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INWARD BUCKLING OF FLEXIBLE GRAPHITE FILLED SPIRAL WOUND GASKETS FOR PIPING FLANGES

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ABSTRACT

The application of flexible graphite filler for spiral wound gaskets has been widely adopted as the preferred alternative to asbestos counterpart gaskets for piping flanges within the petrochemical and refining industry. For the most part, the transition to flexible graphite has occurred with relatively good success consistent with its improved sealing performance. However, recent experiences reported with the inward buckling of flexible graphite filled spiral wound gaskets warrants another look at our industry practices covering this type of gasket.

The paper will present findings from 2 different but related instability problems involving spiral wound flexible graphite filled gaskets. The first involves Class 1500 & 2500 spiral wound gaskets fitted with inner retaining rings which suffered severe inward buckling with initial boltup. The second experience pertains to Class 600 and lower gaskets supplied without inner retaining rings. Gaskets supplied in both cases complied fully with ASME B16.20 requirements, which highlights possible inadequacies in this standard for spiral wound gaskets filled with flexible graphite.

The principal objective of this paper is to alert users of spiral wound flexible graphite filled gaskets about the potential for inward buckling. It will also focus on the need for industry wide attention to several apparent deficiencies with current design and manufacturing standards and practices associated with this type of gasket.

INTRODUCTION

Since their initial use during the 1910's, spiral wound type gaskets with asbestos filler would have to be considered one of the principal gaskets used within the refining and petrochemical industry. As currently specified by ASME B16.20 (adopted from API 601 in 1993), the application of spiral wound gaskets with asbestos filler proved to be very reliable with favorable sealing performance for most piping flange services.[1][2] For many users, they typically represented the gasket of choice for Class 300 to 600 piping and equipment flanges, especially at elevated temperatures (up to 1100°F).

With the move to non-asbestos sealing alternatives, flexible graphite would have to be considered one of the principal filler materials used today for spiral wound gaskets. This is definitely the case for refining and petrochemical applications to take advantage of flexible graphite's favorable sealing performance at elevated temperatures and inherent firesafe characteristics.[3] While these gaskets have generally demonstrated good experience, there have been several recent instances reported with buckling instability type problems with standard ASME B16.20 spiral wound flexible graphite filled gaskets for standard ANSI B16.5 piping flanges.[4]

The inward buckling of spiral wound gaskets is not a new phenomena but reported instances were typically isolated cases associated with large diameter or other special spiral wound gaskets.[5] Unlike these past instances, this paper addresses 2 separate experiences with Spiral Wound Flexible Graphite (SWFG) gaskets for standard piping flanges which proved to be widespread problems for both the locations involved. These experiences can be summarized as follows:

1. Inward buckling and distortion was experienced with the **inner retaining ring** of NPS 8 size and larger Spiral Wound Flexible Graphite (SWFG) gaskets for Class 1500 and 2500 piping flanges of a high pressure hydrocarbon processing plant located in Europe. Of approximately 80 gaskets surveyed, about half were found to have unacceptable buckling.

2. The second, more recent experience involved the gross radial inward buckling of the **inner spirals** found on about 12% of 1200 total SWFG gaskets installed without inner rings for NPS 16 and smaller size Class 150, 300 and 600 flanges. The gaskets were installed at a refinery expansion located in North America.

While these experiences involve 2 different styles of gaskets, it is apparent that the buckling concern is related to the extent of radial pressure generated by the initial compression of the gasket windings and the graphite filler material.

INNER RETAINING RING BUCKLING OF CLASS 1500 & 2500 SWFG GASKETS

All of the Class 1500 and 2500 SWFG gaskets covered as the first experience by this paper were supplied to API 601 requirements (now incorporated within ASME B16.20). Except for the carbon steel outer centering ring, the metallic components including the spirals and inner retaining ring were constructed from Type 316L stainless steel. Gaskets ranging in sizes up to NPS 20 for Class 1500 and NPS 10 for Class 2500 were supplied by 2 principal European manufacturers. About half of 80 gaskets inspected were found to have severe to moderate inward buckling of the inner retaining ring. The problem concentrated on 8, 10 and 12" NPS gaskets, especially for Class 1500, where the inner ring width is small, only 0.177" (4.5 mm).

All of the subject flange joints were made up with multi-head stud tensioning equipment to achieve 50 ksi (345 MPa) target bolt stress uniformly using detailed controlled boltup procedures. This preload is typical refinery practice to compensate for bolt relaxation effects. Attention was also paid during initial assembly to achieve proper flange alignments.

The inner ring buckling problem was first observed when initially installed gaskets were removed after system hydrostatic tests. This led to a further sampling of installed gaskets, even for systems which still had not been pressure tested. **Table 1** gives a summary of the gasket sizes above 6" NPS removed for inspection and the number found with either severe inward buckling or moderate distortion of the inner ring. There was no indication of problems with any of the approximate 700 total 6" NPS and smaller Class 1500 and 2500 gaskets installed on the unit so these have been purposely omitted from the table.

As can be seen by **Table 1,** about 47% of the gaskets inspected were found with severe to moderate inward buckling of the inner retaining ring. The buckling problem is mainly concentrated on 8, 10 and 12" NPS gaskets, especially for Class 1500, where the inner ring width is small, only 0.177" (4.5 mm), as specified by ASME B16.20.

