2004 Continuous Mixer and Extruder User's Group

88 mm TSE Scale Up Facility; IHDIV,NSWC

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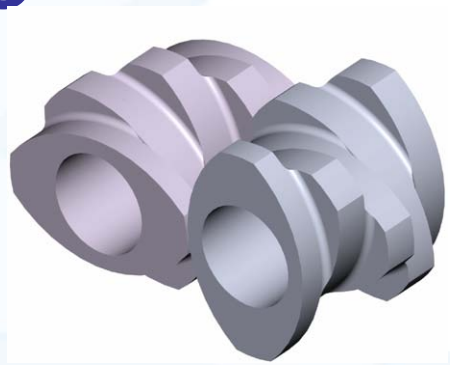


October 2004

- Background
- Facility Description
- Schedule
- Process Review Board
- Extruder Alignment
- Extruder Screw Deflection
- Conclusion

Background

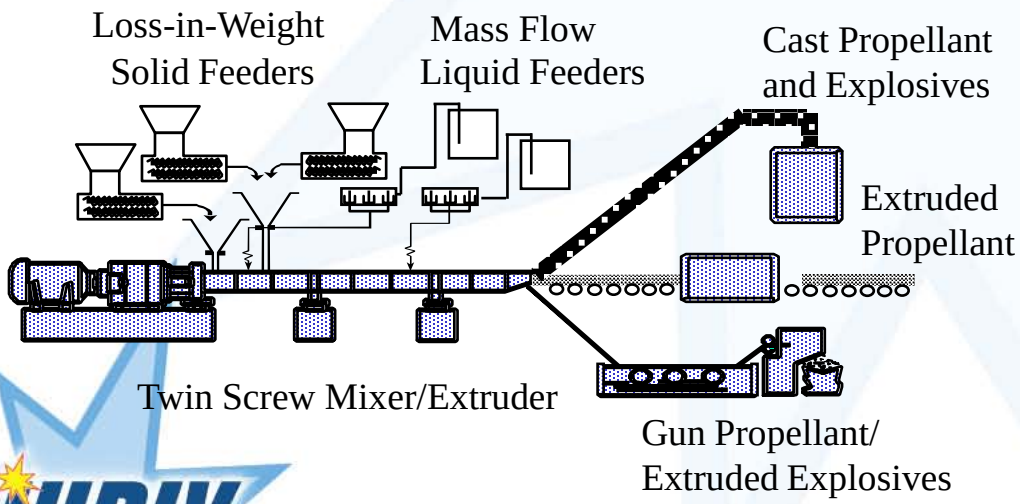
- Indian head has been developing continuous processing for producing energetics for 20 years
- Next step...technology scale up
- EX-99 LOVA chosen for first platform

IHD Continuous Processing Objectives

- Continue to provide leading edge energetic solutions
- Reduce cost of facility ownership
- Reduce time and cost to take products from R&D to manufacturing
- Improve safety of operations and materials
- Reduce environmental impacts
- Enhance transition of technology to industry

Continuous Processing Scale-Up Facility

- FY 99 MILCON
- SOO and SRD contract approach
- Contractor wrote SOW
- Administered via NAVSUP
- July ’00 contract awarded to Washington Group Int’l.



- Scale-up continuous processing technology
- Validate and quantify benefits
- Transition technology to industry
- Transition new materials from R&D into use
- Support variety of energetics requirements (first being nitramine propellant for Navy guns)

Facility

- 2,900 ft^2 building composed of three rooms
  - A processing bay, an electrical equipment room and a mechanical equipment room
- There is an air lock entrance into the processing bay
- Over the extruder there is an equipment stand/ mezzanine
- Air in the processing bay is controlled at 70° +/- 5° and 40 grains moisture +/- 10, with 8 air changes per hour

Solid Feed Systems

- There are 4 solids feed systems designed with refill capability
- Each system is composed of a K-Tron loss in weight feeder and a Matcon IBC discharge station
- Feeders are sized to provide a wide range of feed rates
- Feed systems are designed to be portable
  - Can be moved to support feeding to any of 5 solids feed ports in the extruder
- There is one volumetric feeder dedicated for purging the extruder

Liquid Feed Systems

- There are 3 liquid feed systems that do not have refill capability
- One 150 gallon tank & 2 (each) 75 gallon tanks
- Liquids are metered using Gear pumps and mass flow meters in a closed PID loop
- A progressive cavity pump for feeding slurries

