Turbomachinery Symposium 2007
Case study

ROOT CAUSE ANALYSIS

EXPANDER INTAKE FLANGE STUD FAILURE

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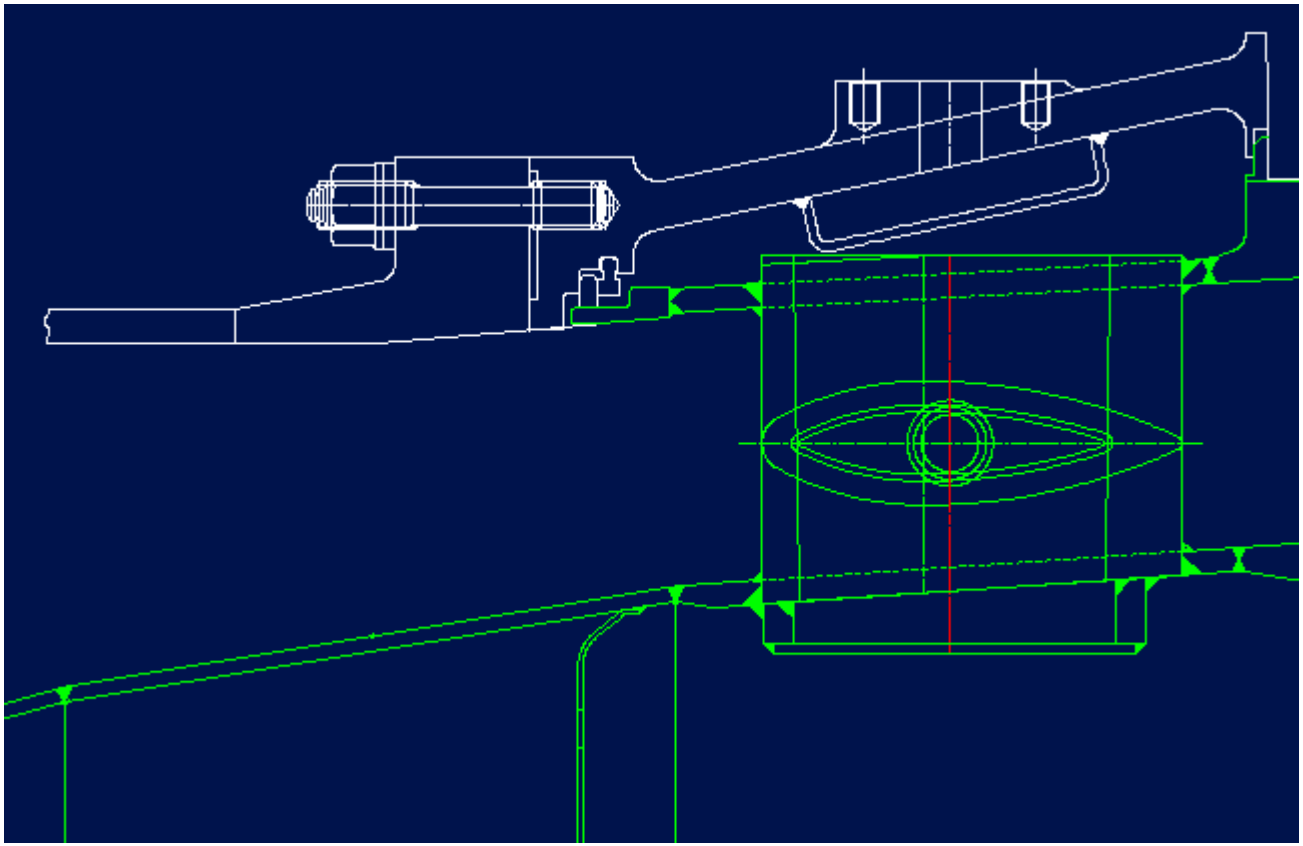
Picture Intake Casing

Started in March 2001. Five studs were found broken during a scheduled shutdown in September 2003.

Assembly Drawing



STUD

1¼-12 UNF, 2A, IN718 PER AMS 5663
UTS: AT ROOM TEMP 185 ksi,
AT 1,200°F 145 ksi

BELLEVILLE WASHER

IN X-750, Rated For 45,000 lbs.
UTS: AT ROOM TEMP 160 ksi
AT 1,200°F 135 ksi

Minimum Required Mechanical Properties

Tensile Test Results for Stud Samples (ksi):