Table 1

CLASS 1500 & 2500 SWFG GASKETS WITH INNER RING BUCKLING

Number of Gaskets Observed with Inward Buckling by Class

Flange Size, NPS	Class 1500				Class 2500			
	Severe	Medium	Good	Total	Severe	Medium	Good	Total
8	2	4	7	13	2		4	6
10	11	9	14	34	2	3		5
12	5	1	7	13				
16			8	8				
18			3	3				
20			1	1				
Subtotal	18	14	40	72	4	3	4	11

Ratio of All Gaskets Severely & Moderately Buckled / to Total Surveyed = 39 / 83 = 47.0%

Figure 1 provides two photographic views of a typical 10" NPS Class 1500 SWFG gasket with severe buckling of the inner ring. As can be seen, the buckling damage has occurred over about half of the inner gasket circumference. The maximum inward peak is about 5/8" (16 mm) deep over an 1" (25 mm) circumferential width. The photos also show the relative thinness (0.177") of the inner retaining ring in relation to the gasket width.

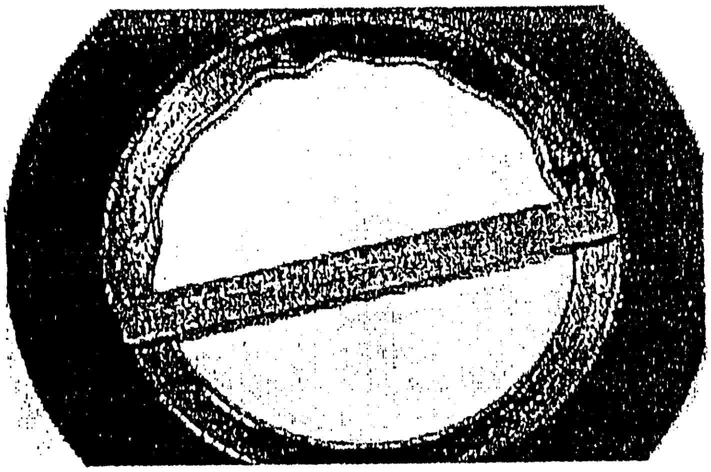


Fig. 1a - Spiral Wound NPS 10 Class 1500 Flexible Graphite Gasket with Buckled Inner Ring

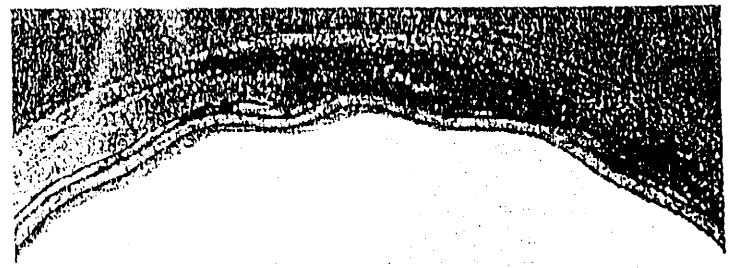


Fig. 1b - Blowup of Buckled Inner Ring of Same NPS 10 Class 1500 Gasket

Dimensions (mm) of Spiral Wound Gaskets per ASME B16.20 and Raised Face Flanges per ANSI B16.5 for Sch. 10, 120 and Welding Neck Flanges