Extruder

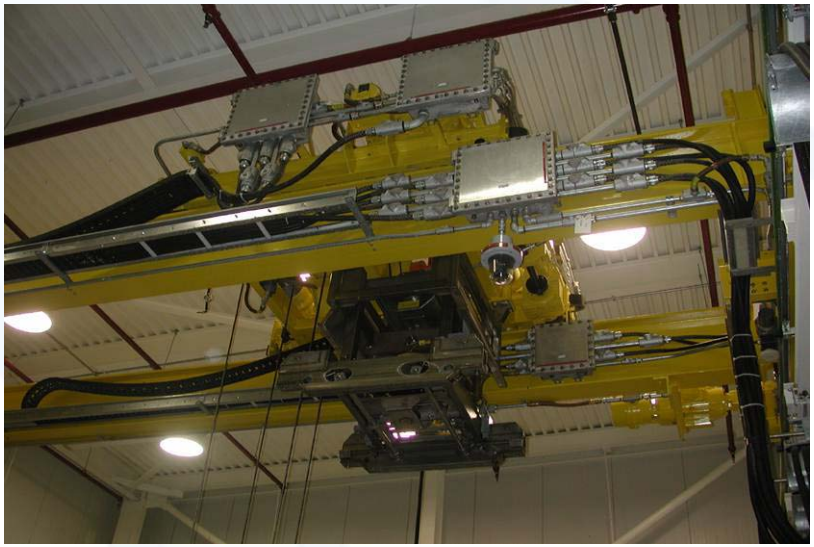
- 88 mm screw diameter with L/D of 30 manufactured by Clextral
- Designed with a horizontally split barrel
- Barrel design is modular for maximum flexibility
  - Five barrel zones with independent temperature controls
  - Mid barrel screw support to allow for shorter screw length
- Drive and barrel clamping are hydraulic

Product Take Away

- Designed around extruded LOVA gun propellants
- Plan to extrude eight 0.430” diameter EX-99 LOVA strands
- 8 strand pelletizer supplied by Romeo Engineering
  - Based on 4 strand prototype purchased for the 40 mm TSE
- Cut grains are collected in baskets which are in a tank on an indexing turn table
  - Grains will be collected in water
- Baskets are sized to collect 3,500 lbs of cut grains

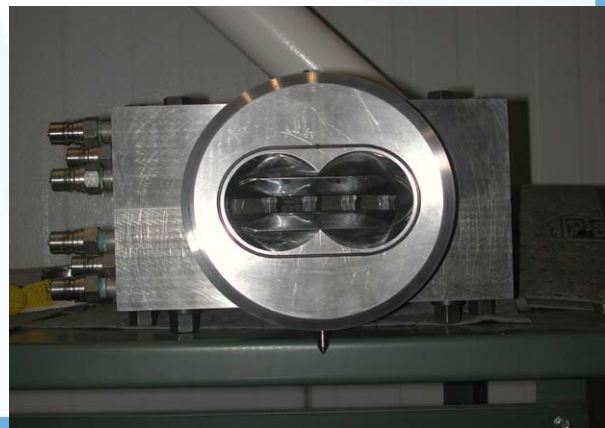
Crane

- Custom designed top running, double girder, explosion proof crane with a specialized gripper for handling Matcon refill bins
  - Supplied by American Crane and Equipment Company
- 5 ton main hoist with a 3 ton auxiliary
- Electrical hazard class - Class I, Div. 1 Groups C&D, Class II, Div. 1, Groups E, F &G
- Remotely operated main hoist



Process for LOVA Gun Propellants

- There are 2 feed streams: Lova feedstock & solvent
- 8 strand die
- Charge the Building with ~3,000 lbs LOVA feedstock & solvent
- Ramp up and run until the Lova feedstock is almost exhausted
- Ramp down, stop, remove product & refill
- Ramp up and resume process



Project Milestones

- Award contract... Design- 7/00
- Facility construction – 4/01
- Mechanical construction –5/01
- Equipment commissioning- 6/02
- Process inert materials – 8/03
- Process Review Board – 2/04
- *Process energetic materials- 12/04*
  - *EX-99 LOVA*
- *Deliver 15K pounds to support gun system qualification testing –4/05*

