

LEAK RATE AND LOCATION ANALYSIS THROUGH SLITS AND CRACKS IN PIPES BY NANO POROUS CERAMIC HUMIDITY SENSORS

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Abstract: Nano porous sol gel thin film humidity sensor was studied using commercially available reference humidity sensor from Honeywell Corporation. The main advantages of our developed set up for humidity measurements is low cost and high resolution yielding a full set of information on the variation of humidity at 250°C. Humidity is considered to be one of the most effective indicators of the leakage. On this ground we developed nano porous sensor which can be used for LBB (Leak before break) application. The ceramic sensors, based on sol gel thin film are shown to increase its capacitance upon water adsorption over the temperature range upto 250°C. The variation of capacity to voltage is shown to provide useful information on both break rate and location. The sensor installation spacing on the outer surface of the piping is determined as a function of the detection sensitivity. In this paper we have summarize the results of the development and characterization of ceramic humidity sensor for leak rate and location analysis by a microcontroller device.

Index Terms: Nano porous H. sensor, Linearization, Microcontroller circuit, Leak location.

1. INTRODUCTION

Humidity measurements have become increasingly important, in the industrialized world since it has been recognized that humidity has a significant effect on quality of life, quality of product, safety, cost, and health. This has brought about a significant increase in

A digital hygrometer describe in this paper also used a ceramic capacitor as the sensing element. Its capacitance changes non-linearly with relative humidity (RH) and temperature. Temperature dependent is small compared to dielectric sensitivity i.e. capacitance changes due to RH. The capacitance change should be detected in a digital form for linearization. The simplest circuit to perform such a function is a monostable oscillator. To encode only the capacitance change into a digital form, the dry capacitance when RH=0 is cancelled. Finally, a prototype hygrometer based on these techniques will described for use in leak detection.

2. SENSOR AND ITS FABRICATION PROCESS

The fig-1 shows the structure of the sensor. Its fabrication process is as follows.



Fig-1: Picture of the Nano Porous Thin Film Sensor

The Alumina sol solution was mixed with a calculated amount of PVA (Poly Vinyl Alcohol) in hot condition for 2 hours. The solution was made 100% bubbles for thin film preparation. Films coated on a gold coat α -Alumina Substrate of size (10 mm x 20 mm x 1 mm). Second electrode is formed on film coated substrates. It is then finally fired at

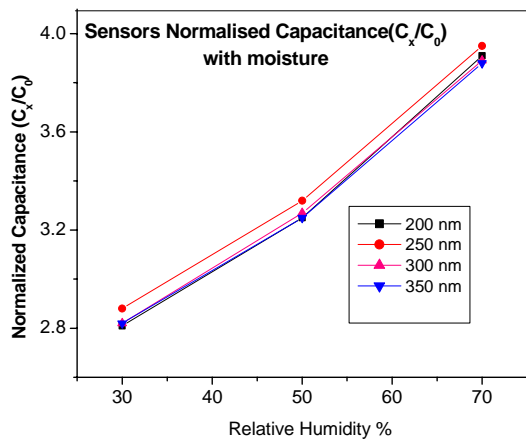


Fig-2(c): Normalized Capacitance (C_x/C_0) With Relative Humidity

Table-1: Sensor Characteristic At 30% RH

Sensors	Film Thickness (nm)	Dry Capacitance C_0 (pF)	Normalized Capacitance C_x/C_0 (pF)	Condition	
				RH%	Temperature
A	200	72.43	2.81	30	28 C
B	250	64.32	2.88	30	28 C
C	300	56.54	2.82	30	28 C
D	350	48.46	2.82	30	28 C
E	400	39.78	2.98	30	28 C

The comparison shows that the fractional capacitance changes of the ceramic based RH sensors are almost independent of their fabrication process and film thickness. The response time for the step change between 40 and 80% change is shorter than 12 s. these facts indicate that the capacitance change of sensor can be explained by the increase in the apparent dielectric constant ϵ_s of the hygroscopic film due to physical sorption of water vapour. Absorbed water can be regarded responsible as being distributed uniformly throughout the film because the fractional capacitance change is independent of film thickness. Therefore the sensor capacitance C_x is given by

$$C_x/C_0 = L_p/\epsilon_p \left(\int_0^{L_p} \frac{dl}{\epsilon_s} \right) = \frac{\epsilon_s}{\epsilon_p}$$

Where ϵ_p is the dielectric constant of the alumina thin film ($\epsilon_s= 8$) and L_p is the thickness of the hygroscopic film.

