Calgary Pump Symposium 2011

Piping (Nozzle) Loads.

Applying the API 610 standards
To A Centrifugal Pumpset
{Pumpset = Pump + Baseplate}

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API 610 {10th Edition} Requirements

5.3.3a The **pressure casing** shall be designed to <u>operate without leakage or internal contact</u> between rotating and stationary components while subject <u>simultaneously</u> to the <u>MAWP</u> and the worst-case combination of <u>twice</u> <u>(2x)</u> the allowable nozzle loads of Table 4 applied through each nozzle.

NOTE: The twice-nozzle-load requirement is a <u>pressure-casing design criterion</u>. Other factors such as casing support or baseplate stiffness affect allowable nozzle loads.

6.3.5 The **pump and its baseplate** shall be constructed with sufficient structural stiffness to <u>limit displacement of the pump shaft at the drive end</u> to meet values per API Table 12 when subjected to (1x) API 610 Table 4 nozzle moments.

5.5.1 Three factors to consider:

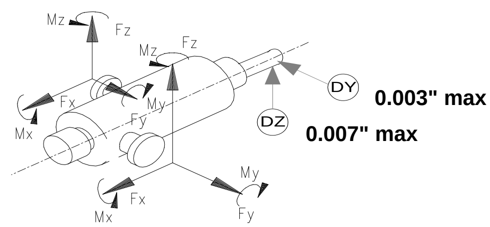
1. Pump casing stress. Total to be within ASME allowable. (5.3.4)
2. Pump casing distortion. (5.3.3)
3. Misalignment of pump and driver shafts. (6.3.5)

5.5.5 Annex F gives methods of qualifying nozzle loads in excess of those in Table 4. **Annex F is used by the piping designer - not the pump designer.**

It also goes on to say that user must be aware that the use of Annex F methods can result in 50% greater misalignment than would occur using the loads of Table 4

API 610 {10th Edition} Requirements

6.3.6 If specified, the vendor shall test to demonstrate that the pump and its baseplate assembly, anchored at foundation bolt hole locations, are in compliance with 6.3.5. The pump casing shall be subjected to moments *MY*C and *MZ*C applied to either nozzle, but not both, such that the corresponding shaft displacements can be measured and recorded. *MY*C and *MZ*C shall not be applied simultaneously to either nozzle. The shaft displacement measurements shall be absolute (not relative to the baseplate).



Nozzle Load Test at Pump Vendor's Facility

Moments MYC & MZC are applied via a hydraulically operated rotary actuator.
Shaft-end movements are measured via dial indicators.

Applied moment to suction nozzle for My

Measure deflection caused by My

Nozzle	Size (in)	MY (ft-lb)	MZ (ft-lb)
Suction	10	1800	2800
Discharge	6	870	1300

Calculated Moment Loads – (ft- lbs)
MYc = MY (discharge) + MY (suction) = 870 + 1800 = 2670
MZc = MZ (discharge) + MZ (suction) = 1300 + 2800 = 4100

Loading	MYc	MZc
Moment applied (ft-lb)	2708	4166
Shaft displacement	DZ	DY
Dial indicator (in)	0.0008	0.0005

Loading Condition	Maximum allowable pump shaft displacements (in)	
	Base intended for grout	Un-grouted type base
MYc	DZ = 0.007	N/A
MZc	DY = 0.003	N/A

Purchaser's Requirements

To reduce the complexity / cost of the supply / return piping design layout, purchasers request that pump suppliers modify the pumpset to accommodate higher nozzle loads.

Question:
When a purchaser specifies that the pump allowable nozzle loads shall be twice (2x) Table 4 values - What does this actually mean?

