad and platen
    - Missing or improperly installed conditioning disk
    - Incorrect pad (if pad stack thickness not same as target value)
  - Monitor pad lifetime
    - End-of-pad-life indicator
    - Set consumables change intervals and detect atypical behavior
  - Enable closed-loop control of pad wear profile
    - Dwell time profile can be controlled to provide uniform wear over pad lifetime
    - Improved pad wear profile can extend pad lifetimes

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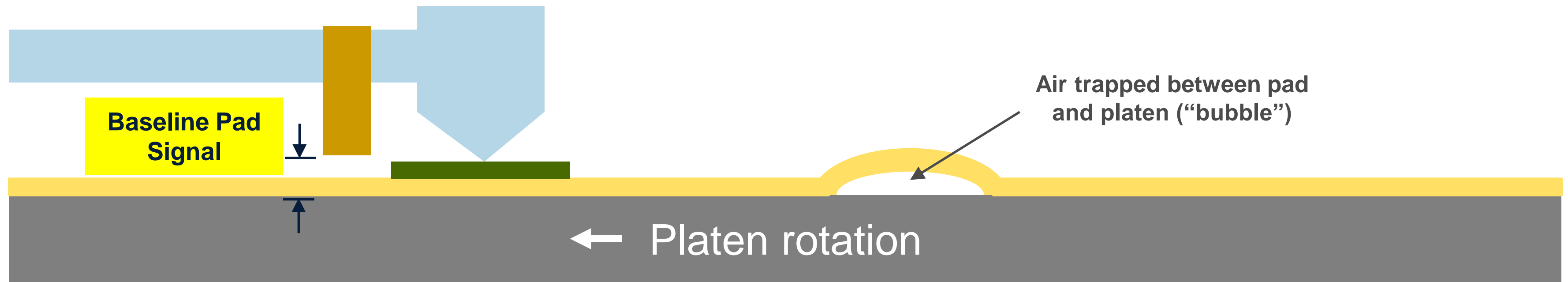
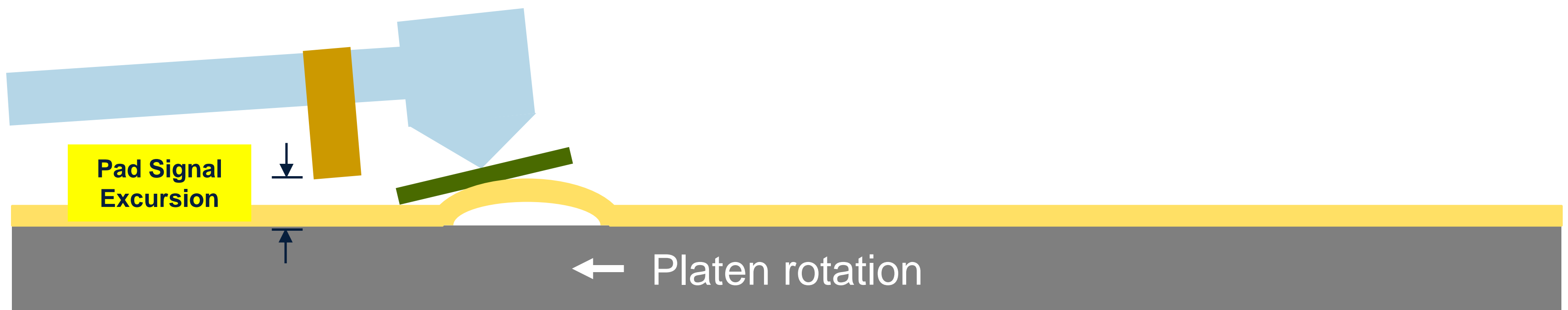
Pad Installation Issues





- Integrated pad thickness sensor can be used to detect pad installation problems
  - Sensor does not contact pad surface, conditioning disk serves as probe
  - Air trapped between pad and platen will show up as a localized region of excessive pad thickness

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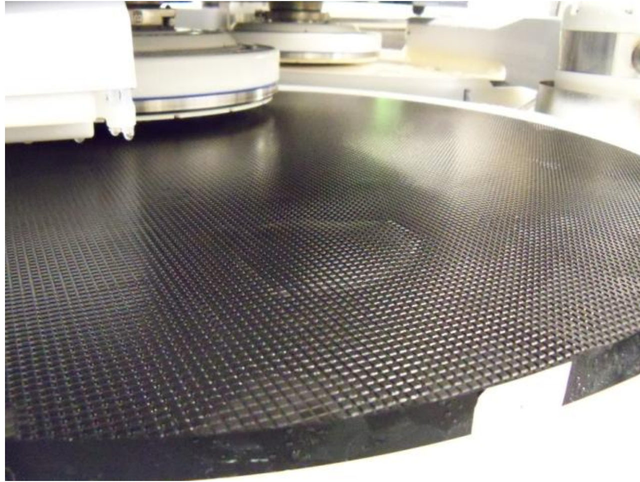
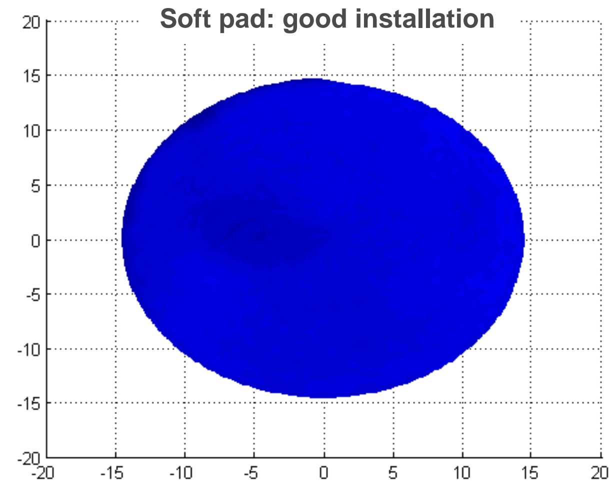
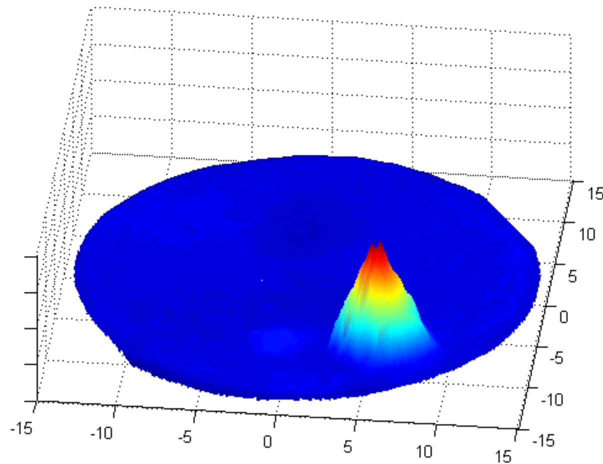
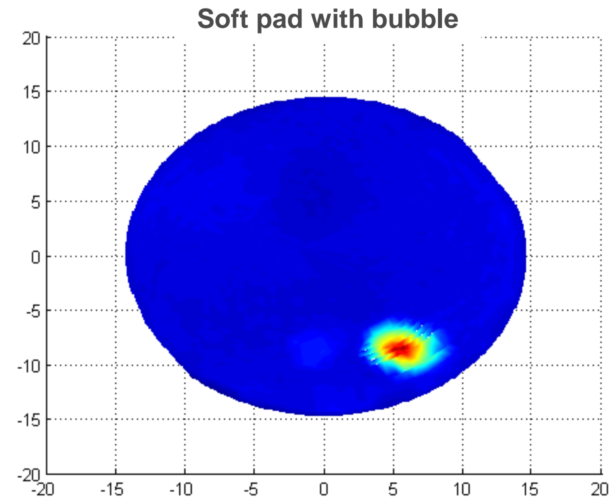
Bubble Detection: Soft Pad



