

CV QIKR NOZZLE Extension 925 Preliminary Analysis

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QIKR Nozzle with 10 mm seal welds

- The QIKR Nozzle model from 9/5/24 includes
 - 10 mm seal welds on the outer surfaces
 - Plate structures instead of forgings
 - Intermediate flange between front and wider rear sections
 - 12 mm bolts on 75 mm centers for side plates
 - 4 25 mm diameter bolts to attach to beltline
- Abaqus model additions
 - 2 Inconel shear pins
 - Inconel rings for interface with shear pins

SpaceClaim model from 9/5/24



Section View

Beltline section







Abaqus model with all welds merged

Abaqus half symmetry model

Side Plates removed to show bolting and merged welds



• Insert not included

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- Fillet and groove welds included
- Bolt caps not included
- 2 Shear pins and beltline holes added
- 2 25 mm Diameter Bolts added



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Fillet and skip welds merged with flanges and Groove welds merged with top and bottom plates in front and rear sections

Beltline Part



Beltline mesh with 89,403 C3D10 elements



Front part

Front beam guide Part 1



C3D8R Mesh with 22494 elements







Front flange (R2W)



Mesh with C3D10 elements





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Front Section top plate

Bottom plate has similar geometry with merged weld material

Top front plate (R3W) – bottom (R4W) similar



Mesh model with C3D10 elements



Front side Wall (R5)

Chamfers to mate with welds -bolt holes 12 mm diameter-face partitions to define contact and weld areas



C3D10 elements with Finer mesh around weld areas



Intermediate Flange

Flange (R7W) with merged fillet and skip welds



C3D10 Mesh model



Top rear plate (R8W) with merged groove weld

Top plate



C3D10 Mesh model



Rear Bottom plate

60 mm thick bottom plate (R9W)

C3D10 Mesh



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Rear Side Walls

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Representative C3D10 mesh with nominal 5 mm element size in weld and 20 mm in plate middle



Rear Flange

Rear flange (R12W) with merged welds



C3D10 mesh model



Bolts

12 mm diameter bolt





Array of 84 bolts in model



Inserts for QIKR Nozzle

7541lbs (3420.6kg)



9228lbs (4185.6kg)



LOADS DURING OPERATION (INSERT + OPTICS)

Wheel loads from Interface dwg

- 2110 kg front wheels
- 1713 kg rear wheels







Wheel to plate contact analysis

- An idealized analysis of the wheel to plate contact was made
- The intent was to find the contact stress distribution in the nozzle plate structure using a finer mesh than could be used for full assembly model
- The load on a front wheel from the mass of the insert and optics was 2110 Kg
- A quarter symmetry model of the wheel was made and the load applied by increasing the material density to give ¼ of the total load
- Linear elastic material properties for steel or inconel were used

Insert SpaceClaim model







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Wheel geometry with crown surface





Major Diameter	0
Minor Diameter	1000mm
Fillet Radius	500mm
Area	3053.4385mm ²
Perimeter	293.9622mm

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Wheel cross section and curvature on contact face





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Wheel Abaqus model

Idealized 1/4 symmetry wheel model



C3D10 mesh with 0.1 mm size in contact area





Bottom center to edge elevation change 0.107 mm



10 mm thick Inconel block

Contact block 10 mm thick



C3D10 mesh with 0.1mm spacing in contact region







50 mm thick 316L block



C3D8 Hex mesh







Boundary Conditions

Bottom fixed nodes



Top surface nodes of "mush" fixed to have a vertical constraint



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Symmetry boundary conditions

X symmetry



Z symmetry



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Assembly model loads and materials

Loads



1/4 wheel mass 529 kg



Mass properties: Volume : 18e-06 Volume centroid: 0.214,-0.390,2.83 Mass: 528 Center of mass: 0.214,-0.391,2.83 Koment of inprita about the center of mass (Ixx, Iyy, Izz, Ixy, Iyz, Izx): 0.0395,0.0260,0.0260,8.69e-05,0.00736,8.69e-05

Material input

** MATERIALS
**
*Material, name=SS316L
*Density
8000.,
*Elastic
2e+11, 0.292
*Material, name=mush
*Density
1.,
*Elastic
2e+06, 0.3
*Material, name=steel_wheel
*Density
1.055e+08,
*Elastic
2e+11, 0.3
**

