Analysis of Rotary Bayonets and Piping

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INTRODUCTION

This report quantifies certain characteristics of the rotary bayonets and associated platform piping on the D0 detector. The Vacuum Jacketed 4" x 6" and 1.5" x 3" and the 4" and 6" vacuum pipe articulating jumpers are considered here.

DISCUSSION

Table I presents the basic data for the pipe sections used in this analysis. Table II provides information on the rotary bayonets and unions. Table III concentrates on the pipes in each set-up under load.

Complete explanations and sample calculations are contained in the Appendices. Appendix A defines and discusses each column in the tables in more detail and includes some relevant formulas and models. Appendix B takes the 4" x 6" pipe set-up (and the 4" vac. set-up where the calculations are different) through sample calculations for the values in all three tables.

CONCLUSIONS

The values of greatest importance are the forces required at the bayonet moment arms given in Table II and the stresses summarized in Table III. The forces required should be noted and checked that they are acceptable to the problem. The maximum bending stresses of the vacuum pipes do not exceed 1000 psi and are essentially negligible. The 4" x 6" vacuum jacketed line experiences the maximum bending stress of 10,300 psi. According to code B31.1, the maximum allowable bending stress is 25,500 psi.

The major sources of error in these calculations should be summarized. First, all weights used were approximations and all lengths used were scaled from drawings. Second, while the **FRAME MAC**™ models resemble the vacuum pipe articulating jumpers, they are definitely simplified. For instance, they do not account for the different stiffnesses of the unions. Finally, the bayonets in the **ANSYS** models consist of an outer jacket and an inner pipe fixed together at the end of the male sleeve. The actual bayonets are more complex and are composed of various sizes of tubes and pipes which affect the stiffness of the section.

TABLE I: THE PIPES AND THEIR SECTIONS

PIPE	INSIDE RADIUS (in)	OUTSIDE RADIUS (in)	CROSS-SECTIONAL AREA (sq. in)	MOMENT OF INERTIA (in**4)	SECTION MODULUS (in**3)	WEIGHT PER UNIT LENGTH (lb/in)
4 x 6	3.1785 2.13	3.3125 2.25	4.38	18.36	6.11	1.24
1.5 x 3	1.63 0.841	1.75 0.95	1.89	2.07	1.18	0.54
4" vacuum	2.13	2.25	1.65	3.96	1.76	0.47
6" vacuum	3.1785	3.3125	2.73	14.4	4.35	0.77

TABLE II: THE ROTARY BAYONETS AND UNIONS

BAYONET (OR UNION) FOR PIPE...		APPROXIMATE WEIGHT (lb)	MOMENT ARM LENGTH (In)	FORCE REQUIRED AT MOMENT ARM (lb)	NECESSARY ANGLES OF ROTATION (degrees) *
4 x 6	top bayonet	35	14.5	198	43
	middle			309	94
	bottom			333	51
1.5 x 3 (LN2 Feed Line)		10	8.71	130	30
				99	74
				79	44
1.5 x 3 (GAr Make-up)		10	8.71	140	28
				110	71
				85	43
1.5 x 3 (drain)		10	8.71	101	41
				83	91
				53	50
4" vacuum		40	8	34	24
				42	64
				89	40
6" vacuum		55	8	47	43
				59	94
				101	51

* see Appendix for explanatory diagram

TABLE III: PIPES UNDER LOAD

PIPE	MAX. BENDING STRESS* (psi) (warm and cold considered)	MAX DEFLECTION (in)
4 x 6	10316	0.107
1.5 x 3 (LN2 Feed Line)	9245	0.143
1.5 x 3 (GAr Make-up)	9241	0.154
1.5 x 3 (drain)	7312	0.101
4" vacuum	538	0.00392
6" vacuum	239	0.00083

*According to B31.1, the maximum allowable stress is 25,500 psi.

APPENDIX A

General Discussion of
Table Information

Table I-supplemental

INSIDE and OUTSIDE RADII were acquired from data on schedule 10S pipes.

CROSS-SECTIONAL AREAS were calculated directly from the inside and outside radii using $A = \pi(R_o^2 - R_i^2)$. Areas for the double pipes were added directly.

THE MOMENT OF INERTIA for a pipe is given by $I = 0.25\pi(R_o^4 - R_i^4)$. The moment of inertias for the double pipes were assumed concentric in bending and added directly.

THE SECTION MODULUS for a pipe is given by $S = I/R_o$. The section moduli for the double pipes were also assumed concentric in bending and added directly.

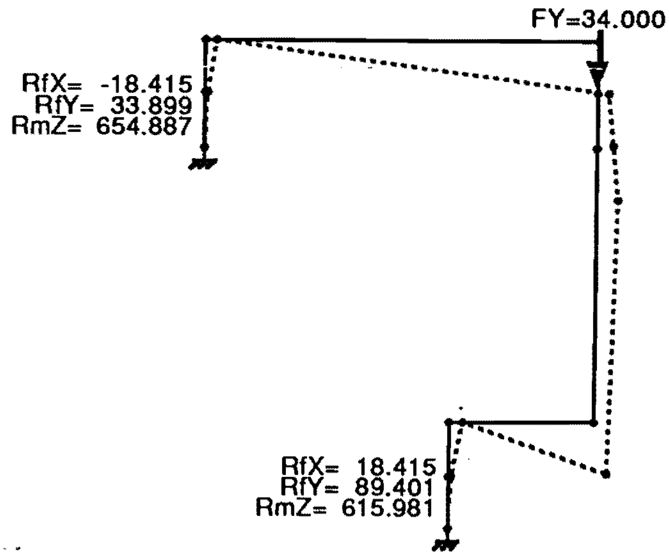
THE WEIGHT PER UNIT LENGTH is calculated using $W = Ap$ where p is the density of steel (0.284 lb/in^3).

