DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **ME-5**

NON SLIDING CONTACT BELLOWS SHIELD : MECHANICAL DESIGN

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1. Introduction

The RF shield of the bellows placed between the DAΦNE arcs and straight sections is obtained by a series of Cu-Be waving strips. The ends of the strips are fixed on two flanged blocks, bolted on the outer body (see Fig. 1).

The bellows is assembled with an axial stroke of about 35 mm, so that when the beam runs, the strips are as straight as possible, to lower the impedance value due to parasitic shield resonances [1].

During the baking phase the axial elongation of the chamber will put the bellows in its almost undeformed configuration.

This solution avoids the use of sliding RF contacts, which are a potential source of trouble in all storage rings, but introduces hard mechanical problems.

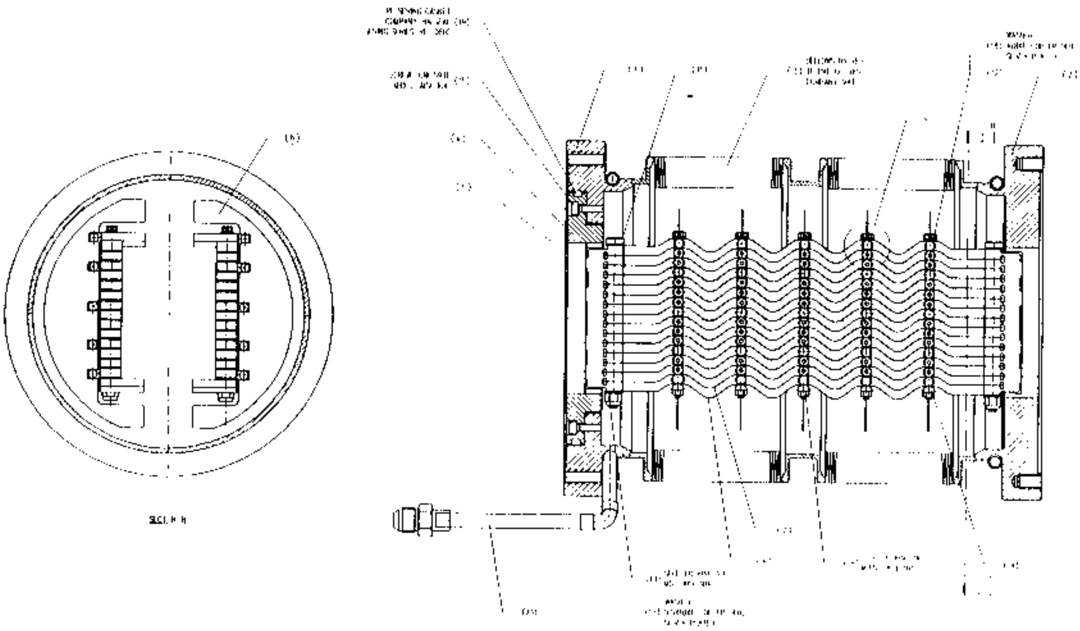


Fig. 1 - The bellows prototype assembly drawing

The parameters which limit mechanical and thermal stresses are:
- Mechanical and thermal material properties.
- Strip thickness.

2. Material properties

The Cu-Be alloy properties depend on the Be percentage and on the mechanical and thermal treatments of the semimanifactured. Higher Be percentage improves mechanical properties, but worsens thermal and electrical conductivity. These properties are more affected by thermal treatment [2].

The ASM main alloys for springs production are C17000 (1.7 Be, 0.3 Co) and C17500 (0.6 Be, 2.5 Co). Tables 1 and 2 show the typical mechanical properties and electrical conductivity of the mentioned materials. Co provides the dispersion of strengthening inter metallic particles and improves thermal treatments.

Tempers reported in the table give the best mechanical properties; they are:
a) Solution treated (ASM TB00)
b) Solution treat. + cold worked (ASM TD0X)
c) Solution treat. + cold worked + precipitation hardened (ASM TH0X)

Table 1 - C17000 Properties

Temper designation	Tensile strength MPa	Yield strength MPa	Elongation %	El. Conductivity %IACS
TB00	410-540	190-370	35-60	17-19
TD01	520-610	310-520	10-35	16-18
TD02	590-690	450-620	5-25	15-17
TD04	690-825	550-760	2-8	15-17
TH01	1100-1280	930-1170	3-6	22-25
TH02	1170-1340	1000-1210	2-5	22-25
TH04	1240-1380	1070-1240	1-4	22-25

