FEASIBILITY STUDY OF A CAPACITANCE HUMIDITY SENSOR FOR STRATOSPHERIC APPLICATIONS *

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ABSTRACT

This paper reports a feasibility study of an air-capacitor humidity detector for stratospheric applications. The change in the dielectric constant of air has been calculated as a function of pressure, temperature, and the pressure of water vapor present. It has been found that at approximately 1.0132 bar, the range of zero to 100 per cent relative humidity corresponds to a change of approximately 400 ppm in the dielectric constant, while at approximately 84.62 millibar the corresponding change is of the order of .03 ppm. In these calculations a standard atmosphere was assumed together with a linear relationship between dielectric constant and the pressures of the constituent gases.

It is concluded that if frequency variations of at least one part per million can be monitored, the device has potential in the troposphere. Presently we are working on such a monitoring device.

INTRODUCTION

Stratospheric humidity measurements are important in meteorology, but at the present, monitoring in the stratosphere is impractical. The available sensors have a slow response and low sensitivity at low dewpoints. A new method of humidity detection is necessary.

The purpose of this paper is to determine if a capacitance humidity sensor could be used in the stratosphere. This sensor would use the local air as the dielectric, and changes in the humidity would be determined by the corresponding change in capacitance.

THEORY

Using standard atmosphere data[1], the densities of air and saturated water vapor were determined at altitudes from zero to fifty kilometers. The authors assumed that the polarization, P, of air under the influence of a constant electric field is directly proportional to the density of molecules present. Under this assumption, the electric susceptibility, χ, is also proportional to the density by virtue of the relation[2]

$$P = \chi E \epsilon_0{}^{*}$$

Thus, χ may be given as a superposition of the susceptibilities of the components of the air.

$$\chi = \chi_{\text{water vapor}} + \chi_{\text{dry air}}$$

By the above proportion

$$\chi_{\text{water vapor}} = \kappa_1 N_w$$

and

$$\chi_{\text{dry air}} = \kappa_2 N_a$$

where κ_1 and κ_2 are constants of proportionality, and N_w and N_a are the densities of water and air molecules, respectively. κ_1 and κ_2 were determined using a known value of dielectric constant[3] at given densities of air and water, and the equation[2] relating susceptibility and dielectric constant, ϵ_R:

$$\epsilon_R = \chi + 1$$

Thus, at a given density of dry air, the contribution to ϵ_R due to water is

$$\frac{\chi_{\text{water vapor}}}{\epsilon_R}$$

In air, ϵ_R is very close to unity, so that the fraction of the dielectric constant due to water is very nearly the susceptibility of the water vapor.

DISCUSSION

Using the CDC 3400 digital computer at the South Dakota School of Mines and Technology campus, values for $\chi_{\text{dry air}}$, $\chi_{\text{water vapor}}$, and ϵ_R were computed at various altitudes from 0 to 50 km, using the above assumptions. From this data it was determined that at sea level, where standard atmospheric pressure is 1.0132 bar[4], a change of zero to 100 per cent relative humidity resulted in a change in dielectric constant of 400 ppm. At altitudes of 17.5 km and 50 km (corresponding to pressures of 84.6 mbar and .800 μbar), the same change in humidity resulted in changes in the dielectric constant of 5 ppm and 61 ppm respectively.

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*ϵ_0 is the permittivity of free space.

However, all particles in the influence of the earth's gravitational field obey a form of the law of atmospheres, which gives an exponential decrease in particle density with height. The maximum density of particles at an arbitrary height is then less than the maximum number at a lower altitude. Calculations gave a minimum water-vapor susceptibility at saturation of 3.45E-8. This occurred at an altitude of 17.5 km. Since χ is assumed proportional to the molecular density, the maximum value of χ_{water} above 17.5 km is necessarily less than 3.45E-8, corresponding to a very low relative humidity.

To measure the change in dielectric constant, the authors are constructing a system which will use an L-C oscillator circuit whose resonant frequency, ω_0, will be given by $\omega_0 = \sqrt{1/(LC)}$. Since the capacitance, C, is directly dependent on dielectric constant, ω_0 will be determined by humidity for a given dry air density.

To accurately determine the oscillator frequency, ω_0 will be modulated by a frequency standard, and the resulting beat frequency will be digitized and counted.

Commercially available, state-of-the-art frequency measurement instrumentation is capable of an accuracy of 0.1 ppm, with a response time of $\sim$ 5 sec[5]. The practical limit on the use of this sensor will then be those altitudes where changes in humidity cause a change of 0.1 ppm in $\chi_{water\ vapor}$. These altitudes have been determined to lie within the troposphere.

CONCLUSIONS

The authors have assumed that a standard atmosphere[1] provides a good first order approximation for calculation of the electric susceptibility of air. As the pressure ranges from 1.0132 bar to 84.6 mbar, an air capacitor could function as a humidity sensor in the troposphere if frequency variations of less than 1 ppm can be monitored. However, due to the small amounts of water present, this device would not be practical in the stratosphere.

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