DOE for Ruggedness Testing

By Mark J. Anderson, PE, CQE, Engineering Consultant
Stat-Ease, Inc., Minneapolis, MN
mark@statease.com

Maximizing this educational opportunity

Welcome everyone! To make the most from this webinar:

- Attendees on mute
- Chat addressed afterward
- Send further questions to mark@statease.com

PS: Presentation posted to www.statease.com/webinars/

Please press the raise-hand button if you are with me.

Talking Points

- Design of experiment (DOE) tools provide confidence that newly developed systems will withstand multifactor field conditions.
- The ASTM E1169 Standard Practice for Conducting Ruggedness Tests provides a tried-and-true protocol, not just for methods, but for processes and products.
- Low-resolution designs such as Plackett-Burmans, provide a go/no-go test based on practical importance of the observed effects (significance not an issue initially).
- Foldovers deliver a way forward for resolving what causes significant failures in ruggedness.

Agenda

- **Ruggedness testing methodology**
- Moisture method mess-up
- Memory wire fails on basis of range
- Foldover reveals pH sensor issues
- Take-homes

Ruggedness Testing Methodology*

- Vary key factors over ranges that are expected to be encountered during normal use of a "system" (process, product, method…).
- This application of DOE boils down to a go/no-go test.
- Ideally:
  - None of the factors emerge statistically significant, with
  - All potential effects being unimportant.

*(Introduced by W. J. Youden & E. H. Steiner, *Statistical Manual of the AOAC*, Association of Official Analytical Chemists, Washington D.C., 1975.)

ASTM E1169 Standard Practice for Conducting Ruggedness Tests

ASTM E1169 advocates Plackett-Burman designs (PB's) for:

- ✓ Simplicity – Two levels only
- ✓ Flexibility – Multiples of 4 rather than standard powers of 2
- ✓ Efficiency – Minimum runs (Resolution III) suffice for a pass/fail test on up to N-1 factors (saturated)
- ✓ Adaptability – Fold-over resolves main effects (III => IV)
- ✓ Convenience – Can easily lay out by hand from seed rows (std run 1):

N = 8*	+1,+1,+1,–1,+1,–1,**+1** ↰ (2nd row: **+1**, +1,+1,+1,–1,+1,–1)
N = 12	+1,+1,–1,+1,+1,+1,–1,–1,–1,+1,–1
N = 16*	+1,+1,+1,+1–1,+1,–1,+1,+1,–1,–1,+1,–1,–1,–1
N = 20	+1,+1,–1,–1,+1,+1,+1,+1,–1,+1,–1,+1,–1,–1,–1,–1,+1,+1,–1

Second row shifts one place to the right, rotating in the last sign to the beginning.
Continue cycling N-2 times until reaching the final row—this being all minus.
*PS: "Geometric" PBs—N being a power of 2, are equivalent to 2^{k-p} factorials.

Story Behind Plackett and Burman

Plackett and Burman invented their experiment designs during WWII for development of proximity fuses for anti-aircraft shells.

The British Ministry of Supply kept them secluded in a Scottish castle under guard. Data would come to the castle and matrices would come out to be delivered to engineers in manufacturing. The story was that this effort was as secret as the storied Ultra secret code-breaking effort.

The PB designs remained classified until after the war when in 1946 the inventors published “The Design of Optimum Multifactorial Experiments” in *Biometrika* (33, 305-325).

Agenda

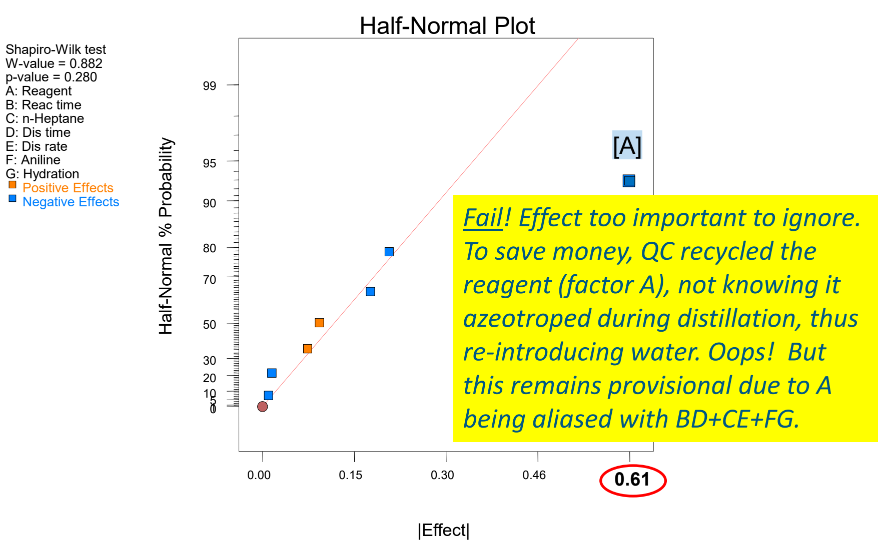
- Ruggedness testing methodology
- **Moisture method mess-up**
- Memory wire fails on basis of range
- Foldover reveals pH sensor issues
- Take-homes