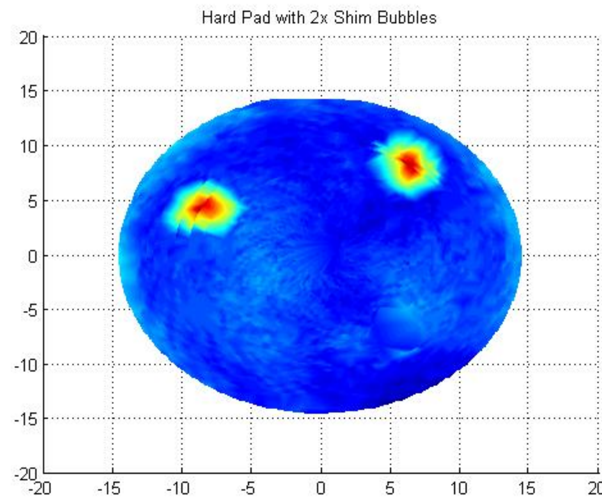


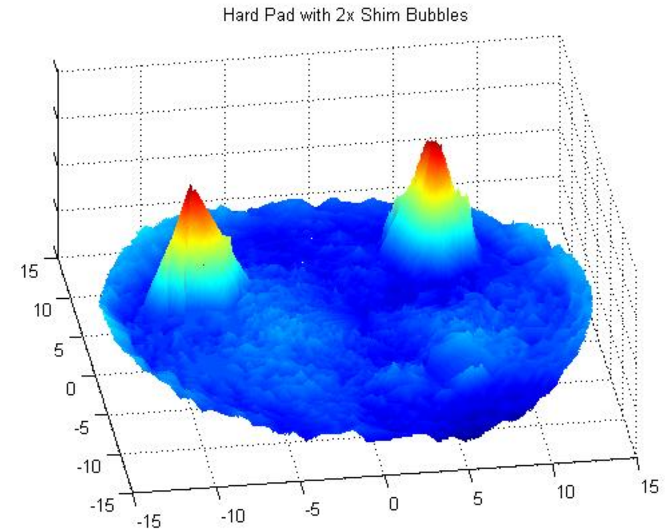




Thickness Monitor Can Detect Bubbles Under an Improperly Installed Soft Pad

Bubble Detection: Hard Pad





- Bubbles between hard pad and platen were simulated using plastic shims
  - Circular pieces 1 to 3 cm in diameter were cut from sheet stock 5 to 15 mils thick
  - Integrated sensor measurement taken immediately after pad installation clearly shows location of two “bubbles”
  - Shim stock thicknesses were on the order of common objects such as
    - Pad backing sheet, latex gloves, etc.

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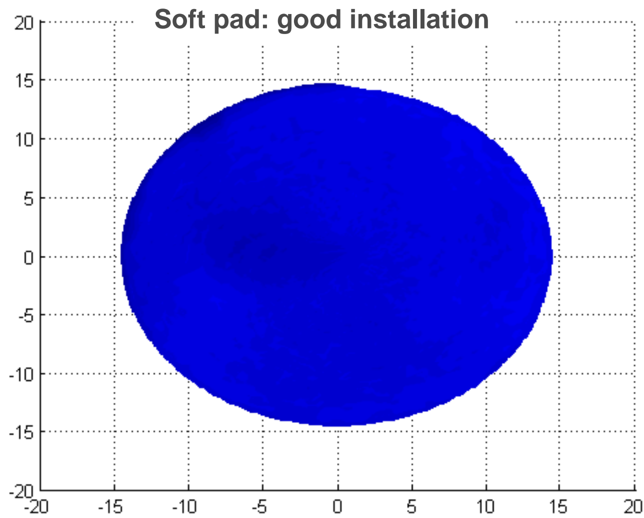
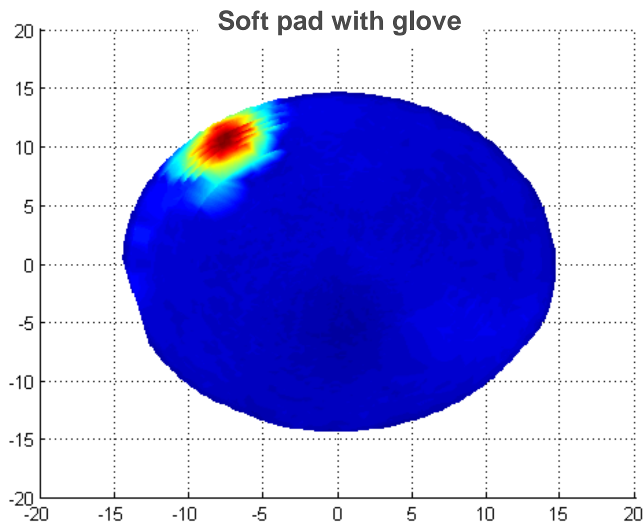
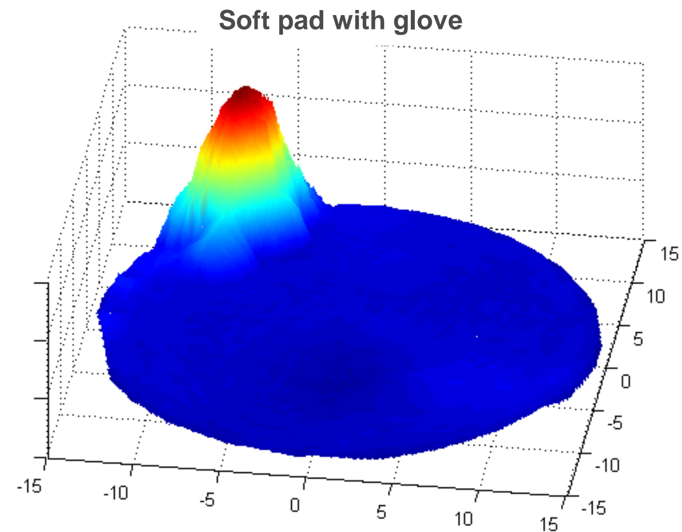
Presence of a "Foreign Object…"