Process Review Board

- Indian's Heads new process validation requirements:
  - Process Description
  - Material flow, storage and disposal
  - Hazardous Materials
  - Process Hazard Analysis
  - Scale Up Justification
  - Facilities
  - Equipment
  - SOPs
  - Operator Training & Qualification
  - Quality
  - Configuration Management
  - Controls System Hazard Analysis

Process Review Board

- 3 Volumes, approx. 1000 pages
- 35 hours of formal presentation to PRB
- 127 action items assigned
- Inert Process Audit
- Major Focus
  - Hazard Analysis
    - Equipment Design
    - OSH & A
    - Controls
  - Inert Process Audit

Two PRB Areas of Concern

- Mechanical Set up of Extruder
- Screw/Barrel Contact as a result of cantilever extruder design

Mechanical Setup of Extruder

- Galling of barrel liners and elements was experienced twice
  - During facility commissioning
  - During inert processing
    - Both times attributed to material incompatibility of hardware

Facility Commissioning

- During equipment setup by vendor, the extruder was inadvertently run for an excess of 1 hour at 75 RPM with screws in machine
- Hardware galled as a result of material incompatibilities
  - IHD requested stainless screws and barrel liners with a minimum of 5 HRC differential between the parts. Actual parts measured at 43 HRC for liner and 33 HRC for screw elements.
    - Barrel Liner, stainless steel (European standard #1.4418)
    - Screw Element, stainless steel 440C
  - Clextral did not endorse this material selection by IHD

New Parts

- Extensive material selection process was performed
- New hardware selected identical to that used by SNPE
  - Brass compound for screws
    - 78% Cu
    - 12% Al
    - 5% Fe
    - 5% Ni
    - 98 HRB
  - Nitrided stainless steel for liners
    - 55 HRC

Repaired Parts

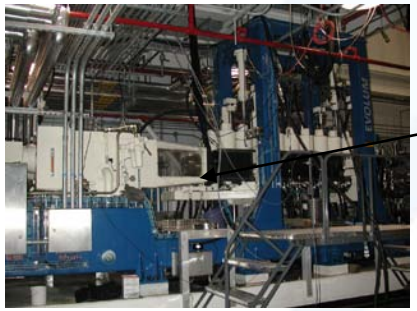
- Damaged parts were repaired to use for inert processing
  - Surfaces were machined to remove galling marks
  - Liners were machined out to remove damage
  - Screw built up with a Stellite 21 compound on tips to maintain desired clearances
- Inert trial was performed..parts galled again
  - Hardness of barrel liners and screw elements was very similar, approx. 43 HRC.
  - This was believed to cause the galling
- Mechanical alignment of extruder was questioned
  - Gearbox output shafts to barrel bores

Extruder Alignment

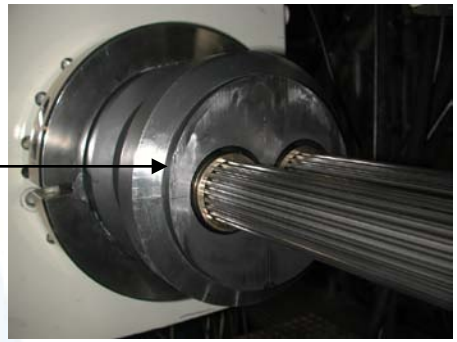
- Oasis Alignment Services
  - Measure and check alignment using an optical technique
  - Barrel out of alignment at gearbox end by 0.013” and die end by 0.021” in horizontal axis
  - Barrel out of alignment by 0.007” at gearbox end and 0.011” at die end in the vertical axis
  - Machine design (0.012-0.013”); clearances “lost”
  - Extruder out of level by 0.050” at the base
  - Inconsistent readings at rear barrel stop
  - Clextral was also there during measurements
    - Machine as good as it can be and “ready to run”

What we found

- The inboard end of the barrel was found to be higher and to the right of the output shaft centerline
- The outboard end of the extruder was found to be higher and to the right of the output shaft centerline
- The barrel bores were inspected and the centerlines were parallel to 0.001”
- The inboard end of the barrels are located by a shaft seal, no hard mechanical stops are used



Seal used as inboard barrel stop



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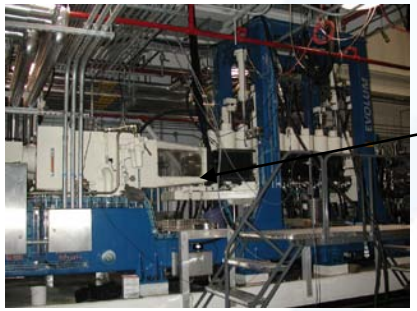