Moisture Method Mess-Up

During manufacturing startup of a new adhesive, <u>all</u> the product failed due to high moisture—per tests from the plant QC testing. R&D engineers were called in to fix the process. When they set samples back to the Analytical lab, results showed all moistures in spec! Although too late for all the product dumped, the engineers ran a ruggedness test on the moisture method as done by QC (low) versus what Analytical did:

Factor	Units	Low Level (−)	High Level (+)
Reagent		used	new
Reac time	min	0	15
n-Heptane	ml	190	210
Dis time	min	45	90
Dis rate	drops/sec	2	6
Aniline	ml	8	12
Hydration		ca 2	ca 5

Moisture Method Ruggedness Test
Results per Half-Normal Plot of Effects

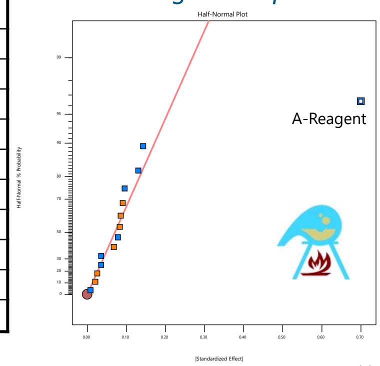


Example of Complete Foldover*

*(easily done with Design-Expert® software Design Tools ☺)

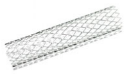
Std	Blk	A	B	C	D	E	F	G
1	1	used	0	190	90	6	12	2
2	1	new	0	190	45	2	12	5
3	1	used	15	190	45	6	8	5
4	1	new	15	190	90	2	8	2
5	1	used	0	210	90	2	8	5
6	1	new	0	210	45	6	8	2
7	1	used	15	210	45	2	12	2
8	1	new	15	210	90	6	12	5
9	**2**	**new**	**15**	**210**	**45**	**2**	**8**	**5**
10	**2**	**used**	**15**	**210**	**90**	**6**	**8**	**2**
11	**2**	**new**	**0**	**210**	**90**	**2**	**12**	**2**
12	**2**	**used**	**0**	**210**	**45**	**6**	**12**	**5**
13	**2**	**new**	**15**	**190**	**45**	**6**	**12**	**2**
14	**2**	**used**	**15**	**190**	**90**	**2**	**12**	**5**
15	**2**	**new**	**0**	**190**	**90**	**6**	**8**	**5**
16	**2**	**used**	**0**	**190**	**45**	**2**	**8**	**2**

[A]=A+BD+CE+FG (Res III)
Upgraded to
[A]=A+BCG+BEF+CDF+DEG
Results confirm A (reagent) being the culprit



Agenda

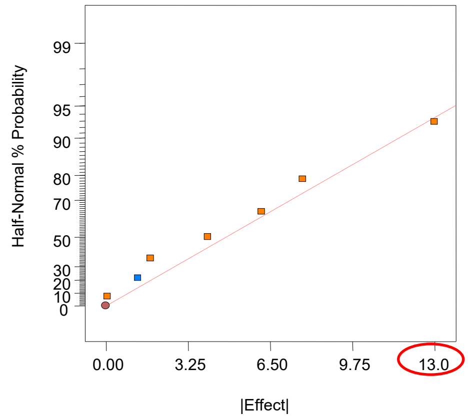
- Ruggedness testing methodology
- Moisture method mess-up
- **Memory wire fails on basis of range**
- Foldover reveals pH sensor issues
- Take-homes



Memory Wire Fails on Basis of Range

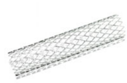
Per E1169 a nitinol wire, e.g., for medical stents, was tested via an 8-run PB for ruggedness against 7 factors.*

No effects stood out, but the range could not be accepted as a practical matter. Thus, this is a <u>fail</u> for ruggedness being <u>important</u>, albeit insignificant.



*Simpson, J., "Evolving ASTM Nitinol Standards", *The SMST (Shape Memory and Superelastic Technologies) Society Newsletter.* Issue 0, January 2004.

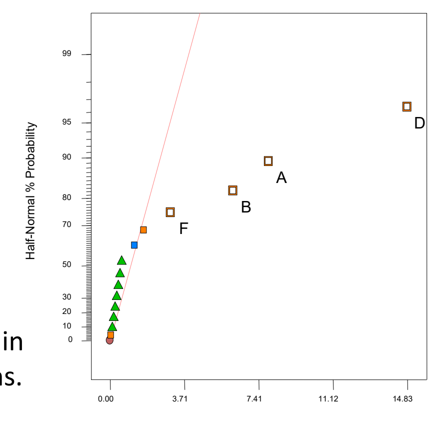
Memory Wire Testing Results from Replication



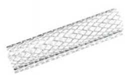
The old E1169 standard called for a complete replicate in a second block of 8 runs.