Thickness Monitor Can Detect Bubbles or Foreign Objects Trapped Under Pad

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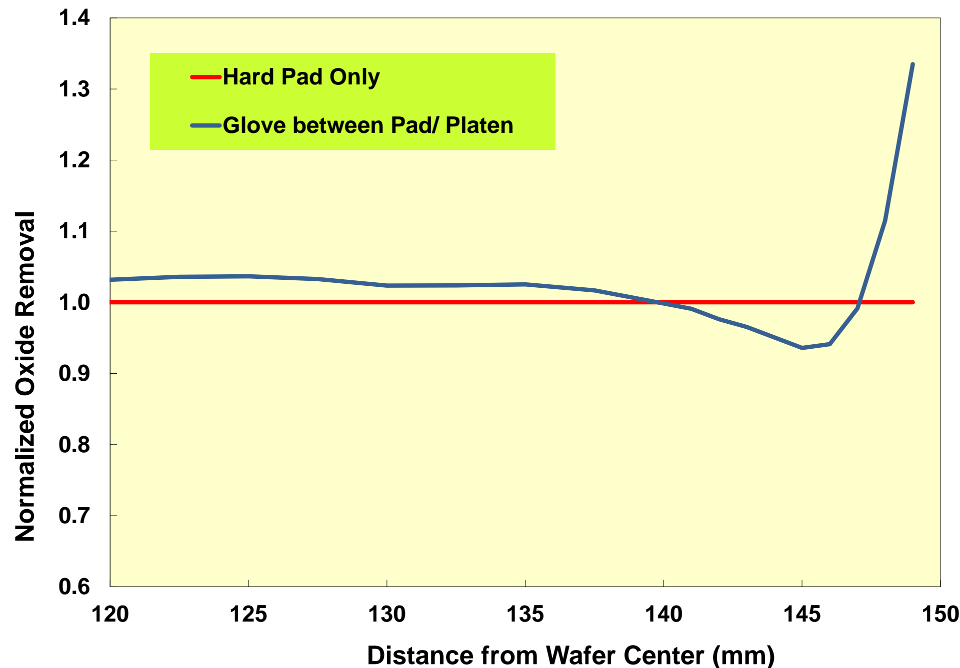
…Degrades Polish Performance



- Significant effect on within-wafer non-uniformity
  - Example: part of a glove placed under a hard pad (IC1010)
  - Film removal profile excursion near wafer periphery

Problems Can Be Detected Early, Preventing Wafer Scrap

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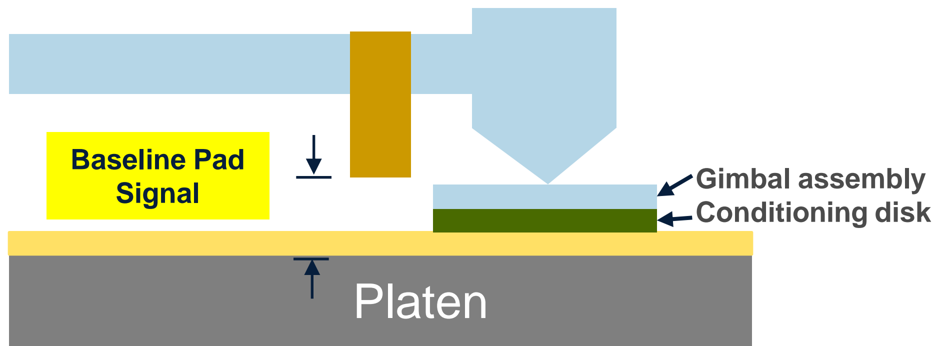
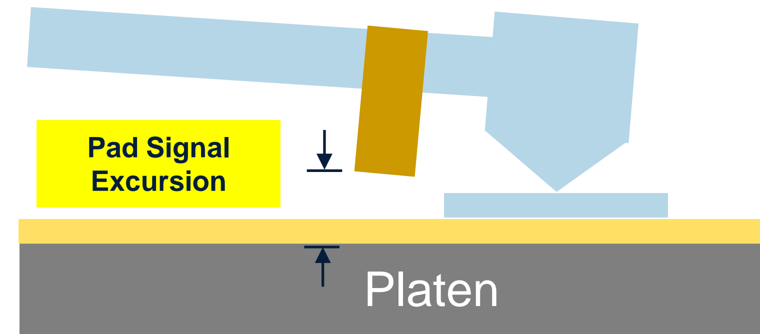
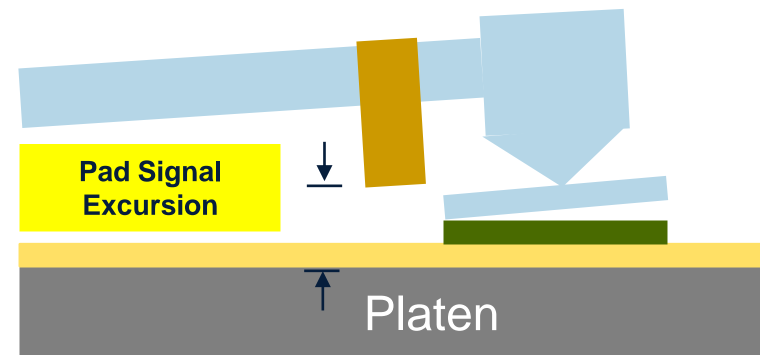
Disk Installation Issues