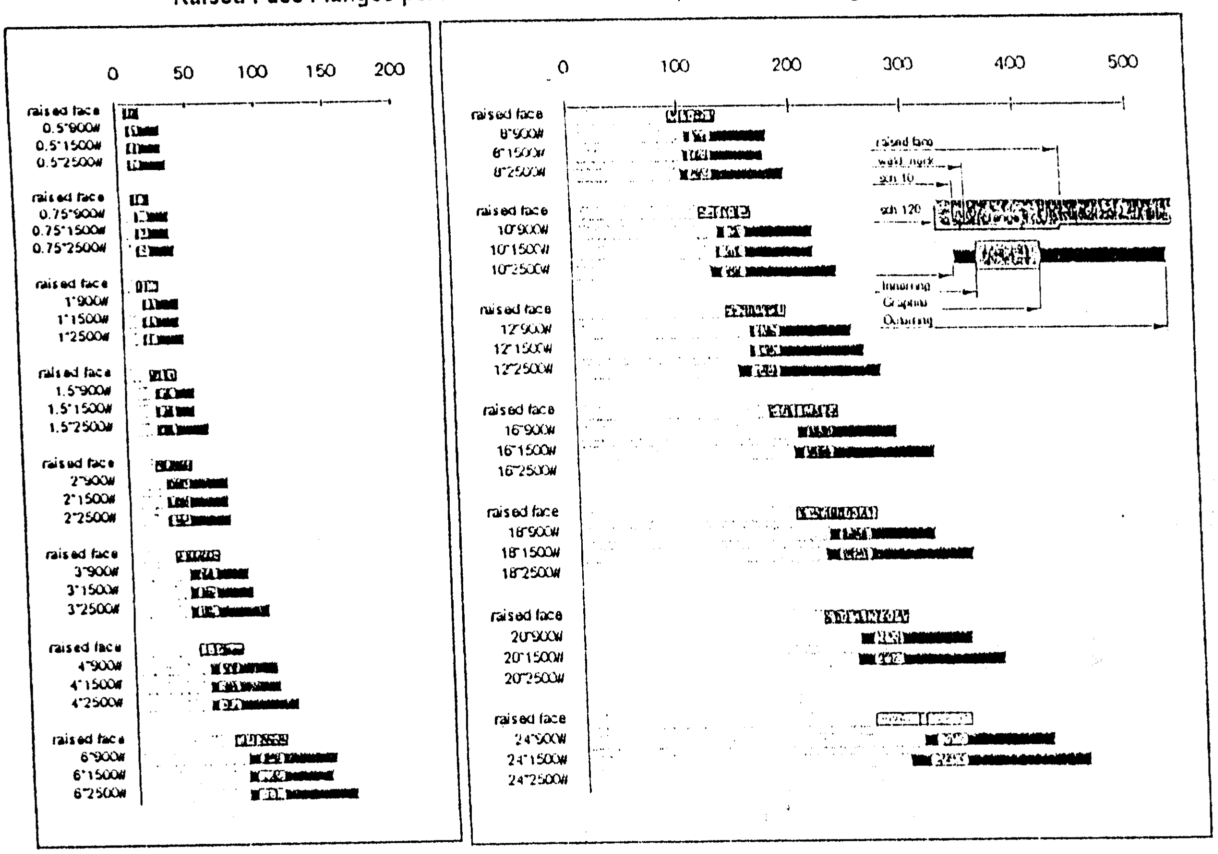


Fig. 2 Comparision of Spiral Wound Gasket & Inner Retaining Ring Widths per ASME B16.20 to ANSI B16.5 Raised Face Flange Inside Diameters for Sch. 10, 120 and WN Flanges

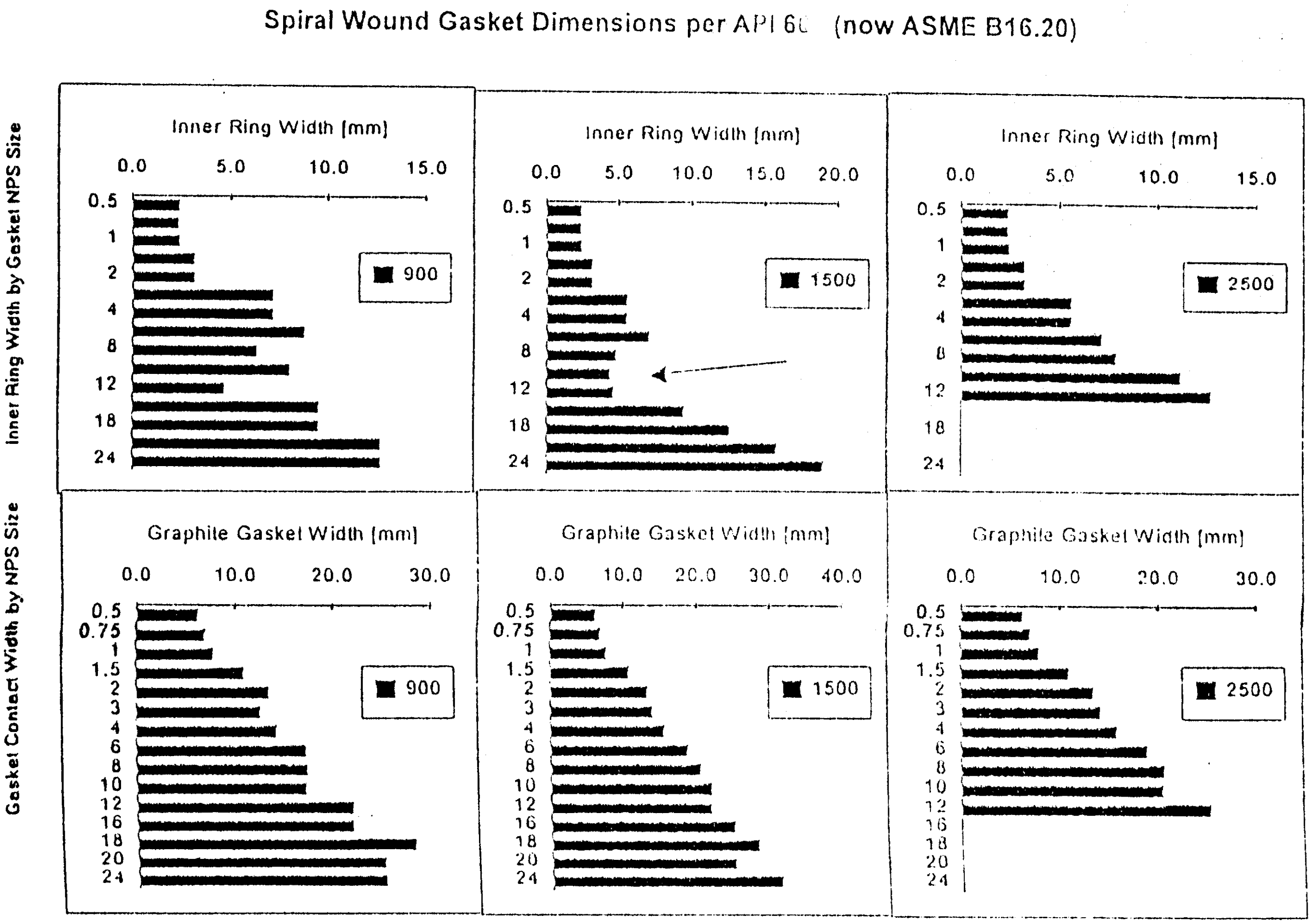


Fig. 3 - Summary of Inner Retaining Ring and Gasket Spiral Widths per ASME B16.20

The buckling is difficult to describe because there were a great variety in shapes. Some buckling was very local, with inward peaks as much as 1" (25 mm) deep over 1-1/2" (38 mm) radial width. Others were polygonal like in shape. Gaskets were classified as severe when the amount of buckling seriously affected the graphite circumferential distribution and the stability of the gasket.