Table 2 - C17500 Properties

Temper designation	Tensile strength MPa	Yield strength MPa	Elongation %	El. Conductivity %IACS
TB00	240-380	140-205	20-35	20-30
TH04	760-895	690-825	8-15	50-60

It is possible to notice that there is a wide range of mechanical properties depending on the tempers, but the electrical conductivity is always between 15% and 60% IACS (for all possible tempers).

a) By heating above ~ 700 ^{o}C, depending on the Be content, the γ phase dissolves in the α, and if quenched in water will remain in solution (solution treated) [3]. In these conditions it resembles pure Cu, being soft, ductile and capable of accepting a significant amount of cold work.
b) The cold worked temper can have various grades, depending on the cross section reduction.
c) If the alloy is heated to 315-350 ^{o}C the γ phase agglomerates and precipitates out of solution. This causes disturbance of the crystal lattice making the material less ductile but giving a considerable increasing in hardness. Moreover this increase in hardness can add to that obtained from cold work.

It is important to remark that, in severely deformed materials, recrystallization occurs at lower temperature.

Special care in material treatment has to be taken during welding. The weld area must be thoroughly cleaned, and must have any oxide coating mechanically removed. The material should be in the annealed or softened condition for best results, but can be joined while in the solution treated condition. The parts must not be in the aged condition.

3. Strip thickness effects on mechanical and thermal behavior

The circulating current distribution due to the beam has been estimated with 120 bunch. In this condition the power loss for the central strip is 712 mW for C17000 and 504 mW for C17500 [4]. These are the highest values, reached in the central strip considering only conduction.

The f.e.a. plot in Fig. 2 shows the ASM C17500 strip temperature; of course there is a linear relationship between the maximum temperature and the strip thickness (the ASM C17000 strip temperature is obtained multiplying by a factor 2.8 [4]).