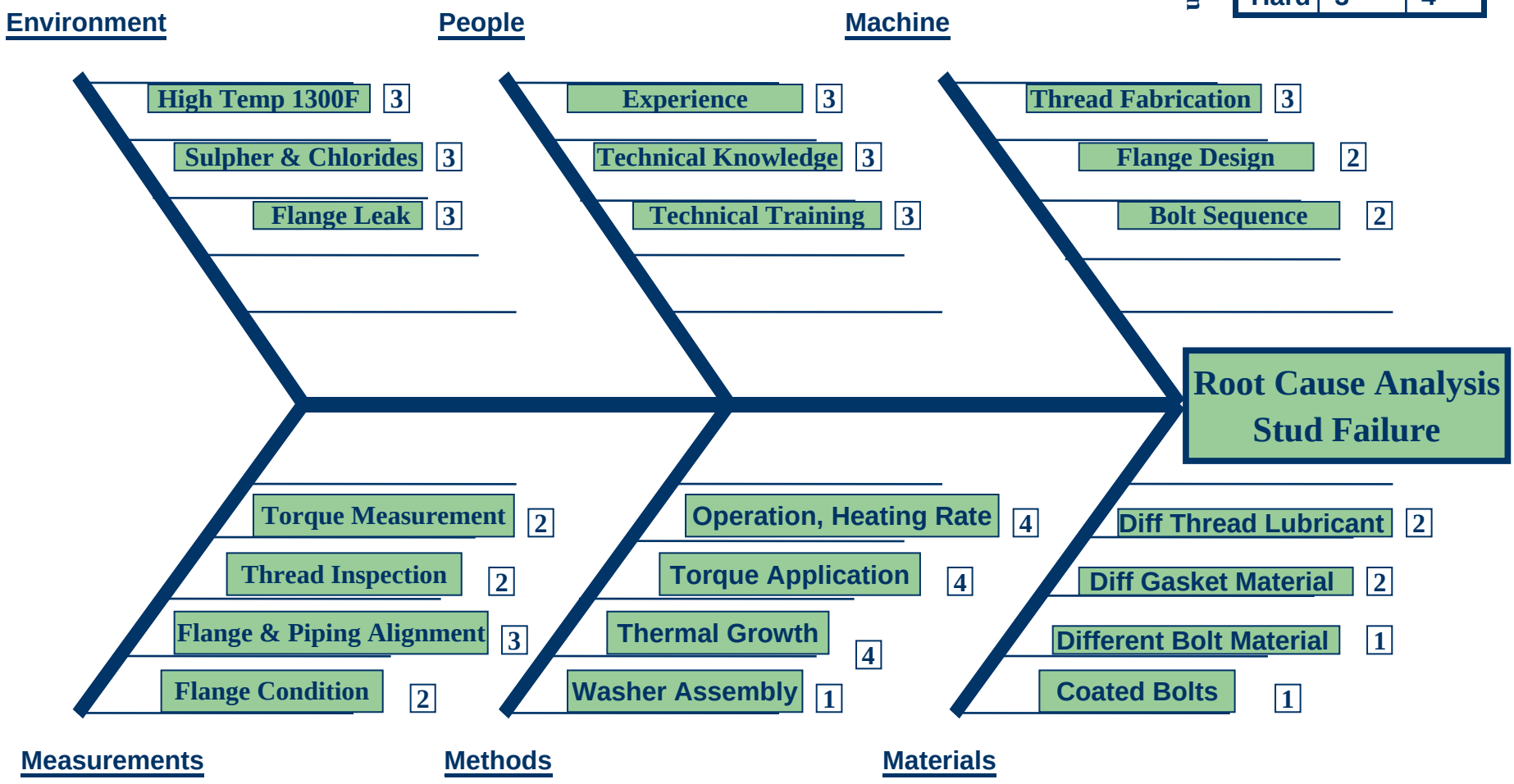
Order/PO #	Room Temperature		AT 1,200°F	
	UTS	YS	UTS	YS
Batch 1	203.0	173.0	170.0	148.0
	202.0	170.0	166.0	143.0
Batch 2	206.8	172.9	165.8	145.4
Batch 3	203.8	164.8	166.4	151.1
	206.8	176.7	169.0	150.7
Batch 4	205.6	172.1	171.6	136.8
	201.5	165.0	164.0	141.4
Standard Deviation	2.2	4.4	2.7	5.2
Average Value	204.2	170.6	167.5	145.2