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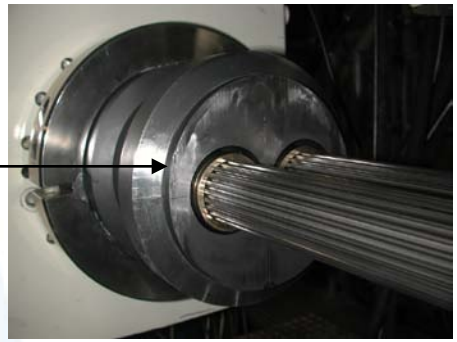


What we did

- Action items:
  - Re-level extruder base frame
  - Design, fabricate and install hard mechanical stops on inboard end of barrels
  - Shim or adjust extruder barrels to improve condition in both vertical and horizontal axis
- After action items completed:
  - Barrel out of alignment at gearbox end by 0.003” (0.013”) and die end by 0.001” (0.021”) in horizontal axis
  - Barrel out of alignment by 0.002” (0.007”) at gearbox end and 0.007” (0.011”) at die end in the vertical axis

Screw Deflection

- Address HA failure mode of screws contacting barrel or each other
- Extruder Design
  - Extruder is cantilevered design. L/D- 30:1
  - There is no fixed clearance as in a batch mixer
  - Screws are designed to float & self center using the process material as “fluid bearing”
  - At the start of the process, the screw are resting on the barrel
  - The designed “operating window" between elements & barrel is 0.0128”-0.0133”

