IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

A METHOD FOR COMPENSATING BELLOWS PRESSURE LOADS WHILE ACCOMMODATING THERMAL DEFORMATIONS*

M.H. Woodle
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, New York 11973

Introduction

Many metal bellows are used on storage ring vacuum chambers. They allow the ring to accomodate deformations associated with alignment, mechanical assembly and thermal expansion. The NSLS has two such electron storage rings, the VUV ring and the X-Ray ring. Both rings utilize a number of welded metal bellows within the ring and at every beam port.

There are provisions for 16 beam ports on the VUV and 28 ports in the X-Ray ring. At each of these locations the bellows are acted on by an external pressure of 1 atmosphere, which causes a 520 lb. reaction at the vacuum chamber beam port and at the beamline flange downstream of the bellows.

The use of rigid tie rods across the bellows flanges to support this load is troublesome because most storage ring vacuum chambers are baked in situ to achieve high internal vacuum. Significant forces can develop on components if thermal deformation is restrained and damage could occur.

The Effect of Bellows Induced Pressure Loads on a Vacuum Chamber

Initial survey and alignment of the vacuum chambers are usually done at atmospheric pressure which facititates any chamber relocation. However, subsequent evacuation can cause uncompensated bellows loads to distort the vacuum chamber severely enough to misalign beam ports from their original positions.

Typically, storage ring vacuum chambers are made from aluminum or stainless steel. A primary structural design criteria for chamber wall thickness is to withstand an external pressure of 1 atmosphere. This usually results in a structure that has relatively low stiffness about its longitudinal axis. When chamber supports are relied on to counteract bellows pressure loads, the fact that the loads must travel through a relatively long slender curved member from their application point to their reaction point, results in ample opportunity for deflections to develop.

In more conventional bellows applications, tierods are used to counteract the axial pressure loads. This method, however, is not appropriate in our case due to relatively large thermal deflections which the evacuated structure experiences, as discussed below.

Thermal Deformations of Vacuum Chamber

In situ bakeout of vacuum chambers to desorb surface gas molecules is a requirement for any system which expects to run in the 10^{-9} Torr range. For our aluminum chambers, bakeout is done at 150 to 175 degrees celsius. Thermal expansion calculations for the NSLS VUV and X-ray rings (see figures 1 and 2 have shown that the beam ports can either "grow" or "shrink " from room temperature position, depending on their location relative to the vacuum chamber anchors points. Additionally, movement in the radial direction occurs which must also be accommodated. Table 1 gives the maximum thermal deflections calculated for both the VUV and the X-ray Rings.

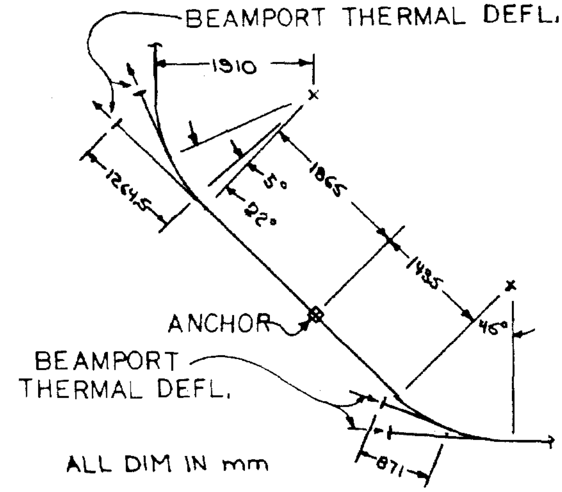

FIGURE 1 VUV PORT GEOMETRY

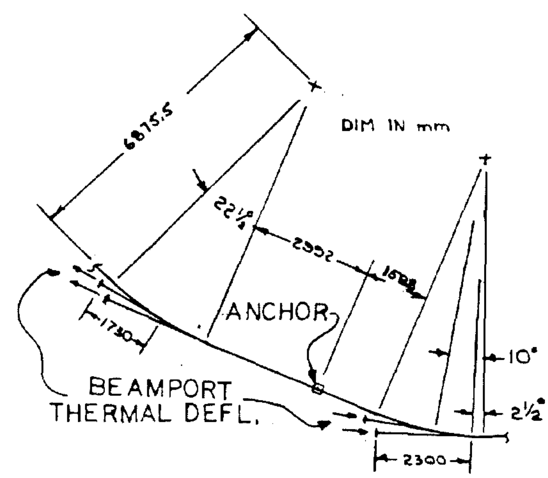

FIGURE 2 XRAY GEOMETRY

TABLE 1
MAXIMUM BEAM PORT THERMAL DEFLECTIONS

RING	POSITIVE	NEGATIVE	LATERAL
VUV	0.415	0.179	0.218
XRAY	0.705	0.202	0.160

All dimensions in inches.