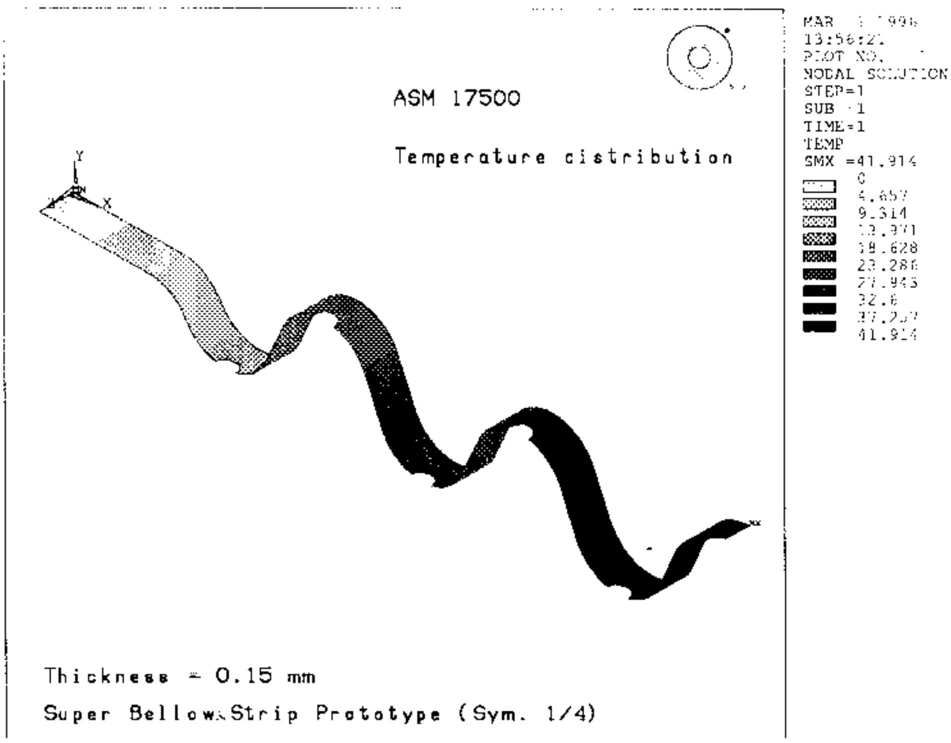


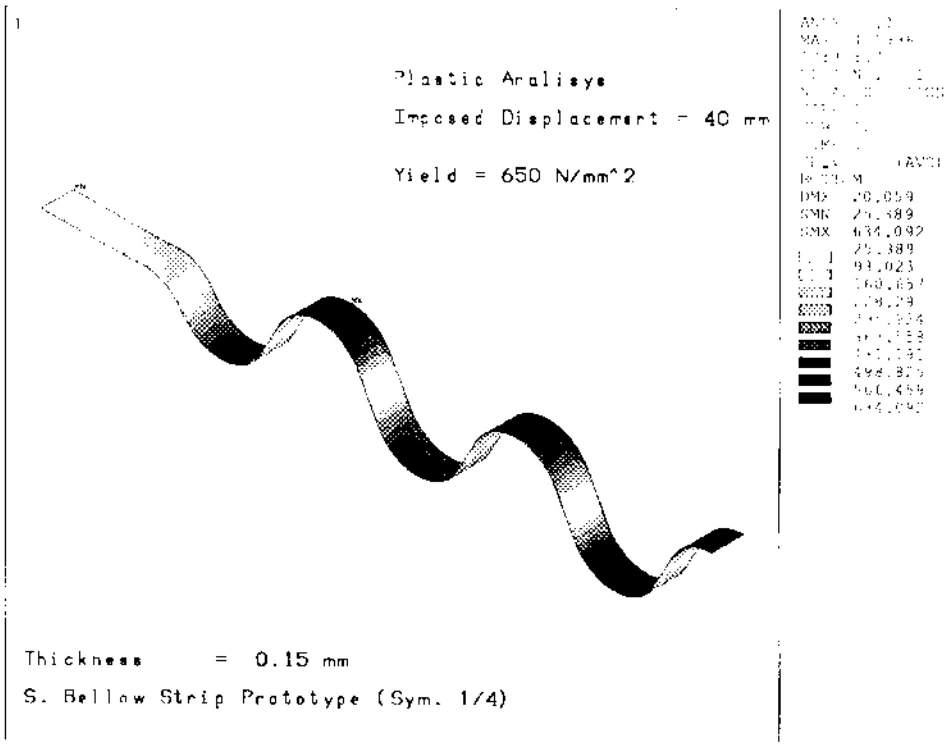
Fig. 2 - Temperature distribution in C17500 strip

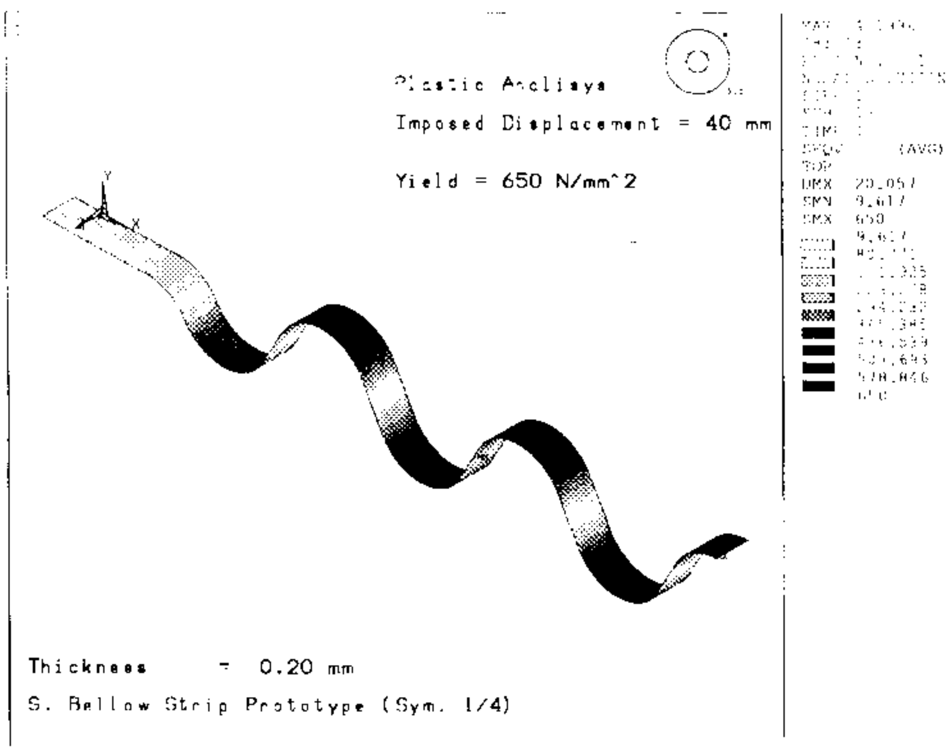
Due to its large cross section, the vacuum chamber is not affected by the bellows stiffness. Then, when the bellows is strain assembled, the shield will undergo to an imposed axial elongation, not dependent on the strip thickness.