Assembly Von Mises Stress with 1250 MPa scale

Assembly S Mises 1250 MPa scale peak 2643 MPa



Wheel S 1250 MPa scale



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Vertical Displacements

Wheel







Block









Step: Step-1, gravity wheel plate Increment 17: Step Time = 1.000 Primary Var: U, U2 Deformed Var: U Deformation Scale Factor: +5.000e+01



Inconel plate

S 1250 Scale 50x displacements



Block Contact pressure –peak 2286 MPa





Inconel plate contact surface

Pressure with mesh shown



Contact area roughly .5mm x 6mm or 1mm x 12 mm for full model Block Contact status



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Wheel contact pressure and stress



Wheel Contact pressure

Wheel S 1250 MPa scale mesh with cut to interior



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Assembly stress with 170 MPa scale



Bottom 316L section Stress peak 91 MPa



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Comparison to ideal cylinder on plate

Summary

- Ideal contact give a bearing width of 1
 mm and contact pressure of 1220 MPa
- Crown on Abaqus model wheel width reduces the contact width by about half and doubles the contact pressure
- Abaqus results appear consistent with ideal case with accounting for reduced contact area

46 mm Diameter – 21 mm wide cylinder with 2110 kg gravity load



Contact model Analysis Summary

- Elastic analysis gives subsurface Von Mises stresses of approximately 1200 MPa for wheel and mating plate
- The 316L material beneath a 10 mm thick plate has a peak stress of approximately 90 MPa
- No analysis of the loading from the axle included for the wheel
- The 2110 kg/4642 lbs load is less than half the rated 10,000 lbs
- Local yielding can be expected in the mating plate
- A reasonable approximation of the contact area is an axial length of 1 mm and a horizontal width of 12 mm
Assembly Mesh Model

- 3,462,970 elements
- C3D10 tet elements except for front in green C3D8R elements



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• Each of 84 12 mm bolts was tied on the head surface to the facing plate and tied within the threaded zone of the side plates

- Each bolt surface given a unique name
- Each plate surface give unique name
- No pre-load assumed

Typical bolt head tie

🜩 Edit Constraint 🛛 🗙
Name: B1H Type: Tie
Master surface: R3W-1.H1 ↓ Slave surface: s_Surf-12 ↓
Discretization method: Analysis default
Exclude shell element thickness
Position Tolerance
Use computed default
O Specify distance:
Note: Nodes on the slave surface that are considered to be outside the position tolerance will NOT be tied.
Adjust slave surface initial position
Tie rotational DOFs if applicable
Constraint Ratio
Use analysis default
O Specify value
OK Cancel

Typical threaded zone tie

<table-cell-rows> Edit Constraint</table-cell-rows>			
Name: B1T			
Type: Tie			
Master surface: S0	3060000-CV-NE-QI	IKR-R2_5-1.T1	()
Slave surface: s_	Surf-22 🔉		
Discretization method:	Analysis default	\sim	
Exclude shell eleme	nt thickness	hand	
Position Tolerance			
Use computed def	ault		
 Specify distance: 			
Note: Nodes on the considered to tolerance will	slave surface that a be outside the posi NOT be tied.	ition	
Adjust slave surface	initial position		
Tie rotational DOFs	if applicable		
Constraint Ratio			
Use analysis defau	lt		
O Specify value			
ОК		Cancel	

Front flange top bolt tie constraints - bottom constraints similar

Upper bolt head to flange tie



Threaded area tie to beltline



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Shear Pin Surface to Surface Interactions – top shown – bottom similar

	Edit Interaction	×
	Name: Shear_pin_R2W_T	
	Type: Surface-to-surface contact (Standard)	
$\langle \rangle$	Step: Initial	
	Master surface: m_Surf-193 📘	
	Slave surface: R2W-1.Shear_top	
	Sliding formulation:	
	Discretization method: Surface to surface	
	Exclude shell/membrane element thickness	
	Degree of smoothing for master surface: 0.2	
	Use supplementary contact points: Selectively Never Always 	
	Contact tracking: Two configurations (path) Single configuration (state))
	Slave Adjustment Surface Smoothing Clearance Bonding	
	No adjustment	
	Adjust only to remove overclosure	
	○ Specify tolerance for adjustment zone: 0	
	🔿 Adjust slave nodes in set:	
	Contact interaction property: IntProp-1	M #
Y	Options: Interference Fit	
×	Contact controls: (Default)	
	Active in this step	
z	OK	

