# Sensitivity of CEBAF 5-Cell Cavities to External Pressure*

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## ABSTRACT

During cooldown of cavities in large assemblies like cryomodules large temperature gradients and pressure excursions caused by the operating conditions of the refrigeration system might occur.

For the safe operation of the cavities it is important that these external loads do not cause plastic mechanical deformations, which would result in field profile distortions, detuning and deviations in the external Q-value of the input coupling system.

A test system, which permits exposure of the cavities to external pressures up to 50 psig (0.34 MPa) at room temperature, has been devised. The mechanical deformations introduced by these external loads have been measured for the various parts of the cavity like cavity cells, fundamental coupler waveguide and higher order mode coupler by exciting various rf-resonances in these cavity subassemblies.

This paper describes the test-system and test-results obtained in these investigations.

## INTRODUCTION

The CEBAF acceleration system consists out of 338 cavities made from high purity niobium. Two of these cavities are paired together to form a cryo-unit when inserted into the helium vessel. Four cryo-units then are assembled into a cryomodule, the fundamental building block of the accelerator.

* This work was supported by the U. S. Department of Energy under contract DE-AC05-84ER40150.

During cooldown of these components to 4.2K and 2K, respectively, large temperature gradients and pressure excursions caused by the operating conditions of the refrigeration system might occur. If these excursions would exceed the elastic deformation limits of the rf-cavities, the pressure relief system on the cryostats and transfer lines has to be designed to limit their magnitude. The objective of this investigation was the measurement of the threshold pressures for inelastic changes in cavity subassemblies like cavity cells, fundamental coupler waveguides and higher order mode waveguides.

## TEST-SETUP

The test set-up is schematically shown in Figure 1. A thick wall plexiglas pipe of 24" diameter and 1" wall thickness with stainless steel end plates sealed against the faces of the pipe by double O-rings forms a container for liquid. The cavity under test is bolted with indium and viton O-ring gaskets to the endplates from the inside, leaving access to the cavity interior for field profile measurements by pulling a metallic needle through the cavity on axis. Stainless steel bellows in the beam pipes prevent the container end plates from exerting forces on the cavity.

Various feedthroughs for instrumentation and rf as well as filling ports, pressurizing ports and relief valves are mounted to the end-plates. In some of the tests, strain gauges have been attached to cells and waveguide parts of the cavity to monitor the direction of the stresses.

## TEST PROCEDURE

After the pressure vessel has been filled with demineralized water, baseline measurements of the fundamental mode frequency of the cavity, of the $TE_{101}$ mode of the higher order mode coupler and $TE_{101}$ - mode of the fundamental power coupler are taken with a network analyzer (HP Model 8753C). In addition, the transmission losses of the cavity and the field profile in the accelerating mode is measured. During all rf-measurements dry nitrogen gas is bleeding through the cavity and the water temperature of the water bath is kept constant.

The pressure in the tank was raised in steps of 5 psig by pumping additional water into the vessel; at each step frequency measurements, transmission loss measurements, field profile measurements and readouts of the strain gauges were taken. After each of these measurements, the pressure was relieved to atmospheric pressure and another set of data was obtained.

## TEST RESULTS

Two cavities were investigated as described above; they differed in the mechanical design of the fundamental and higher order mode couplers:

a). Cavity CEBAF#13 had couplers fabricated from 1/8" thick reactor grade niobium sheets with stiffening braces at the fundamental power coupler.

b). Cavity CEBAF#4 had couplers machined out of solid niobium slabs with wall thicknesses of 1/4".

Both coupler materials differed also in their mechanical properties as listed in Table 1, where in addition the mechanical properties of the high purity cell material are shown:

**Table 1. Mechanical Properties of the Niobium used in fabrication of 5-cell cavities**

| Niobium | Cavity Part | RRR | Grain bf Size | Yield Strength | Elong. |
|---|---|---|---|---|---|
| Reactor Grade 1/8 " | Couplers CEBAF#13 | ≅ 40 | ASTM > 6 | >13500 psi | >25% |
| Reactor Grade Solid | Couplers CEBAF#4 | ≅ 40 | ASTM > 3 | >12000 psi | >25% |
| RRR | Cells | >300 | ASTM>5 | >10700 psi | >25% |

The test results can be summarized as following:

a). No measurable change in field flatness was observed up to an external pressure of 50 psig. This indicates uniformity of the mechanical properties of the cell material.

b). No measurable permanent change in the frequency of the fundamental cavity mode was observed up to a pressure of 50 psig.