The tensional state inside the strips is mainly due to bending stresses. Taking into accunt that the deformed geometry does not depend on the thickness, $d\varepsilon/ds$ (ε axial strain, s axial coordinate through the thickness) among different thickness strips, will be the same.

Therefore, as the mechanical stress is concerned, it is better to decrease the strip thickness. The same conclusion can be reached by applying the *Principle of Virtual Work.*

These considerations were verified by f.e. plastic analysis on different thickness strips (Figs. 3 and 4). It is possible to note that for the 0.15 mm strip the stresses are limited in the elastic field, while for the 0.20 mm strip there is a wide part underwent plastic strain (see § 7 for material characteristics detail).





Figs. 3, 4 - Stress comparison between two different thickness strips

4. Strip spacers geometry optimization

The strips are held in their relative positions by spacers, which are assembled by means of tie rod (Fig. 5). To allow a good flexibility of the shield also in the direction perpendicular to the bellows axis the first solution considers the spacers of a cylindrical shape. As it is known for such environment (high vacuum), between two closely tightened elements a *cold welding* could take place. During the stretch of the shield, due to the shape of the joint between strip and spacers, the stress concentration breaks the cold welding, and in a few cycles this might reduce the resistance of the strip.

Shaping a plane contact zone between strip and spacers, and forcing the plane zones to be always in contact by tightening the tie rod with a proper torque, the possible cold welding does not break.

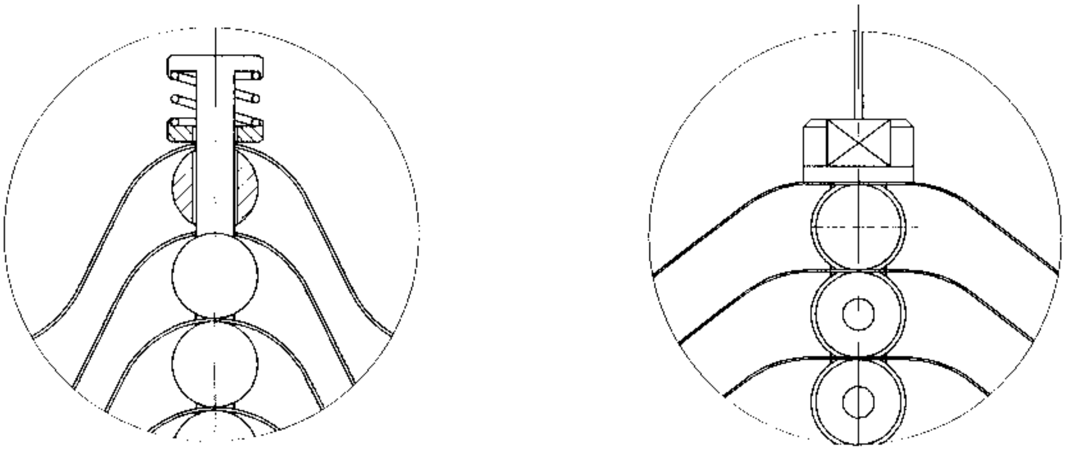


Fig. 5 - Comparison between the two spacers solution

The tightening of the tie rod increases the contact pressure between the strip and the spacers; this parameter is very important to reduce the thermal resistivity of the joint, so that the side strips contribute in reducing the central strips temperature (the RF losses decrease going from the center to the side of the shield); in order to increase the conductivity the spacers is made of Cu, Ag coated.

ANSYS® analysis showed that with the contribution of all the strip in heat transfer the maximum temperature is about 50% less than considering only the central strip (see § 6).

5. Strip forming test

Tests on strip forming have been performed in order to speed up the project considering the possibility of designing the strip die in LNF, and possibly to produce the shields.

The material employed is Cu Be 25 in 1/2 H state, equivalent to ASM 17000 TH02. Many tests showed that due to springback it is not possible to obtain the desired geometry easily, even using up progressive dies; therefore a 3 steps treatment before and after forming has been attemped:

1) Solution treated (15 min. at 780 ^{o}C, quenched in water).
2) Forming.
3) Precipitation hardened (3 h. at 335 ^{o}C, quenched in oven).

By using this procedure the forming is very precise and the material is almost in a ASM TF00 temper (solution-treated and precipitation-hardened temper - Table 3). After the treatment material hardness has been measured (~ 300 HV).