- Integrated pad thickness sensor can be used to detect disk installation issues
  - Missing disk → pad thickness too low
  - Improperly installed (angled) disk → pad thickness too high



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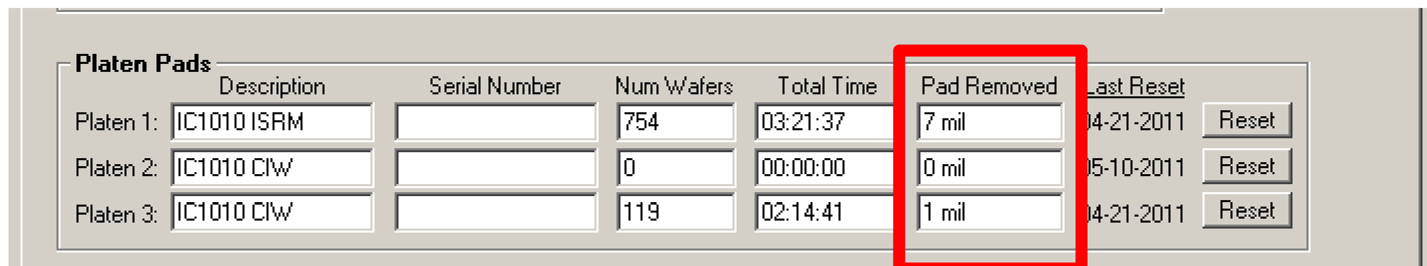
Pad Wear Monitor



- The Usage Statistics screen presents the average total pad wear for each platen individually
- Pad Removed can serve as an end-of-pad-life and consumables change indicator
- Using fixed wafer target leads to underestimation of pad life

Direct Measurement Accounts For Reduced Pad Wear Due To Disk Age

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End of Pad Life

- Conditioning wears away pad top surface, including slurry grooves
- Non-uniform pad wear can prematurely reduce pad lifetimes
  - Edge balding
    - Uneven conditioning at the edge
    - May lead to increased WIWNU

  - Groove depth variation
    - Non-uniform pad wear rate
    - May result in removal rate variation

  - Fastest-wearing region limits useful pad life
- Improved pad wear profiles reduce pad change frequency
  - Improved tool uptime/availability

Uniform Pad Wear Maximizes Useful Pad Life

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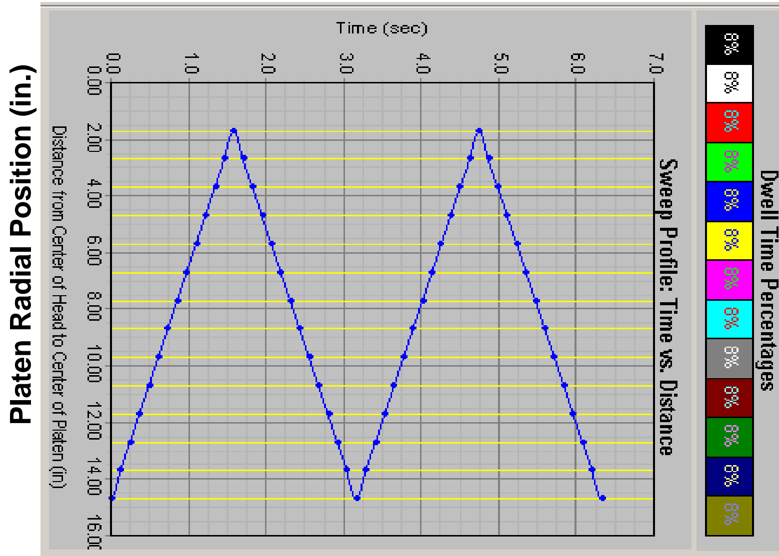
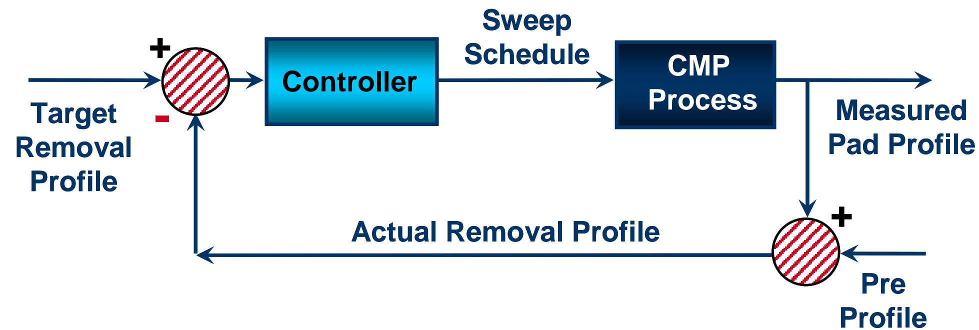
Closed-Loop Control of Pad Profile





- Open loop operation
  - Fixed sweep schedule (dwell time profile), does not self-correct
- Closed-loop control
  - Sweep recipe modifications can be implemented during *in-situ, ex-situ* or both

CLC can maintain a uniform profile or correct a non-uniform profile or non-uniform removal

