Available online at www.sciencedirect.com
SciVerse ScienceDirect
Physics Procedia 33 (2012) 1670 – 1676
Physics Procedia

2012 International Conference on Medical Physics and Biomedical Engineering

The Design of Microwave Resonator to Accurately Measure The Atmospheric Refractivity

Mingyi Zhu,Jianhua Liu

Department of Automobile,Henan Mechanical and Electrical Engineering College,Xinxiang, Henan Province, China
zmingyi@126.com,ljh999ljh@163.com

Abstract

The measuring accuracy of atmospheric refractivity directly affects the precision of radar refraction error correction and atmospheric duct measurement. Because the conventional gas sensor can not accurately measure the atmospheric refractivity, the sensor—high Q microwave resonator that can accurately measure the atmospheric refractivity on-line is proposed basing on the principle that resonant frequency will change as different medium pass through the microwave resonator. Many aspects of the microwave resonator, such as the size, electromagnetic coupling， ventilation， material and processing technology， are designed to ensure the measuring accuracy of the sensor. The results of experiment show that the sensor has the advantages of higher measuring accuracy and faster measuring speed, and the measuring accuracy of atmospheric refractivity can meet the request of radar refraction error correction and the atmospheric duct measurement.

Keywords : atmospheric refractivity; sensor; high Q microwave resonator

---

1. Introduction

The inhomogeneity in time and space of refractive index can produce refractive error of the radar measurement [1]. The radio wave bending up to a certain degree can make atmospheric duct effects which affect the operating range of radar and communication systems [2, 3] .In order to improve the measuring accuracy of the radar and judge the presence of atmospheric duct, we need accurate measurement of the atmospheric refractivity [4, 5].

The precision of atmospheric refraction error correction and atmospheric duct measurement are both depended on the measuring precision of atmospheric refractivity. Because the atmospheric refractivity is function of the atmospheric temperature, humidity and pressure [6], the common calculation methods for

doi:10.1016/j.phpro.2012.05.269

atmospheric refractivity are by measuring the atmospheric temperature, humidity and pressure [1]. Moreover, the commonly used measuring instruments in atmospheric refractivity are type 59 radiosonde and electric radiosonde. Due to measuring accuracy limitation of the gas sensor, the accurate measurement of the refractivity can not implement [7], which restricts the precision of radar refraction error correction and atmospheric duct measurement improving to some extent.

The sensor—high Q microwave resonator as the accurate measurement instrument of atmospheric refractivity is proposed basing on the principle that resonant frequency will change as different medium pass through the microwave resonator. Compared with other test equipments, it has smaller size, lighter weight, higher precision, faster measuring speed and it is one of the accurate ideal measurement instruments for atmospheric refractivity.

2. Basic principle of accurate measurement for atmospheric refractivity

The instrument for measuring atmospheric refractivity is called refractometer, it is made up of gas sensor (high Q microwave resonator), measuring frequency stabilization unit, standard frequency stabilization unit, mixing unit and the output. Fig.1 shows the composition unit of refractive index meter.

When using refractive index meter to measure atmospheric refractivity, the main component is the gas sensor, in fact it is the high Q microwave resonator which causes the gas through the both opening ends. If measuring, we use frequency stabilization tracking unit to control frequency that can make the output measuring frequency keep consistent with Cavity resonant frequency [8]. Mixing with the standard frequency stabilization unit we can get the atmospheric refractivity information through the resonator.

The cavity resonator adopts cylindrical cavity. To ensure the measuring accuracy of atmospheric refractivity, the resonator must have high quality factor Q.

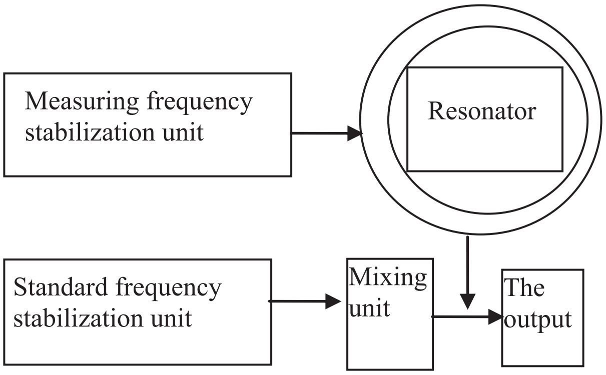


Fig. 1 The composition unit of refractometer

The cavity resonator adopts cylindrical cavity. To ensure the measuring accuracy of atmospheric refractivity, the resonator must have high quality factor Q. According to electromagnetic theory, the minimum loss of all the modes in cylindrical cavity is TE_{011} [9], that is the quality factor is the highest, so the most ideal ,working mode of cylindrical cavity is TE_{011} mode.