Option 1):
A 2x multiplier must be applied to all paragraphs in API 610 that pertain to Table 4 nozzle loads:
5.3.3a The pressure casing shall be designed to operate without leakage or internal contact between rotating and stationary components while subject simultaneously to the MAWP and the worst-case combination of four-times (**4x**) the allowable nozzle loads of Table 4 applied through each nozzle.
6.3.5 The pump and its baseplate shall be constructed with sufficient structural stiffness to limit displacement of the pump shaft at the drive end to meet values per API Table 12 when subjected to (**2x**) API 610 Table 4 nozzle moments.
F.1.2a) The individual component forces and moments acting on each pump nozzle flange shall not exceed the range specified in Table 4 by a factor more than **4**.

Option 2):
A 2x multiplier is only applied to the shaft deflection criteria:
6.3.5 The pump and its baseplate shall be constructed with sufficient structural stiffness to limit displacement of the pump shaft at the drive end to meet values per API Table 12 when subjected to (**2x**) API 610 Table 4 nozzle moments.

Challenges For Pump Vendor

When purchasers mandate the acceptance of nozzle loads in excess of API 610 Table 4 the pump vendor may be able to meet these requirements, however, this provision will require additional analysis, which may include a 3D casing Finite Element Analysis (FEA) at additional cost and increased lead time.

- The pump pressure casing may need to be modified.
- ASME flange ratings may need to be increased. {Use class 600# on a pump with a MAWP of 740 psig}.
- Pump pedestal and baseplate sub-frame design will need to be modified.
- Analytical studies may find that it is not possible to meet acceptance criteria for reliable operation under the specified high nozzle load conditions.

Non-Standard Pump Nozzle Loads = Not a simple task:

2.) LOAD CASE 1: ALL INDIVIDUAL NOZZLE LOADS BELOW API-610, TABLE-4 VALUES ("1x API"):

2.1 No analysis required (nozzle loads are acceptable)

3.) LOAD CASE 2: SOME INDIVIDUAL NOZZLE LOADS ABOVE "1x API" AND ALL INDIVIDUAL NOZZLE LOADS BELOW *TWICE* API-610, TABLE-4 VALUES ("2x API"):

3.1 Pressure casing not adversely affected, see API-610, 10th edition (ISO 13709), paragraph 5.3.3.a:

3.2 Use reinforced baseplate design

4.) LOAD CASE 3: SOME INDIVIDUAL NOZZLE LOADS ABOVE "2x API":

4.1 Calculate pump support stiffnesses using FEA. Provide customer with the corresponding stiffness values & **request re-calculation of piping loads**:

4.2 Use reinforced baseplate design

4.3 Perform baseplate stiffness calculation, considering *all* applied nozzle forces and moments acting simultaneously (all forces & moments acting in either "positive" or "negative" direction).

4.4 Check Resultant Nozzle Loads:

4.5 Check Nozzle Stresses using 2.008.025 (Nozzle Stresses under MAWP, temperature and external loads). Check pump hold-down bolt & anchor-bolt stresses using 2.018.002 ("Load calculation for Connection Bolts"). Consider API-610, Table-3 Casting Factors by means reducing the Yield Strength (2.008.025) or Maximum Allowable Stress (2.018.002) when evaluating results. Skip 4.6 below.

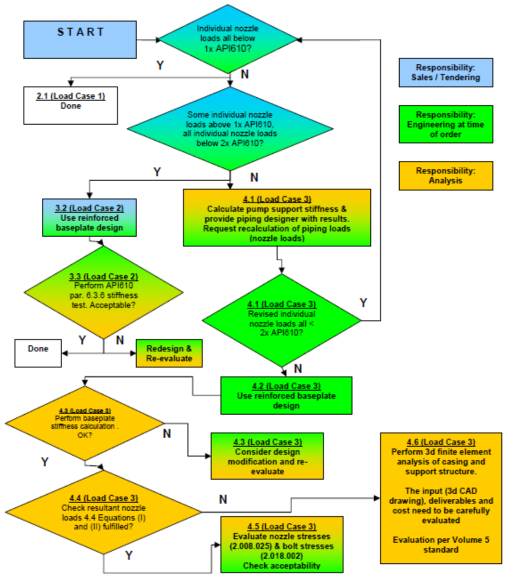
4.6 Perform 3d finite element analysis of casing investigating casing stresses, tightness / leakage, hold-down bolt and anchor-bolt stresses under MWAP, temperature and external loads.