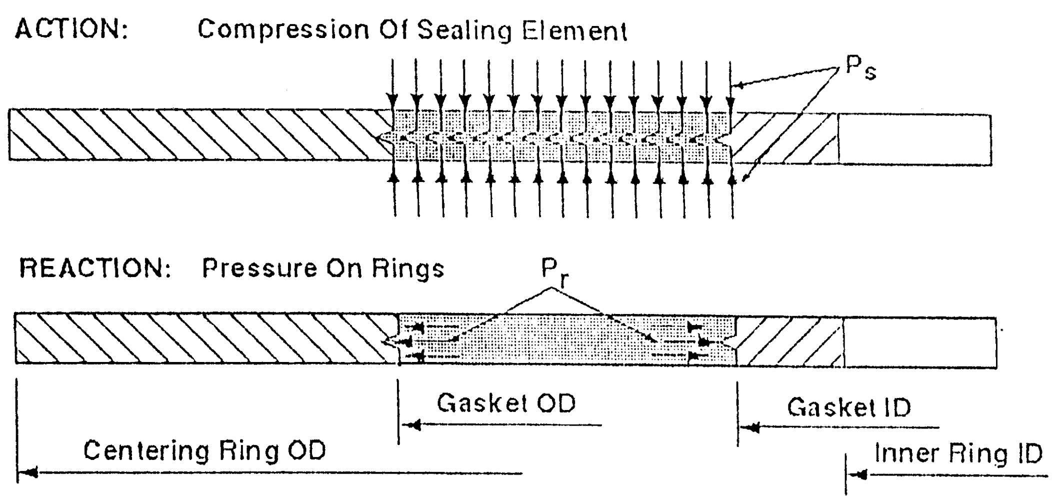
A summary diagram is provided by **Figure 2** to show the dimensions of Class 900, 1500 and 2500 spiral wound gaskets with inner rings as specified by ASME B16.20 for flanges sizes up to 24" NPS. As noted by this diagram, the inner rings of 8, 10, and 12" NPS Class 1500 gaskets are particularly smaller in proportion than the gasket width as compared to other gaskets. **Figure 3** covers this better by showing the pertinent dimensions for just the inner ring width and spiral gasket width for all ASME B16.20 gaskets up to 24" NPS size. The relatively thin inner ring is considered to be a contributing factor to the buckling problem.

Observations / Analysis of Inner Ring Buckling

From markings on the rings it could be seen that the deformation took place before the gasket was compressed to the limit of the outer centering ring thickness and before there was any compressive load on the inner rings which would have limited deformation. The outer rings are only in contact with the raised face at their inner edge when the gasket is fully compressed. It should again be noted that most of the failed gaskets had not been exposed to either test or operating pressures and hence only compressed with gasket seating.

The evidence clearly showed that the inner rings were buckled inwards in the plane of the gasket by radial pressure generated by the compression of the gasket windings and graphite filler material. In addition, the much wider outer centering rings were bent across their width due to similar radial pressure which tends to force them to a conical or dish like shape. **Figure 4** provides a simplified force diagram to illustrate the radial pressure involved in compressing the spiral wound material during initial gasket sealing.

It is worth recalling that the more recent buckling experience has been predominately with graphite filler (and with PTFE) material as compared to the favorable earlier experience demonstrated by asbestos filled spiral wound gaskets. The previous lack of problems with the inner spirals of asbestos gaskets tends to suggest a different behavior of the graphite



For Compressible Material: $P_r \approx P_s F_c$

Where: P_s = Gasket Seating Stress (Pressure)

P_r = Radial Pressure on Inner / Outer Rings

F_c = Some Undefined Compressibility Factor for Composite Gasket

Fig. 4 Spiral Wound Gasket Compression Forces and Resultant Radial Pressures to Inner Ring filler with respect to the radial loads generated. Relative to flexible graphite, the asbestos filler possesses greater compressibility which allows for the compaction of the gasket with significantly less radial force imposed on the windings. This logic is consistent with the apparent lack of inward buckling of inner spirals experienced with spiral wound asbestos filled gaskets in piping flanges.

Considering the greater incompressibility properties of graphite filler it then follows that greater loads are generated radially at the inner and outer rings. This would appear to be further aggravated by the apparent tightness of the spiral windings and their fit-up within the inner and outer rings.

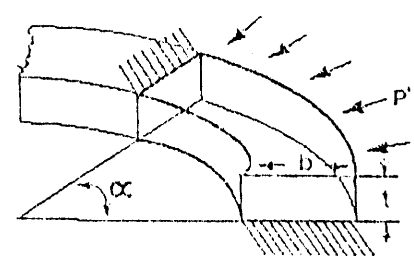
Testing and analysis work performed in conjunction with the gasket manufacturers confirmed that the standard width inner rings per ASME B16.20 yielded in compression for Class 1500 and 2500 SWFG gaskets during bolt-up of the flanges.[6] Finite element analyses were also conducted of the inner ring under uniform external loading to show that yielding can occur at relatively low loads of 650 to 870 psi (4.5 to 6.0 MPa) depending on the mode of clamping provided by the flange. The results compared well with an assessment of critical buckling pressures summarized by **Figure 5** for various size ring segments of the gasket assumed to be unrestrained by the mating flanges .[7]

$$P'_r = \frac{p'}{t} = \frac{EI}{r^3 t}(k^2 - 1)$$

Where:

P'_r	=	Critical Radial Pressure
p'	=	Uniform Radial Pressure lb/in.
E	=	Modulus of Elasticity, psi
I	=	Moment of Inertia
r	=	Mean Radius of Inner Ring, in
b	=	Inner Ring Width, in
t	=	Inner Ring Thickness, in
α	=	Angle of Circular Arc with Ends Fixed
k	=	Factor Dependent on α

Unrestrained Segment of SW Gasket Inner Ring



For NPS 10 Class 1500 Gasket:	If α	k	P'_r (psi)
	30°	17.2	14,500
r = 5.16" (131 mm)	60°	8.62	3,610
b = 0.175" (4.5 mm)	90°	5.80	1,600
t = 0.125" (3 mm)	120°	4.37	890
	180°	3.00	400
	360°	2.00	150