According to the electromagnetic field equations and boundary conditions, the TE_{011} mode resonant frequency of cylindrical cavity has been gotten [9]:

$$f = \frac{c}{n}\sqrt{\frac{1}{4L^2} + \left(\frac{1}{1.64R}\right)^2} \tag{1}$$

Where L is the axial size of resonator; R is the radius of resonator; n is the gaseous refractive index of resonator and c is the electromagnetic wave propagation velocity in vacuum.

When the resonant is in a vacuum state, the refractive index is 1, and the resonant frequency is:

$$\mathrm{f}_0 = c\sqrt{\frac{1}{4\mathrm{L}^2} + \left(\frac{1}{1.64R}\right)^2} \tag{2}$$

When the resonant are filled with medium, the resonant frequency has changed compared with the vacuum, the variable quantity is as follows:

$$\Delta\mathrm{f} = \mathrm{f}_0 - f = (n-1)f \tag{3}$$

As the relation between atmospheric refraction index n and atmospheric refractivity N is [6]:

$$\mathrm{N} = (n-1)\times 10^6 \tag{4}$$

So the atmospheric refractivity N can be gotten:

$$N = \frac{\Delta f}{f}\times 10^6 \tag{5}$$

The atmospheric refractivity is close to the vacuum state, Δf is smaller than f , both f and f_0 are very big, thus (5) can be written as:

$$N = \frac{\Delta f}{f_0}\times 10^6 \tag{6}$$

When the resonator is filled with atmosphere, the variable quantity of resonant frequency is proportional to atmospheric refractivity. Therefore, if measuring the variable quantity of resonant frequency, we can get the atmospheric refractivity. The primary role of the refractive index meter is to measure the variable quantity of resonant frequency. Generally speaking, the atmospheric refractivity N does not exceed 500, if the design of resonator center frequency is 11GHz and measurement accuracy of atmospheric refractivity is 0.5, we must assure the detection range of resonant frequency change is 5.5MHz and the frequency resolution is 5.5KHz.

3. Design of the sensor

3.1. Index of the sensor

The overall requirements of sensors (microwave resonator) are as follows. Firstly, both ends of the resonator must be opening so the gas can be passed smoothly; secondly, with the change of the ambient temperature, the resonator frequency has a high stability, in other words, the impact of ambient temperature change reduces as much as possible; thirdly, there is a high-Q design, thus the frequency changes can accurately reflect the small changes of atmospheric refractivity. To this end, we give the main specifications of high-Q resonant:

Center working frequency of resonator: f_0=11GHz
Adjustable range of center frequency: ± 25MHz
No-load quality factor：Q>10000
Input VSWR：$\rho \leq 1.4$
Temperature coefficient of resonant frequency：α <1×10-7℃

3.2. Structure design of the sensor

In order to avoid possible interference of other models, from the cylindrical cavity model map we can see that the relationship between resonant frequency of cylindrical cavity of working in TE_{011} vibration mode and geometry size should meet[10]:

$$(fD)^2 = 9\times10^{20}\left[\left(\frac{3.832}{\pi}\right)^2+\left(\frac{1}{2}\right)^2\left(\frac{D}{l}\right)^2\right] \tag{7}$$

Where L is the axial size of resonator, cm; R is the radius of resonator, cm and f is working frequency, Hz.

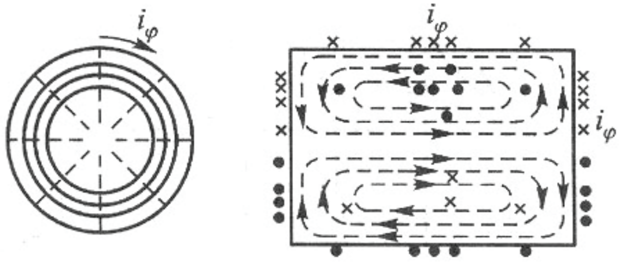
When l is equal to D, the loss of model is the smallest, and Q is the largest [10]. We can get $l = D = 33.39mm$ from (7). If considering the exact value of light velocity less than 3×10^{10}cm/s, the resonant frequency will reduce after opening at both ends, so we choose $l = D = 35.94mm$. The axial length of resonant does not include the length of front and rear cover here.

