Possibilities of using a microwave cavity to measure seismic vibrations

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Abstract. The study of dangerous natural and technological processes involves their quantitative measurement. Increasing demands on seismic devices require the search for the new high-precision methods for converting mechanical vibrations. It is shown that the creation of a highly reliable broadband and simple seismic converter is possible on the basis of a high-quality microwave generator based on a volume resonator with an H01 type wave, an important parameter of which is the frequency stability of the generated vibrations. The use of H01 type wave in a volume resonator based on a circular waveguide provides a high-quality factor of the resonator (cavity). A wave of type H01 has anomalous properties. The attenuation of this wave as it moves away from the critical frequency asymptotically tends to zero with an unlimited increase in frequency due to the presence of transverse (ring) currents. Moreover, with the radius of the waveguide R = (3÷4) λ losses several orders of magnitude are lower than that of the conventional waveguides. The design features of the resonators with ring currents of the H01 wave lead to the sneak wave currents self-filtering and to work on a “clean” wave of the H01 type. In addition to small losses, the use of an H01 wave can provide several other advantages.

1. Introduction

The study of dangerous natural and technological processes involves their quantitative measurement. The ever-increasing volume of ongoing seismic studies and recent efforts to create the metrological tools for an extensive fleet of seismic equipment require the development of a unified metrological support system for seismometry. The development of integrated monitoring systems for seismic, volcanic and other dangerous endogenous and exogenous processes, in-depth studies using seismic methods present new requirements for the seismic equipment characteristics in particular, and for any equipment in general [1-16]. This is a complex scientific and technical problem, one of the tasks of which is to create exemplary seismic transducers (EST). Based on the needs of the practical needs of seismometry, the main requirements for the EST are [17, 18]:

1. The frequency range and amplitude-frequency characteristics (AFC) of at least 95% of all seismic measurements, including regional and engineering seismic, are carried out in the range of 0.01-100 Hz, although some unique studies are conducted in the range of at least 0.01 Hz, and above 100 Hz. Based on the input signals’ maximum dynamic removal requirement, the most optimal is the frequency response, uniform in acceleration. In addition, for ease of use, the EST must have an electrical outlet and be equipped with the necessary electronic devices that allow it to interface with
virtually any radio measuring device without violating the EST operating conditions and metrological characteristics.

2. The sensitivity threshold and the dynamic range of the EST should be no worse than that of any of the transducers used for measurements. The EST power spectral density subjectively noise, brought to the input and equivalent to noise acceleration, should be less than 1016 m2·s·Hz-1, while the EST dynamic range should be at least 120 dB so as to maximize the range of measured seismic signals.

2. Types of waves propagating along the transmission lines

When considering the EST requirements, as well as when using the ideological and technical solutions in seismology, the studies carried out in the laboratory of geophysical and radio measurements of the Geophysical Institute of the VSC RAS showed [19-23] that the creation of a highly reliable broadband and simple EST is possible on the basis of a high-quality generator ultrahigh frequencies based on a volume resonator with an H01 type wave, an important parameter of which is the frequency stability of the generated vibrations. The use of a wave of type H01 in a volume resonator based on a circular waveguide provides a high-quality factor of the resonator. A wave of type H01 has anomalous properties. The attenuation of this wave as it moves away from the critical frequency asymptotically tends to zero with an unlimited increase in frequency due to the transverse (ring) currents' presence. Moreover, with the waveguide radius R = (3÷4)λ losses several orders of magnitude are lower than that of the conventional waveguides. Design features of resonators with ring currents of the H01 wave lead to self-filtering of stray wave currents and to work on a “clean” wave of the H01 type.

Two classes of waves can propagate in the transmission lines [24]:

1) First class: waves that have only the transverse field components, do not have dispersion, and do not have a critical frequency and can therefore propagate at all frequencies, including direct current. Such waves are called transverse electromagnetic waves or waves of the TEM type. TEM type waves include the waves in free space, as well as the waves of the main or fundamental type in two-wire, coaxial or some other transmission lines.

2) The second class of waves in the transmission lines is characterized by the presence of not only transverse, but also longitudinal components of the field, the existence of dispersion, and the existence of a finite critical wavelength (finite critical frequency). Wave propagation of the second class is possible only at the frequencies satisfying the inequality V>Vcr. The waves having along with the transverse field components the longitudinal component of the magnetic field Hz when the longitudinal electric field Ez is equal to zero, are called the transverse electric waves (since the electric field lines lie entirely in the plane of the lines' cross section). These transverse electric waves are abbreviated as TE type waves. They are also often called “magnetic” waves or H type waves.

To solve our problem, a wave of type H01 is of interest, since it has anomalous properties in circular waveguides. The attenuation of this wave, falling with the distance from the critical frequency, asymptotically tends to zero with an unlimited increase in frequency. The reason for this is the existence of only transverse (ring) currents of the H01 wave, the value of which decreases with increasing frequency, i.e. with increasing ratio R/λ, moreover, with the radius of the waveguide R ≈ (3÷4)λ, the losses should be several magnitude orders lower than that of the conventional waveguides. However, simultaneously with the H01 wave, more than a hundred other types of waves can propagate along a similar waveguide, which should be considered to be spurious. These waves can be excited at permanently present inhomogeneities, including even at smooth bends of the waveguide. As a result of this, part of the energy of the H01 wave can be converted into energy in other types of waves having a much larger attenuation coefficient. The energy “transfer” occurs especially intensively when the phase velocities of the working and spurious waves are close. From this point of view, E11 wave is very undesirable, having in the case of an ideal round waveguide the same critical wavelength as H01.