Table II-supplemental

THE WEIGHTS for the bayonets were approximated by scaling drawings to find a total volume of steel and multiplying by the density. The weights for the unions on the vacuum pipes were taken from previous approximations, after confirming they were realistic.

THE MOMENT ARM LENGTHS for the bayonets were taken as the length of the male bayonet shaft. The moment arm lengths for the unions were taken as the distance between the centers of the bearings on the shafts.

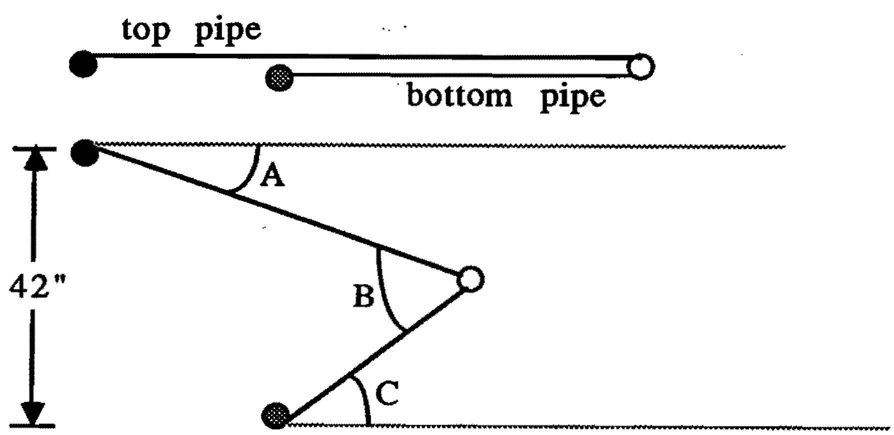
THE FORCES REQUIRED AT THE MOMENT ARMS were calculated using **FRAME MAC™** for the 4" and 6" vacuum pipes and **ANSYS** for the vacuum jacketed pipes. The **FRAME MAC™** models used resemble the following diagram:



The force on the vertical pipe represents the extra weight of the rotating union at that pipe. The supported nodes (7,10) represent the lower bearings of the end unions. Table II reports the largest reaction forces (RfY) at those supports as the forces on the end unions. The forces on the middle unions were obtained by taking the moment at that node and dividing by the moment arm length.

The forces on the VJ bayonets were calculated from the moments found in the **ANSYS** analysis.

THE NECESSARY ANGLES OF ROTATION were calculated from the following diagram (top view):



The angles in Table II are listed as A, B, and C (from top to bottom).

Table III-supplemental

THE MAXIMUM BENDING STRESSES AND THE MAXIMUM DEFLECTIONS were calculated by **FRAME MAC™** for the vacuum pipes using the same model described earlier. The maximum bending stress is calculated by the program as the moment divided by the section modulus. It occurred at the bottom bayonet for the 4" model and at the top bayonet for the 6" model. The maximum deflection occurred on the longest horizontal pipe in both cases.

THE MAXIMUM BENDING STRESSES AND THE MAXIMUM DEFLECTIONS were calculated using **ANSYS** for the vacuum jacketed lines. Each of the four models consisted of an internal pipe encumpassed by an external pipe. The internal pipe was fixed at the male end of the end bayonets and secured to the outer jacket at the end of the middle bayonet male sleeve. The external pipe is fixed at the end bayonets and contains bellows in each horizontal stretch of pipe(SEE FIG. 1). This allows the internal pipe to contract horizontally opposed only by the spring rate of the bellows. In this way, the stress is reduced well below the allowable B31**3** code stress of 25,500 psi.

However, this model does not allow for the vertical displacement that the bellows provides. The question was asked whether or not this freedom, which rests the weight of the outer jacket on the inner line, increases the stress. To answer this, another analysis was performed on the 4" x 6" line. This model had the outer jacket beginning and ending at the locations of the bellows. The outer jacket is then attached to the inner line at the middle bayonet. At each end of the outer line, a spring is attached which only hinders horizontal movement(SEE FIG. 1). The result is a maximum stress approximately 3000 psi less than the first model. Thus, the first model is more conservative and was used to analyze the VJ lines.

The models are available as **ANSYS** files archived under the username [Jeff]. The file names for the four original models are BELL46GRAV.LIS, BELL13GRAV.LIS, BELL13LGRAV.LIS, and DRAIN13GRAV.LIS. The second model of the 4" x 6" line is called SPRING46BELL.LIS.