c). Elastic deformations in all subassemblies (cells, Higher Order Mode - couplers and Fundamental Power-couplers) occurred instantaneously when the pressure was raised, with the exception of the Higher Order Mode - Coupler of cavity #4 (see Figures 2 and 3).

d). The fundamental coupler waveguide of cavity #4 started to deform plastically above 20 psig. This indicated that the mechanical properties of the solid niobium bar (1" thick), which was used for the machining of the coupler, were below specified values.

e). During pressurization the bandwidth of the cavity increased and the transmission losses decreased, indicating that the $Q_{ext}$ - values of the rf-probes had decreased due to a change of the waveguide heights under pressure. At the same time, the frequencies of the $TE_{101}$ - modes excited in the higher order mode - and fundamental coupler increased, indicating that the whole waveguide section is deflecting under pressure in two dimensions.

f). Permanent mechanical deformations in the presently manufactured cavity style (braces at the FPC, unbraced HOM-couplers of 1/8" thick material) occurred above 45 psig in the higher order mode coupler.

The experimentally determined limits have to be compared to computer model calculations using the code MSC/NASTRAN.[1] These calculations predict the stresses, which will occur in the subassemblies under certain load conditions. The experimental results and the model calculations agreed reasonably well given the complexity of a cavity assembly:

for example the stresses in the cells were calculated to be roughly only half of the yield strength of the niobium under a 45 psig load. On the other hand, under such a load the stresses in the HOM-assembly were calculated to be as high as 11000 psi, a number getting close to the specified yield strength of the reactor grade niobium.

## CONCLUSION

From the experimental results obtained in this investigation it was concluded that a deformation-free operation of the CEBAF - cavities is possible, if the load on the cavities does not exceed 45 psig during any time of the operation. The relief -valve system on the cryostats and transfer lines has to take the sensitivity of the cavities into account and the limits have been set to 40 psig.

## ACKNOWLEDGEMENT

We would like to thank R. Sundelin for his valuable guidance during this investigation and L. Turlington for providing major portions of the hardware for the test setup.