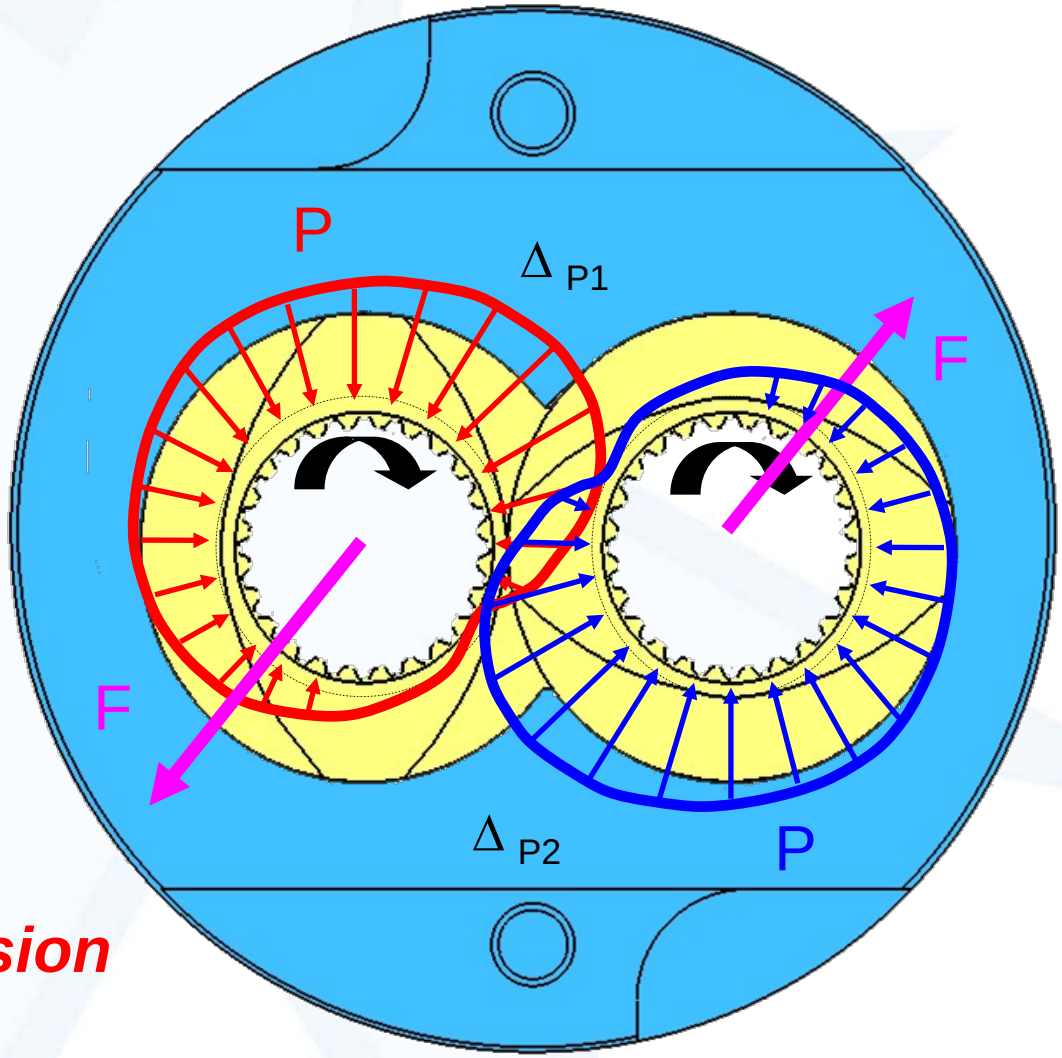
Pressure and load distribution

From Clextral

P : Net pressure distribution around screw element.

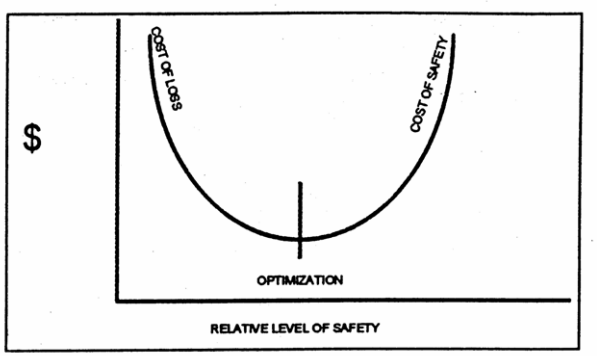
F : net force on screw

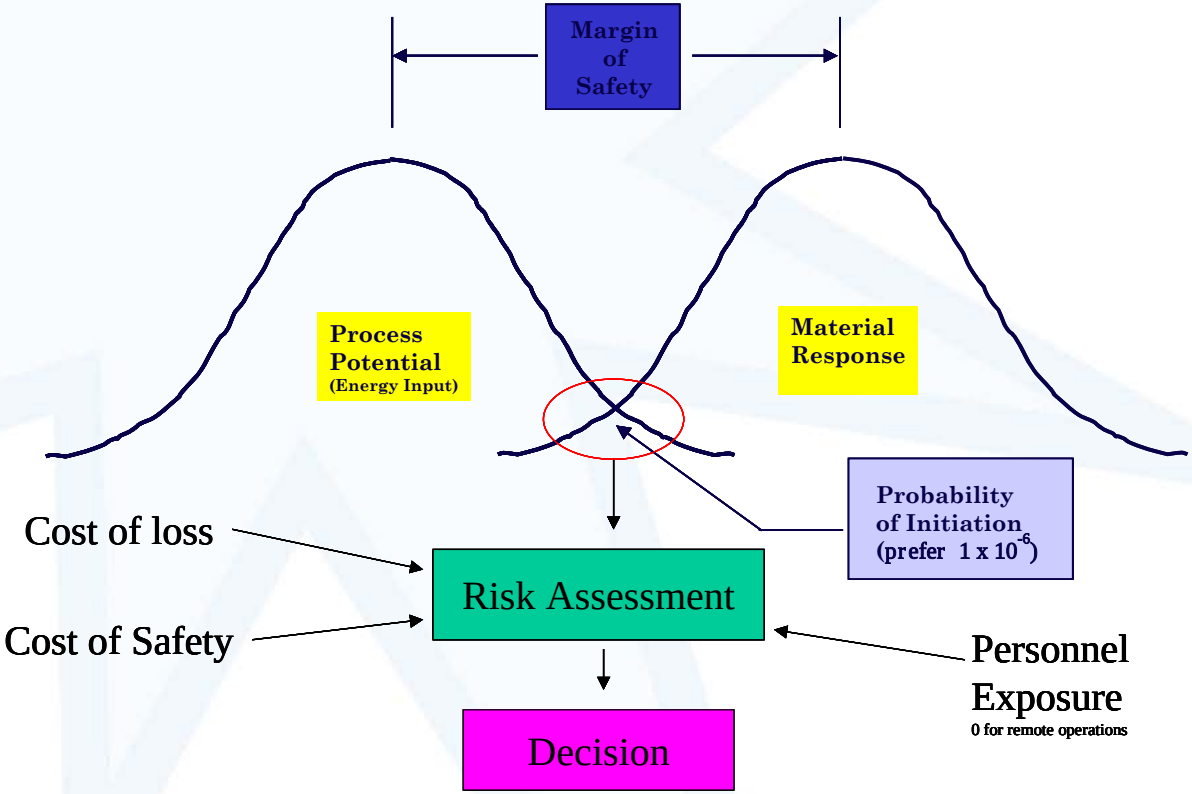
Typical location of wear in twin-screw extrusion



Acceptable Safety

- We know contacts occurs by “design”, what are we willing to accept?