The upper design can rule out other interference patterns, but the lines of TM_{111} mode and TE_{011} mode coincide, which requires the choice by coupling to suppress.

In order to further suppress or eliminate other modes and adjust the resonant frequency, we increase a non-contact tuning piston in a port, so that not only eliminating the good electrical contact difficulties between the piston and the cavity wall, but also restraining the unwanted interference patterns and cross-interference patterns with the electric current of axial z, radial r, which makes TE_{011} mode separate from TM_{111} mode. We put a black bakelite-depleting substance in the back of piston to absorb other modes leaking into the cavity-backed energy.

3.3. Coupling design of the sensor

In practice, the resonant must have an excitation device to drive resonator oscillation, and a coupling device to make the electromagnetic field of resonant couple to detection circuit. According to the reciprocity of passive devices [9], the excitation and coupling of resonant can be achieved by coupling hole. We should weaken coupling with other unwanted waveform as much as possible in order to obtain the correct work wave coupling. The electric field around the inner wall surface of resonant for TE_{011} mode is zero, so the coupling for TE_{011} mode must be the magnetic coupling that can be gotten through the connection between the keyhole and the waveguide. Fig.2 shows the distribution of electromagnetic field and wall current of TE_{011} mode in cylindrical cavity. The coupling hole is opened in the middle of cylindrical cavity wall length where the maximum of axial direction component H_z of field and the greatest coupling position for the work wave are. The axial direction component of field is zero for the TM mode, so wall coupling does not drive TM mode.



(a) The distribution of wall current (b) The distribution of electromagnetic field

Fig. 2 The distribution of electromagnetic field and wall current of TE_{011} mode in cylindrical cavity

The correct orientation of coupling between coupling hole and waveguide is on the basis of their magnetic fields and work wave in the cavity which have the strongest public magnetic field component in the coupling, at the same time , the magnetic field is parallel to each other in the coupling. According to the aperture coupling theory, we can get the preliminary size of the coupling hole, then adjusting the size of coupling hole in the simulation experiment to obtain the accurate results that satisfy the actual situation. It should be noted in the design the coupling hole must match with the connecting waveguides and make the Q value largest.

When considering many factors, such as transmitting broadband electromagnetic wave, the actual size of resonator and the working frequency, normative rectangular waveguide BJ120 is selected as the coupled waveguide. In order to couple to the maximum electromagnetic energy of cylindrical cavity in a smaller band, we need to choose the proper position that rectangular waveguide is relative to the coupling hole.

Taking into all the factors above, we can get the suitable coupling hole radius which is 3.1mm, connecting the wave-guide center and deviating from coupling hole center 1.5mm.

3.4. Ventilation design of the sensor

The cavity that is used to measure atmospheric refractivity is different from the techniques of other frequency stabilization system. In order to make the atmosphere flow through the cavity, the lid must be opening at both ends that would bring about stray field and make the Q value decrease. We know from the distribution map of electromagnetic field and wall current of cylindrical cavity (Fig.2) that along the circumferential direction current is zero and the radial component of the magnetic field intensity Hr is zero in the position of end cover radial r equal to zero, so the opening is on the edge. By calculating the distribution of end face current, the opening area should not exceed one third of the entire face so as to ensure the Q value decreased less than 20%. To reduce the stray field we make the end cover thickness a quarter waveguide wavelength and approximatively equivalent to the short circuit of inner surface opening department. The shape of opening department is circular-arc for the purpose of reducing the smoothing effect of atmospheric turbulence. Fig.3 shows the concrete design of the ventilation opening.