Table 3 - Properties of the TF00 temper

Alloys	Tensile strength MPa	Yield strength MPa	Elongation %	El. Conductivity %IACS
C17500	690-825	550-690	10-20	45-60
C17000	1030-1240	895-1140	4-10	22-25

6. Material choice effects on maximum working temperature

F.e.a. have been executed to find out the working temperature of the shield, which depends on the choice of the strip material.

Table 4 shows the maximum temperature in different materials configurations. The analyses have been performed considering different conduction efficiency of the joint (η % with respect to pure Cu conductivity). The considered room temperature is 20 ^{o}C.

Table 4 - Maximum working temperatures

Materials arrangement	T_{max} (^{o}C)			
	($\eta\cong0\%$)	($\eta=10\%$)	($\eta=50\%$)	($\eta=100\%$)
All strips made of C17000	144	70	67	67
2 central st. made of C17500	117	59	57	57
4 central st. made of C17500	85	50	50	50
All strips made of C17500	62	38	36	36

7. Summary

The working temperature is one of the critical parameters for the non sliding shield; the alloy that should be employed is the most conductive, but to have a precise forming, at the beginning of the process the material has to be in the annealed condition, so that at the end its temper is ASM TF00. As shown in Table 3 there is a significant difference in yield strength between the two alloys.

The f.e.a., considering an elastic-plastic behavior for the material with 650 MPa yield stress, shows a zone near the holes in which plasticity occurs (see Fig. 6). Even if the plasticity is concentrated in a very small area (see Fig. 7), using C17500, the stress state could not be acceptable, considering that in TF00 temper the yield strength can be lower than 650 MPa, and even optimizing the forming process for the C17500 TH04, its strength could not be enough (Cu Be alloys suffer from the *Relaxation Stress* phenomenon; few tests on this item have been started, but it's a very demanding subject to handle).

The f.e.a. on C17000 strip's temperature distribution shows that, if the heat exchange between the strips and the spacers is 10% of a welded joint, the working temperature is about 70 ^{o}C (we state that all the thermal analyses consider only conduction exchange, with the flange temperature of 20 ^{o}C); then it is necessary to evaluate the conductivity of the joint, because the working temperature decreases strongly with its thermal resistivity.

The design of the spacers and the proper tie rod pretensioning should provide adequate exchange efficiency, but in any case we are going to set up tests on this item.

If the joint conductivity will not be enough, the mixed solutions with the central strips made of C17500 can be adopted.