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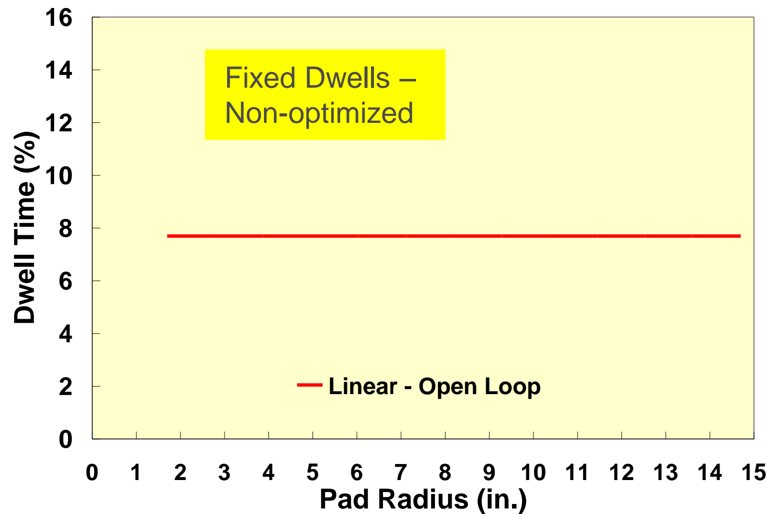
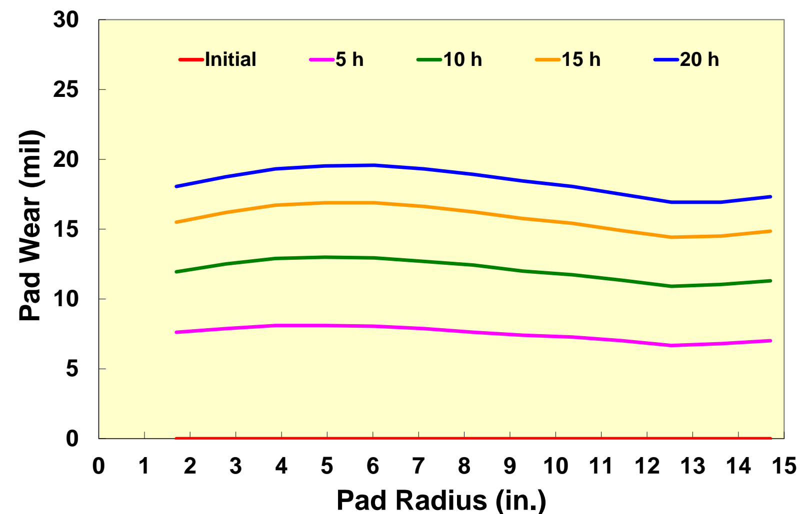
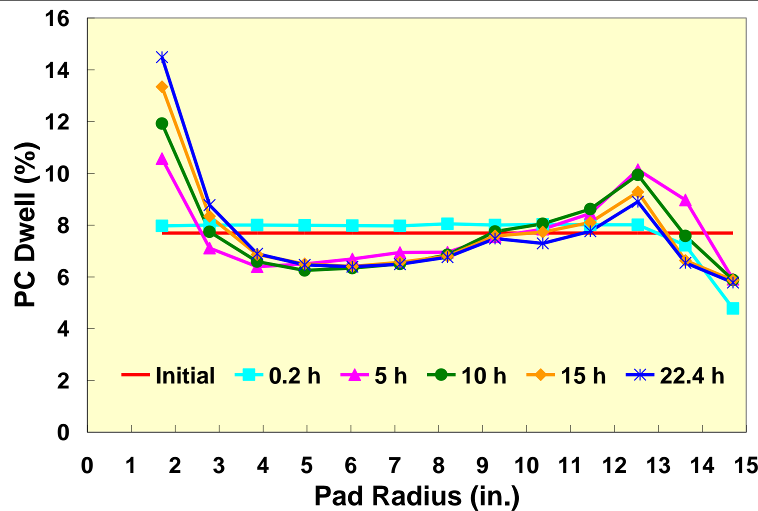
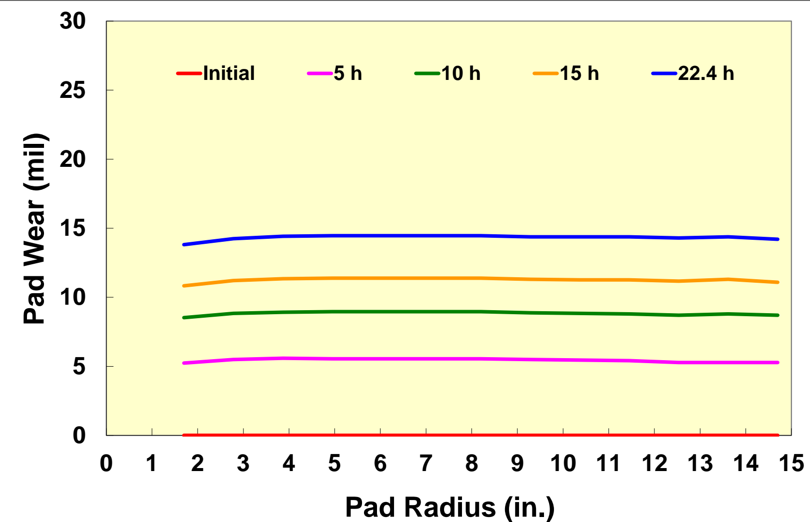
Closed-Loop Control of Pad Profile





Open Loop





Closed-Loop

- Significant improvement in within-pad range observed with profile CLC

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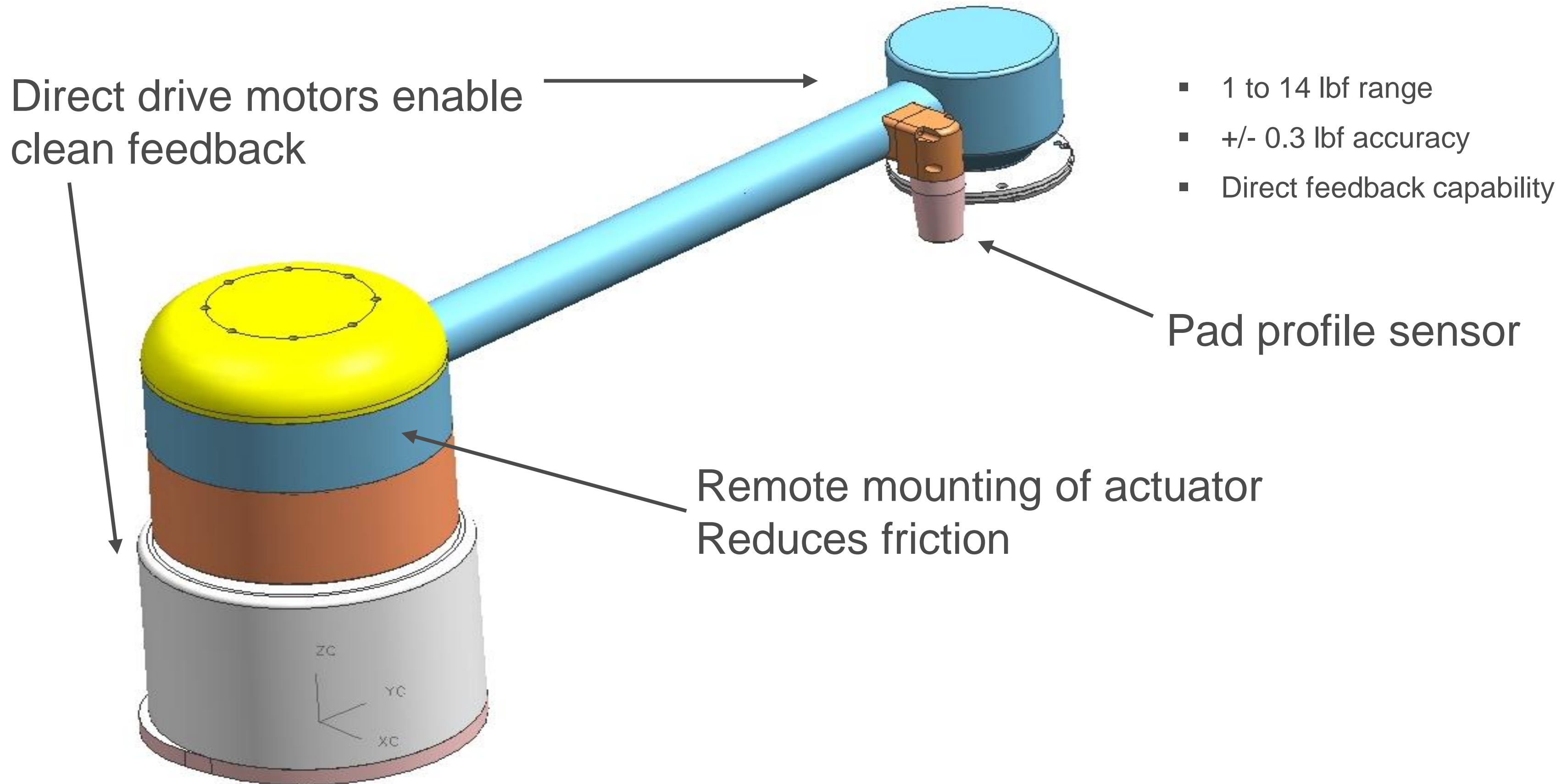
High Performance Pad Conditioner