Minimum Required	185	150	145	125

Fishbone Diagram

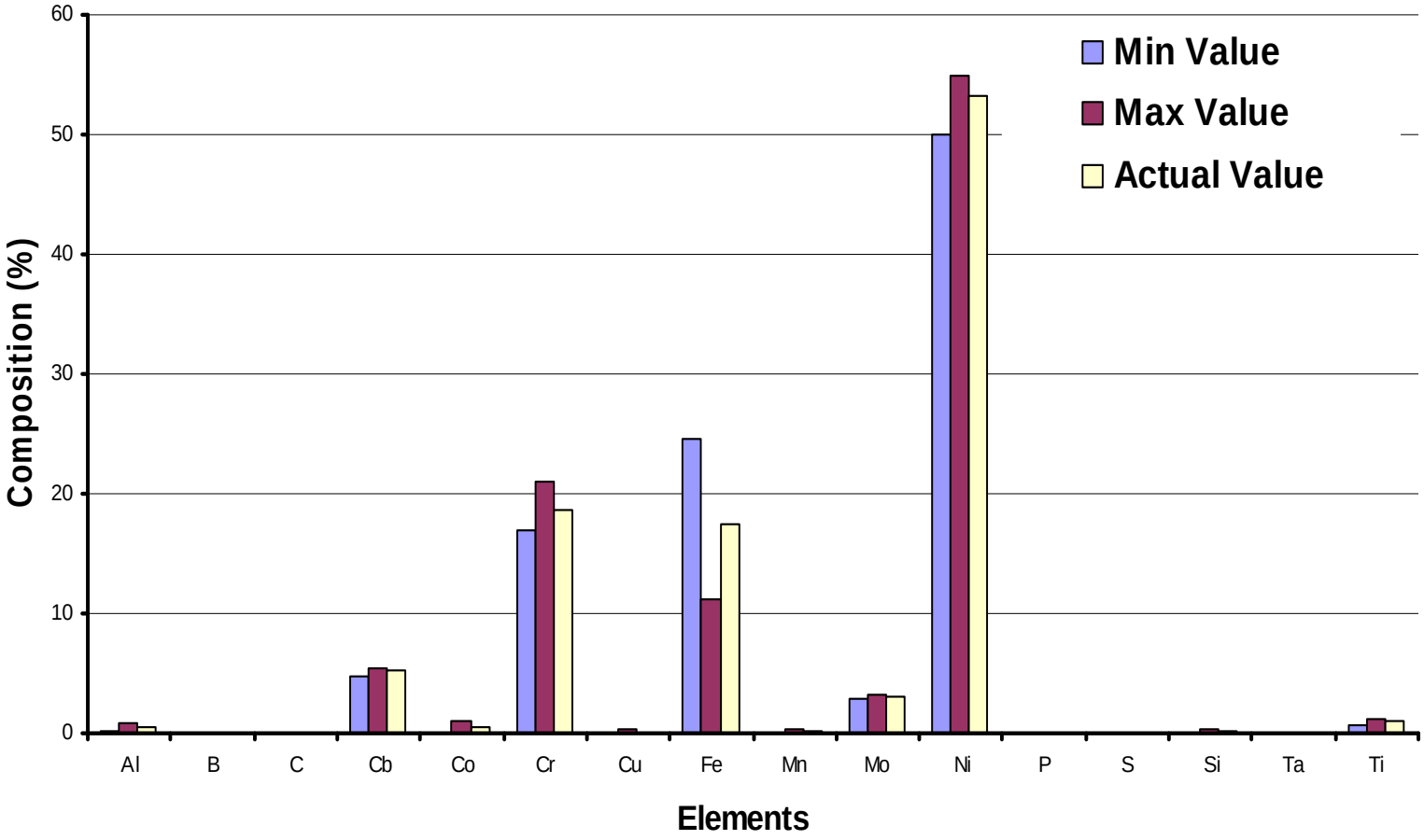
Impact

Implementation	High	Low
Easy	1	2
Hard	3	4



Chemical Properties

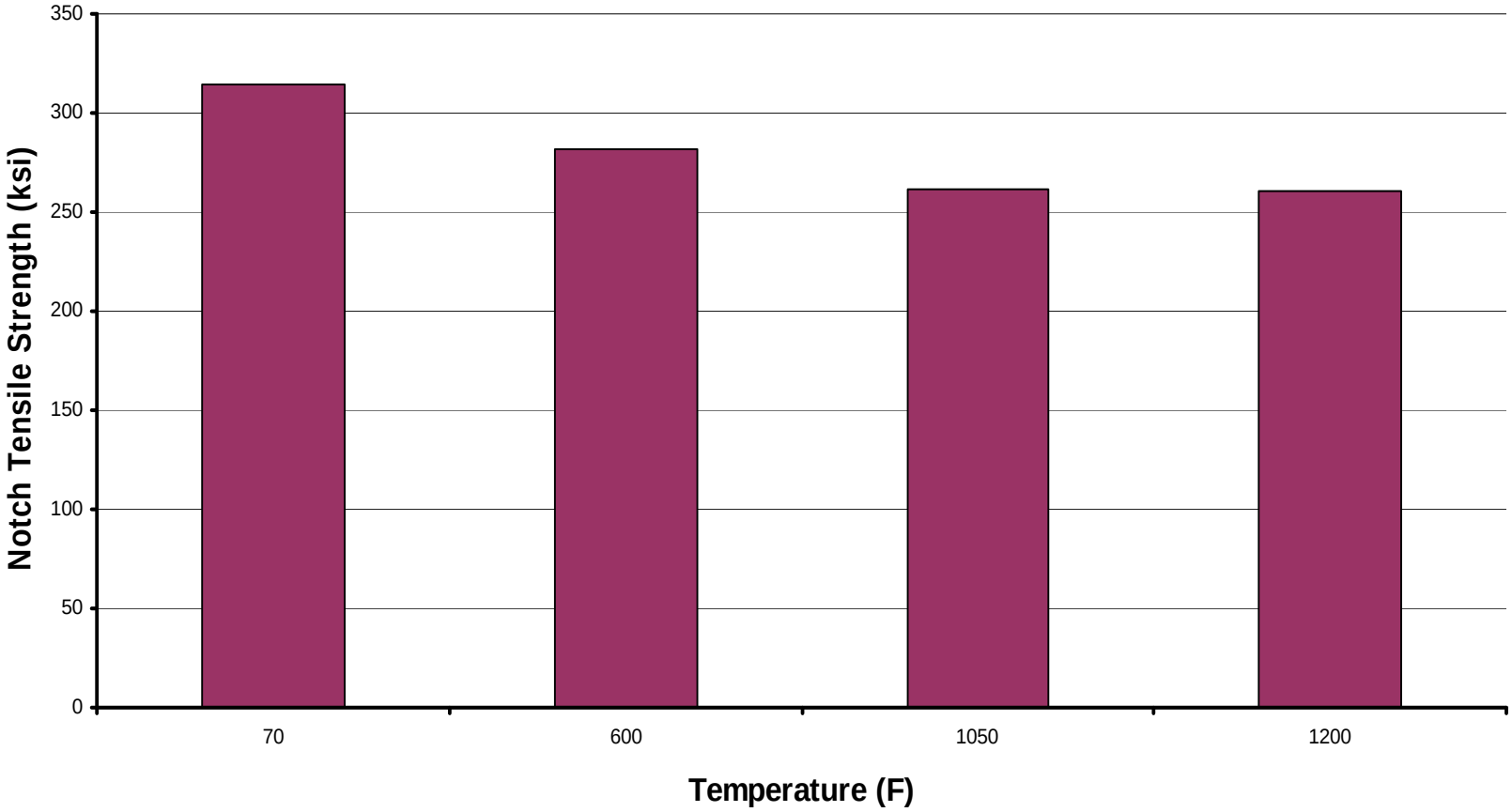
Chemical Composition Comparison



CHEMICAL COMPOSITION WITHIN SPECIFICATION LIMIT

Mechanical Properties

Notch Tensile Strength For Broken Stud



ROOM TEMP NTS 314 KSI (AVE NTS 274 KSI)

BROKEN STUD HARDNESS 389 BRINELL (42C), MIN REQUIRED 331 BRINELL (36C)

Initial Load Condition

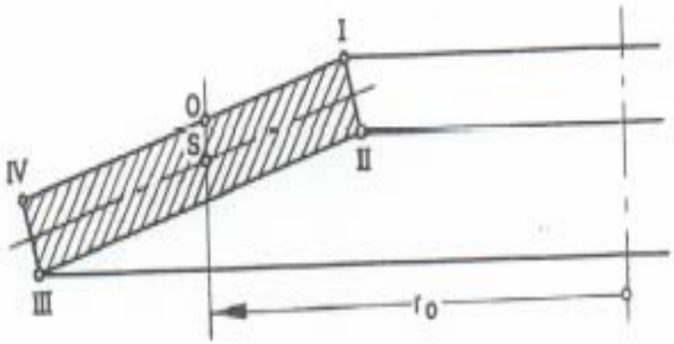
Stress Developed on Stud for 535 ft.lb Initial Torque : 43,228 psi
Load on Belleville Washer 46,400 Lbs for 535 ft.lb Initial Torque

Stress Developed on Belleville Washer for 0.008” Compression At Different Locations (UTS 160 ksi, YS 105 ksi)

Stress Developed :
> YS
< UTS

FC, Spring Force, Compression 0.008, (lb) =	45,987
F_C, Spring Force Compressed Flat (lb) =	45,939