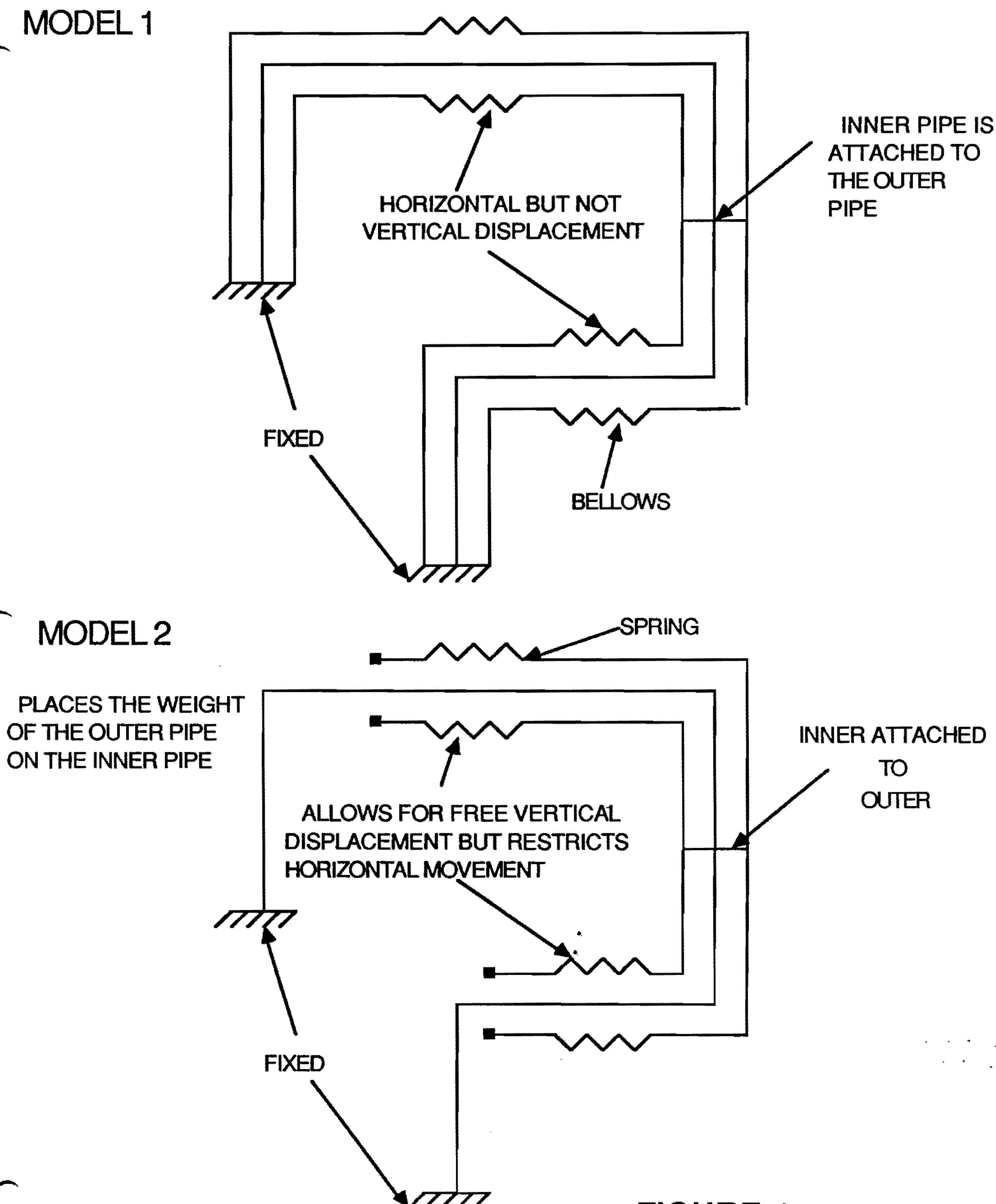

MODEL 1
INNER PIPE IS ATTACHED TO THE OUTER PIPE
HORIZONTAL BUT NOT VERTICAL DISPLACEMENT
FIXED
BELLOWS
MODEL 2
SPRING
PLACES THE WEIGHT OF THE OUTER PIPE ON THE INNER PIPE
INNER ATTACHED TO OUTER
ALLOWS FOR FREE VERTICAL DISPLACEMENT BUT RESTRICTS HORIZONTAL MOVEMENT
FIXED

FIGURE 1

APPENDIX B

Sample Calculations for
4" x 6" VJ and 4" Vac. Piping

TABLE I

1. Inside radii — 2.13 in., 3.1785 in.
2. Outside radii — 2.25 in., 3.3125 in.

(Sch 10S raw data)

3. Cross-sectional area

$$A = \pi (R_{out}^2 - R_{in}^2)$$
$$= \pi[(3.3125)^2 - (3.1785)^2] \quad \text{and} \quad = \pi[(2.25)^2 - (2.13)^2]$$
$$= 2.73 \text{ in}^2 \quad \text{and} \quad = 1.65 \text{ in}^2$$

Total $A = 2.73 + 1.65 = 4.38 \text{ in}^2$

4. Moment of inertia

$$I = \frac{\pi}{4}(R_{out}^4 - R_{in}^4)$$
$$= \frac{\pi}{4}[(3.3125)^4 - (3.1785)^4] \quad \text{and} \quad = \frac{\pi}{4}[(2.25)^4 - (2.13)^4]$$
$$= 14.40 \text{ in}^4 \quad \text{and} \quad = 3.96 \text{ in}^4$$

Total $I = 14.40 + 3.96 = 18.36 \text{ in}^4$

5. Section modulus

$$S = I / R_{out}$$
$$= 14.40 / 3.3125 \quad \text{and} \quad = 3.96 / 2.25$$
$$= 4.35 \text{ in}^3 \quad \text{and} \quad = 1.76 \text{ in}^3$$

Total $S = 4.35 + 1.76 = 6.11 \text{ in}^3$

6. Weight per unit length

$W = A\rho$ where A = cross-sectional area
ρ = density of steel (0.284 lb/in^3)

$$W = (4.38)(0.284)$$
$$= 1.24 \text{ lb/in.}$$

TABLE II

1. Approximate weight of bayonet

I found the cross-sectional areas for the bayonet material from a drawing and multiplied by length and then by the density of steel, $\rho = 0.284\ lb/in^3$. The bayonet was approximated by a finite number of simple cylinders.