## REFERENCES

1. M. Wiseman, L. Harwood; CEBAF Technical Note SRF-89-07-05-EXA.

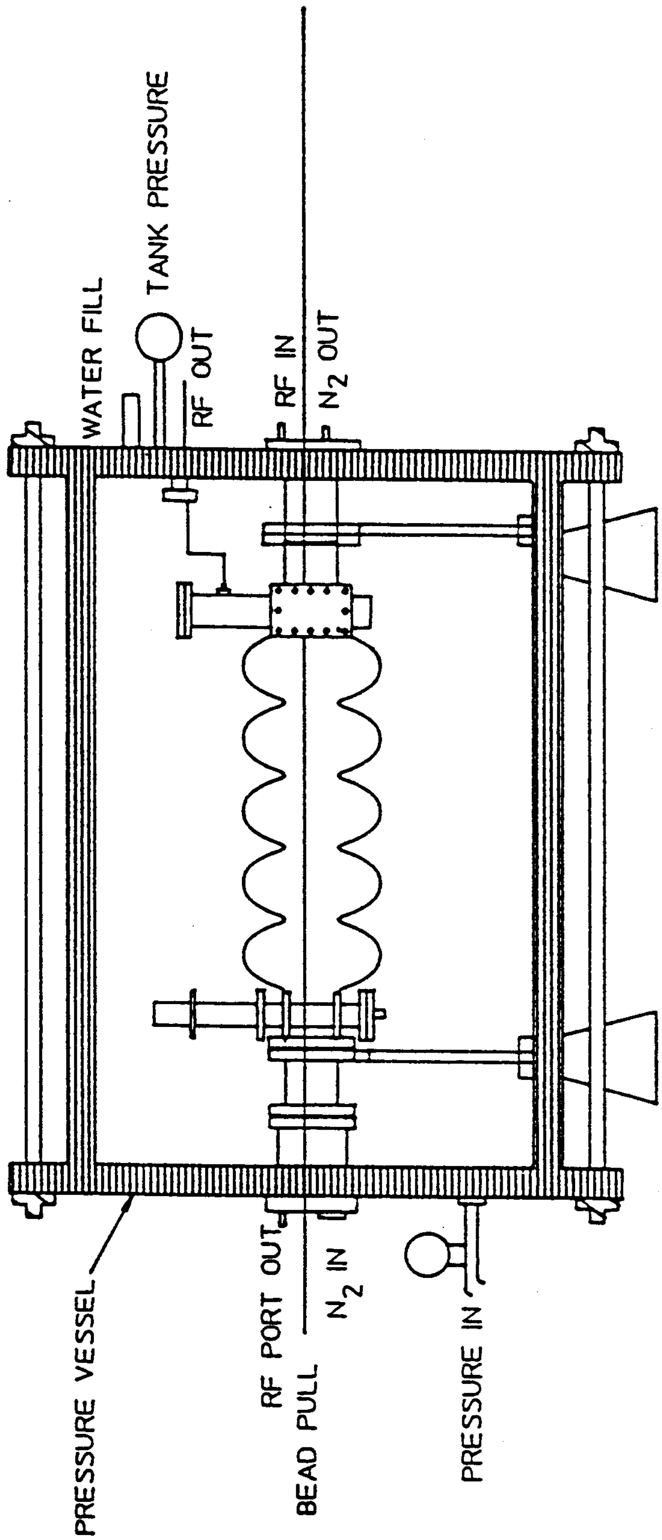


Fig. 1: Schematic of Experimental Test Setup

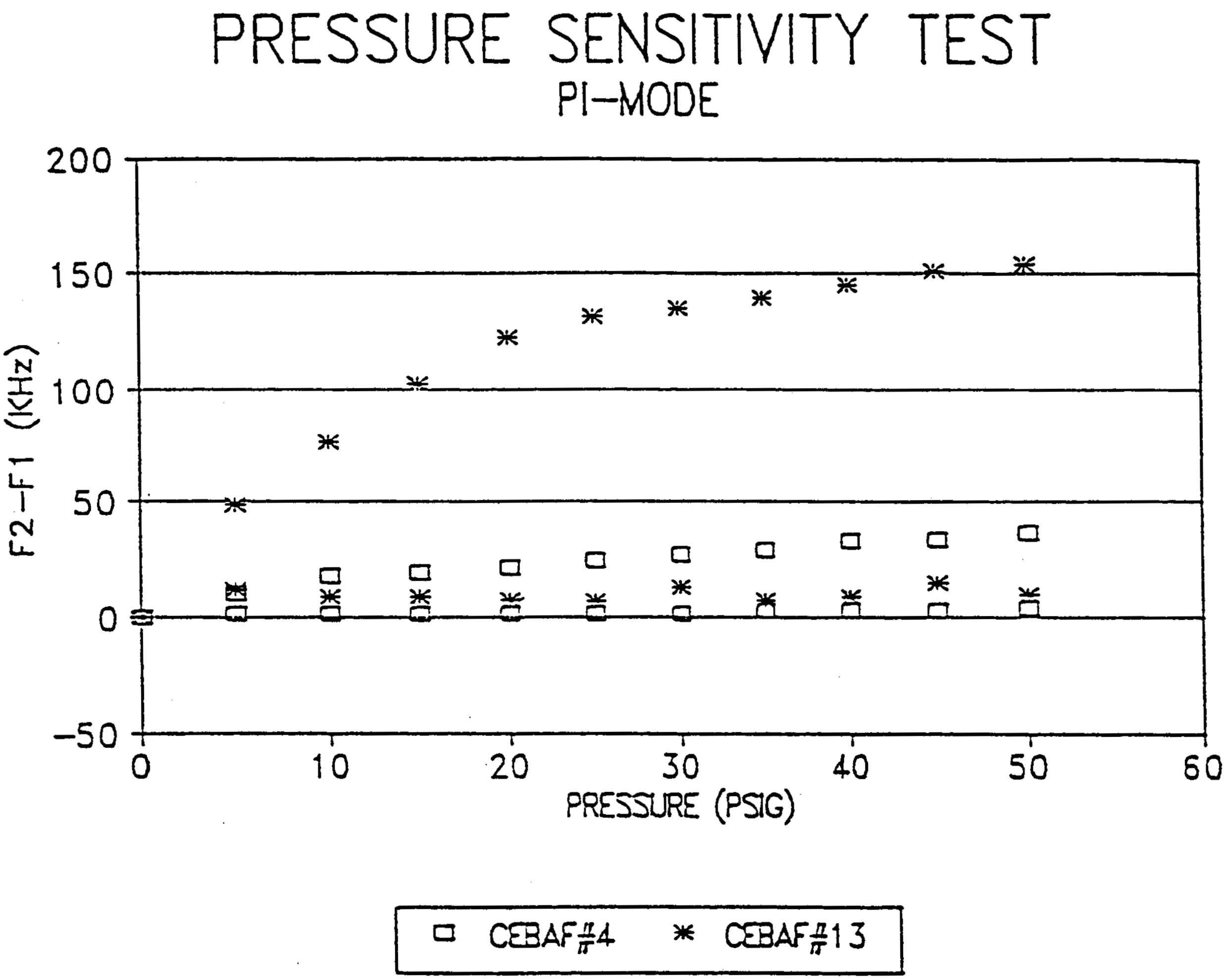


**Fig. 2:** Frequency change of Fundamental Mode Frequency as a function of external pressure; F2 is frequency under pressure, F1 is frequency at ATM pressure.