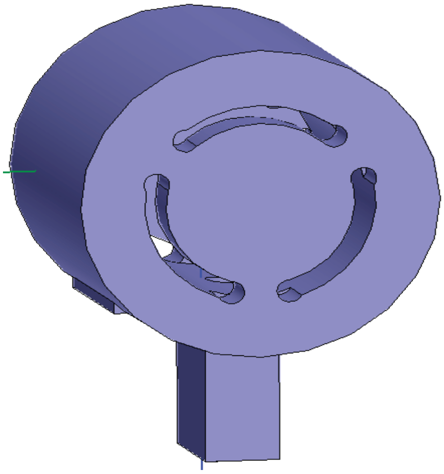


Fig. 3 The simulation model drawing of ventilation opening

3.5. Other considerations

We select the super-Invar alloy steel which can meet the requirements of linear expansion coefficient, and a certain temperature compensation measures to ensure that the temperature has a little effect on the resonant frequency of resonator.

We should ensure more than or equal to secondary processing precision so as to improve the accuracy of cavity size. Different metals have different skin depth, in order to enhance conductivity, it need to plate silver or gold in the inner wall of the cavity. ∇_{12} is selected as the finish of cavity inner wall in processing for the purpose of improving the quality factor Q of the cavity.

4. Experimental results analysis

The refractometer is preheated an hour in order to test the measurement accuracy of the developed sensor (resonant cavity), when the machine completely stable, the sensor with glass cover sealing is pumped vacuum so that there is no atmosphere flow(the atmospheric refractivity N is equal to zero in vacuo). Hundreds of thousands of measured datas are gotten through continuous multiple measurements of atmospheric refractivity N. Table 1 shows the average results.

Through the analysis of Table 1, we know the measuring atmospheric refractivity error of sensor is less than 0.5, and it can meet the design requirements.

At present the common instruments for measuring atmospheric refractivity are mainly 59 types of radiosonde and electric radiosonde. Comparing to the standard atmosphere of ICAO (International Civil Aviation Organization), we can calculate the atmospheric refractivity measurement error caused by these two types of meteorological parameters testing that is 2.46 and 4.98. So the measuring accuracy of refractive index meter is much higher than common instruments of type 59 radiosonde and electric radiosonde.

In addition, when using the meteorological instruments to measure atmospheric refractivity, the large lag coefficient of temperature, humidity and pressure sensors make the reaction rate slow ,prevailing atmospheric condition. The refractive index meter only measures changes of there resonant frequency has no delay problem and can accurately reflect the current atmospheric refractivity, so it has faster reaction rate and can realize on-line measurement. Refractive index meter lays a foundation for accurate measurement of atmospheric refractivity, improving the precision of radar refraction error correction and the atmospheric duct measurement.

TABLE I THE MEASUREMENT ERRORS OF REFRACTOMETER

Sampling length (min)	5	10	15	20	25	30	40	50	60
The average of atmospheric refractivity N	0.49	0.40	0.38	0.34	0.33	0.25	0.22	0.22	0.22

References

[1] Y. Zhang, *Electromagnetic Wave Propagation in Space*, Xi'an: Xidian University Press, 2007.

[2] W. Li, A.D. Zhang, J.Q. Zhang, “Influence of atmospheric ducts on radar distance and height measurement”, *Modern Defence Technology*, vol. 36, no. 2, pp.100-103, April 2008.

[3] H. Wang, “The effect of duct condition on shipborne ultrashor wave communication,” *Ship Science and Technology*, vol. 26, no. 1, pp.39-41, February 2004.

[4] Ch.Y. Jiang, B.D. Wang, “Atmospheric refraction corrections of radiowave propagation for airborne and satellite-borne radars,” *Science in China (Series E)*, vol. 31, no. 2, pp.19-27, February 2001.

[5] J. Huang, *Correction for Atmospheric Refractive Error of Radio Wave*, Beijing: National Defence Industry Press, 1996.

[6] B. R. Bean, E. J. Dutton, *Radio Meteorology*, New York: Dover Publication Inc, 1968.

[7] Y. Zhang, F.L. Yang, X.D. Wu, X. Gao, “The limitation of type 59 radiosonde on accuracy of refraction correction,” *Chinese Journal of Radio Science*, vol. 16, no.3, pp.404-408, June 2001.

[8] Y.X. Zuo, R.J. Jia, Zh. C. Xu, “A high Q cavity’s resonant frequency tracking system used in refractometer,” *Chinese Journal of Radio Science*, vol. 13, no.1, pp.102-105, February 1998.

[9] Y. Zhang, W.H.Hao, J.H.Gao, *Microwave Technology and Application*, Xi'an: Xidian University Press, 2006.

[10] J.H. Gu, *Microwave Technique*, Beijing: Science Press, 2004.