Acceptance criteria: See 5.002.016 ("Classification, Evaluation, and Allowable Levels of Stresses in Pressure Retaining Pump Parts"), 5.002.023 ("Stress Evaluation of Bolts and Nuts"), 5.002.024 ("Allowable Stresses for Pump Supports"), and 5.018.006 ("Allowable Values for Coupling Displacements"). Consider API-610, Table-3 Casting Factors by means reducing the tensile material properties used for results evaluation.

The cost & time involved in this type of analysis can be considerable, needs to be established on a per-job basis with the responsible analyst and should be considered in the overall pricing.

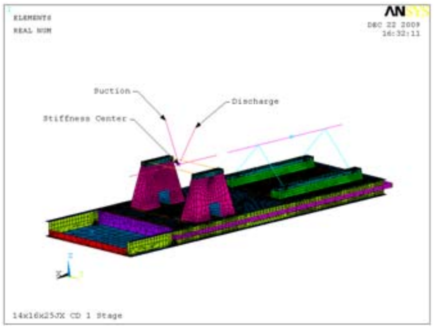
1.) PURPOSE

This standard defines the recommended procedure to determine acceptability of applied nozzle loads in excess of 1x API-610, Table-4 loads. The flow-chart shows the process which is detailed in the following sections.



Pump Support [Baseplate] Stiffness Evaluation

- The pump is considered stiff for the analysis.
  - Unit loads are individually applied to the "stiffness center" of the pump
  - The stiffness center is where the nozzles meet the pump casing; the nozzles can be considered to originate from this point and connect to the piping for the piping analysis.
- Location of nozzles from the stiffness center (API coordinate system was used).
- The baseplate was analyzed with and without grout.
  - With grout, the baseplate was held at the anchor bolt locations and at the underside of the baseplate simulating bonded epoxy grout
  - Without grout, the baseplate was held at the anchor bolts only.



FEA model of baseplate & pump with API coordinate system

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Pump Support [Baseplate] Stiffness Evaluation Results

Provide customer / piping designer with the information below and request re-calculation of applied nozzle loads, considering the non-rigid pump support stiffness:

Stiffness Values without Grout

Load	Unit	Displacement			Rotations			Translational Stiffness			Rotational Stiffness		
Type	Load	Ux	Uy	Uz	Rotx	Roty	Rotz	kx	ky	kz	mx	my	mz
[-]	[lb], [lb-in]	[in]	[in]	[in]	[rad]	[rad]	[rad]	[lbf/in]	[lbf/in]	[lbf/in]	[lbf-in/rad]	[lbf-in/rad]	[lbf-in/rad]
Fx	1	8.9195E-07	1.7017E-09	1.9953E-08	-3.1076E-11	1.9957E-08	1.5372E-09	1.1E+06	5.9E+08	5.0E+07	-3.2E+10	5.0E+07	6.5E+08
Fy	1	1.7017E-09	1.2059E-06	1.0973E-08	-7.3670E-09	6.0462E-11	1.9180E-10	5.9E+08	8.3E+05	9.1E+07	-1.4E+08	1.7E+10	5.2E+09
Fz	1	1.9953E-08	1.0973E-08	4.1512E-07	-9.2126E-10	6.3455E-10	-1.1762E-11	5.0E+07	9.1E+07	2.4E+06	-1.1E+09	1.6E+09	-8.5E+10
Mx	1	-3.1076E-11	-7.3670E-09	-9.2126E-10	2.9708E-10	-1.1086E-12	-7.4194E-12	-3.2E+10	-1.4E+08	-1.1E+09	3.4E+09	-9.0E+11	-1.3E+11
My	1	1.9957E-08	6.0462E-11	6.3455E-10	-1.1086E-12	7.3893E-10	2.7255E-11	5.0E+07	1.7E+10	1.6E+09	-9.0E+11	1.4E+09	3.7E+10
Mz	1	1.5372E-09	1.9180E-10	-1.1762E-11	-7.4190E-12	2.7255E-11	2.7224E-10	6.5E+08	5.2E+09	-8.5E+10	-1.3E+11	3.7E+10	3.7E+09