In this case, the power provided by replication produced a dramatic improvement for seeing important effects (pure error measures represented by triangles).

However, these main effects remain aliased with two-factor interactions.



Aliasing in PB Design Unresolved by Replication



[A] = A – BF – CD – EG

[B] = B – AF – CG – DE

[D] = D – AC – BE – FG

[F] = F – AB – CE – DG

Could the smallest effect [F] be [AB], a good possibility based on heredity? Or perhaps correct model may be some other combination of main effects and interactions. There's no way to know due to aliasing! A foldover would have been a far better investment in 8 more runs than a simple rep.

PS: The current Ell69 protocol calls for foldover, not replication. ☺

Ruggedness Testing 15

Re Ruggedness Test Outcome: Importance vs Significance

Many are unclear on this difference!

		Significant	
		No	**Yes**
Important	No	☺	😐
	Yes	? ☹	\!/ ☹

Ruggedness Testing 16

Agenda

- Ruggedness testing methodology
- Moisture method mess-up
- Memory wire fails on basis of range
- **Foldover reveals pH sensor issues**
- Take-homes

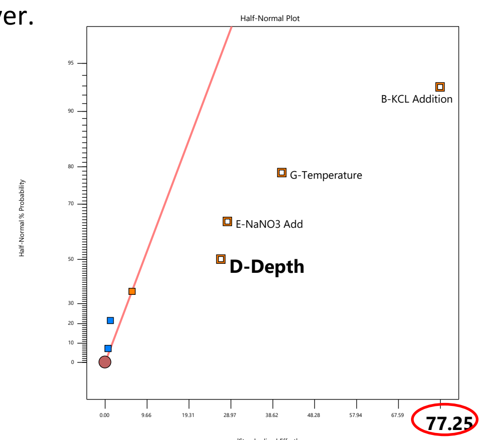
Foldover Reveals pH Sensor Issues
Results from First Block of Runs

Results from the first block of 8 runs on 7 factors show that this instrument is not rugged to field conditions—too broad a range. Continue on with a foldover.

milli pH

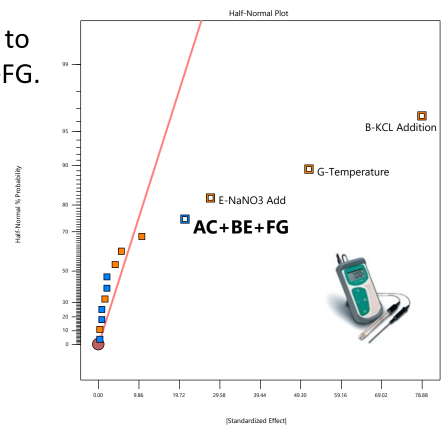
A: Dilution
B: KCL Addition
C: Equil time
D: Depth
E: NaNO3 Add
F: Stirring
G: Temperature

Positive Effects
Negative Effects



Foldover Reveals pH Sensor Issues
Second Block of Runs Dealiases Main Effects

Main effect of D is now revealed to be its aliased interaction AC+BE+FG. A semifold* (easily done with Design-Expert's Design Tools) would nail this down —most likely to BE based on heredity (B and E being main effects).



*Anderson & Whitcomb, "How To Save Runs, Yet Reveal Breakthrough Interactions by Doing Only A Semifoldover on Medium-Resolution Screening Designs", *55th Annual Quality Congress,* ASQ, https://cdnm.statease.com/pubs/semifold.pdf.

Agenda

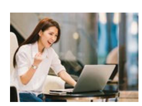
- Ruggedness testing methodology
- Moisture method mess-up
- Memory wire fails on basis of range
- Foldover reveals pH sensor issues
- **Take-homes**

Take-Homes
DOE for Ruggedness Testing

- Design of experiment (DOE) tools provide confidence that newly developed systems will withstand multifactor field conditions.
- The ASTM E1169 Standard Practice for Conducting Ruggedness Tests provides a tried-and-true protocol, not just for methods, but for processes and products.
- Low-resolution designs such as Plackett-Burmans, provide a go/no-go test based on practical importance of the observed effects (significance not an issue initially). *My preference is the 12-run option being more powerful than only doing 8.*
- Foldovers deliver a way forward for resolving what causes significant failures in ruggedness.

Stat-Ease Training:
Sharpen Up Your DOE Skills

- Modern DOE for Process Optimization
- Mixture Design for Optimal Formulations
- Private class tailored to your team



Individuals	Teams (6+ people)
Improve your DOE skills	Choose your own date & time
Ideal for novice to advanced	Customize via select case studies

Learn more & then register:
www.statease.com
Contact:
workshops@statease.com

StatEase
statistics made easy®

Make the most from every experiment!℠

via DOE for Ruggedness Testing

Stay on for some chat if you like.

Mark J. Anderson, Engineering Consultant
Stat-Ease, Inc., Minneapolis, MN
mark@statease.com