Shear Pin to Front Flange

Shear Pin to Beltline

Edit Interaction Nome: Shear_pin_bettine_T Type: surface-to-surface contact (Standard) Step: Initial Master surface: bettineW-1.bettine_shear_Top Master surface: bettineW-1.bettine_shear_Top States surface: s_surf-192 Stating formulation: Finite sliding Small sliding Discretization method: Surface to surface Discretization method: Surface to sufface Discretization method: Surface to sufface Discretization method: Surface Smoothing Clearance Bonding No adjustment Adjust noty to remove overclosure Specify tolerance for adjustment zone: 0 Adjust slave nodes in set Contact interaction property: IntProp-1 Options: interference find Contact controls: Options: interference find Contact to note: Option: interference find Contact to note				
Contact interaction property: [mProp-1 Adjust slave nodes in set: K Cancel K Cancel				
Name: Shear_pin_betkline_T Type: Surface-to-surface contact (Standard) Step: Initial Master surface: betkline_shear_Top Save surface: s_Surface to surface Stave surface: solution: Stave Adjustment Surface Smoothing Adjust only to remove overclosure solution: Specify tolerance for adjustment rome: solution: Adjust slave nodes in set: solution: Option: Centeer tente Contact controls: (Default) Active in this step K		Edit Interaction	>	
Master surface: \$sturface: \$stur surface: \$sturface: <td< th=""><th></th><th>Name: Shear_pin_beltline_T Type: Surface-to-surface contact (Standard) Step: Initial</th><th></th><th></th></td<>		Name: Shear_pin_beltline_T Type: Surface-to-surface contact (Standard) Step: Initial		
Contact tracking: Two configurations (path) Single configuration (state) Slave Adjustment Adjust only to remove overclosure Specify tolerance for adjustment zone: Adjust slave nodes in set: Contact interaction property: IntProp-1 Options: Interference Fitue Contact controls: (Default) Active in this step K Cance		Master surface: beltineW-1.beltine_shear_Top Slave surface: s_Surf-192 Sliding formulation: Image: Finite sliding Discretization method: Surface to surface Exclude shell/membrane element thickness Degree of smoothing for master surface: 0.2 Use supplementary contact points: Image: Selectively Never Always		
Slave Adjustment Surface Smoothing Clearance Bonding No adjustment Adjust only to remove overclosure Specify tolerance for adjustment zone: Adjust slave nodes in set: Contact interaction property: IntProp-1 Contact interaction property Contact controls: (Default) Contact controls: (Default) Contact controls: (Default) Contact interaction property Contact interaction property Contact interaction property Contact controls: (Default) Contact interaction property Contact interac		Contact tracking: Two configurations (path) Single configuration (state)		
No adjustment Adjust only to remove overclosure Specify tolerance for adjustment zone: Adjust slave nodes in set: Contact interaction property: IntProp-1 Options: Interference Fite Contact controls: (Default) Active in this step K Cancel		Slave Adjustment Surface Smoothing Clearance Bonding		
Adjust unit to remove evectosate Specify tolerance for adjustment zone: Adjust slave nodes in set: Contact interaction property: IntProp-1 Options: Interference Fit= Contact controls: (Default) Active in this step OK Cancel		No adjustment		
Adjust slave nodes in set Contact interaction property: IntProp-1 Options: Interference Fit: Contact controls: (Default) Active in this step OK Cancel		Specify tolerance for adjustment zone: 0		11
Contact interaction property: IntProp-1		O Adjust slave nodes in set:		
Contact interaction property: IntProp-1				
Y Options: Interference fit Contact controls: (Default) ✓ Active in this step OK		Contact interaction property: IntProp-1	- 1	3
Z Contact controls: (Default) Active in this step OK Cancel	Y	Options: Interference Fit		
Z Active in this step OK Cancel		Contact controls: (Default)		
OK Cancel		Active in this step		
	z	OK Cancel		

Weld Tie Constraints



Front Flange (R5W) and Beltline welds

Front Flange to Part 1



Beltline to Part 1



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CAK RIDGE Front Flange (R2W) welds

