HDD Reliability Modeling and Failure Prediction

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Background

- Reliability is more important than ever
- CE environment brings tougher operating conditions
- This requires either longer and more expensive testing or ‘intelligent’ reliability design
- ‘Intelligent’ reliability design requires design guidelines
- Traditional reliability models frequently lack credibility
- Need a realistic reliability model for the drive
  - before it is built and tested and
  - for the early stages of development...

- We have developed such a model for our drives
  - Data illustrating the model in this presentation do not necessarily represent the performance of commercial Samsung drives
HDD operating conditions depend on Application

Table 1. Non-PC Consumer Applications Employing Storage

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Set-Top Boxes (STBs) with DVR</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital Video Recorder (VCR Replacement)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital Audio Player/Recorders: Mini-Portable (MP3) Jukebox (Portable, Automotive, Home)</td>
<td></td>
<td>X</td>
<td></td>
<td>High</td>
<td></td>
<td>Medium-High</td>
</tr>
<tr>
<td>Personal Digital Assistants (PDAs) (Pilot, Windows CE)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital Video Cameras, Still: Consumer Professional</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>High</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Digital Video Cameras, Motion: Consumer Professional</td>
<td>X</td>
<td>X</td>
<td></td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Attached Storage (NAS) Networks</td>
<td></td>
<td>X</td>
<td></td>
<td>Medium-High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-Capacity Removable (RTR Media Replacement)</td>
<td>X</td>
<td></td>
<td></td>
<td>Medium-High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Game Machines: (Playstation2) Appliances: Phone-Based Handheld</td>
<td></td>
<td>X</td>
<td></td>
<td>Medium-High</td>
<td></td>
<td>Medium-High</td>
</tr>
<tr>
<td>Global Positioning Systems (GPS): Portable Automotive</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Low</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Personal Video Recorders (PVRs, Standalone) Laser Printers</td>
<td></td>
<td>X</td>
<td></td>
<td>Low</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Video-on-Demand (Hotels, Movies) eBooks</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home Appliances: (Clothing Machine, Refrigerators, etc.) (Inter)Net TV (WebTV)</td>
<td></td>
<td>X</td>
<td></td>
<td>Low</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

Source of the table: IDEMA Insight May/June 2001

Operating conditions:
- Cold/Hot
- Dry/Humid
- Low/High Duty Cycle
- High mechanical Shock
- Cyclical stress

Low-capacity HDD < 2 GB
2 GB < Medium-capacity HDD < 40 GB
High-capacity HDD > 40 GB

Flash
Optical

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HDD operating conditions depend on location

Operating conditions:
- Very Cold/Hot
- Very Dry/Humid
- Low/High Duty Cycle
- High mechanical Shock
- Cyclical stress

- High Altitude
- High Humidity
- Low Temperature
- High Temperature
HDD Operating conditions and their effects on reliability

- HDD reliability is **negatively impacted** by extremes in the following operating conditions:
  - Temperature
  - Altitude
  - Humidity
  - Duty cycle
  - A combination of the above conditions
  - A history of the above combinations
Example: Failure Acceleration vs. Temperature

HDD reliability decreases with increasing temperature.

Temperature is a major factor impacting reliability.
Failure Modes and Failure Modeling

A generic HDD Failure Mode Pareto

- Not related to head-disk interface
- Possibly related to head-disk interface

- Mishandling
- CND
- Head degradation
- Scratch
- Grown defect
- Motor
- PCB
- TA
- High-fly write
- Write abort

Reliability Modeling is possible

HDI-related

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Failure Modes and Failure Modeling: Focus on HDI

A generic HDD Failure Mode Pareto

- Head-disk interface design is the key to HDD reliability

- We need to predict these failure modes!

- What controls HDI reliability?
Clearance is the key to HDI (and HDD) reliability

- Clearance is the space between the slider and disk.
- Small clearance means stronger signal, higher recording density.
- Small clearance also means increased risk of head-disk contact.
- Zero or negative clearance means eventual failure.
Head-Disk Clearance is Sensitive to Temperature

Above is an example of head-disk clearance measured vs. HDD temperature.