The apparent dielectric constant ϵ_s of the hygroscopic film is given by Looyengas empirical equation [17].

$$\epsilon_s = \left\{ \gamma \left(\epsilon_w^{1/3} - \epsilon_p^{1/3} \right) + \epsilon_p^{1/3} \right\}^3 \dots\dots\dots(1)$$

Where γ is the fractional volume of water in the film and ϵ_w is the dielectric constant of water given by [16]

$$\epsilon_w = 78.54 \left\{ 1 - 4.6 \times 10^{-4} (T - 298) + 8.8 \times 10^{-6} (T - 298)^2 \right\} \dots\dots\dots(2)$$

Where T is the temperature in Kelvin. The fractional volume γ can be obtained from the measured capacitance C_x using (1) and (2).

4. LEAK LOCATION WITH MICROCONTROLLER DEVICE

In order to reduce the construction cost and radiation exposure associated with maintenance of piping restraints, local humidity sensors are recently used for high sensitivity and accuracy of leak location [5-7, 10-15]. Such a humidity based local sensor suggested in Reg. Guide [4] 1.45 is already implemented in European power

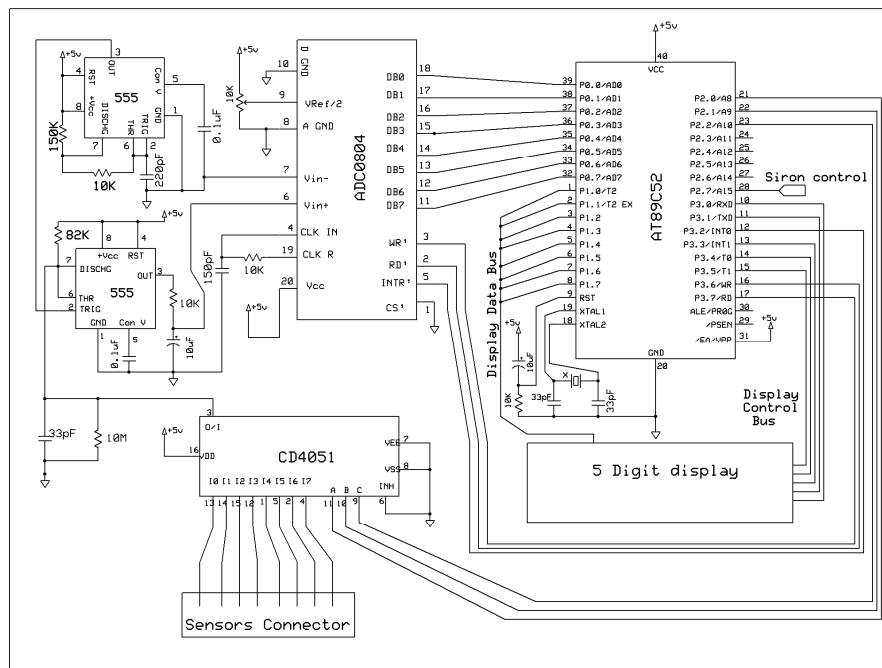


Fig-3(B): Schematic Diagram Of The Location Analysis Circuit.

The sensors are mounted on the surface of the stream pipe and the terminals from the sensors are connected in the input of analog multiplexer. The microcontroller select one sensor at a time by providing multiplexers' selector input and read corresponding moisture around that sensor with the help of ICM7556 and ADC. After that it checks the moisture level for the boundary limit of the moisture. If this moisture level crosses the boundary level it gives an alarm and displays the corresponding sensor location in the address field of the sensor and moisture value in the moisture field.

5. ANALYSIS OF LEAK DETECTABILITY

LEAKAGE DISTRIBUTION

Humidity response test results show that nanoporous $\alpha\text{-Al}_2\text{O}_3$ sensor can detect humidity at 300°C . Local humidity monitoring around the pipe can be a sensitive and rapid method to detect high temperature steam leakage.

The above equations represent relative humidity as a function of distance from leak location and time.