Stress Developed	Elastic Stress	Neuberized Stress
F_O, Spring Stress at Point 0 (ksi) =	-281	-127
F_I, Spring Stress at Point I (ksi) =	-398	-149
F_{II}, Spring Stress at Point II (ksi) =	372	144
F_{III}, Spring Force at Point III (ksi) =	220	117
F_{IV}, Spring Stress at Point IV (ksi) =	-203	114



Normal Operating (At 1,200°F)
ASME Code Calculation

ASME, SEC VIII, APPENDIX-2

Minimum Stress Required for Joint Seal on Stud (52) = 5,098 (PSI)

FLANGE STRESS FOR THE GIVEN PARAMETERS:

TYPE	t	g0	g1	h	SH	SR	ST	COMMENT
6	3.5	0.906	1.632	4.167	3,266	1,082	797	OK

MAX PERMITTED VALUE FOR: SH = 6,600(PSI)	SR & ST = 4,400(PSI)
MAX PERMITTED VALUE FOR: (SH+SR)/2 OR (SH+ST)/2 = 4,400(PSI)	

SH = LONGITUDINAL STRESS IN HUB, PSI	SR = RADIAL STRESS IN FLANGE, PSI
ST = TANGENTIAL STRESS IN FLANGE, PSI	t = FLANGE THICKNESS, IN.
g0 =THICKNESS OF HUB AT SMALL END, IN	g1 = THICKNESS OF HUB AT BACK OF FLANGE, IN
h = HUB LENGTH, IN	