For this particular HDI design, clearance decreases at the rate of 0.035 nm per degree.

For example, clearance drops by ~1.5-2 nm between 30C and 77C.
Above is an example of head-disk clearance measured vs. altitude.
For this particular HDI design, clearance decreases at the rate of 0.13
nm per kPa.
For example, clearance drops by ~5-6 nm between the sea level and
14000 feet altitude.
We have observed and quantified the head-disk clearance dependence on drive humidity.

We have also developed a theoretical model describing this relationship (to be published).
HDD Reliability modeling: failure rate prediction method

**INPUT PARAMETERS**

- Test time
- Temperature
- Ambient humidity
- Duty cycle
- Population clearance and clearance sigma
- Clearance sensitivity to temperature
- Clearance sensitivity to altitude
- Clearance sensitivity to humidity
- Write protrusion
- ...
- ...

- Drive contamination level
- ...
- ...

**DELIVERABLES**

- Failure rates
- “Failure/No failure” conditions
- “Better/Worse” designs
- “High/Low” importance factors
- ...

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HDI reliability model: main contributors

- HDI reliability is dependent on head-disk clearance.
- Parameters affecting clearance include
  - Incoming clearance distribution
  - The other factors are summarized below

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Flying clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature ↑</td>
<td>Crown ↓</td>
<td>Reduced crown draws ABS dots away from disk at high temp</td>
</tr>
<tr>
<td></td>
<td>Thermal protrusion ↑</td>
<td></td>
</tr>
<tr>
<td>Altitude ↑</td>
<td>Pitch angle ↓</td>
<td>Contact may occur at rear ABS dots due to decrease of pitch</td>
</tr>
<tr>
<td></td>
<td>Lower ambient pressure ↓</td>
<td>Less air-bearing lift</td>
</tr>
<tr>
<td>Humidity ↓ ↑</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Duty cycle ↑</td>
<td>Seek Clearance ↓</td>
<td>Contact may occur at the edge or corner or near the writer</td>
</tr>
<tr>
<td></td>
<td>Write Clearance ↓</td>
<td></td>
</tr>
</tbody>
</table>
HDI reliability model: Details

Objective

- Many companies have some “altitude clearance-based model.” We need to account for temperature and humidity as well.
- We need to create a credible statistical model for the entire drive population predicting clearance and reliability under given conditions.

Model structure

- Empirical expression used to predict flying clearance:

\[
\text{Clearance} \ (nm) = z_0 - a\Delta T - b\Delta P - f(RH)
\]

where,

- \(z_0\) = clearance under ambient condition (ex: 5.3 nm)
- \(a\) = temperature sensitivity (ex: 0.035 nm/ºC)
- \(\Delta T\) = drive temperature change (ex: 50 ºC)
- \(b\) = altitude sensitivity (ex: 0.15 nm/kPa)
- \(\Delta P\) = altitude change (ex: 40 kPa)
- \(RH\) = Relative humidity in the drive
HDI reliability model: Structure and Demonstration

Clearance (nm) = \( z_0 - a\Delta T - b\Delta P - f(RH) \)

- **Constant value or other distributions**
- **Incoming clearance (nm)**
- **Temperature sensitivity (nm/°C)**
- **Altitude sensitivity (nm/kPa)**
- **Clearance dependence on RH**
- **Probability**
- **Temperature sensitivity (nm/°C)**
- **Altitude sensitivity (nm/kPa)**

**Head-disk contact**

- **T=65°C, RH=30%, Altitude=101.3kPa**
  - No failure
- **T=65°C, RH=80%, Altitude=101.3kPa**
  - 6.2% failure rate

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Each parameter – Temperature, Altitude, and Humidity - plays an important role in decreasing flying clearance. 