Fig. 5 Buckling Pressure for Unrestrained Segment of Spiral Wound Gasket

Principal conclusions resulting from the field observations and limited analyses conducted in connection wtih this inner ring buckling experience can be summarized as follows:

1. Yielding of the inner rings is considered to be related to the requirements of ASME B16.20 (Par. 3.2.6) to achieve a certain gasket stiffness by stipulating a required compression of the gasket under a bolt stress of 30,000 psi (207 MPa). Because of graphite's lower compressibility properties, large compressive forces generated in the gasket due to this stiffness requirement can translate to very high compressive forces on the inner ring. Based on the tests performed, it is evident that the gasket stress generated under these conditions is not consistent with either the required seating stress or gasket geometry.

2. The buckling problem is amplified by the narrow widths of the inner rings per B16.20, which are based on the inside diameter of Schedule 30 or 40 pipe. Yielding of the inner ring by itself is not necessarily detrimental to gasket performance. However, yielding of the inner ring in conjunction with uneven bolt load or flange misalignment can lead to inner buckling and loss of gasket sealing.

   As an interim measure, SWFG gaskets for use in Class 900, 1500 and 2500 flanges should be provided with an inner ring width based on Schedule 80 pipe. The inner ring thickness should also be made equal to the outer centering ring thickness. Figure 3 provides some indication on the effect of inner ring width based on differences between various pipe schedule inside diameters.

3. The practice of achieving high bolt preloads (typically 50 ksi bolt stress) during assembly is not considered to be a contributing factor to the buckling because the test work shows that inner yielding occurs prior to full gasket compression.

A complete solution to the problem of inner ring buckling requires a more thorough assessment into the design parameters for high pressure graphite filled spiral wound gaskets. Further investigations into this buckling experience should therefore focus on the design and construction of the gasket. It should also consider fabrication and quality control related issues in the manufacturing of graphite filled spiral wound gaskets.

SWFG GASKET INNER WINDING BUCKLING EXPERIENCED WITH LOWER FLANGE CLASSES

Moving on to the second experience, gross radial inward buckling was found to occur with the inner spirals of a large number of SWFG gaskets without inner rings installed at a refinery expansion located in North America. In this case, the gaskets were supplied by 3 different manufacturers of North American origin. The problem was first identified during final commissioning activities of the project when "dishing" type distortions were observed with the outer centering ring of several installed SWFG gaskets. The removal of these and other gaskets representative of those installed on the project ultimately led to the fact that a significant number of gaskets had suffered inward buckling of the inner spirals.

About 1200 of the installed SWFG gaskets were ultimately checked to reveal 12% had in fact suffered buckling of the inner spirals. Essentially all of the gaskets involved were 16" NPS and smaller size distributed among 150, 300 and 600 flanges, and again were all without inner retaining rings. The majority of the gaskets were only loaded during assembly and hence had not seen hydrostatic or service pressure conditions.

A summary of inspection findings are provided by **Table 2** to show the distribution of buckling experienced by gasket size and rating. Observed radial buckles typically projecting more than 1/4" (6 mm) inward generally resulted in the loosening of the inner windings. The table clearly shows that the inner spiral buckling problem was quite widespread for 6" NPS and larger gaskets for all 3 flange ratings involved.

Table 2

SUMMARY SWFG GASKETS WITH INWARD BUCKLING OF SPIRALS

Number of Gaskets Observed with Inward Buckling by Class

Flange Size, NPS	Class 150		Class 300		Class 600	
	Total	# Buckled	Total	# Buckled	Total	# Buckled
3	28	0	31	* 2	1	0
4	39	0	19	0	5	* 1
6	213	12	322	59	60	3
8	194	2	71	22	12	4
10	83	6	20	11	1	0
12	45	1	3	2	26	12
14	10	0	18	3	0	0
16	0	0	0	0	18	4
Subtotal	612	21	484	99	123	24

* While buckled, windings tight and not extended into bore for two 3" Class 300 & one 4" Class 600 gaskets

Ratio of All Gaskets Buckled / to Total Surveyed = 144 / 1219 = 11.8%

Figures 6 through 9 are photographs of representative gaskets showing different modes of buckling experienced. The 6" NPS Class 300 gasket shown in **Figure 6** has buckled with a single peak having an inward projection of about 7/8" (22 mm) over a 3/4" (19 mm) circumferential width. By comparison, **Figure 7** shows the same size gasket but with 4 smaller peaks equally spaced. The apparent preferential location of the buckle peaks tend to indicate non-uniform bolt preloads or relaxation effects due to adjacent bolt interactions during flange assembly. Non-parallel flange misalignments or uneven flatness of the faces may also be contributing factors. The buckles logically will occur where there is least clamping restraint.