Meets ASME Requirements

Normal Operating (At 1,200°F)
Initial Torque And Thermal Loads

Stress Developed on Stud for 535 ft.lb Initial Torque: 43,230 psi

Stress Developed on Stud Due To Thermal Loading : 56,890 psi

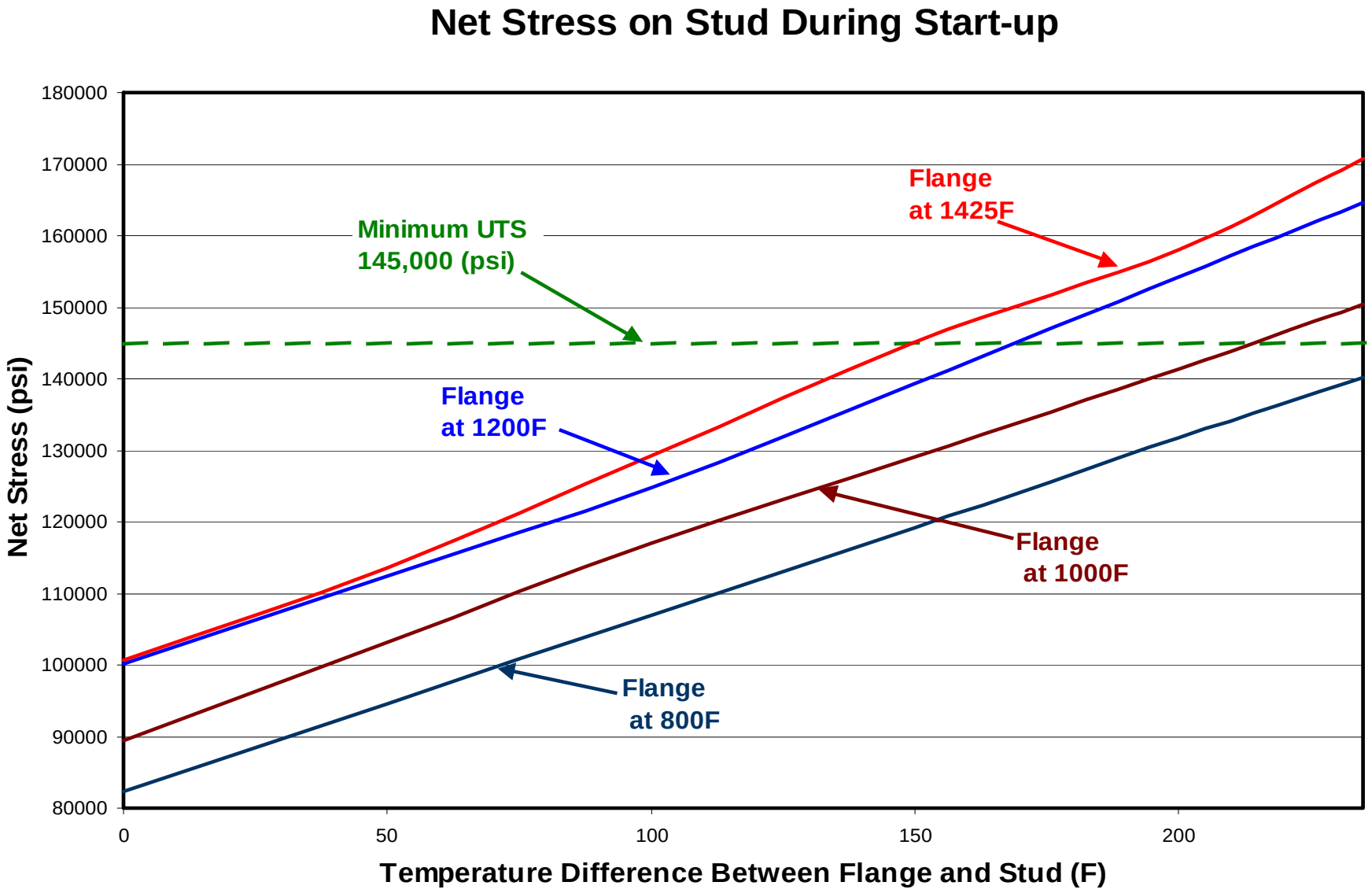
Net Stress Developed on Stud (Int. Torq. + Thermal): 100,120 psi