Combined effect on clearance could be even larger.
Environmental tests examples vs. Model predictions

1. **Temperature/Humidity/CSS test:**
   a) 50k CSS at 0C/ambient RH
   b) 50k CSS at 70C/80%RH
   Weakly impacted by head-disk clearance

2. **Altitude/Temperature test**
   a) Up to 16K feet at 0C
   b) Up to 16K feet at 25C
   c) Up to 16K feet at 60C
   Strongly impacted by head-disk clearance
### CSS Test: Model Predictions and Experiment

<table>
<thead>
<tr>
<th>Test Conditions &amp; Model Setting</th>
<th>Test Failure Rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test 1</strong></td>
<td></td>
</tr>
<tr>
<td>T=0°C</td>
<td>3.4</td>
</tr>
<tr>
<td>RH = ambient</td>
<td></td>
</tr>
<tr>
<td>Alt = 101.3 Kpa</td>
<td></td>
</tr>
<tr>
<td>50K CSS</td>
<td></td>
</tr>
<tr>
<td><strong>Test 2</strong></td>
<td></td>
</tr>
<tr>
<td>T=70°C</td>
<td>20</td>
</tr>
<tr>
<td>RH = 80%</td>
<td></td>
</tr>
<tr>
<td>Alt = 101.3 Kpa</td>
<td></td>
</tr>
<tr>
<td>50K CSS</td>
<td></td>
</tr>
</tbody>
</table>

*Engineering Sample Data*

- Agreement between the model predictions and the experimental results is satisfactory.
**Altitude test at 0ºC: Model Predictions and Experiment**

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Altitude (kft)</th>
<th>Failure rate Mean clearance &lt;0 nm</th>
<th>Experiment data (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75.2</td>
<td>8</td>
<td>3.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>69.7</td>
<td>10</td>
<td>24.4%</td>
<td>28.6%</td>
</tr>
<tr>
<td>64.4</td>
<td>12</td>
<td>68.9%</td>
<td>66.7%</td>
</tr>
<tr>
<td>59.5</td>
<td>14</td>
<td>95.0%</td>
<td>95.2%</td>
</tr>
<tr>
<td>54.9</td>
<td>16</td>
<td>99.5%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Good correlation between the model prediction and experimental results is observed

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Altitude test at 25°C: Model Predictions and Experiment

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Altitude (kft)</th>
<th>Failure rate</th>
<th>Experiment data (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean clearance &lt; 0 nm</td>
<td></td>
</tr>
<tr>
<td>75.2</td>
<td>8</td>
<td>2.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td>69.7</td>
<td>10</td>
<td>19.5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>64.4</td>
<td>12</td>
<td>66.6%</td>
<td>66.7%</td>
</tr>
<tr>
<td>59.5</td>
<td>14</td>
<td>93.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>54.9</td>
<td>16</td>
<td>99.6%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Good correlation between the model prediction and experimental results is observed
Altitude test at 60ºC: Model Predictions and Experiment

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Altitude (kft)</th>
<th>Failure rate</th>
<th>Experiment data (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean clearance &lt; -1.0</td>
<td></td>
</tr>
<tr>
<td>75.2</td>
<td>8</td>
<td>21.2%</td>
<td>16.7%</td>
</tr>
<tr>
<td>69.7</td>
<td>10</td>
<td>63.7%</td>
<td>66.7%</td>
</tr>
<tr>
<td>64.4</td>
<td>12</td>
<td>94.3%</td>
<td>100.0%</td>
</tr>
<tr>
<td>59.5</td>
<td>14</td>
<td>99.5%</td>
<td>100.0%</td>
</tr>
<tr>
<td>54.9</td>
<td>16</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Again, good correlation between the model prediction and experimental results is observed.
Summary

- Clearance-based reliability prediction model was developed and successfully tested. Model shows excellent correlation with experiment.

- The following parameters (affecting flying clearance) have been measured and incorporated in the model:
  - Clearance distribution
  - Temperature
  - Altitude
  - Humidity (Developed theoretical model of humidity affect on Clearance)

- Model applications:
  - Design for reliability
  - Early HDD design evaluation & reliability prediction
  - Design optimization for PC, Server and CE environments
  - Methodology was applied to improve reliability of Samsung drives

- Future plans:
  - Add complexity and refinement to the model
  - Expand the scope of the model to add other factors impacting HDD reliability