Note: There is a significant difference in elastic spring constants for cavity #4 and #13, probably due to workhardening of the niobium of cavity #4, which needed significantly more tuning.

Upper symbol: under pressure; Lower symbol: at ATM

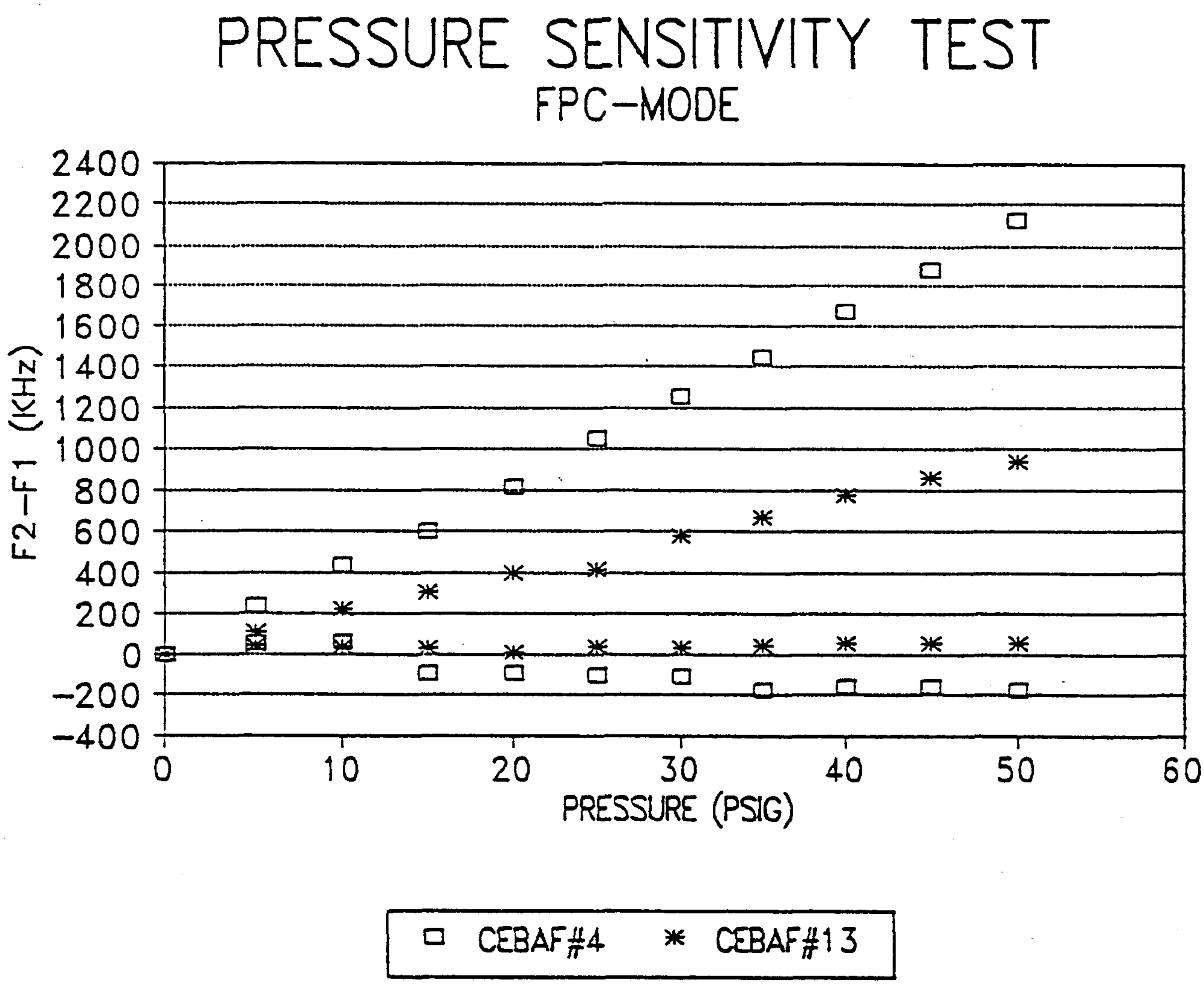


**Fig. 3:** Frequency change of $TE_{101}$ - Mode excited in the Fundamental Power coupler as a function of pressure. Upper symbol: under pressure; Lower symbol: at ATM