Net Bolt Stress < 125,000 psi (YS), Acceptable

Net Bolt Stress > Min Required For Joint Seal, Acceptable

Load on Belleville Washers 107,470 Lbs, Failure will Occur

Startup Stress, Torque 535 Ft.lb



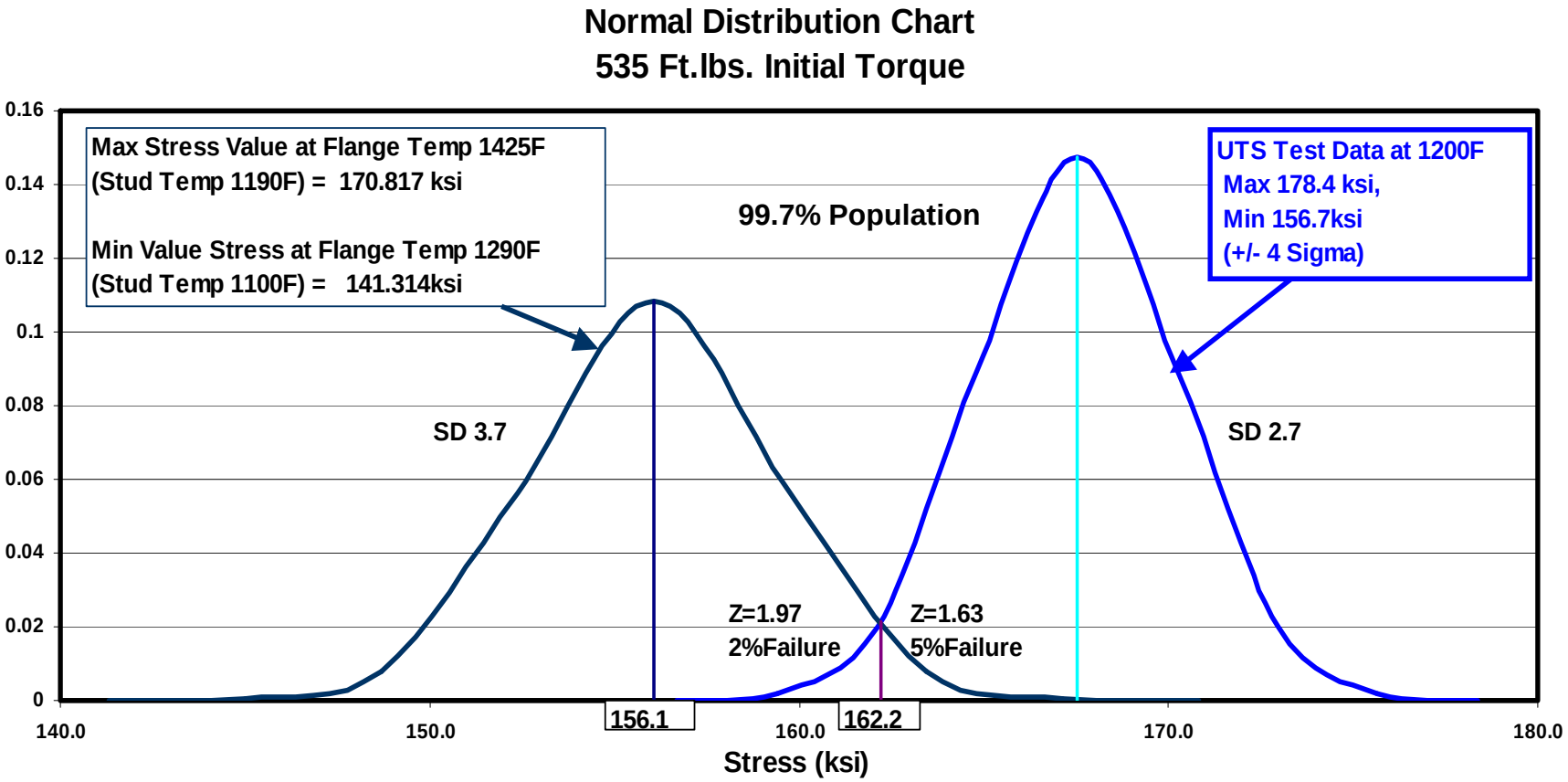
Start-up Thermal Bolt Stress, Flange At 1,200°F

Bolt Thermal Load For Different Temperature Lags, Flange at 1,200°F

Temperature Difference Flange/Stud (F)	Bolt Material		Flange Material		Thermal Strain (in/in)	Bolt Thermal Stress (psi)	Net Bolt Extension (in)	Bolt Force Due To Thermal Load (lb)
	Thermal Exp Coeff. (in/in/DegF)	Elasticity Modulus (psi)	Thermal Exp Coeff. (in/in/DegF)	Elasticity Modulus (psi)				
0	8.400E-06	2.480E+07	1.043E-05	2.070E+07	0.00229	56889	0.00803	61063
50	8.350E-06	2.500E+07	1.043E-05	2.070E+07	0.00277	69198	0.00969	74275
100	8.300E-06	2.520E+07	1.043E-05	2.070E+07	0.00324	81570	0.01133	87555
150	8.200E-06	2.565E+07	1.043E-05	2.070E+07	0.00375	96185	0.01312	103243
200	8.100E-06	2.610E+07	1.043E-05	2.070E+07	0.00425	111001	0.01489	119146
235	8.030E-06	2.638E+07	1.043E-05	2.070E+07	0.00460	121323	0.01610	130225

Start-up Probability of Failure, Torque 535 Ft.Lb

Stud Temperature Lags 235°F For Flange Temperature 1,425°F
Stud Temperature Lags 190°F For Flange Temperature 1,290°F