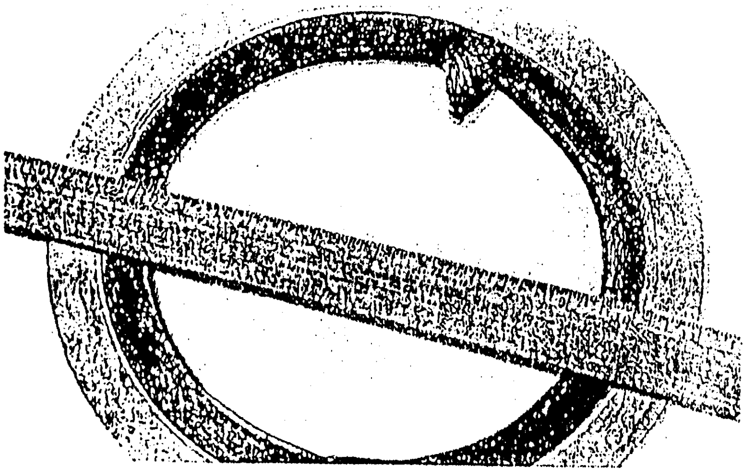


Fig. 6 - NPS 6 Class 300 SWFG Gasket with
Buckled Inner Spirals - Single Peak

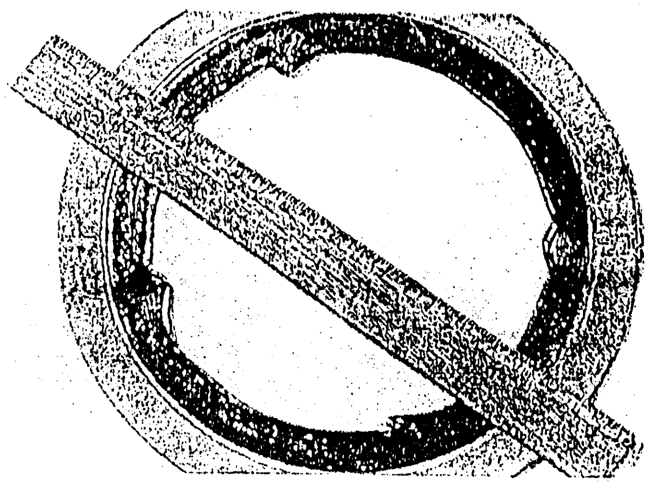


Fig. 7 - NPS 6 Class 300 SWFG Gasket with
Buckled Inner Spirals - Quad Peaks

Figures 8 and 9 show two different gaskets of the same 10" NPS Class 300 size with a higher number of buckle modes. These were in fact test gaskets installed in standard piping flanges at site which were made up with controlled boltup procedures using a hydraulic torque wrench as shown by the photograph in **Figure 10**. These boltup procedures employed a multi-pass tightening sequence, typically a minimum of 6 rounds, to gradually achieve a uniform 50 ksi (345 MPa) bolt stress preload as determined by bolt elongation measurements. Surface roughness checks were also sampled on around 100 flange faces which were found to be well within the range of project (125 to 250 micro inch RMS) and ASME B16.5 requirements.

The 8" Class 300 gasket shown by the photograph in **Figure 11** was also one used during the site controlled bolt up tests, and as compared to the test gaskets in **Figures 8 and 9** has not suffered any apparent buckling. What is interesting here is that these gaskets had different relative fit-up tightness with their respective outer rings. The outer ring for the 10" Class 300 gasket of **Figure 8** was found to be very tight and could not be rotated about the windings. The similar gasket of **Figure 9** was moderately tight but still difficult to rotate within the outer ring. By comparison, the 8" NPS Class 300 gasket of **Figure 11** had a relatively loose fitting outer ring. While these may have been isolated examples, looser fitting centering rings will logically help relieve the high radial forces developed in compressing the flexible graphite gasket.

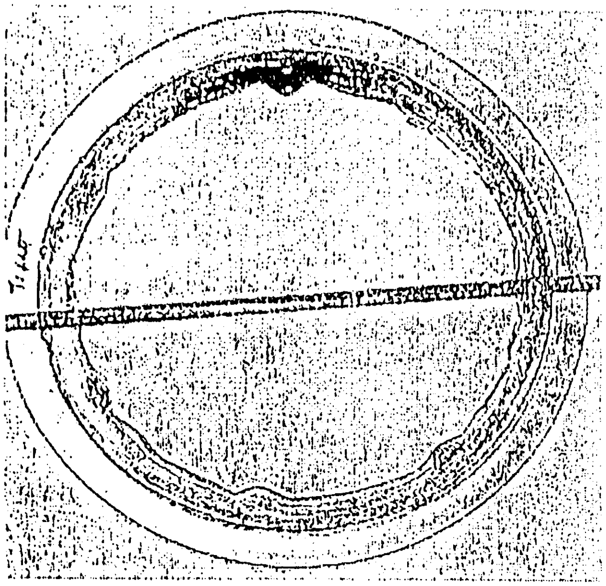


Fig. 8 - Test NPS 10 Class 300 SWFG Gasket with Buckled Inner Spirals - Very Tight Outer Ring

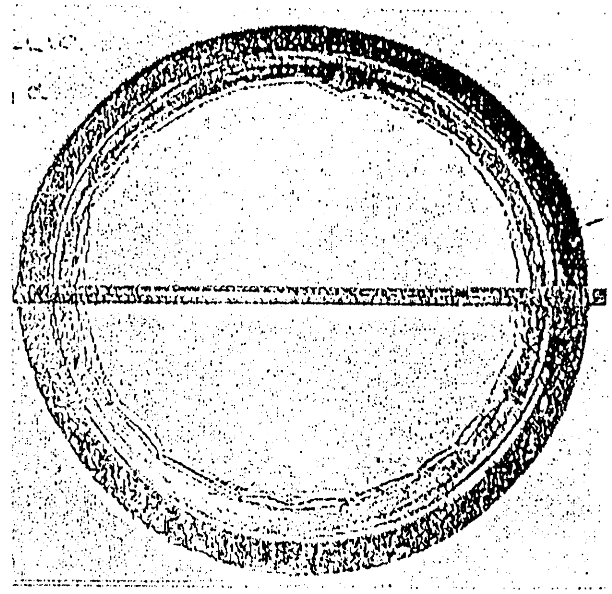


Fig. 9 - Test NPS 10 Class 300 SWFG Gasket with Buckled Inner Spirals - Tight Outer Ring