- 1 to 14 lbf range
- +/- 0.3 lbf accuracy
- Direct feedback capability

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Conditioning Torque

- Conditioning torque data can be used to
  - Flag issues with consumables installation
    - Missing or improperly installed conditioning disk
  - Monitor diamond disk conditioning effectiveness over disk lifetime
    - Relationship between down force and torque changes as disk ages (increased diamond wear)
  - Control conditioning down force through conditioning torque feedback
    - Down force CLC can maintain uniform MRR over lifetime of pad and disk pair

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Disk Installation Issues

	New	H/w Fault / Raised Arm	Poor Install	Old Disk	Different Disk	No Disk
Normalized Conditioner Torque	100.0%	19.0%	99.0%	70.0%	110.0%	84.0%
Normalized Pad Stack Thickness	100.0%	145.0%	107.0%	100.0%	99.0%	70.0%

- Conditioning torque values and pad stack thickness values can be established for particular disk-and-pad pairs

- Excursions from expected values can indicate issues with
  - Consumables installation
  - Hardware fault (disk not engaged with pad surface)
  - Incorrect pad conditioning recipe (down force higher or lower than intended)

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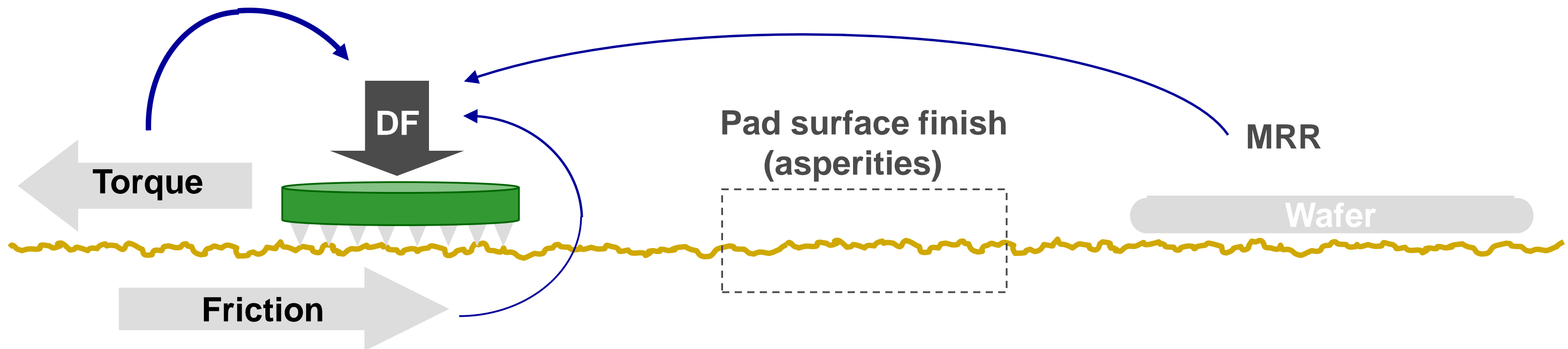
DF - Conditioning Torque - MRR Relationship



τ α DF (& disk state)

MRR α DF (through asperities)

MRR α τ

- Direct relationships between:
  - Down force and conditioning torque (τ), asperity generation
  - Asperity generation and material removal rate (MRR)