4"×6" bayonet approximate weight = 35 lb.

2. Moment arm length

This was taken as the length of the male bayonet shaft (the thinnest part). For the 4"×6" bayonet, L = 14.5 in.

3. Force required at moment arm

$$\text{Force} = \frac{\text{moment from program}}{\text{moment arm}}$$

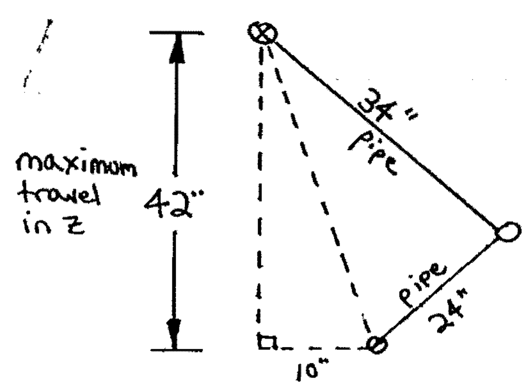
ie. for 4"×6" top bayonet:

$$F = \frac{2871\ lb\ in}{14.5\ in} = 198\ lb.$$

see also Appendix A.

4. Necessary angles of rotation

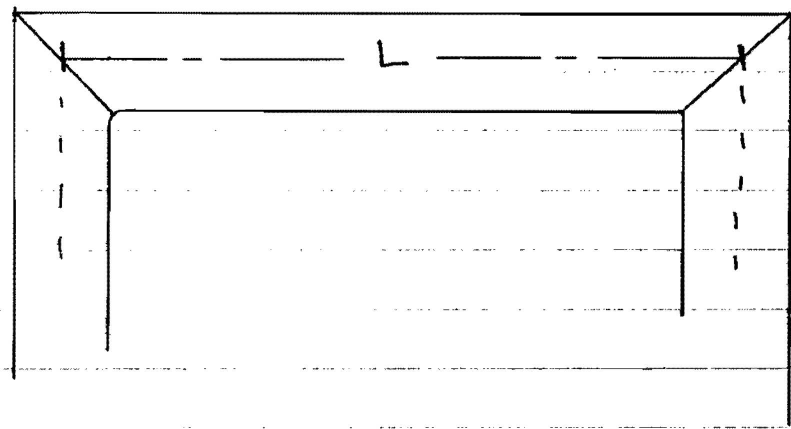
Working from the following plan view diagram:



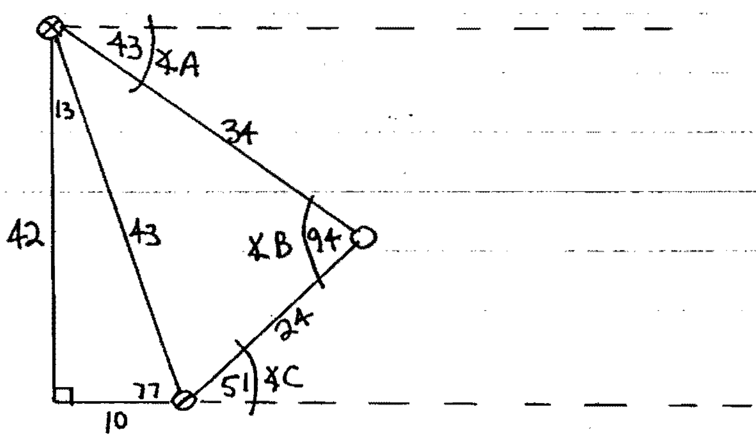
where ⊗ = high bayonet
⊘ = low bayonet
○ = center bayonet (free)

4. (Necessary angles - cont.)

The pipe lengths are taken as the lengths of the horizontal pipes' center axis.



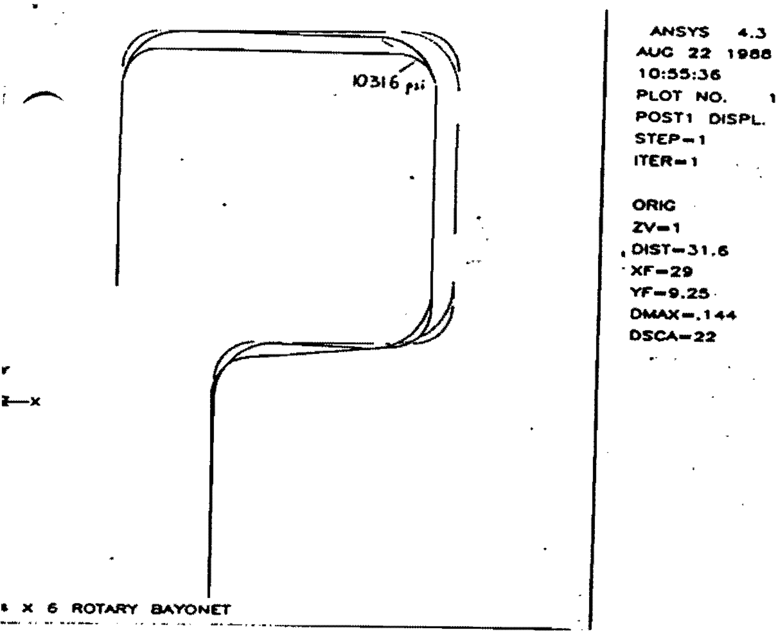
The laws of sines and cosines can be used to find the following:

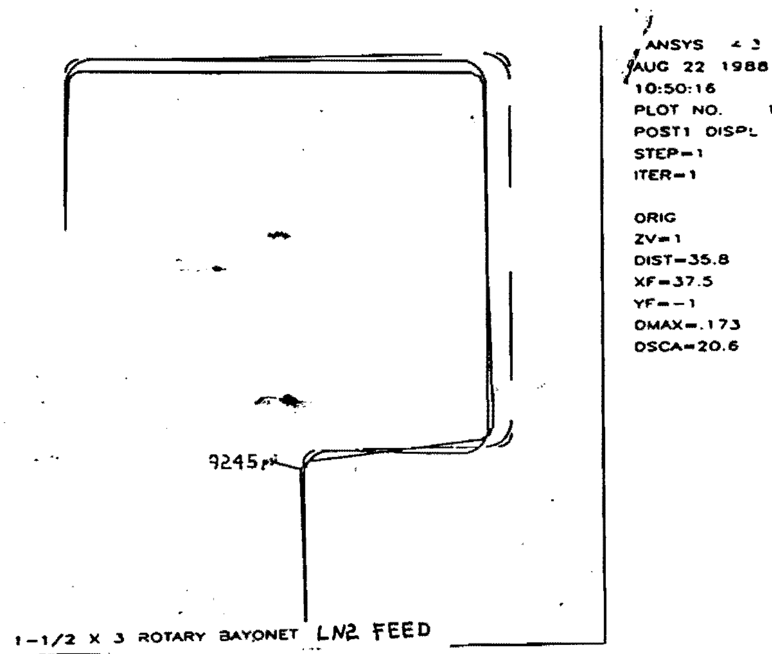


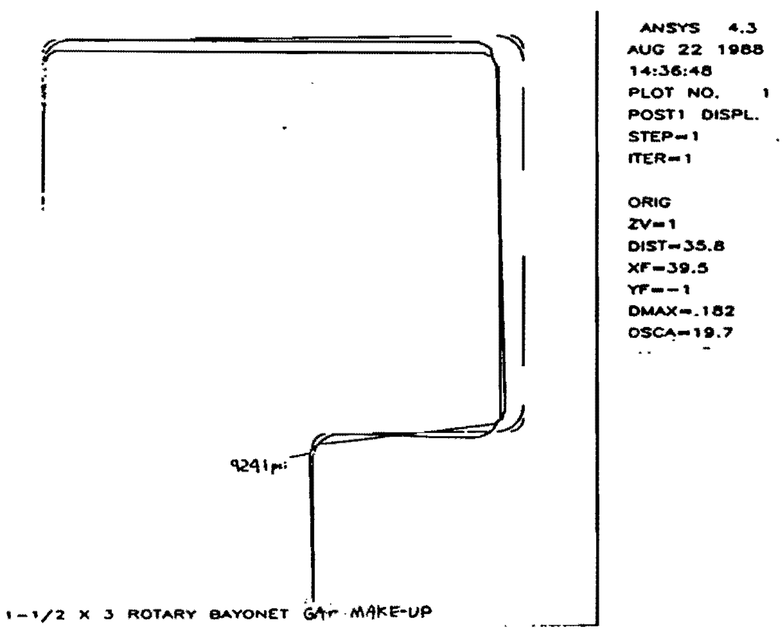
<A = 43°
<B = 94°
<C = 51°

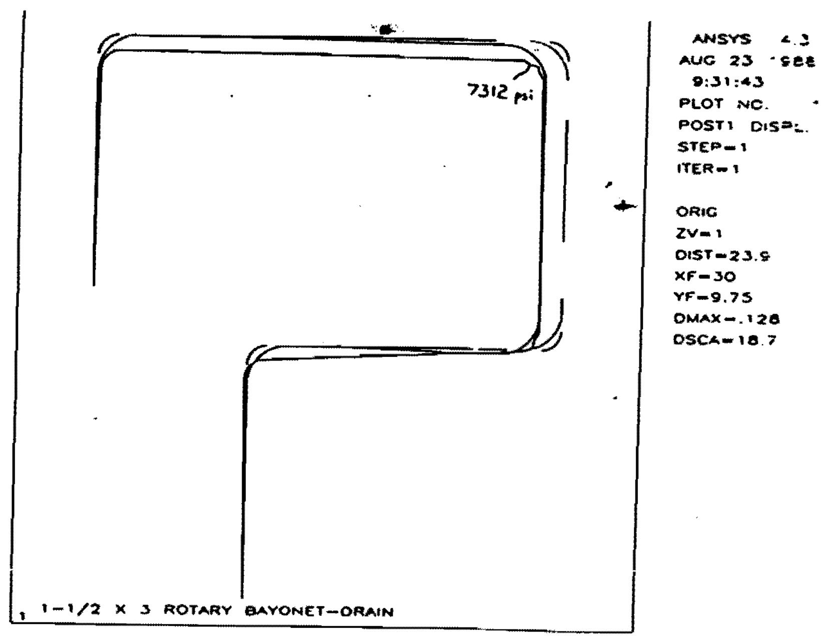
TABLE III

Calculations in this table were done by FRAME MAC™ and ANSYS.