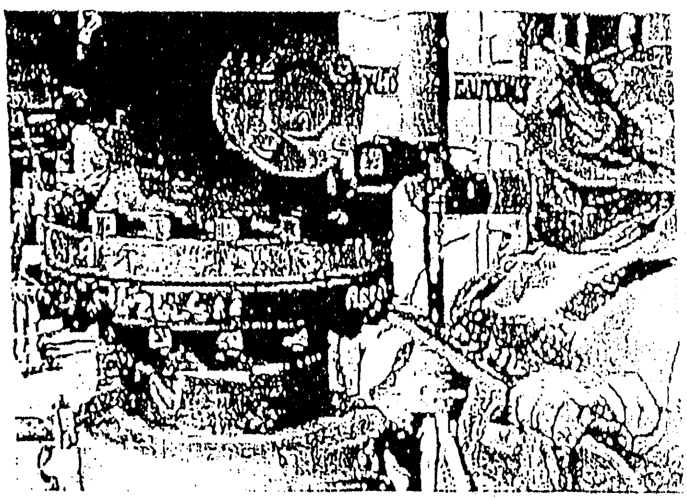


Fig. 10 - Assembly of NPS 10 Class 300 Flange Using Hydraulic Torque Wrench for Boltup

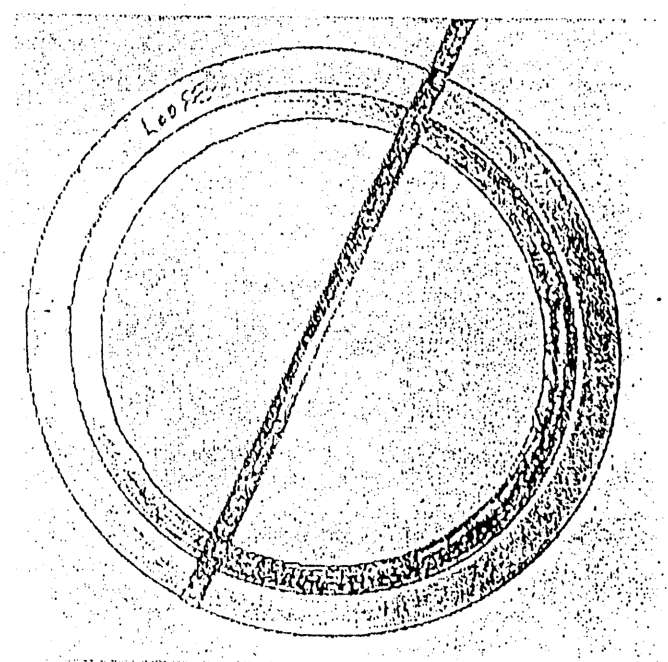


Fig. 11 - Test NPS 8 Class 300 SWFG Gasket with No Buckled Inner Spirals - Loose Outer Ring

Observations / Assessment of Inner Spiral Buckling

While the type and extent of buckling differs from the higher class flanges with inner retaining rings, the phenomena is clearly related to the incompressible properties of the flexible graphite and the tightness of the spiral windings. The radial pressure generated by the compression of the gasket windings and graphite filler material can result in the instability of the inner spirals to buckle inwards in the plane of the gasket. More investigation is clearly required however on the various parameters potentially effecting buckling before definitive conclusions can be reached on its root cause. The following highlights key observations and initial conclusions for consideration in subsequent investigations towards this aim:

1. Compared to the long standing experience gained with asbestos filled gaskets, the relatively incompressible property of flexible graphite clearly has a different effect on spiral wound gasket behavior.

2. Catastrophic failure of spiral wound flexible graphite gaskets without inner rings is considered unlikely since the spirals are confined within the clamped outer centering ring required for standard piping flange gaskets. However, there is the remote possibility of loose inner spirals detaching and migrating into downstream circuits which could be a problem especially for rotating equipment.

3. The design of SWFG gaskets without an inner retaining ring is considered to be marginal for NPS 6 and larger size gaskets in view of the extensive buckling experience.

4. SWFG gasket behavior would appear to be sensitive to several possible factors contributing to potential inward buckling. These include for example:
   - fit-up of outer ring (should be loose without dislodging from spirals)
   - spiral winding density and tightness, including number of unfilled inner/outer windings
   - flexible graphite thickness and density
   - flange alignment, especially "out of parallelism" of flange faces
   - imposed external flange moments or other loads resulting in asymmetric relaxation
   - extent of flexible graphite residues on flange face with replacement gaskets
   - smoothness of flange face finish
   - flange makeup procedures and bolt interaction affecting uniformity of gasket stress
   - applied bolt preloads to achieve even gasket compression.

5. As confirmed with the gasket manufacturers involved, the controlled boltup procedures, including the 50 ksi (345 MPa) preload target, implemented on the project were

considered to be within the normal application range of their respective gaskets without inner retaining rings.

SW GASKET BUCKLING RAISES DESIGN / MANUFACTURING CONCERNS

The recent buckling experience with SWFG gaskets raises several design and manufacturing concerns that should be ultimately addressed by the industry to avoid the reoccurrence of similar widespread instances. Both experiences reported should prompt manufacturers to relook at their design, fabrication, and quality control parameters for flexible graphite filled spiral wound gaskets. Current requirements of ASME B16.20 covering SWFG gaskets for piping flanges should also be reviewed for possible changes in light of the buckling concerns. Some follow-up considerations along these lines are as follows:

Manufacturing Considerations

1. A fundamental design review of spiral wound gaskets would seem in order to strive for a better balance between the inherent resiliency of the spirals and its mechanical stiffness. This ultimately should lead to an evaluation of the overall gasket design to assess when inner retaining rings are required and their sizing criteria to preclude buckling.