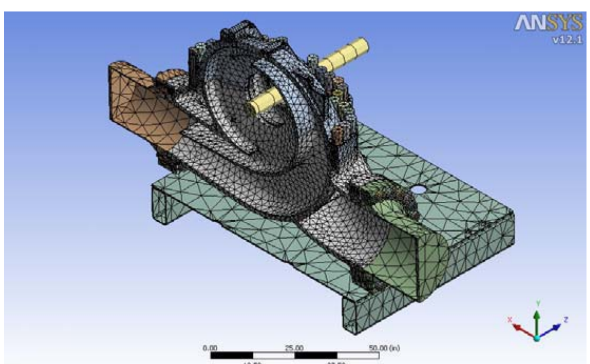
Stiffness Values with Grout

Load	Unit	Displacement			Rotations			Translational Stiffness			Rotational Stiffness		
Type	Load	Ux	Uy	Uz	Rotx	Roty	Rotz	kx	ky	kz	mx	my	mz
[-]	[lb], [lb-in]	[in]	[in]	[in]	[rad]	[rad]	[rad]	[lbf/in]	[lbf/in]	[lbf/in]	[lbf-in/rad]	[lbf-in/rad]	[lbf-in/rad]
Fx	1	1.1014E-07	-3.1881E-12	1.9423E-10	-1.0760E-12	1.4829E-09	3.6447E-10	9.1E+06	-3.1E+11	5.1E+09	-9.3E+11	6.7E+08	2.7E+09
Fy	1	-3.1881E-12	3.1397E-07	2.2351E-10	-5.5742E-11	-1.0906E-13	-1.2766E-12	-3.1E+11	3.2E+06	4.5E+09	-1.8E+10	-9.2E+12	-7.8E+11
Fz	1	1.9423E-10	2.2351E-10	3.1337E-08	-7.5687E-11	9.9402E-13	6.3026E-13	5.1E+09	4.5E+09	3.2E+07	-1.3E+10	1.0E+12	1.6E+12
Mx	1	-1.0760E-12	-5.5742E-11	-7.5687E-11	5.6830E-11	-5.1856E-14	-2.9827E-13	-9.3E+11	-1.8E+10	-1.3E+10	1.8E+10	-1.9E+13	-3.4E+12
My	1	1.4829E-09	-1.0906E-13	9.9402E-13	-5.1856E-14	2.2493E-10	3.4168E-12	6.7E+08	-9.2E+12	1.0E+12	-1.9E+13	4.4E+09	2.9E+11
Mz	1	3.6447E-10	-1.2766E-12	6.3026E-13	-2.9827E-13	3.4168E-12	1.2043E-10	2.7E+09	-7.8E+11	1.6E+12	-3.4E+12	2.9E+11	8.3E+09

Load, Displacement, and Stiffness values for Baseplate & Pump

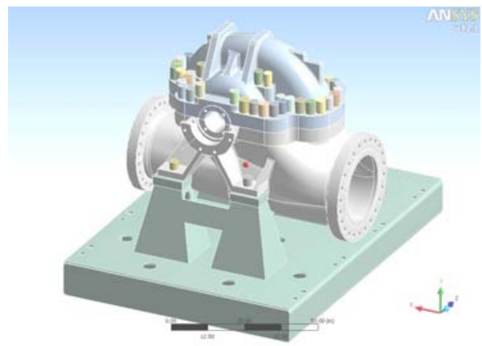
3-Dimensional FEA of Pump Case - Example

- When considering acceptability of nozzle loads in excess of 2x API-610 values, the aforementioned effects need to be investigated.
- A finite element model of a 20 x 24 x 32 HSB casing was used to investigate the effect of high nozzle loads onto casing stresses and deflections.