Questions

- How can we relate the process potential (friction) to the allowable material response?
- How can we correlate safety data (friction) to process potential imparted by moving parts?
- What we know is friction (ABL friction tester) sensitivity of energetic and stress to yield screws. How can we use this data?

- We contacted :

-Dr. Chris Rauwendaal, Rauwendaal Extrusion Engineering, Inc.

-Dr. Dilhan Kalyon, Highly Filled Materials Institute

-Dr. Amr M. Baz, Director of Structures Research Center, UMCP

-Jose Cheio De Oliveira, Clextral Extruder Engineering Manager

-John Kelly, NSWCIH

-Dr. Mitch Gallant, NSWCIH

SNPE

-Autoliv

-Nexplo/Bofars/SNPE

Safety Management Services to perform an analysis to correlate Ex-99 friction data to the necessary energy required exceed barrel yield stress (the worse case impact) and use probit data to calculate risk

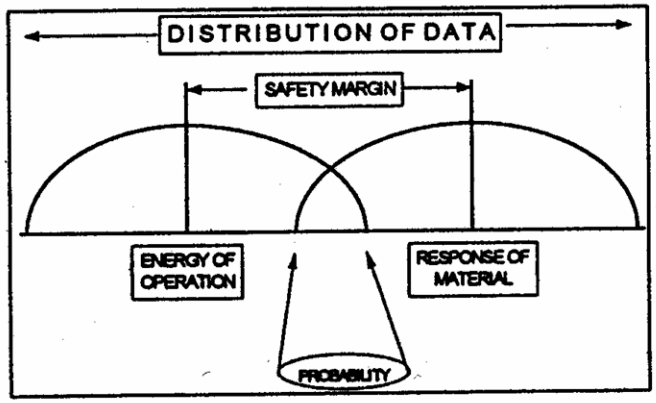
Threshold Initiation Level (TIL)

- The TIL represents the minimum energy required to initiate the sample
- TILs provide a simple comparison of materials for ranking
- The level which produces 20 consecutive “No-Go” reactions with at least one “Go” reaction at the next higher energy level is the TIL

Probit Analysis

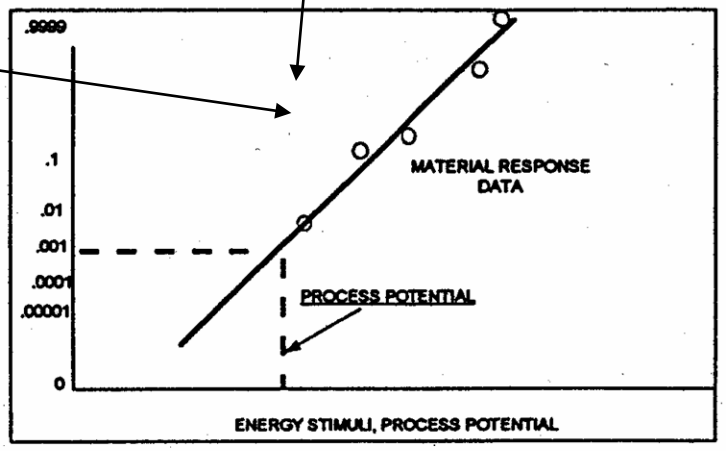
- Once the TIL has been determined:
  - 10 trials are performed at 4 different energy levels above the TIL
  - The results can be statistically analyzed
  - A resulting probit curve is given as the probability of initiation vs the stimuli input energy.
- Results can be used to calculate the probability of initiation

REDUCE DATA TO ENGINEERING TERMS. DETERMINE QUANTITATE PROBABILITIES.