Design Concept

The design requirement ideally was to provide a simple mechanism to exert a force counteracting that tending to collapse the bellows yet also allow for relative movement across the bellows to accomodate thermal deformations.

The solution selected was that of spring assemblies having relatively low spring constants which could be preloaded to balance the axial pressure force. The spring constant would be low enough so that additional deflection, either positive or negative, would not change the preload by an appreciable amount. Additionally, the device would be guided so that lateral deflections of the bellows are allowed.

*Work performed under the auspices of the U.S. Department of Energy.

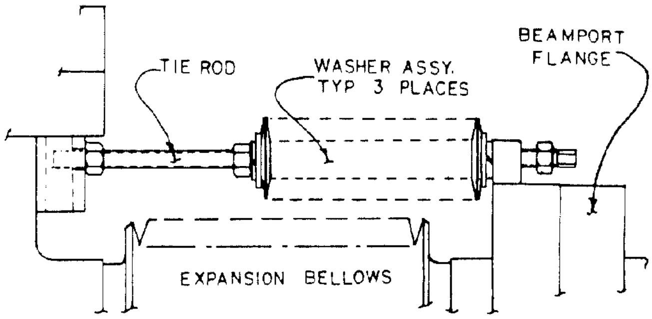

FIGURE 3 INSTALLATION

An additional constraint was that the device in most cases must be retro-fitted without disassembly of existing components (see figure 3). This severely limited the available space and precluded the possibility of using conventional helical springs. An alternate choice was to use belleville washers. These disk springs can exert considerable force while requiring only a small volume. They can also be arranged in series to decrease their effective spring constant.(see Fig. 4).

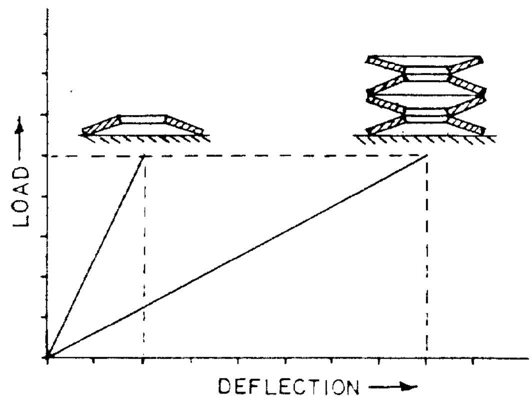

FIGURE 4 SINGLE & SERIES WASHERS

Design of Disc Springs

Conical disc springs were first patented in France in 1867 by J.F. Belleville[1]. It wasn't until 1936 that equations describing load, deflection and stress relationships were derived[2] which marked the start of their wider use.

The basic equations are as follows:[3]

$$P = \frac{Ef}{(1 - u^2)Ma^2} \left[(h - f)(h - f/2)t + t^3\right]$$

$$St_1 = \frac{Ef}{(1-u^2)Ma^2} \left[C_1(h-f/2) - C_2 t\right]$$

$$St_2 = \frac{Ef}{(1-u^2)a^2} \left[T_1(h-f/2) - T_2 t\right]$$

$$Sc = \frac{Ef}{(1 - u^2)Ma^2} \left[C_1(h - f/2) + C_2 t\right]$$

$$Pf = \frac{Eht^3}{(1-u^2)Ma^2}$$

Where:

a = OD/2

$$C_1 = \frac{6}{\pi \ln R} \left[\frac{R - 1}{\ln R} - 1\right]$$

$$C_2 = \frac{6}{\pi \ln R} \left[\frac{R - 1}{\ln R}\right]$$

E = Modulas of elasticity, psi

f = Deflection, in.

h = Inside height, in.

ID = Inside diameter, in.

$$M = \frac{6}{\pi \ln R} \frac{(R - 1)^2}{R^2}$$

u = Poisson's ratio

OD = Outside diameter, in.

P = Load, lbs.

Pf = Load at flat position, lbs.

R = OD/ID

Sc = Stress on convex side, psi.

St_1 = Stress concave side ID, psi.