Net probability of Failure ~7% (4 out of 52)

Conclusion

Initial Condition:

- **Failure Will Not Occur For Studs or Washers**
- **Stress Values Are Well Within Permissible Limits**

Normal Operating Condition:

- **Studs Will Not Fail, However, Washers Will Fail**
- **Stress Values Are Within Permissible Limits For Studs**

Start-up Condition :

- **Probabilistic Analysis Result:**
- **7% Failure For Initial Torque of 535 (Ft.Lbs)**

Corrective Action

Corrective Actions Taken:

1. **Belleville Washers Replaced by Regular Flat Washes**
   (Belleville Washer For Load Capacity over 45,000 lbs. Not Available)
2. **Initial Bolt Torque Reduced From 535 (Ft.Lbs) To 400 (Ft.Lbs)**
3. **Evaluated the Bolt Stress For Above loading**

Corrective Action Normal Operating (At 1,200°F)

Stress Developed on Stud for 400 ft.lb Initial Torque: 32,330 psi

Stress Developed on Stud Due To Thermal Loading : 56,890 psi

Net Stress Developed on Stud (Int. Torq. + Thermal): 89,220 psi

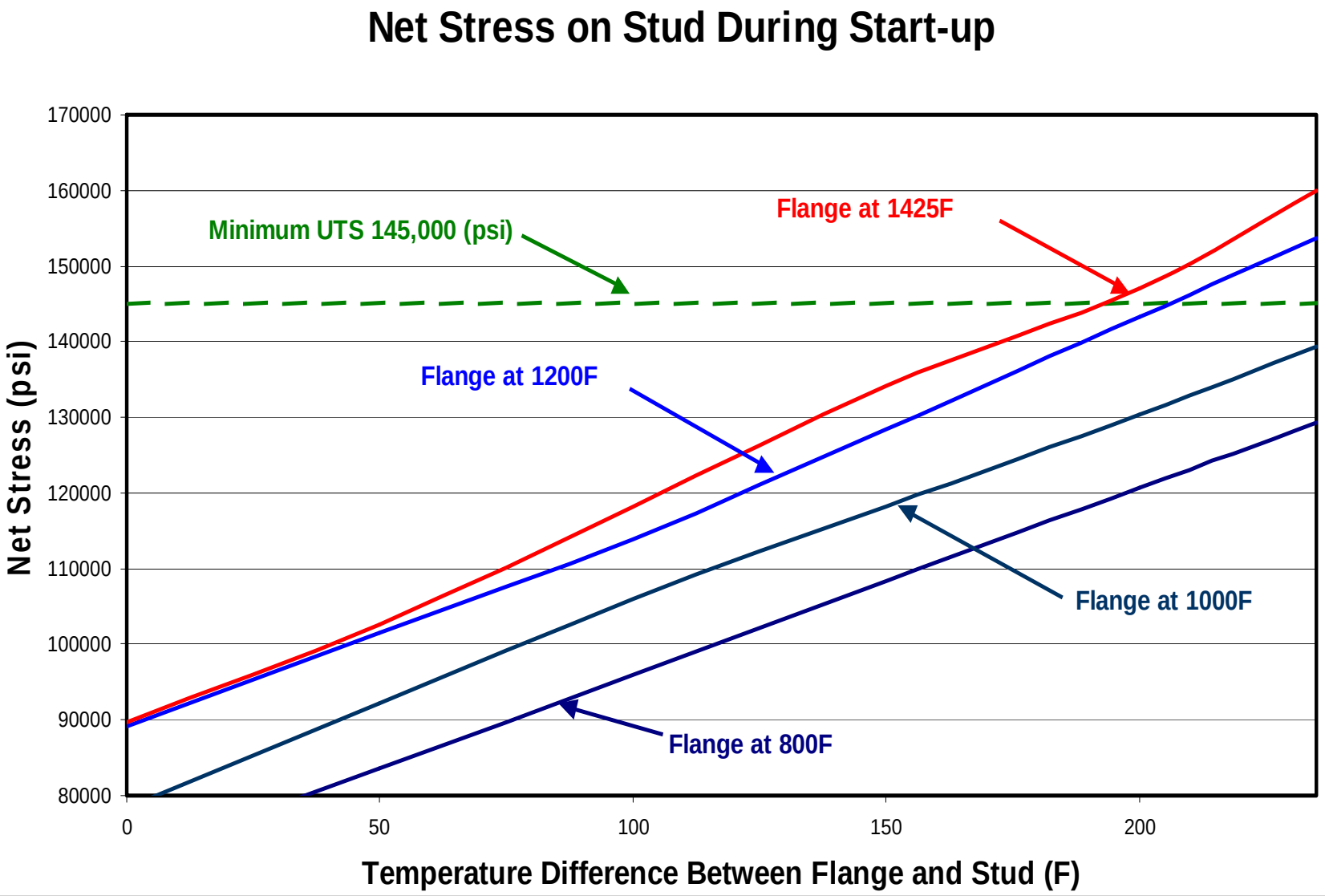
Net Bolt Stress < 125,000 psi (YS), Acceptable