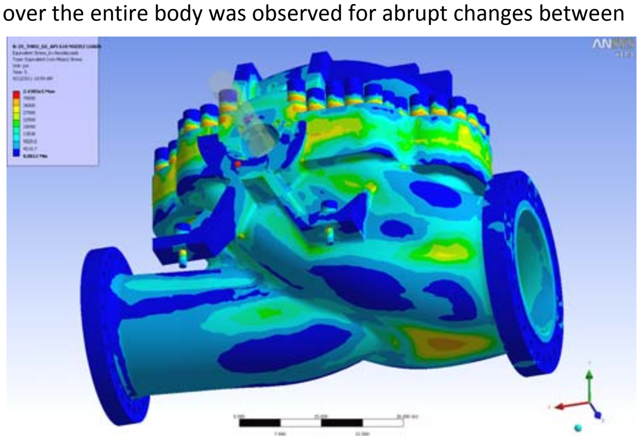
3-Dimensional FEA of Pump Case - Example

- The finite element model was subjected to 2,4,6 and 8 times API 610 Table-4 nozzle loads.
- For each loading condition the model was checked for:
  - Casing stresses (absolute and change)
  - Case deformation around rotor seals.
  - Case tightness / potential for leakage
  - Pump hold-down bolt stresses

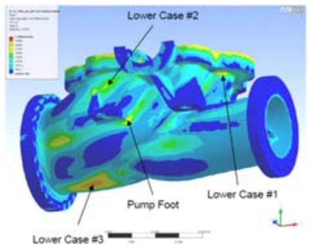


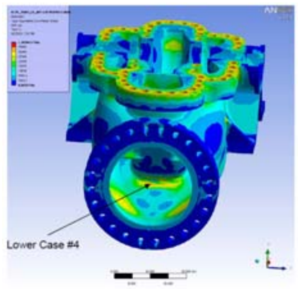
3-Dimensional FEA of Pump Case - Example

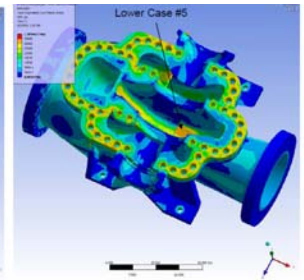
- Several areas of concern were chosen for observation at each nozzle loading condition. These locations typically exhibited higher concentration of stress than its surrounding areas. Linearized stress paths were inserted at these locations.
- Stress distribution over the entire body was observed for abrupt changes between nozzle loadings.



3-Dimensional FEA of Pump Case - Stress Results







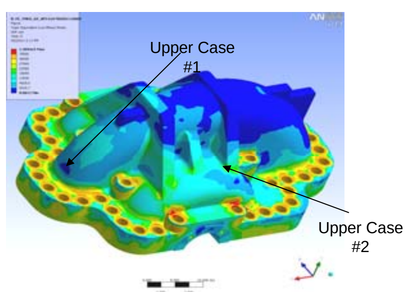
Case Material	Properties (psi)
A216 Gr. WCB	36,000 Yield 70,000 Tensile

NOZZLE LOADINGS

LOWER CASE HALF STRESSES [Membrane + Bending]	Zero Loading Internal Pressure Only (1480 psi)	2X API psi	2X API % change	4X API psi	4X API % change	6X API psi	6X API % change	8X API psi	8X API % change
Pump Foot	30,228	30,224	-0.01	30,198	-0.10	29,903	-1.08	29,404	-2.73
LowerCase#1	28,955	29,326	1.28	29,530	1.99	30,046	3.77	30,345	4.80
LowerCase#2	22,868	23,255	1.69	23,418	2.41	23,716	3.71	24,145	5.58
LowerCase#3	40,576	40,465	-0.27	40,302	-0.68	40,140	-1.07	39,982	-1.46
LowerCase#4	12,866	15,350	19.31	15,253	18.55	15,059	17.04	14,894	15.76
LowerCase#5	52,955	53,172	0.41	53,688	1.38	53,000	0.08	52,747	-0.39

Conclusion: Nozzle loadings do not significantly influence stresses in the lower case half.