As process potential is increased, Probability increases

Probability is based on statistical sample, More data=higher confidence

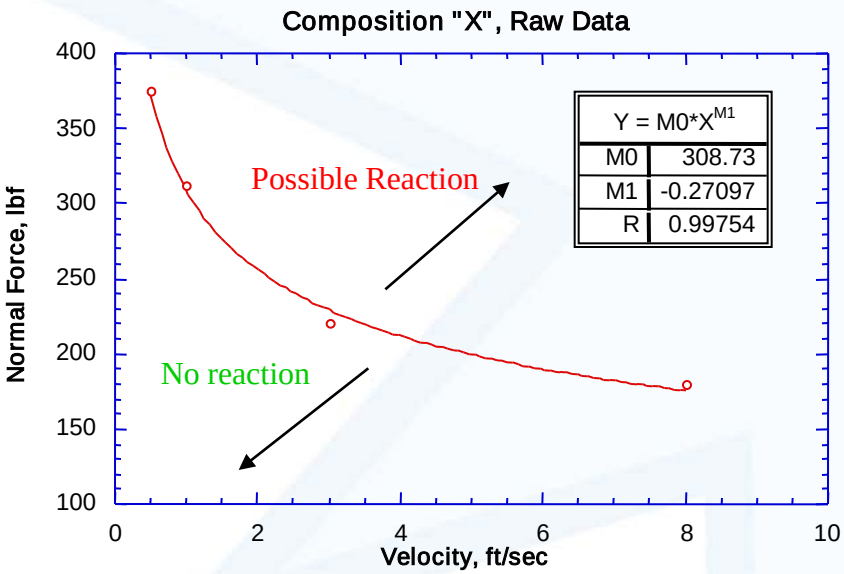


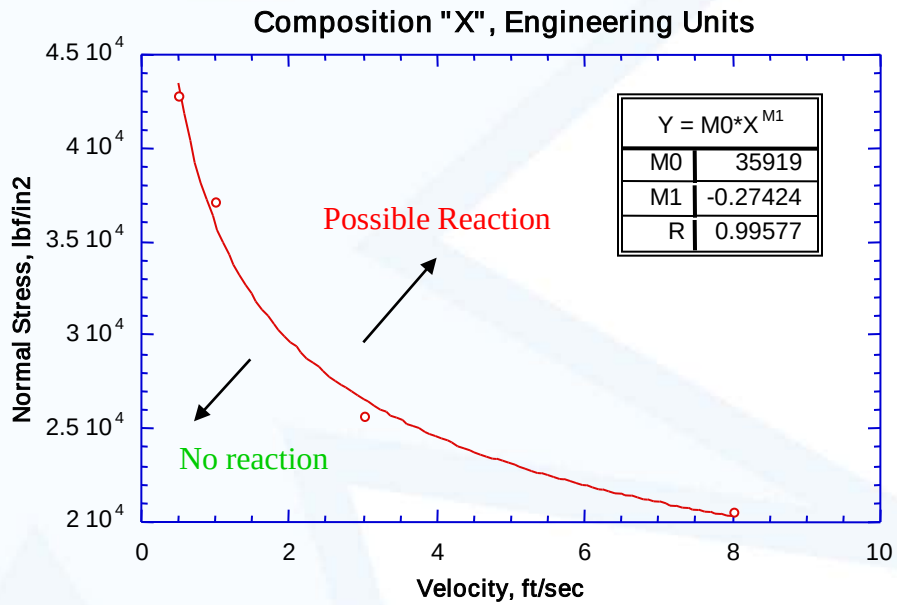
PROBIT Analysis. At least 10 trials are performed at four levels above the TIL. The data received from these trials are statistically analyzed. The resulting PROBIT curve is given as the probability of initiation versus the energy input. The results are used to calculate margins of safety and the probability of initiation of the material from the tested stimuli.

TIL: SLIDING-FRICTION MAP
(Example)

Data - Reduced to Engine

- **TIL's of Composition (Based on 20 trials)**
  - **Reflects actual process conditions.**