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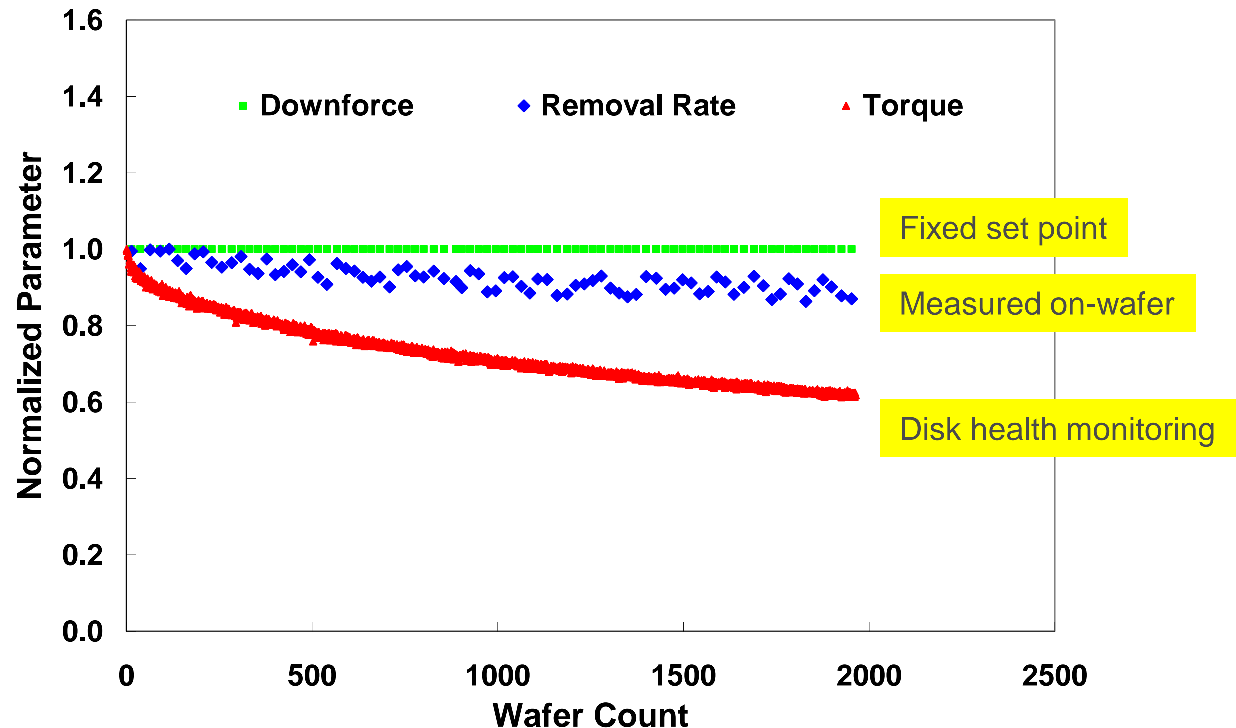
Open Loop behavior under fixed down force



- Extended run in open loop
  - Down force held constant
  - Oxide removal and conditioning torque both decrease as disk ages
  - Conditioning torque levels can be used to identify end of disk life

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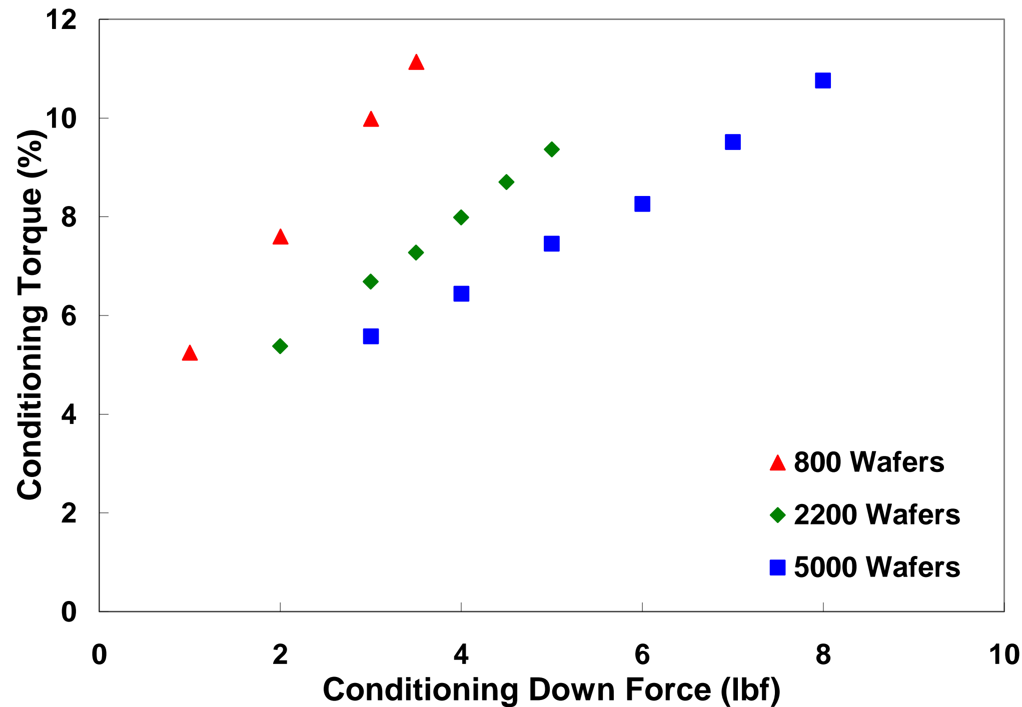
DF – MRR – Conditioning Torque Relationship



- Relationship between down force and torque changes as disk ages (increased diamond wear)
- Conditioning torque and down force completely characterize disk state

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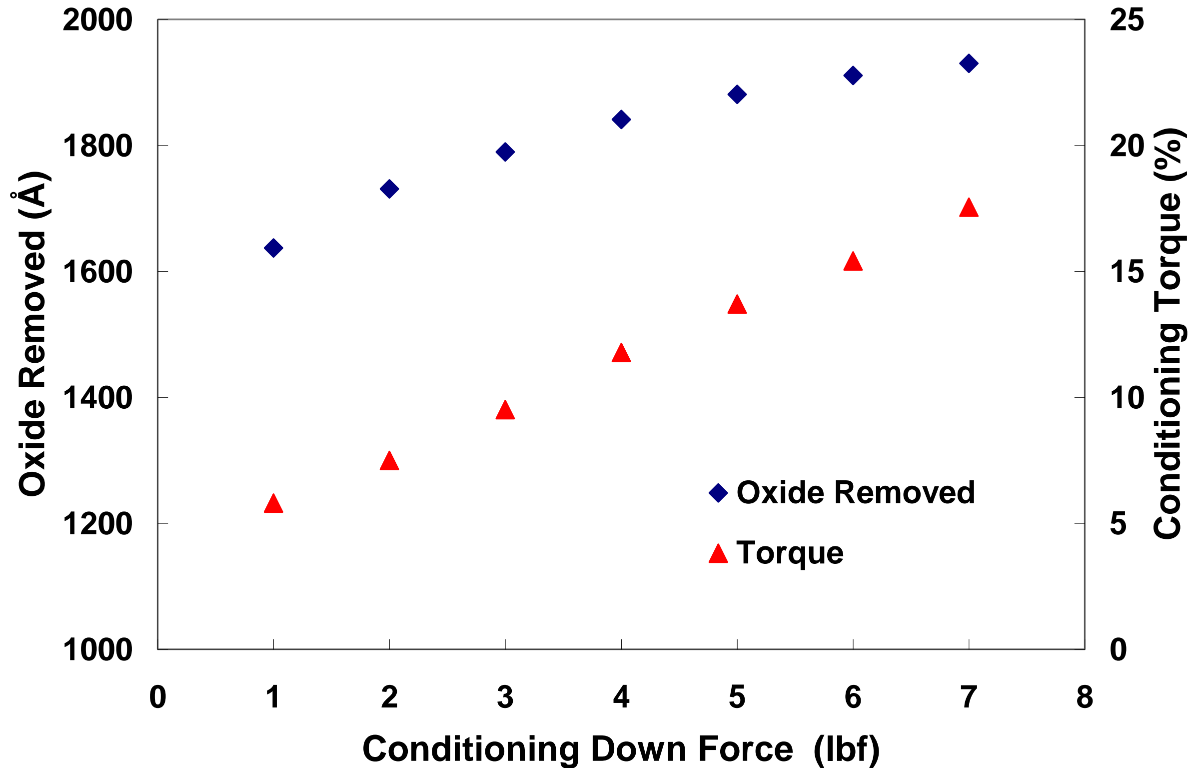
DF – MRR – Conditioning Torque Relationship