Front Flange to front top plate



Front Flange to front side plate



Front Flange to front bottom plate



Front 10 mm Groove welds

Front top plate groove weld



Front bottom plate groove weld



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CAK RIDGE Intermediate flange (R7W) welds

Intermediate flange to front top plate



Intermediate flange to front side plate



Intermediate flange to front bottom plate



Skip weld ties around Intermediate flange – 11 total



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Groove Weld Tie Constraints to rear side wall

Rear Top Groove Weld



Rear Bottom Groove Weld



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Rear Flange Weld tie constraints

Rear Flange to top plate inside



Rear Flange to side plate

	<
	♣ Edit Constraint × Name: R12W_R11 Type: Tie
-] #3	Master surface: R12W-1.R12W_R11_inside Slave surface: S03060000-CV-NE-QIKR-R2_11-1.R11_R12W Discretization method: Analysis default Exclude shell element thickness
	Position Tolerance
	□ Adjust slave surface initial position ☑ Tie rotational DOFs if applicable ⊂ Constraint Ratio ④ Use analysis default
	O Specify value OK Cancel

Rear Flange to bottom plate inside



Skip weld tie constraints with rear flange - total 14

Typical top or bottom skip Centerline skip weld Typical side wall skip weld weld 🚔 Edit Constraint 📥 Edit Constraint 🖨 Edit Constraint Name: R12W R8W skip1 Name: R12W_R8W_skip2 Name: R12W_R11_skip5 Type: Tie Type: Tie Type: Tie Master surface: R12W-1.R12W_R8W_skip1 1-1 Master surface: R12W-1.R12W_R8W_skip2 Master surface: R12W-1.R12W_R11_skip5 Slave surface: R8W-1.R8W R12W sklip1 -Slave surface: R8W-1.R8W_R12W_slkip2 Slave surface: S03060000-CV-NE-QIKR-R2_11-1.R11_skip5 Discretization method: Analysis default Discretization method: Analysis default Discretization method: Analysis default Exclude shell element thickness Exclude shell element thickness Position Tolerance Exclude shell element thickness Position Tolerance Use computed default Position Tolerance Use computed default O Specify distance: Use computed default O Specify distance: Note: Nodes on the slave surface that are O Specify distance: considered to be outside the position Note: Nodes on the slave surface that are tolerance will NOT be tied. Note: Nodes on the slave surface that are considered to be outside the position considered to be outside the position tolerance will NOT be tied. Adjust slave surface initial position tolerance will NOT be tied. Tie rotational DOFs if applicable Adjust slave surface initial position Adjust slave surface initial position Constraint Ratio Tie rotational DOFs if applicable Tie rotational DOFs if applicable Use analysis default Constraint Ratio O Specify value Use analysis default Use analysis default Specify value OK Cancel) Specify value OK Cancel OK Cancel

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Inconel pad tie constraints to bottom plate (3 locations)

The SpaceClaim model included 4 mm screws and mating holes in the corners of the pads and bottom plate which were defeatured for the Abaqus model

Front Wheel pad tie

📥 Edit Constraint

Name: W1 R9W

Position Tolerance

○ Specify distance:

Use computed default

Master surface: W1 R9W

Slave surface: R9W-1.R9W_W1

Discretization method: Analysis default

Note: Nodes on the slave surface that are

tolerance will NOT be tied.

Adjust slave surface initial position

Tie rotational DOFs if applicable

Use analysis default

OK

Specify value

considered to be outside the position

Cancel

Type: Tie

Rear Wheel tie

📥 Edit Constraint Name: W3 R9W Type: Tie 🚺 Master surface: W3_R9W 📘 Slave surface: R9W-1.R9W W3 Discretization method: Analysis default Exclude shell element thickness Position Tolerance Use computed default O Specify distance: Note: Nodes on the slave surface that are considered to be outside the position tolerance will NOT be tied. Adjust slave surface initial position Tie rotational DOFs if applicable Use analysis default) Specify value OK Cancel

Bottom plate tied surface



Shear pin tie constraint

- With only frictionless surface to surface interactions for the shear pins there would be no axial restraint
- For numerical stability a very low modulus (.01 GPa) extrusion was added to the rear and tied to the beltline
- No significant effect on stress or displacement