At 80 RPM-Tip speed is approx 1.2 ft/sec

Applied Stress

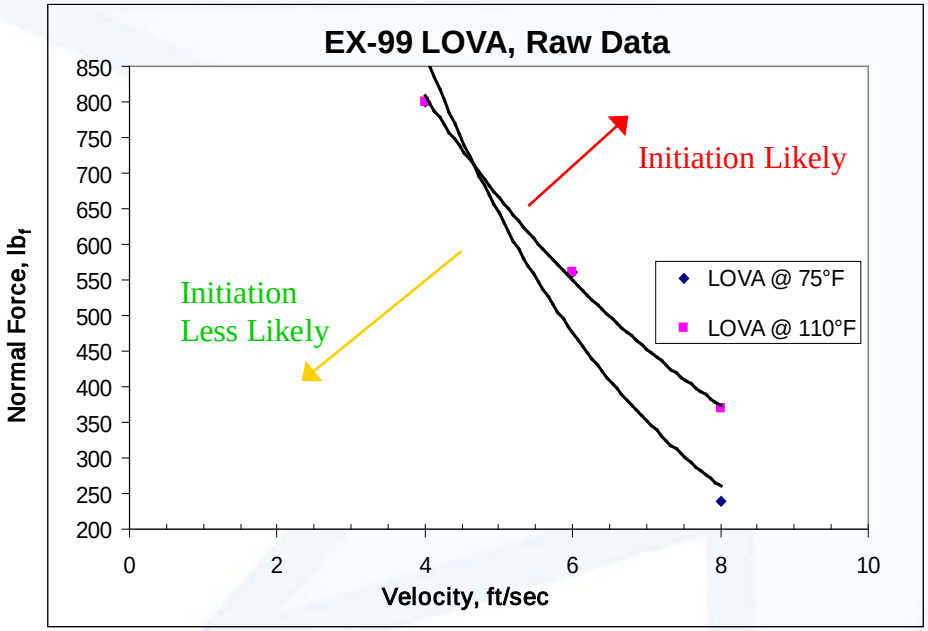
–Gouge in screw element (screw elements are much softer than barrel)

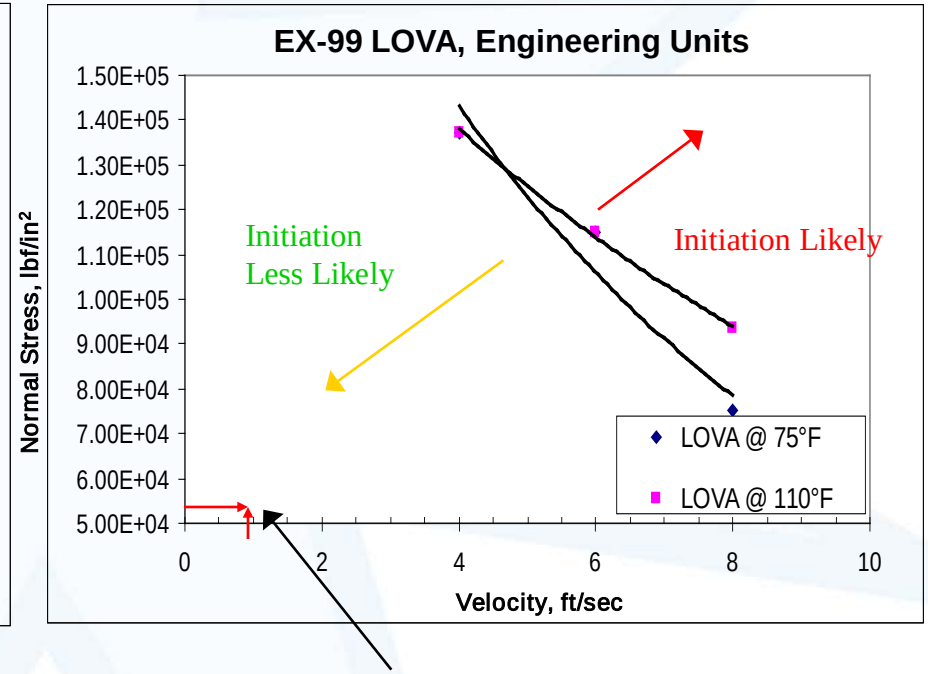
–Yield strength of brass was exceeded (gouged)

–Applied Stress: ≥ 58,000 psi.

TIL: SLIDING-FRICTION MAP
LOVA at 75°F and 110°F
Raw Sensitivity Data - Reduced to Engineering Terms.

- **TILs of EX-99 LOVA (Based on 20 trials)**





Screw Mat'l yield stress:57440 lb/in2

Force need to gouge screws

In-process potential of screw-to-barrel contact (5.744E4 lb/in^2 @1.2 ft/sec tip speed)

Takes a lot more energy to initiate material than to yield screws

Conclusion

- Output shafts to barrel bores are as “good” as they can be within design and machining tolerances
- For EX-99 LOVA, process is run at process conditions which indicate the process potential is far below the material response concerns