3-Dimensional FEA of Pump Case - Stress Results



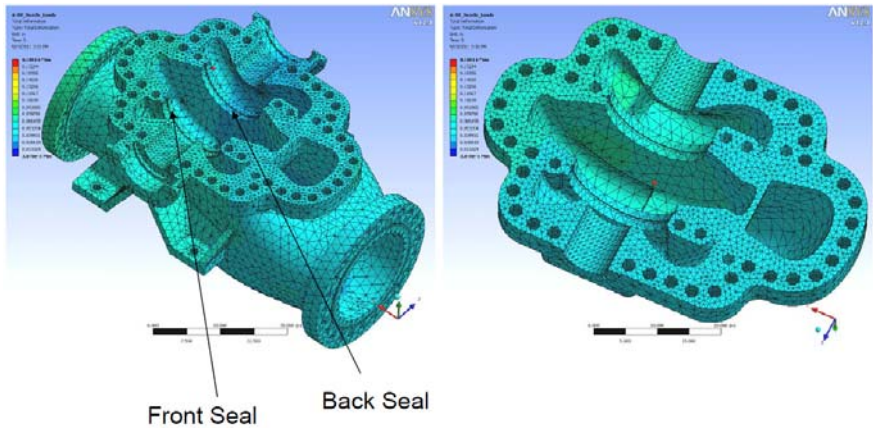
Case Material	Properties (psi)
A216 Gr. WCB	36,000 Yield 70,000 Tensile

NOZZLE LOADINGS

UPPER CASE HALF STRESSES [Membrane + Bending]	Zero Loading Internal Pressure Only (1480 psi)	2X API psi	2X API % change	4X API psi	4X API % change	6X API psi	6X API % change	8X API psi	8X API % change
Upper Case #2	32,421	32,883	1.43	32,762	1.05	31,794	-1.93	32,523	0.31
Upper Case #1	19,190	18,575	-3.20	19,115	-0.39	19,087	-0.54	18,723	-2.43

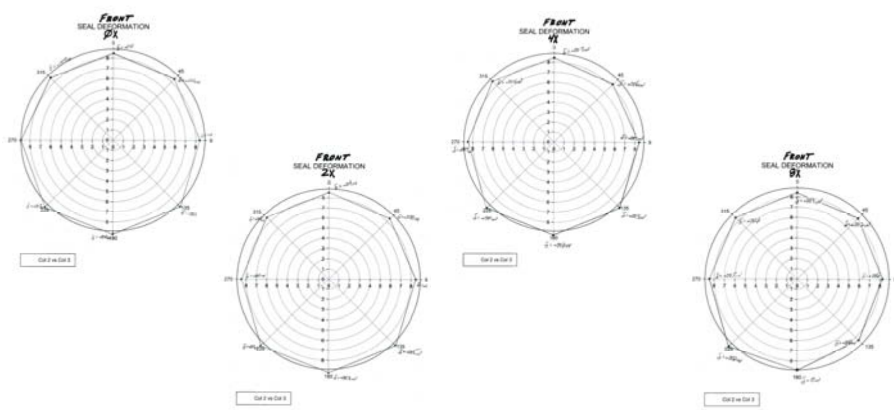
Conclusion: Nozzle loadings do not significantly influence stresses in the upper case half.

3-Dimensional FEA of Pump Case - Deformation Evaluation



The stationary eye ring must not experience contact with Impeller Eye Ring. Maximum radial clearance is 0.012 in.