St_2 = Stress concave side OD, psi.

t = Thickness, in.

$$T_1 = \frac{R \ln R - (R-1)}{\ln R} \frac{R}{(R-1)^2}$$

$$T_2 = \frac{0.5R}{R - 1}$$

In order to assure timely delivery, a standard size spring washer from Schnorr Corp. was selected. To satisfy the previously mentioned space constraints, the number of washers selected for each of the three compensator assemblies was 40 for the VUV Ring and 32 for the X-Ray ring. The results of the calculations are presented in figure 5. The compensator design requires that the washers be guided by means of bushings. In order to evaluate the effect of guide friction on preload, testing of an assembled compensator was performed on an Instron test machine. These results are also presented in figure 5. As can be seen, the calculations predict lower spring rates for the assembly than testing showed. Based on the test results, Table 2 shows the predicted loads exerted on a beam port flange during bake out.

TABLE 2
CALCULATED BEAM PORT LOADS DURING BAKEOUT

RING	TENSION	COMPRESSION	W/O COMPENSATOR
VUV	90 lbs	198 lbs	520 lbs
XRAY	135 lbs	345 lbs	520 lbs

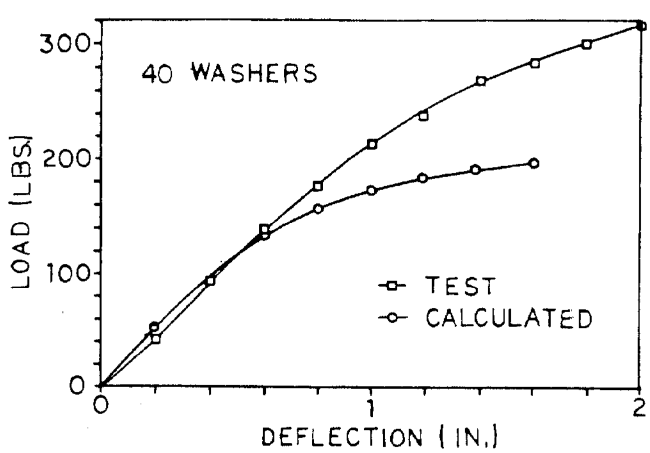

FIGURE 5 LOAD VS DEFLECTION

Testing of Compensators

The test setup for the bellows compensators is shown in figure 6. It consisted of two sets of 40 belleville washers and guide assemblies mounted on a threaded rod between two loading blocks. The assembly was placed into an Instron Model 4202 Tensile Test Machine where it was compressed to solid height. Load vs. Deflection plots were obtained. The load was applied and released three times. The test was repeated for three different sets (40 washers each) of belleville washers to check for uniformity of performance.

The results summary, is plotted in Fig. 5, and showed very consistant performance between disk washer assemblies. The effective spring constant, however, was greater than that predicted by calculations.

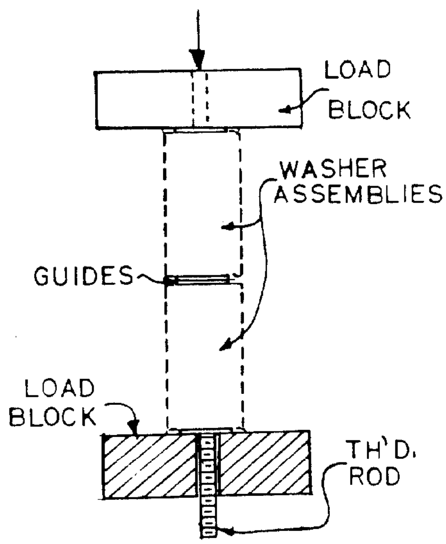

FIGURE 6 TEST SETUP

Installation and Results

Bellows compensator assemblies were installed on the VUV Ring beam lines during a maintenance shutdown in the fall of 1984. Survey of the ring and beam lines was performed at that time. After the initial survey and realignment at atmospheric pressure, the ring was evacuated and baked out. Subsequent surveys showed that vacuum chambers movement had been reduced on the average by an order of magnitude. This eliminated in all but the worst cases the need to readjust the vacuum chambers and beamlines.

Conclusions

The use of tie rods combined with preloaded disc spring assemblies is a viable method of compensating for bellows pressure loads and thermal deformations.

References

1. Associated Spring Corporation, Solving Spring Design Problems with Belleville Spring Washers 1969
2. Adolph Schnorr Gmbh and Co, Disc Spring Handbook, 10th Edition
3. J.O. Almen and Laszlo, The Uniform Section Disc-Spring, Transactions of ASME, vol. 58, no. 4 p 305-314 (1936)