ANSYS 4.3
AUG 22 1988
10:55:36
PLOT NO. 1
POST1 DISPL.
STEP=1
ITER=1
ORIG
ZV=1
DIST=31.6
XF=29
YF=9.25
DMAX=.144
DSCA=22
10316 psi
X 6 ROTARY BAYONET


ANSYS 4.3
AUG 22 1988
10:50:16
PLOT NO. 1
POST1 DISPL
STEP=1
ITER=1
ORIG
ZV=1
DIST=35.8
XF=37.5
YF=-1
DMAX=.173
DSCA=20.6
9245 psi
1-1/2 X 3 ROTARY BAYONET LN2 FEED


ANSYS 4.3
AUG 22 1988
14:36:48
PLOT NO. 1
POST1 DISPL.
STEP=1
ITER=1
ORIG
ZV=1
DIST=35.8
XF=39.5
YF=-1
DMAX=.182
DSCA=19.7
9241 psi
1-1/2 X 3 ROTARY BAYONET GAS MAKE-UP


ANSYS 4.3
AUG 23 1988
9:31:43
PLOT NO.
POST1 DISPL.
STEP=1
ITER=1
ORIG
ZV=1
DIST=23.9
XF=30
YF=9.75
DMAX=.128
DSCA=18.7
7312 psi
1-1/2 X 3 ROTARY BAYONET-DRAIN

APPENDIX C

The allowable stress of 25,500 psi is calculated by using table A-1 and section 302.3.5 of the ANSI/ASME B31.3 1984 edition. The information is enclosed within this appendix.

TABLE 302.3.3C
INCREASED CASTING QUALITY FACTORS E_c

Supplementary Examination in Accordance with Note(s)	Factor E_c
(1)	0.85
(2)(a) or (2)(b)	0.85
(3)(a) or (3)(b)	0.95
(1) and (2)(a) or (2)(b)	0.90
(1) and (3)(a) or (3)(b)	1.00
(2)(a) or (2)(b) and (3)(a) or(3)(b)	1.00

NOTES:
(1) Machine all surfaces to a finish of 250 μin. arithmetic average roughness height per ANSI B46.1, thus increasing the effectiveness of surface examination
(2) *(a)* Examine all [illegible] of [illegible] casting (magnetic material [illegible]ly) by the magnetic particle method in accordance with ASTM E 709* or E 138*. Judge acceptability in accordance with MSS SP-53, using reference photos in ASTM E 125*.
(b) Examine all surfaces of each casting by the liquid penetrant method, in accordance with ASTM E 165*. Judge acceptability of flaws and weld repairs in accordance with Table 1 of MSS SP-53, using ASTM E 125* as a reference for surface flaws.
(3) *(a)* Fully examine each casting ultrasonically in accordance with ASTM E 114*, accepting a casting only if there is no evidence of depth of defects in excess of 5% of wall thickness.
(b) Fully radiograph each casting in accordance with ASTM E 142*. Judge in accordance with the stated acceptance levels in Table 302.3.3D.
*These standards have been approved by ANSI as American National Standards.

which may be used for certain types of welds if additional examination is performed beyond that required by the product specification.

302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains

(a) Internal Pressure Stresses. Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of 304.

(b) External Pressure Stresses. Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of 304.

(c) Longitudinal Stresses S_L. The sum of longitudinal stresses due to pressure, weight, and other sustained loadings S_L shall not exceed S_h in 302.3.5(d). The thickness of pipe used in calculating S_L shall be the nominal thickness $\overline{T}$ minus mechanical, corrosion, and erosion allowance c.

(d) Allowable Displacement Stress Range S_A. The allowable displacement stress range (see 319.2.3) for the computed displacement stress range S_E (see 319.4.4) shall be

TABLE 302.3.3D
ACCEPTANCE LEVELS FOR CASTINGS

Material Examined (Thickness)	Applicable Standard	Acceptance Level (or Class)	Acceptable Discontinuities
Steel (to 1 in.) (25mm)	ASTM E 446[1]	1	Types A, B, C
Steel (over 1 in. to 2 in.) (25 to 51mm)	ASTM E 446[1]	2	Types A, B, C
Steel (over 2 in. to 4½ in.) (51 mm to 114 mm)	ASTM E 186[1]	2	Categories A, B, C
Steel (over 4½ in. to 12 in.) (114 mm to 305 mm)	ASTM E 280[1]	2	Categories A, B, C
Aluminum & Magnesium	ASTM E 155[1]	. . .	Shown in reference radiographs
Copper, Ni-Cu	ASTM E 272[1]	2	Codes A, Ba, Bb
Bronze	ASTM E 310[1]	2	Codes A and B

NOTE:
(1) These standards have been approved by ANSI as American National Standards.

$$S_A = f(1.25\, S_c + 0.25\, S_h) \quad \text{(1a)}$$

In the above equation:

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis. [See Note (2) of Appendix A, 302.2.4, and 302.3.]

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis. [See Note (2) of Appendix A, 302.2.4, and 302.3.]

f = stress-range reduction factor for displacement cycle conditions[2] for the total number of cycles over the expected life (from Table 302.3.5). Expected life[3] means the total number of years the system is expected to be in

[2]Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion resistant materials should be considered where a large number of major stress cycles is anticipated.

[3]The designer is cautioned that the fatigue life of materials operated in the creep range may be reduced.