Net Bolt Stress > Min Required For Joint Seal, Acceptable

Load on Belleville Washers 95,770 Lbs. (Failure will Occur)

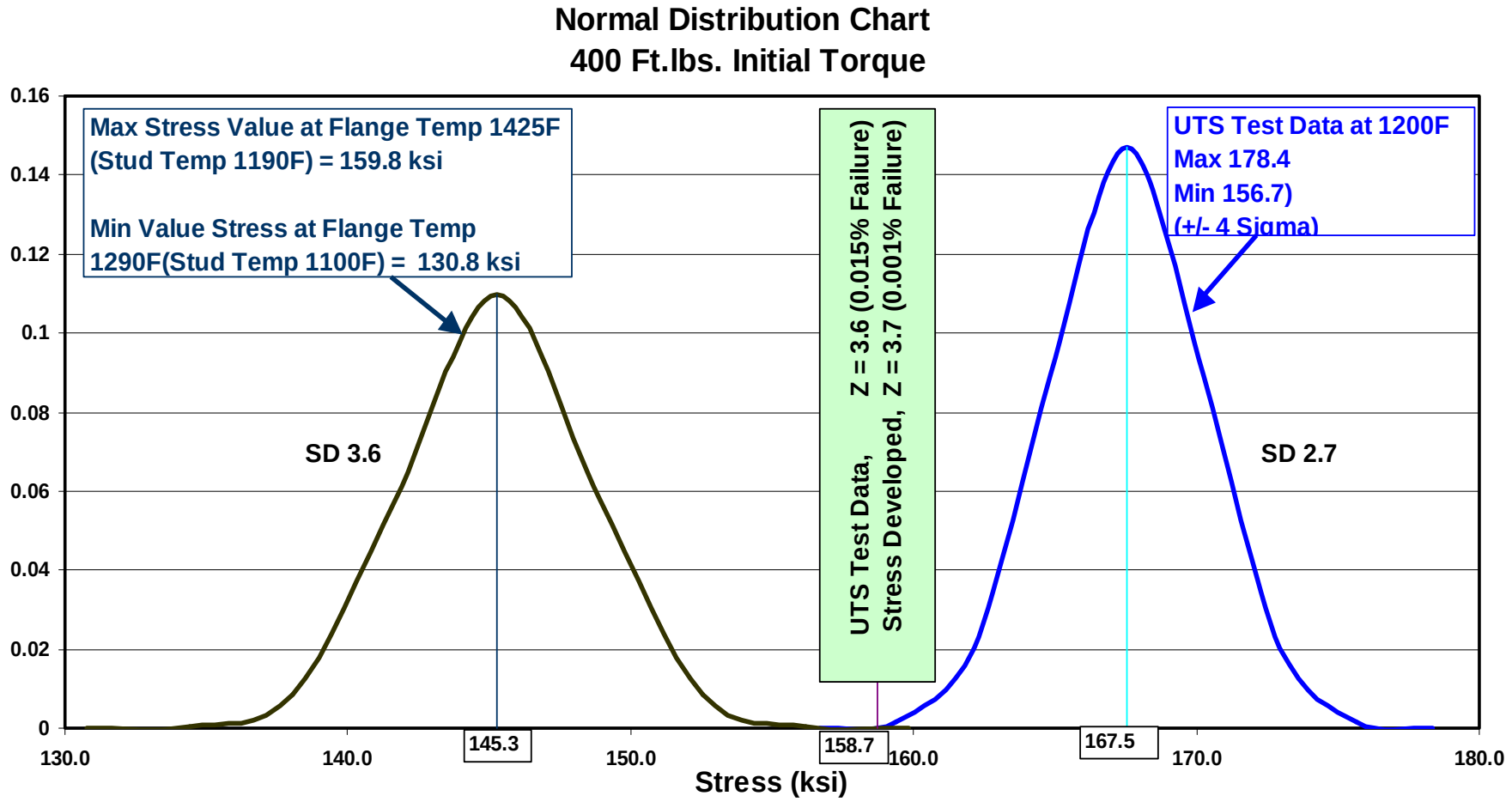
Corrective Action, Startup Stress

Reduced Initial Bolt Torque 400 FT.LB



Corrective Action, Probability of Failure

Reduced Initial Bolt Torque 400 FT.LB



Net probability of Failure ~ 0.016% (16 out of 100,000)

Recommendations and Results

Recommendations:

1. **Use Regular Flat Washes**

   (Belleville Washer For Load Capacity over 45,000 lbs. Not Available)

2. **Reduce Initial Torque From 535 (Ft.Lbs) To 400 (Ft.Lbs)**

   (Exceeds Min Required Bolt Load For Joint Seal)

Results:

No Failure for the Studs Has Been Reported Since Last 4 Years.