Cost Effective Robust Design

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Agenda

- **Define robust design**
- **DOE concepts**
- **How robust design works**

Define

- **What do you think Robust Design is?**

Testing for Robustness

- **Validation testing**
  - **EMI**
  - **Drop tests**
  - **Transportation vibration**
- **Understanding range of use environments**
- **t-test/ ANOVA**
- **Design of Experiments**

Robust Design Principles

- **Real specifications**
  - **Made up**
  - **Huge guard band**
- **Understanding input capabilities**
  - **“we can do that” is not a capability statement**
- **Understanding input and output relationships**
- **Setting nominal values at less sensitive positions**

What is DOE

Tools

- **Factorial Designs**
  - **Full (2^k form)**
  - **Fractional (2^{k-p} form)**
  - **Taguchi - maximum assumptions**
- **Advanced Designs (Response Surface Methods)**
  - **3 level (not a 3^k form)**
  - **5 level (composite with factorial as a basis)**
  - **Optimization**
- **Related Statistical Tools**
  - **Statistical Process Control (SPC)**
  - **Gage R&R studies (measurement system assessment)**
  - **Probabilistic Failure Assessment (PFA)**
    - **New use of old tools (Monte Carlo analysis)**

Model Building

- **The purpose of several tools is to create an equation**
  - **Y = z + a * A + b * B + error**
- **This is from ANOVA and DOE techniques**

Typical DOE Equations (for 3 variables)

One Factor At a Time (OFAT) typical output (main effects)

y = z + a*A + b*B + c*C

Factorial typical output (main and interactions)

y = z + a*A + b*B + c*C + d*A*B + e*A*C + f*B*C + g*A*B*C

Response Surface typical output (main, interactions, quadratic)

$y = z + a*A + b*B + c*C + d[A]^2 + e[B]^2 + f[C]^2 + g[AB] + h[AC] + i[BC] + j[ABC] + p[A]^3 + q[B]^3 + r[C]^3 + s[A^2B] + t[AB^2] + u[A^2C] + v[AC^2] + w[B^2C] + x[BC^2]$

TYPICAL DOE TEST TABLE

Test #	Variable			Response			
	A	B	C	1	2	3	4
1	-	-	-				
2	+	-	-				
3	-	+	-				
4	+	+	-				
5	-	-	+				
6	+	-	+				
7	-	+	+				
8	+	+	+				

Development

- **Uncertain of variable combinations which create desired performance (risk involved)**
- **Concept may or may not physically work as conceptualized**
- **Can be development of deliverable hardware or of a manufacturing process**
- **R&D, Test and Evaluation phase**
- **Example: ETC Propelling Charges, Casting Process**

Verification

- **Design is an application of well understood engineering concepts**
- **Likelihood of meeting objectives of design is high**
- **Test is done to confirm proper execution in testing, calculations or manufacture**
- **Verifying requirements not design (validating)**
- **Hypothesis tests use standard statistics**
- **Can be at design or manufacture stage**
- **Example: Sub-system test, acceptance test, vendor hardware, bench marking**

Qualification

- **Similar to verification tests**
- **Usually customer or regulatory controlled**
- **Can verify requirements or qualify by similarity, analysis, simulation, inspection or demonstration**
- **Example: "Qualified to MIL-SPEC..." with appropriate witnessing**

DOE Set Up

- **Early learning**
- **Progression of validation testing**
- **Including standard deviation as response**
- **Over testing/ test to failure**

Component Qualification Approaches

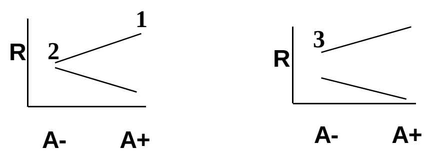
- Nominal confirmation of requirements
- Worst case settings
- Process extremes
- Process extremes plus nominal
- DOE approach
- Component variability (multiple lots) included with any of the above approaches

Robust Design Elements

- Robust design contains a few elements:
- Insensitive to variability in input variables
- Insensitive to environmental noise
- Over testing final product
- Tolerance analysis can be part of this
- A factor of safety is one method to create "robustness" but may not be cost effective

Robustness and Model Interpretation

- If the following style interaction shows up, we need to think about where we want our process to operate
  - Do we pick the maximum value? (1)
  - Do we pick the minimum variation? (2)
  - And if the "gap" is big at A-, what do we do there? (3)
    - Can we extend the curves so they intersect? Is our design space that big?



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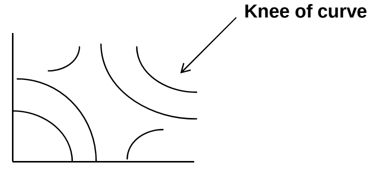
Robustness and Model Interpretation

- If the following style response surface shows up, and we know the item on the x-axis could change value (i.e. via wear)
  - We need to allow for that change and yet allow for stable performance. Let's assume it will shrink – we don't want to be "at the knee of the curve". We want to be beyond it.