TABLE A-1 (CONT'D)
ALLOWABLE STRESSES IN TENSION FOR METALS (1)

Numbers in Parentheses Refer to Stress Table Notes, Which Appear at the Beginning of this Appendix; Specifications ASTM Unless Otherwise Indicated

Material	Spec. No.	P. No. (5)	Grade	Class	Factor E	Min. Tensile Strength, ksi	Min. Yield Strength, ksi	Notes	Min. Temp. (6)	Min. Temp. to 100	200	300	400	500	600
Stainless Steel (4) (Cont'd)															
Electric Fusion Welded Pipe and Tubes (2) (Cont'd)															
25Cr–20Ni Pipe	A 312	8	TP310	...	0.80	75	30	(28) (35) (39)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
25Cr–20Ni Pipe	A 312	8	TP310	...	0.80	75	30	(28) (29) (35) (39)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
16Cr–12Ni–2Mo Pipe	A 312	8	TP316	...	0.80	75	30	(27) (28)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
16Cr–12Ni–2Mo Pipe	A 312	8	TP316H	...	0.80	75	30	(27)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[illegible]Ni–2Mo Pipe	A 312	8	TP316L	...	0.80	70	25	...	–325	13.3	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–13Ni–3Mo Pipe	A 312	8	TP317	...	0.80	75	30	(27) (28)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Ti Pipe	A 312	8	TP321	...	0.80	75	30	(28)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Ti Pipe	A 312	8	TP321H	...	0.80	75	30	...	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP347	...	0.80	75	30	(28)	–425	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP347H	...	0.80	75	30	...	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP348	...	0.80	75	30	(28)	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP348H	...	0.80	75	30	...	–325	16.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–8Ni Pipe	A 312	8	TP304	...	0.85	75	30	(27) (28)	–425	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–8Ni Pipe	A 312	8	TP304H	...	0.85	75	30	(27)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–8Ni Pipe	A 312	8	TP304L	...	0.85	70	25	...	–425	14.2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
23Cr–12Ni Pipe	A 312	8	TP309	...	0.85	75	30	(28) (35) (39)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
25Cr–20Ni Pipe	A 312	8	TP310	...	0.85	75	30	(28) (35) (39)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
25Cr–20Ni Pipe	A 312	8	TP310	...	0.85	75	30	(28) (29) (35) (39)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
16Cr–12Ni–2Mo Pipe	A 312	8	TP316	...	0.85	75	30	(27) (28)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
16Cr–12Ni–2Mo Pipe	A 312	8	TP316H	...	0.85	75	30	(27)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
16Cr–12Ni–2Mo Pipe	A 312	8	TP316L	...	0.85	70	25	...	–325	14.2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–13Ni–3Mo Pipe	A 312	8	TP317	...	0.85	75	30	(27) (28)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Ti Pipe	A 312	8	TP321	...	0.85	75	30	(28)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Ti Pipe	A 312	8	TP321H	...	0.85	75	30	...	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP347	...	0.85	75	30	(28)	–425	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP347H	...	0.85	75	30	...	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP348	...	0.85	75	30	(28)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
18Cr–10Ni–Cb Pipe	A 312	8	TP348H	...	0.85	75	30	...	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 304 A 240	A 358	8	304	2	0.85	75	30	(27) (28) (31) (36)	–425	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 304L A 240	A 358	8	304L	2	0.85	70	25	(36)	–425	14.2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 316 A 240	A 358	8	316	2	0.85	75	30	(27) (28) (31) (36)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 316L A 240	A 358	8	316L	2	0.85	70	25	(36)	–325	14.2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 347 A 240	A 358	8	347	2	0.85	75	30	(28) (30) (36)	–425	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 321 A 240	A 358	8	321	2	0.85	75	30	(28) (30) (36)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 309S A 240	A 358	8	309S	2	0.85	75	30	(28) (31) (35) (36)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 310S A 240	A 358	8	310S	2	0.85	75	30	(28) (31) (35) (36)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 310S A 240	A 358	8	310S	2	0.85	75	30	(28) (29) (31) (35) (36)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 348 A 240	A 358	8	348	2	0.85	75	30	(28) (30) (36)	–325	17.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 304 A 240	A 358	8	304	5	0.90	75	30	(27) (28) (31) (36)	–425	18.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 304L A 240	A 358	8	304L	5	0.90	70	25	(36)	–425	15.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 316 A 240	A 358	8	316	5	0.90	75	30	(27) (28) (31) (36)	–325	18.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 316L A 240	A 358	8	316L	5	0.90	70	25	(36)	–325	15.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 347 A 240	A 358	8	347	5	0.90	75	30	(28) (30) (36)	–425	18.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Type 321 A 240	A 358	8	321	5	0.90	75	30	(28) (30) (36)	–325	18.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TABLE A-1 (CONT'D)
ALLOWABLE STRESSES IN TENSION FOR METALS (1)

Numbers in Parentheses Refer to Stress Table Notes, Which Appear at the Beginning of this Appendix; Specifications ASTM Unless Otherwise Indicated