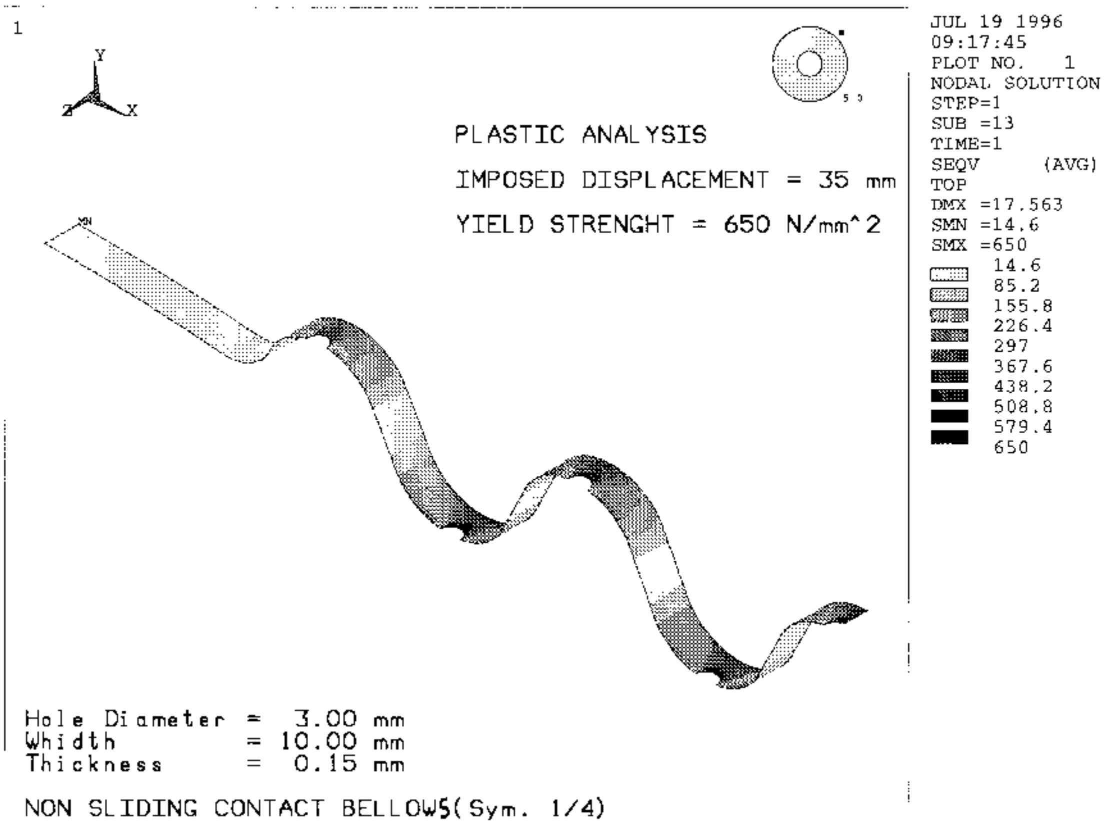


Fig. 6 - Von Mises stress

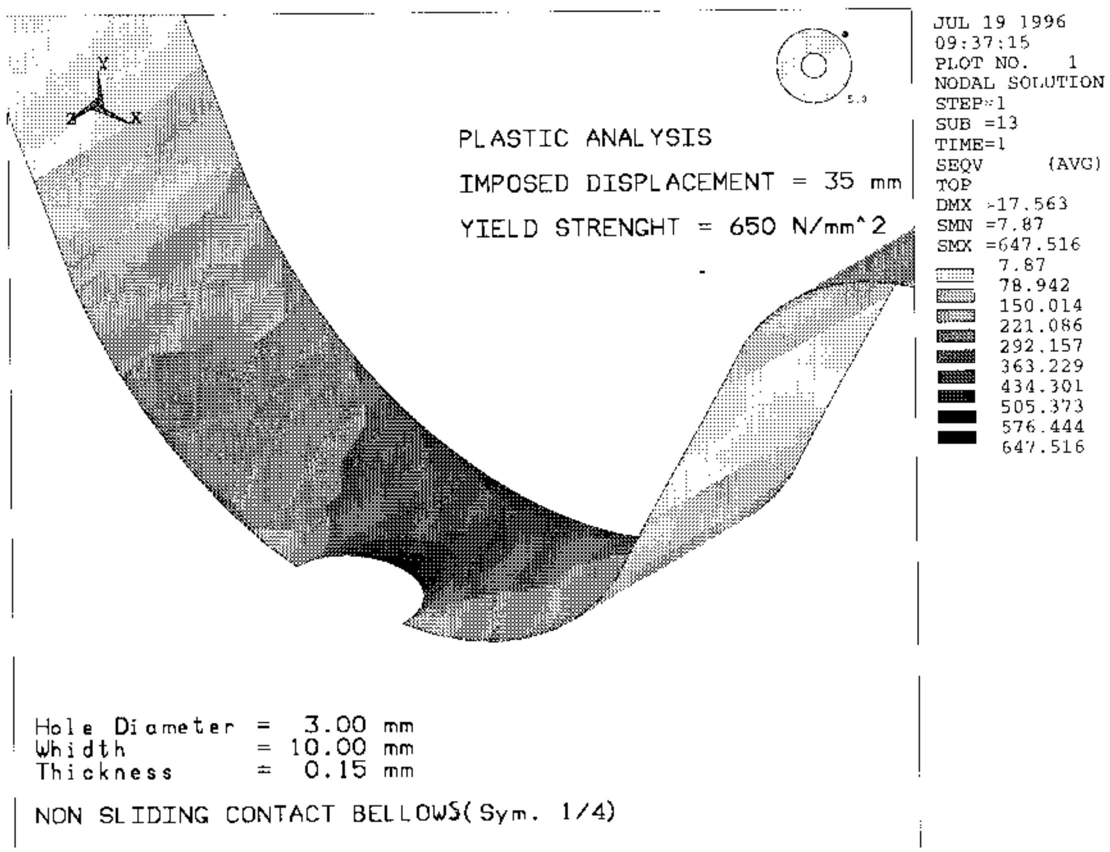


Fig. 7 - Von Mises stress: detail

8. References

[1] A. Gallo, A. Ghigo, F. Marcellini, L. Palumbo, B. Spataro, M. Zobov, "Impedance of DAΦNE shielded bellows", DAΦNE Technical Note, G-39, March 1996.

[2] *ASM Handbook*, ASM International®, 1990.

[3] R.B. Ross, *Metallic Material*, London: Chapman and Hall, 1968.

[4] A. Gallo, F. Marcellini, LNF, personal communication with authors.