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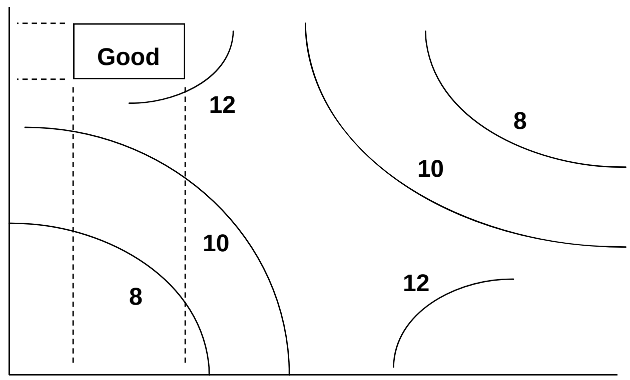
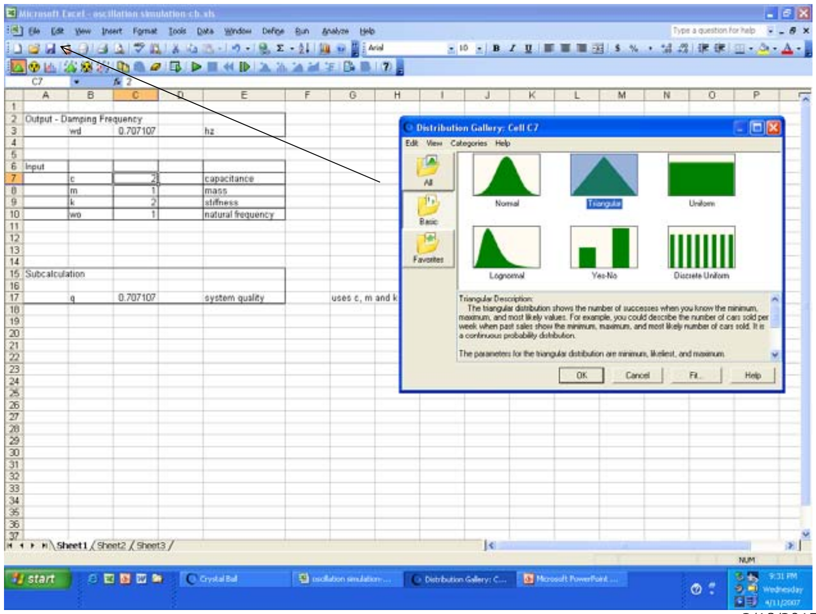
Tolerance "Postage Stamp"



Statistical Tolerancing Demo

- **We will look at a vibration situation**
- **The performance equation is known**



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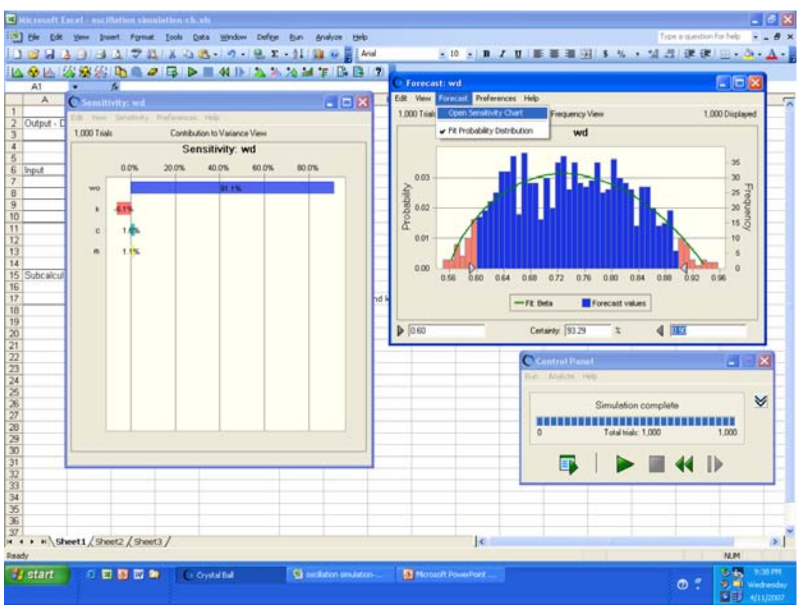

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How Much Time and Money?

- **Using DOE in development saves time so will not be additional project schedule**
  - **Compare this to ruggedness testing after design is complete.**
- **The interaction graphs are part of that process**
- **Knowing worst case conditions via DOE can simplify verification testing**
- **Selective and strategic use**

How Much Time and Money? (cont.)

- **Including standard deviations will cost more**
  - **I do not always use this**
- **Doing Monte Carlo analysis adds hours, not weeks to the overall effort**
  - **This is not always needed either**

Conclusion

- **Robust Design is available with incremental cost impacts**
- **Early DOE work can provide the foundation for knowledge based decisions**
- **If you want to see reference materials – visit our website**
  - **www.PerrysSolutions.com**
  - **If interested, email us to be on our quarterly newsletter where we share recent trends and learning points**
    - **Newsletters are all archived on our publications page**