ELECTROMAGNETIC CAVITIES AS ELECTROMECHANICAL TRANSDUCERS: THEORY AND EXPERIMENT

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Abstract

We study the dependence of the tunable frequency range on the gap spacing between the end of the conical insert and the cavity plate in reentrant 1.0 GHz klystron cavities. Fabricated from aluminum, the cavities tested are 80 mm in diameter with the top plate 1-mm thick. Experiments performed on such cavities have shown tuning coefficients (change in resonant frequency due to variation of the capacitive gap) as high as 60.0 MHz/µm, demonstrating the capability of reentrant cavities as electromechanical transducers in resonant mass gravitational wave antennas.

Introduction

- Theoretical and experimental study on resonance properties of reentrant cavities with conical insert.
- The relationship between the resonant frequency and the cavity dimensions with emphasis on how the frequency varies when the top plate is subjected to mechanical deformation due to an externally applied force.
- Application: For gravitational wave detection

- Searching for core collapse in supernova events, neutron stars going to hydrodynamical instability, quakes and oscillations of neutron stars, excitation of the first quadrupole normal mode of 4-9 solar-mass black holes, and coalescence of neutron stars and/or black holes systems of 4-9 solar-masses.

- The Schenberg detector may probe some "echoes" from the Big Bang – the explosion of the universe creation.

Cavity analysis: A reentrant cavity with a coaxial conical insert as shown below has been modeled as a lumped LC circuit leading to the following parameters:

\[ f_0 = \frac{1}{2\pi} \sqrt{L(C_0 + C_r)} \]

Resonant frequency: \( f_0 \) = 1/2\( \pi \) \( \sqrt{L(C_0 + C_r)} \)

Theoretical and experimental study on resonance properties of reentrant cavities with conical insert. The relationship between the resonant frequency and the cavity dimensions with emphasis on how the frequency varies when the top plate is subjected to mechanical deformation due to an externally applied force.

Results

Insert #1 having the larger \( r_t \) and the smaller gap \( d \) produces the steepest curve. Insert #2, with a smaller \( r_t \), has the effect of flattening the curve relative to curve #1. So the greatest sensitivity of insert #1 is conferred by its large \( r_t \) in conjunction with a small \( r_0 \).

Resonant frequency and displacement sensitivity \( d\delta/dx \) for insert #1 expressed in terms of the decreasing dynamical gap \( x = d \sin \alpha \). The dashed line refers to calculated frequencies.

The following expression gives the deflections due to pure bending of a clamped circular plate loaded at the center:

\[ \delta(x, P) = \frac{Pr^2}{8\pi d} \ln \frac{r}{r_t} + \frac{P}{16\pi d} r_t^2 - r^2 \]

Conclusion

- Investigation of a 1.0 GHz reentrant cavity as a parametric transducer:
  - Sensitivity to deflections of a 1.0 thick aluminum plate when loaded with weights as light as 10 g.
  - Tuning coefficient (change in resonant frequency due to variation of the capacitive gap): \( d\delta/dx \approx 60.0 \text{ MHz/µm} \) converts displacement to electrical units.
  - Examined cavity: 1.0-GHz oversized prototype
  - Actual cavity: 10.0 GHz - dimensions scaled down by a factor of 10 \( \rightarrow \) thus it is expected to be 100 times more sensitive (\( d\delta/dx \) 100 times higher)