3-Dimensional FEA of Pump Case - Deformation Evaluation

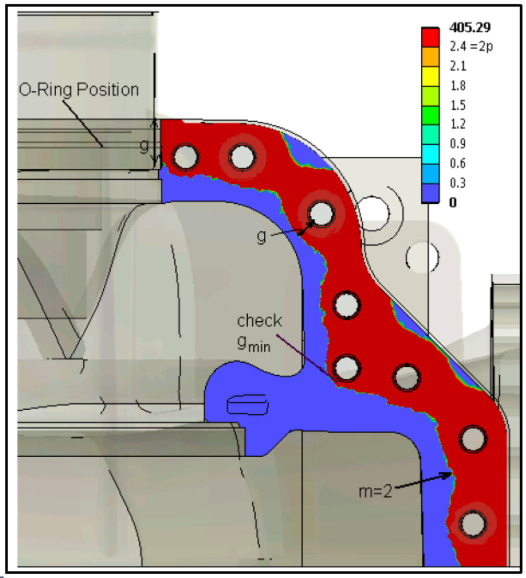


Conclusion: Stationary wear ring does not come into contact with impeller eye ring under any tested loading condition.

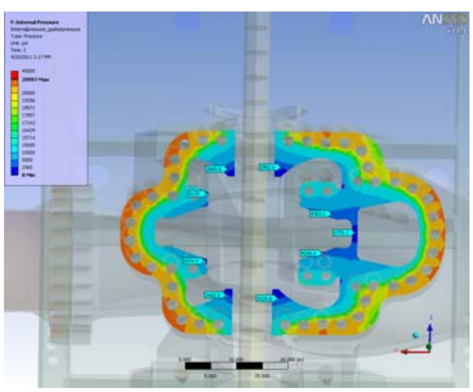
3-Dimensional FEA of Pump Case - Gasket Tightness Evaluation

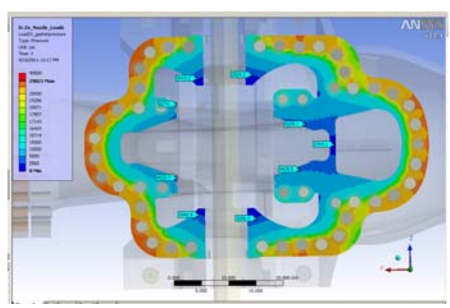
Gasket contact pressure must be maintained when the case is subjected distortion due to internal pressure and nozzle loads.

Pump vendors have specific criteria that needs to be checked.



3-Dimensional FEA of Pump Case - Gasket Tightness Evaluation



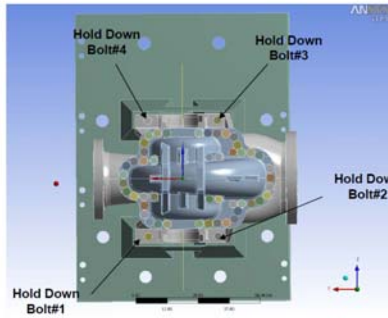


Conclusion:

1.) Gasket pressures around the parting flange bolt holes and mechanical seal bore are >= 2x maximum internal pressure. (Internal pressure is 1480 psi).

2.) No leakage is expected for 2x, 4x, 6x and 8x API-610 nozzle loads. Relative change between load cases is insignificant.

3-Dimensional FEA of Pump Case - Hold-Down Bolt Evaluation



Bolt Material	Properties (psi)
SAE Gr. 5	58,000 Yield 90,000 Tensile

NOZZLE LOADINGS

HOLD DOWN BOLT STRESSES (Tensile)	Zero Loading Internal Pressure Only (1480 psi)	2X API		4X API		6X API		8X API	
		psi	% change	psi	% change	psi	% change	psi	% change
Bolt #1	55,471	55,452	-0.03	55,460	-0.02	55,513	0.08	55,653	0.33
Bolt #2	55,690	55,816	0.23	56,085	0.71	56,801	2.00	58,077	4.29
Bolt #3	55,687	55,662	-0.04	55,769	0.15	56,223	0.96	57,476	3.21
Bolt #4	55,466	55,451	-0.03	55,433	-0.06	55,416	-0.09	55,409	-0.10

Conclusion: Hold down bolts do not experience any significant change in stress.