Empirical relationship between down force, removal and conditioning torque

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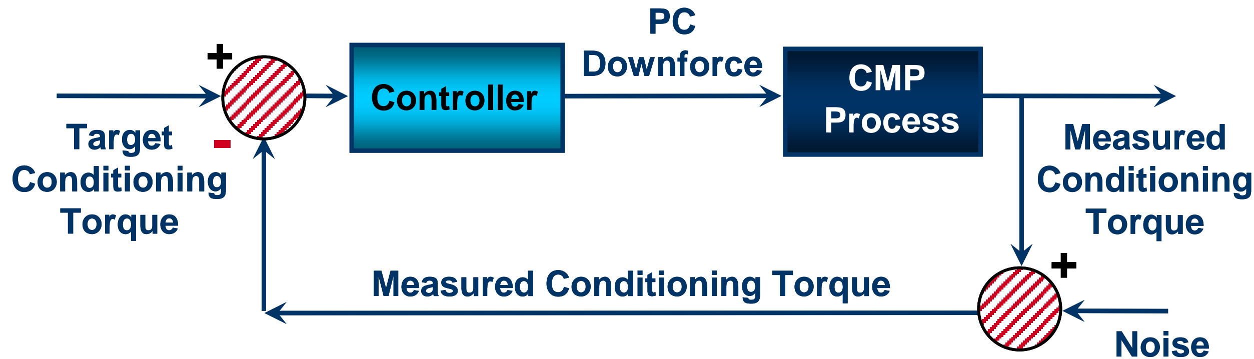
CLC of Conditioning Downforce



- Open loop operation
  - Fixed conditioning down force, does not self-correct
- Closed-loop control
  - Down force modifications made to *in-situ* and/or *ex-situ* conditioning recipes

CLC can maintain uniform MRR over pad and disk lifetimes

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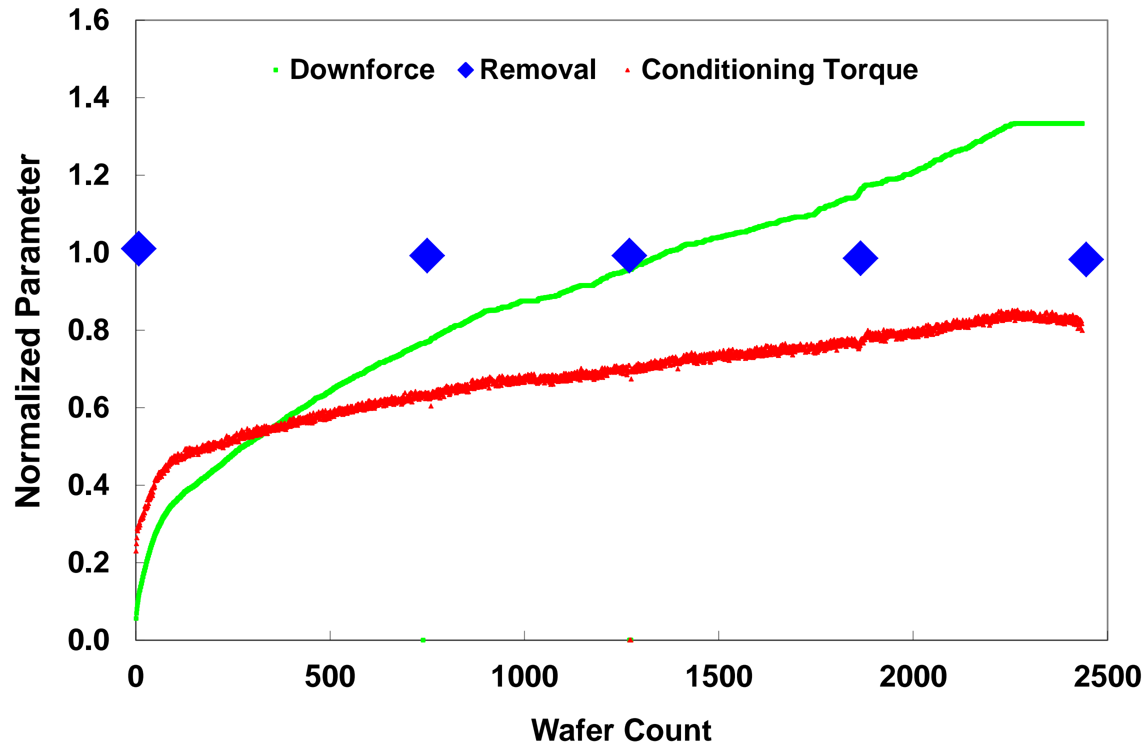
Extended run with CLC



- Extended run with CLC
  - Oxide removal constant throughout run
  - Down force increases throughout run to maintain torque target set by CLC
    - Counteracts loss of conditioning effectiveness over time
    - DF flattened out after hitting pre-programmed upper limit

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Conclusions

- A new High Performance Pad Conditioner has been developed that provides
  - Increased accuracy and down force range
  - Warnings for consumables installation issues
  - Real-time health monitoring of conditioning disk effectiveness & pad profile
- The High Performance Pad Conditioner also enables
  - Extension of pad lifetimes through more even across-pad wear
  - More consistent conditioning performance over lifetime of consumables set (pad and disk)

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