Material	Spec. No.	P-No. (5)	Grade	Factor E	Min. Tensile Strngth., ksi	Min. Yield Strngth., ksi	Notes	Min. Temp. (6)	Min. Temp. to 100	200	300	400	500	600
Stainless Steel (4) (Cont'd)														
Welded Fittings														
18Cr–8Ni	A 403	8	WP304	1.00	75	30	(12) (16) (27) (28) (31) (32)	–425	20.0	[redacted]				
18Cr–8Ni	A 403	8	WP304H	1.00	75	30	(16) (27) (31) (32)	–325	20.0	[redacted]				
18Cr–8Ni	A 403	8	WP304L	1.00	70	25	(16) (32)	–425	16.7	[redacted]				
23Cr–12Ni	A 403	8	WP309	1.00	[illegible]	30	(16) (28) (32) (35)	–325	20.0	[redacted]				
25Cr–20Ni	A 403	8	WP310	1.00	75	30	(16) (28) (32) (35)	–325	20.0	[redacted]				
25Cr–20Ni	A 403	8	WP310	1.00	75	30	(16) (28) (29) (32) (35)	–325	20.0	[redacted]				
18Cr–10Ni–Cb–Ta	A 403	8	WP347	1.00	75	30	(16) (28) (30) (32)	–425	20.0	[redacted]				
18Cr–10Ni–Cb–Ta	A 403	8	WP347H	1.00	75	30	(16) (28) (30) (32)	–325	20.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316	1.00	75	30	(16) (27) (28) (31) (32)	–325	20.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316H	1.00	75	30	(16) (27) (31) (32)	–325	20.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316L	1.00	70	25	(16) (32)	–325	16.7	[redacted]				
18Cr–13Ni–3Mo	A 403	8	WP317	1.00	75	30	(16) (27) (28) (31) (32)	–325	20.0	[redacted]				
18Cr–10Ni–Ti	A 403	8	WP321	1.00	75	30	(16) (28) (30) (32)	–325	20.0	[redacted]				
18Cr–10Ni–Ti	A 403	8	WP321H	1.00	75	30	(16) (30) (32)	–325	20.0	[redacted]				
18Cr–10Ni–Cb	A 403	8	WP348	1.00	75	30	(16) (28) (30) (32)	–325	20.0	[redacted]				
18Cr–8Ni	A 403	8	WP304	0.85	75	30	(16) (27) (28) (31) (32)	–425	17.0	[redacted]				
18Cr–8Ni	A 403	8	WP304H	0.85	75	30	(16) (27) (31) (32)	–325	17.0	[redacted]				
18Cr–8Ni	A 403	8	WP304L	0.85	70	25	(16) (32)	–425	14.1	[redacted]				
23Cr–12Ni	A 403	8	WP309	0.85	75	30	(16) (28) (32) (35)	–325	17.0	[redacted]				
25Cr–20Ni	A 403	8	WP310	0.85	75	30	(16) (28) (32) (35)	–325	17.0	[redacted]				
25Cr–20Ni	A 403	8	WP310	0.85	75	30	(16) (28) (29) (32) (35)	–325	17.0	[redacted]				
18Cr–8Ni–Cb	A 403	8	WP347	0.85	75	30	(16) (28) (30) (32)	–425	17.0	[redacted]				
18Cr–8Ni–Cb	A 403	8	WP347H	0.85	75	30	(16) (28) (30) (32)	–325	17.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316	0.85	75	30	(16) (27) (28) (31) (32)	–325	17.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316H	0.85	75	30	(16) (27) (31) (32)	–325	17.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316L	0.85	70	25	(16) (32)	–325	14.1	[redacted]				
18Cr–13Ni–3Mo	A 403	8	WP317	0.85	75	30	(16) (27) (28) (31) (32)	–325	17.0	[redacted]				
18Cr–10Ni–Ti	A 403	8	WP321	0.85	75	30	(16) (28) (30) (32)	–325	17.0	[redacted]				
18Cr–10Ni–Ti	A 403	8	WP321H	0.85	75	30	(16) (30) (32)	–325	17.0	[redacted]				
18Cr–10Ni–Cb	A 403	8	WP348	0.85	75	30	(16) (28) (30) (32)	–325	17.0	[redacted]				
18Cr–8Ni	A 403	8	WP304	0.80	75	30	(16) (27) (28) (31) (32)	–425	16.0	[redacted]				
18Cr–8Ni	A 403	8	WP304H	0.80	75	30	(16) (27) (31) (32)	–325	16.0	[redacted]				
18Cr–8Ni	A 403	8	WP304L	0.80	70	25	(16) (32)	–425	13.3	[redacted]				
23Cr–12Ni	A 403	8	WP309	0.80	75	30	(16) (28) (32) (35)	–325	16.0	[redacted]				
25Cr–20Ni	A 403	8	WP310	0.80	75	30	(16) (28) (32) (35)	–325	16.0	[redacted]				
25Cr–20Ni	A 403	8	WP310	0.80	75	30	(16) (28) (29) (32) (35)	–325	16.0	[redacted]				
18Cr–8Ni–Cb	A 403	8	WP347	0.80	75	30	(16) (28) (30) (32)	–425	16.0	[redacted]				
18Cr–8Ni–Cb	A 403	8	WP347H	0.80	75	30	(16) (30) (32)	–325	16.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316	0.80	75	30	(16) (27) (28) (31) (32)	–325	16.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316H	0.80	75	30	(16) (27) (31) (32)	–325	16.0	[redacted]				
16Cr–12Ni–2Mo	A 403	8	WP316L	0.80	70	25	(16) (32)	–325	13.3	[redacted]				
18Cr–13Ni–3Mo	A 403	8	WP317	0.80	75	30	(16) (27) (28) (31) (32)	–325	16.0	[redacted]				