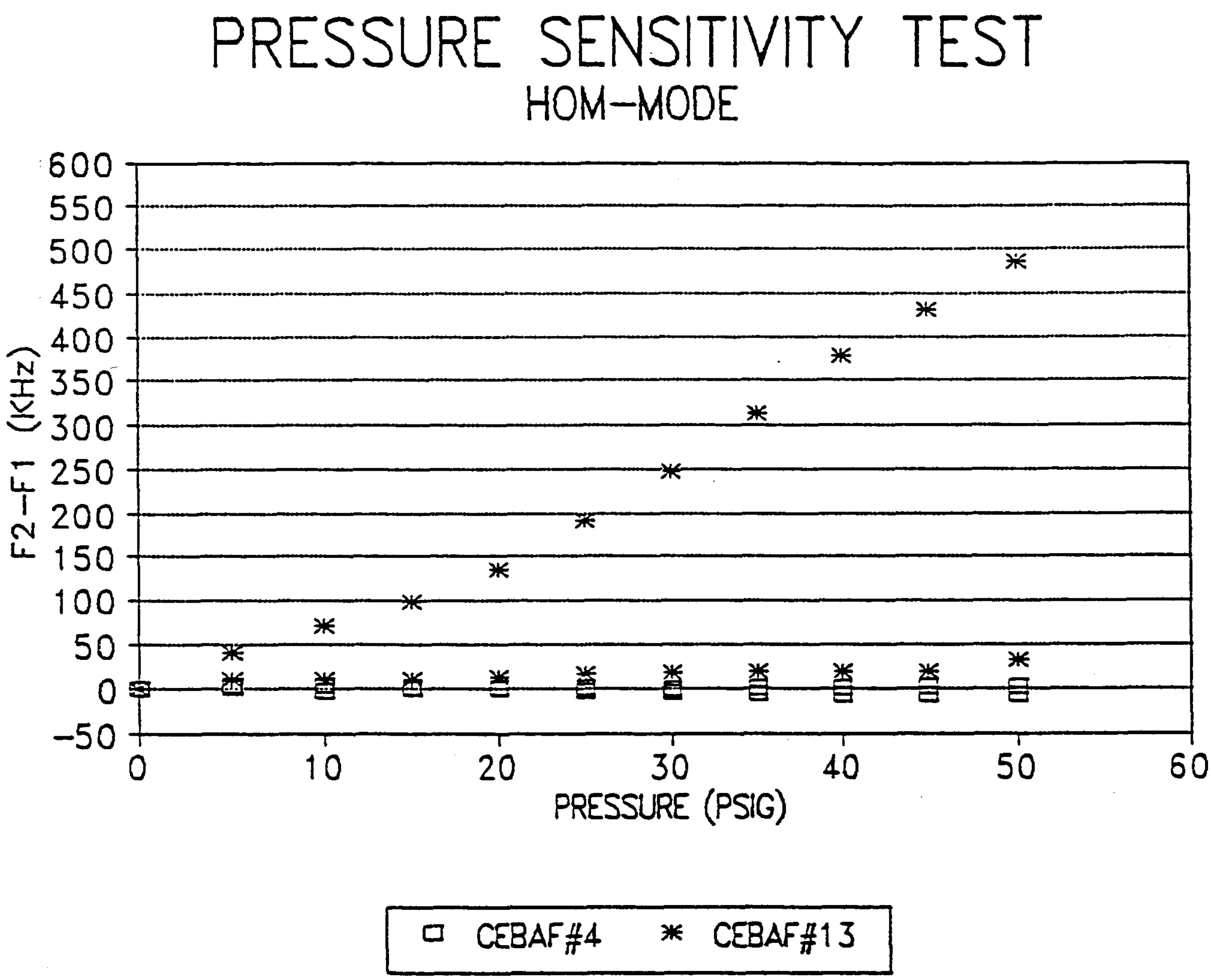


Fig. 4: Frequency change of $TE_{101}$ - Mode excited in the HOM-coupler as a function of applied pressure. Upper symbol: under pressure; Lower symbol: at ATM