2. Manufacturing variations in the winding construction should be reviewed as possible contributing factors in the apparent sensitivity of SWFG gaskets to buckling. Significant variations typically exist, for example, in the number and density of wraps, and thickness and width of flexible graphite filler which influence compression. The relative tightness between the spiral gasket element and confining outer and inner rings should also be investigated.

3. Manufacturers should undertake some sort of standard compression type testing or produce documentary evidence of recent type testing on at least one gasket of each size and rating piping flange. This should be based on actual flange assembly makeup conditions and tools to replicate planned usage of the gasket.

Issues for ASME Standards B16.20

1. The requirements of ASME B16.20 do not mandate inner rings for any B16.5 Class 600 or lower flanges. This should be re-addressed in light of the buckling experiences presented, especially for 6" NPS and larger flanges. Inner rings should also be considered for all SWFG gaskets for Class 900 and larger flanges.

2. Current wording (Par. 3.2.5) of this standard eludes to concerns with inner buckling by recommending "that inner rings be specified by the User where his experience has

shown inward buckling of the gasket". This acknowledges buckling concerns but does not provide proper guidance to the user on where inner rings should be provided.

3. Gasket stiffness as set by the gasket compression range to a thickness of 0.130" ± 0.005" under an applied bolt stress of 30,000 psi should be re-evaluated. It would appear that the gasket stress generated under these conditions is not consistent with either the required seating stress or gasket geometry.

4. As an interim measure, SWFG gaskets for use in Class 900, 1500 and 2500 flanges should be provided with inner ring widths based on the equivalent bore of Schedule 80 pipe (vs. the Schedule 30 or 40 pipe bore currently specified). The inner ring thickness should also be made equal to the outer centering ring thickness.

SUMMARY

The inward buckling of spiral wound flexible graphite filled gaskets for standard piping flanges has been discussed in view of two major experiences. The first involved the buckling of inner retaining rings for SWFG gaskets of Class 1500 and 2500 piping flanges. The second focused on the buckling of inner windings of SWFG gaskets without inner rings for Class 600 and lower flanges. Both experiences showed much higher frequency of occurrence than previously reported within the Industry.

Several recommendations were made to reduce the probability of buckling. These included the more extensive application of inner rings for the lower rated flanges. Increasing the width of the inner retaining ring is also recommended for Class 900 and higher flanges.

The ultimate solution to the buckling problems identified for flexible graphite filled spiral wound gaskets will require a more thorough assessment than that provided by this paper. While interim recommendations have been provided, the principal aim of its author is to draw the attention of the gasket manufacturers, end-users, and standards organizations to the inner buckling problem.

The Standards Committee should also work with the manufacturers and users to strive for a better understanding of the fundamental buckling problem and its impact on long term gasket reliability and leak performance. Dimensional changes to ASME B16.20 should not be discounted if it will overcome the buckling concerns without affecting sealing performance.

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REFERENCES

(1) ASME Standard B16.20, "Metallic Gaskets for Pipe Flanges - Ring Joint, Spiral-Wound, and Jacketed", The American Society of Mechanical Engineers, New York.

(2) API Standard 601 (withdrawn with 7th Edition, 1988), "Metallic Gaskets for Raised-Face Pipe Flanges and Flanged Connections (Double-Jacketed Corrugated and Spiral-Wound)", American Petroleum Institute, Washington, DC.

(3) Payne, J. R., Mueller, R.T., Bazergui, A., "A Gasket Qualification test Scheme for Petrochemical Plants, Parts I & II", Presented at the 1989 PVP Conference, Honolulu, Hawaii, July 23-27, 1989, ASME PVP Vol. 158, pp. 53-78.

(4) *ASME / ANSI Standard B16.5, "Pipe Flanges and Flanged Fittings"*, The American Society of Mechanical Engineers, New York.

(5) Winter, J. R., Leon, G.F., "Radially Inward Buckling of Spiral Wound Gaskets", Proceedings of the 1985 ASME Pressure Vessel and Piping Conference, New Orleans, June 1985, pp. 111-116.

(6) Mueller, R.T., "Recent Buckling Experiences with Spiral Wound Flexible Graphite Filled Gaskets", prepared for presentation at the 1996 ASME Pressure Vessel and Piping Conference, Montreal, July 1996.

(7) Young, W. C., Roark's Formulas for Stress and Strain, Sixth Edition, McGraw-Hill, New York, 1989. Table 34, pg. 679.

ABOUT THE AUTHOR

Rod Mueller, PE, recently completed 31 years with Exxon Research & Engineering Co. and except for several overseas assignments has worked at their facilities located in Florham Park, New Jersey. Although involved with many different types of assignments, his expertise has focused on a broad spectrum of mechanical engineering consulting to Exxon's worldwide refining and petrochemical affiliates with emphasis on the design and analysis of pressure vessels, heat exchangers, tankage and piping systems. He holds BSME and MSME degrees from the New Jersey Institute of Technology and is a registered professional engineer also from the state of New Jersey.

In addition to being an active member of ASME for over 30 years, he has represented Exxon on the Pressure Vessel Research Council (PVRC) since 1986 principally working with the Committee on Bolted Flanged Connections. This has allowed him to be at the forefront of important technology developments associated with flanged joint designs including gasket performance testing and qualification protocols. He also recently became a member of ASME's B16 (Subcommittee G) Standards Committee dealing with gaskets for piping flanges.