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Interactions

- All Hard Frictionless
- Allows separation



Interactions around front flange

oath) 🔿 Single configuration (state

Cancel

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Beltline and Front Flange

Front top plate bottom inside to front flange

Front bottom plate top inside to front flange

	ſ	💠 Edit Interaction	
		Name: beltline_R2V	v
		Type: Surface-to-s Step: Initial	urface contact (Standard)
		Master surface:	beltlineW-1.beltline_R2W
		👂 Slave surface:	R2W-1.R2W_beltline 💊
	6	Sliding formulation:	● Finite sliding ○ Sma
		Discretization metho	d: Surface to surface
		Exclude shell	/membrane element thick
		Degree of smoot	thing for master surface:
		Use supplement	ary contact points: Sel
		Contact tracking	g:
		Slave Adjustment	Surface Smoothing Cl
		No adjustment	
		 Adjust only to re 	emove overclosure
		O Specify tolerand	e for adjustment zone: 0
		O Adjust slave noo	des in set:
0			
		Contact interaction	property: IntProp-1
		Options: Interferen	ee Fit
		Contact controls: (Default) 🗸 🗸
		Active in this step	p
			ОК







Front Side Wall interactions

Front top plate to front side all



Front bottom plate to front side wall

		×
	🜩 Edit Interaction	×
	Name: R4W_R5_SS	
	Type: Surface-to-surface contact (Standard)	
	Step: Initial	
	Master surface: R4W-1.R4W_R5_SS	
	Slave surface: S03060000-CV-NE-QIKR-R2_5-1.R5_bottom	
	Sliding formulation: Finite sliding Small sliding	
	Discretization method: Surface to surface	
	Exclude shell/membrane element thickness	
	Degree of smoothing for master surface: 0.2	
	Use supplementary contact points: Selectively Never Always Contact to a financial of the selection of t	
	Contact tracking: Will configurations (path) O single configuration (state)	
	Slave Adjustment Surface Smoothing Clearance Bonding	
	Adjust only to remove overclosure	
	O Specify tolerance for adjustment zone: 0	
	Adjust slave nodes in set:	
	Contact interaction property: IntProp-1	3
	Options: Interference Fit	
	Contact controls: (Default)	
Z	Active in this step	
	OK	

Intermediate flange interactions

Intermediate flange to rear top plate

Intermediate flange to rear side wall

Intermediate flange to rear bottom plate



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Rear side wall (R11) interactions

Rear top plate to rear side wall



Rear bottom plate to side wall



Boundary Conditions

Beltline side nodes fixed

Rear flange bottom nodes restrained vertically

X symmetry boundary condition







Loads

Gravity



Pressure 1 bar

	 ➡ Edit Load Name: Load-4 Type: Pressure Step-3 (Static, General) Region: Presssure_Assy 	×
	Distribution: Uniform Magnitude: 100000 Amplitude: (Ramp)	(x) ~
	OK Cancel	
2		

Pressure equivalent on rear flange

	 ➡ Edit Load Name: Load-5 Type: Pressure Step: Step-3 (Static, General) Region: Pressure, Rear
	Distribution: Uniform f(x) Magnitude: 153000 Amplitude: (Ramp) A
	OK Cancel
z o i o x	

Uniform Pressure (Pa) loads from inserts on wheel pads

Insert load assumptions

- Insert gravity loads applied to a 1mm x 12m assumed bearing area
- Area approximation from detailed contact model
- Uniform pressure assumed
- Interface loads are 2110 kg for front wheel and 1713 kg for rear wheels

Front wheel load



Rear wheel load

	🜩 Edit Load 🛛 🕹	
	Name: Load-3	
	Type: Pressure	
	Step: Step-3 (Static, General)	
	Region: Wheel3_P	
	Distribution: Uniform	
	Magnitude: 1.399E+09	
	Amplitude: (Ramp)	
V	OK Cancel	
	1 the	



Results

- Step 1 gravity only load
- Step 2 gravity and insert loads
- Step 3 gravity, insert loads and pressure from vacuum operation



Displacements with only gravity and no inserts

U1(x) minimum -.01mm

U2 (y) minimum -0.025 mm

U3 (z) minimum -.03 mm





Assembly Gravity only no inserts peak \$ 87 MPa in bottom shear pin



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Assembly Displacement with gravity including insert loads



