

**NSTX**

Center Stack Casing Bellows

**NSTX-CALC-133-10**

**Rev 0**

**January 2011**

**Prepared By:**

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Peter Rogoff, PPPL Mechanical Engineering

**Reviewed By:**

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

Irv Zatz, PPPL Mechanical Engineering

**Approved By:**

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Peter Titus, Branch Head, Engineering Analysis Division

**PPPL Calculation Form**

Calculation # **NSTXU-133-10-00** Revision #**00** WP # **1672**

 (ENG-032)

### Purpose of Calculation: (Define why the calculation is being performed.)

There are two bellows used on the NSTX center stack, upper and lower. These form a vacuum connection between the center stack casing and the insulated ceramic break and the rest of the vacuum vessel structure. The bellows must maintain the normal vacuum conditions for the necessary operation of the NSTX device under various load conditions, which include the bake-out and other thermal scenarios.

This calculation is intended to justify and recommend convolution geometry and acceptable thickness of the bellows as an initial sizing exercise, and then provide the design specifications for the purchase of the bellows. Ultimately, the bellows manufacturer shall provide the qualification of the bellows. To ensure an adequate initial design, this calculation provides qualification of the acceptable stress state and performance for the following load conditions:

* Halo Current Loads (upper bellows only). Reference calculation #NSTX CALC 133-04-00.
* The upper bellows must allow thermal motion due to the bake-out and the normal operation where heat from the plasma is transferred to the CS casing through the insulating tiles. Reference calculation # NSTX CALC 11-01-00.
* The upper bellows must support the seismic loads, Reference calculation #NSTX CALC 10-01-02.
* The upper and lower bellows transmit some portion of the torsional moment from the upper vessel structure to the center stack casing. This moment comes through the umbrella structure, Reference calculation # NSTX CALC 10-01-02.
* Pressure due to vacuum condition which is always present during any operations of the machine.

### References (List any source of design information including computer program titles and revision levels.)

These calculations were performed using:

* EJMA (Expansion Joint Manufacturers Association) Basic equations presented in section 4.13 of the manual.
* NASTRAN Version MSC FEA x64 2010.1.2 finite element code.

## Assumptions (Identify all assumptions made as part of this calculation.)

Three basic thicknesses ( .02, .025, and .03 inch) were examined to better understand the general behavior of the bellows under different load conditions.

Since EJMA provides basic equations for the design of the Axial and Pressure conditions based on tests and experience, these results were used to justify the finite element simulation obtained through NASTRAN. Complete table of compared results are included in the power point presentation. NASTRAN simulation was then used to include load conditions which EJMA does not provide. Therefore, once basic calculations were justified, NASTRAN model could include all load conditions which add to calculate the maximum stress conditions on the bellows.

It was assumed that the seismic loads do not combine with the Halo Loads (these are of the very short duration compared to seismic). Therefore, for the maximum possible stresses during the seismic event the following loads are considered: pressure, CS thermal, torsional moment and the seismic loads from the center stack with .5% damping.

### Calculation (Calculation is either documented here or attached)

All the calculations are presented in the following attachments:

* Final\_Bellows.ppt
* Final\_ EJMA.ppt
* Final EJMA Calculator
* Seismic\_Stresses.ppt
* LVRBellDisrupt.ppt
* Bellows\_ Mode.ppt
* Spare EJMA Order Sheet

### Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

Comparing the maximum stress for both EJMA and NASTRAN results, bellows of thickness=.03 inch, demonstrates the lowest value. Von Mises combined stress is = 61,600 psi. Considering Inconel plate where Sy = 95,000.psi, this calculated stress value is well within the 2/3 Sy stress condition as specified for the NSTXU project.

For Seismic condition the calculated von Mises stress is = 46,600.psi and this event is extremely unlikely to develop. The combined stresses are well within the acceptable range.

“Global Model” results for seismic analyses show similar acceptable maximum stresses up to 20,000.psi based on standard seismic scenario for the TFTR existing facility.

Lower bellows magnetic disruption analyses, show the maximum stresses for iteration at step #8. These stresses are about 500.psi and considered insignificant.

EJMA Specification Sheet is included bellows and it should be a part of the final drawing.

The specific (selected) bellows design requirements should be as follows:

* t = .030 inch
* w = 1.095 inches, convolution height
* q = 1.0 inches, convolution pitch
* Di = 38.0 inches, Inside diameter
* Do = 40.25 inches (at the outside surface of the convolution), Outside diameter
* General axial length should be determined by the final design. For now it is 7.06 inches.

### Cognizant Engineer’s printed name, signature, and date

**I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.**

Checker’s printed name, signature, and date

|  |  |  |
| --- | --- | --- |
| Customer: Princeton Plasma Physics Laboratory | Date:1/25/2011 | Page: |
| Project: NSTXU | Prepared By: P. Rogoff |
| Item or Tag Number: |  |  |
| Quantity: |  2 |  |
| Size: |  |  |
| Style or Type (single, universal, hinged, gimbal, etc.) |  single |  |
| End Connections | Thickness/Flange Rating |  0.030 inch |  |
| Material |   |  |
| \*Pressure | Design |  14.5 psi |  |
| Operating  |  14.5 psi |  |
| Test |  14.5 psi |  |
| \*Temperature | Design |  Room |  |
| Operating  |  Room |  |
| Installation  |  Room |  |
| Media | Media |  |  |
| Flow Velocity |  |  |
| Flow Direction |  |  |
| Movements and Life Cycle | Installation | Axial Extension |  |  |
| Axial Compression |   |  |
| Lateral |  |  |
| Angular |  |  |
| Number of Cycles |  |  |
| Design | Axial Extension |  |  |
| Axial Compression  |  0.315 inch |  |
| Lateral |  0.020 inch |  |
| Angular |  0.00315 inch |  |
| Number of Cycles |  High |  |
| Operation | Axial Extension |  |  |
| Axial Compression |  0.315 inch |  |
| Lateral | 0.02 0 inch |  |
| Angular | 0.00315 inch |  |
| Number of Cycles |  High |  |
| Materials | Bellows | Inconel (high Yield) |  |
| Liner |  |  |
| Cover |  |  |
| Dimensions | Overall Length | 7.06 inch |  |
| Maximum O.D. | 40.25 inch |  |
| Minimum I.D. | 38.0 inch |  |
| Spring Rates | Maximum Axial Spring Rate | 3,835.2 lbs/inch |  |
| Maximum Lateral Spring Rate | 204,200.lbs/inch |  |
| Maximum Angular Spring Rate | 147,400. In-lbs, for.00315 in displacement |  |
| Quality AssuranceRequired Code | Bellows Long. Seam Weld |  |  |
| Bellows Attachments Weld |  |  |
| Piping |  |  |
| Applicable Codes and Standards B31.1, B31.3, Section 8 Division 1 |