In addition to small losses, the use of a H01 type wave can give a number of other advantages. So, due to the absence of longitudinal currents in the waveguide walls with a wave of type H01, special throttling devices are not required when articulating the individual sections of the waveguide and when disassembling the short-circuit pistons.
3. Theoretical research issues on a wave generator H01

The main requirement for an oscillatory system of a generator with a low noise level and high stability of the generated vibrations’ frequency is the maximum intrinsic Q factor Q0. Among the various types of cavity resonators in this case, preference should be given to a cylindrical resonator occurring in the H011 vibrations form. The intrinsic Q factor of a resonator operating on this oscillation type can reach 105 [19].

The resonant wavelength of a cylindrical resonator operating on the H011 vibrations form is related to its dimensions $R$ and $L$ by a known relation [24]:

$$\lambda_{011} = \frac{2L}{\sqrt{1 + 1.48 \left( \frac{L}{R} \right)^2}},$$  \hspace{1cm} (1)

where $R$ – is the cavity radius, $L$ – is the cavity length.

The main difficulties arising in the practical use of the H011 vibrations type are associated with the suppression of other types of vibrations that can be excited in a cylindrical resonator, therefore, when choosing the dimensions of a hollow resonator (choosing the $L / R$ ratio), the main criterion should be the maximum separation of the working H011 frequencies and the nearest types fluctuations.

Figure 1 shows the resonance wavelengths’ dependences of the cylindrical resonator vibrations’ types on the $L / R$ ratio at a fixed value $(\lambda_{011})_{H011} = 3$ cm. In calculating these dependences, for any $R$ value, instead of $L$, the following value is applied:

$$L = \frac{(\lambda_{011})_{H011}}{2 \sqrt{1 - \left( \frac{(\lambda_{011})_{H011}}{1.64R} \right)^2}}.$$  \hspace{1cm} (2)

Dependency graph $R = f \left( \frac{L}{R} \right)$ at $(\lambda_{011})_{H011} = 3$ cm is shown in Figure 1 by a dotted line.

![Figure 1](image-url)

**Figure 1.** The cylindrical resonator vibrations types’ resonant wavelengths dependences on the ratio of the resonator length to its radius $(\lambda_{011})_{H011} = \text{const} = 3$ cm.
Note that the qualitative nature of the dependencies presented in Figure 1 is preserved for any value $\left(\lambda_0\right)_{H_{011}}$. The analysis of these dependences shows that from the point of view of the vibrations’ types separation, the most optimal is the $L/R$ ratio, which lies in the range 1.1÷1.4.

The most important parameter of a hollow cavity with low noise and high frequency stability, as already noted, is its own Q factor $Q_0$. The $Q_0$ value for the $H_{011}$ vibrations type can be approximately determined from the following expression [24]:

$$
(Q_0)_{H_{011}} \approx \frac{1}{d} \frac{RL}{R+L} = \frac{1}{d} \frac{L}{1+\frac{L}{R}},
$$

where $d$ – is the penetration depth of the current into the cavity walls.

![Figure 2. Dependences of the intrinsic Q factor of a cylindrical resonator excitation in the form of vibrations $H_{011}$ from the cavity length ratio to its radius](image)

Figure 2 shows the dependences of the intrinsic Q factor of a cylindrical resonator excited in the form of $H_{011}$ vibrations on the resonator length ratio to its radius at $\left(\lambda_0\right)_{H_{011}} = 2.5, 3, 3.75$ cm for the case when silver is used as the material for the cavity walls. It is seen (Figure 2) that the ratio $H_{011}$, optimal from the point of view of the vibrations’ types separation, does not provide the maximum intrinsic Q factor of the resonator. The increase in $Q_0$, which can be achieved by changing the $L/R$ ratio, is insignificant, therefore, the criterion for choosing the size of the resonator should be considered the condition for maximum separation of the vibration modes [19, 20].

**Summary**

Microwave devices and systems are increasingly being used to solve a wide variety of problems, including the tasks related to the Earth study, the structure of its outer and inner shells and the processes taking place in them. The well-known advantage of the microwave range is the high information capacity, the possibility of directional information transfer. It is also significant that the level of domestic developments in the field of microwave electronics, which in the recent past mainly had a defense orientation, is quite high.

The ever-increasing volume of ongoing seismic studies and recent efforts to recently create metrological tools for an extensive fleet of seismic equipment require the development of a unified metrological support system for seismometry. This is a complex scientific and technical problem, one of the tasks of which is to create the exemplary seismic transducers (EST).
When considering the requirements for EST, as well as when using ideological and technical solutions in seismology, the studies conducted in the laboratory of geophysical and radio measurements, it was shown that the creation of a highly reliable broadband and simple EST is possible on the basis of a high-quality microwave generator based on a volume resonator with a type wave H01, an important parameter of which is the generated vibrations’ frequency stability. The use of a type H01 wave in a volume resonator based on a circular waveguide provides a high-quality factor of the resonator. A wave of type H01 has anomalous properties. The attenuation of this wave as it moves away from the critical frequency asymptotically tends to zero with an unlimited increase in frequency due to the presence of transverse (ring) currents. Moreover, with the radius of the waveguide $R = (3/4) \lambda$ losses several orders of magnitude are lower than that of the conventional waveguides. The design features of the resonators with ring currents of the H01 wave lead to self-filtering of stray wave currents and to work on a “clean” wave of the H01 type.

In addition to small losses, the use of a H01 type wave can give a number of other advantages. So, due to the longitudinal currents’ absence in the waveguide walls when using a wave of type H01, special throttling devices are not required when articulating the individual sections of the waveguide and when disassembling the short-circuit pistons.

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