U3 (z) minimum -0.01 mm



Peak 1297 MPa in Inconel Pad

Peak without Inconel pads 242 MPa in front flange by bottom shear pin

Beltline Peak157 MPa by bottom shear pin hole





Beltline peak stress location

Part 1 beam line guide peak stress 13.7 MPa by weld to front flange 25 mm Bolts and Shear Pin stresses peak 214 MPa in bottom shear pin



Bottom Shear Pin peak 213 MPa with mesh shown

Front Flange with merged welds peak 242 MPa by bottom shear pin hole Front Flange Peak stress location within 4.25 mm ring and < 100 MPa outside ring



0.5 mm bearing surface offset for rear to avoid common nodes for both surfaces





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Stresses in front top, side and bottom plates – 50 MPa scale - peak 154 MPa Front bottom plate peak at side edge and corner of skip weld tie Intermediate Flange with merged welds – peak 88 MPa



Rear Top, Side and Bottom plates peak stress 77 MPa under front wheel pad

Bottom Plate stress under Inconel pad – 77 MPa peak

Inconel pad Stress Peak 1251 MPa (50x displacement)





¹/₄ symmetry contact model peak was 91 MPa in 316l under pad



1/4 symmetry contact model Inconel peak was 2643 MPa using elastic model with no yielding

Stresses with gravity and insert loads

Rear Flange with merged welds peak stress 38 MPa

Peak 12 mm Bolt stress 42.6 MPa

Highest Stressed bolt – peak 42.6 MPa



Step 3 Gravity, Insert loads and Pressure loads - displacements

U1 minimum -0.188 mm

U2 minimum -0.10 mm

U3 minimum -0.01 mm



Step 3 Gravity, Insert loads and Pressure loads - Stress

Stress 50 MPa scale peak 1292 MPa in pad

No pads – Stress 50 Mpa scale side view peak 294 MPa in bottom plate Bottom plate Peak stress in isolated element under contact area with side wall









Step 3 Gravity, Insert loads and Pressure loads - Stress

Axial cut with 50 MPa scale Displacement factor x1000

Front Flange peak 243 MPa by shear pin hole

Top 25 mm bolt peak stress 150 MPa scale peak156 MPa at isolated node at corner by head


Step 3 Gravity, Insert loads and Pressure loads - Stress

Front, side and bottom plate stress peak 184 MPa

Front Bottom plate stress 150 Mpa scale - peak at edge and corner of skip weld Rear Top,Side and Bottom plate stress 150 MPa scale peak 294 MPa at isolated element



Step 3 Gravity, Insert loads and Pressure loads - Stress

Rear Top Plate 50 Mpa scale peak 43 MPa

Rear Side Plate Stress 50 MPa scale

Rear Side Place Contact Pressure



Step 3 Gravity, Insert loads and Pressure loads - Stress

Rear Bottom plate scale 50 MPa peak 294 MPa

Rear Bottom Plate Contact Pressure

Rear Flange with merged welds 150 MPa scale peak 87 MPa



Step 3 Gravity, Insert loads and Pressure loads – Bolt Stress





External pressure reduces load on bottom bolts- Peak 35 MPa



Shear Pin surface to surface contact ODB: QIKR_925.odb Abaqus/Standard 2020.HF4 Wed Sep 25 17:48:02 Eastern Daylight Time 2024

Step: Step-3, Vacuum Pressure Increment 11: Step Time = 1.000 Primary Var: S, Mises Deformed Var: U Deformation Scale Factor: +5.000e+01



Summary

The stresses and displacements in the model appear acceptable

- All weld stresses are below 100 MPa
- All 316L plate stresses are below 100 MPa, except for one location with two isolated elements with a poor surface to surface mesh interface and at a weld corner singularity
- The highest 12 mm bolt stress was 42 MPa
- The 25 mm bolt stresses were below 150 MPa, except at one node at 156 MPa on head edge with no radii
- Shear pin peak stresses were approximately 215 MPa, well below Inconel yield strength of approximately 1000 MPa
- Use of assumed 4.25 mm Inconel support rings around the shear pins kept mating 316L stress below 100 MPa with ring stress up to about 250 MPa well below Inconel yield strength of approximately 1000 MPa
- The 10 mm Inconel pads under the insert wheels can be expected to have local yielding, in the contact area but they are not part of the pressure boundary