6. LEAKAGE LOCATION ANALYSIS

From previous discussion we see nanoporous sensors have better response to the moisture. Hence for location analysis, all the sensors used are of nanoporous type. Picture of the experimental location analysis circuit during testing at laboratory scale is shown in fig-6(c). The experimental set-up for detection of leakage location of a stream carrying pipe from side view is shown in figure-6(a) and the cross sectional view is shown in fig-6(b). We consider the stream pipe of 18 meters in length and we mount eight nos of high temperature thin film moisture sensors perpendicularly with the surface of the pipe. Separation between the two successive sensors is about 2 meters. Sensors are addressed as “000” to “007” from stream inject side to stream out late side. After mounting the sensors, these are covers with the insulating material and connections from the sensors are taken outside the insulating cover. The microcontroller based control systems continue to check all the sensors and display the highest moisture level present in the surface region of the pipe and the nearest sensor location. If there is any leakage in the pipe the stream comes outside the pipe and moisture of that region increases. The nearest sensor first senses the moisture and the corresponding sensor location and moisture value is displays on the display board. All other sensor data are stored in the microcontrollers’ RAM area. This will be checked after the experiment. Also a siren is on and it continues if the moisture level is in high value range. Experimental results for four set up are summarized in the table-1 and also the response of the sensors for set-up-4 is shown in fig-5. All the tabulated data have been taken 1 minute from the time stream line open.

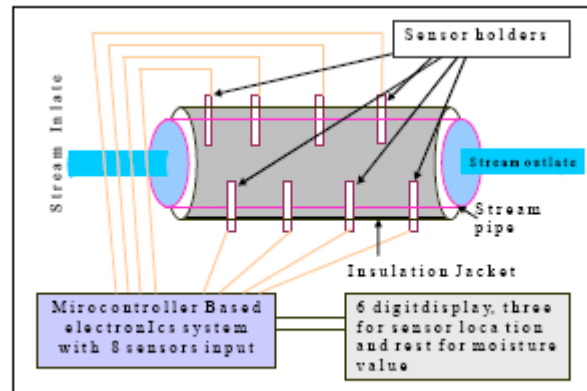


Fig-6(a): Block Diagram Of Experimental Set-Up For Detection Of Leakage Location

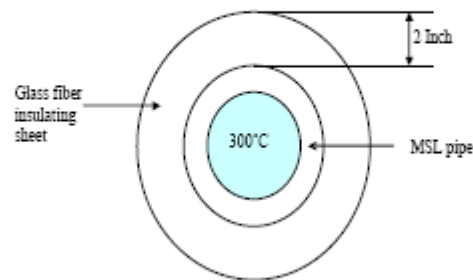


Fig-6(b): Front View Of Experimental Set Up

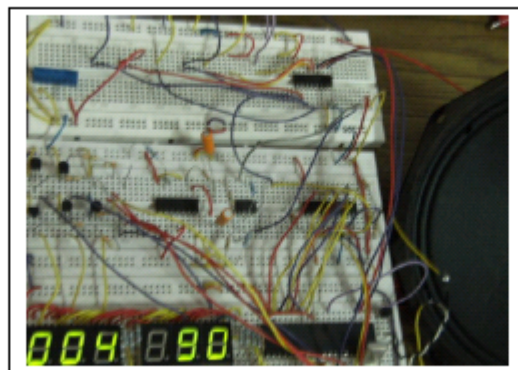


Fig-6(c): Picture Of Location Analysis Circuit During Test.

- [6]. Na Young Lee, Il Soon Hwang, Chang Rock Song and Han Il Yoo, New Leak detection Technique using ceramic humidity sensor for water reactors, *Nuclear Engineering and Design*, 205, 2001, pp. 23-33.
- [7]. T. Nitta, Z. Terada and S. Hayakawa, Humidity-Sensitive Electrical Conduction of MgCr₂O₄-TiO₂ Porous Ceramics, *J Am Ceram. Soc.*, Vol. 63, No [5-6], 1980, pp. 295-300.
- [8]. U.S. NRC, Reactor coolant Pressure Boundary Leakage detection systems, Regulatory Guide 1.45, Rev. 1. 1982.
- [9]. P. Jax, Detecting and locating the smallest leaks early, *Nuclear Engineering International*, 1995, pp. 22-24.
- [10]. K. Mistry, D. Saha, K. Sengupta, Sol-Gel processed alumina thick film template as sensitive, capacitive trace moisture sensor, *Sensors and Actuators B* (accepted Aug. 04), 2004.
- [11]. Anderson, J.H. Parks, GA, The electrical conductivity of silica gel in the presence of absorbed water, *J. Physics Chem* 72 (10), 1968, p. 3662-3668.
- [12]. Z. M. Rittersma, Recent achievements in miniaturized humidity sensors - a review of transduction techniques, *Sensors and Actuators A* 96, 2002, pp. 196-210.
- [13]. Pieter R. Wiederhold, Water vapor measurement-Methods and Instrumentation, Marcel Dekker Inc., New York, Table 13.7, 1997, pp 299.
- [14]. B.E. Yoldas, A transparent porous alumina, *Jr. of Mater. Sci.*, 10, 1856 (1975).
- [15]. Debdulal Saha and K. Sengupta, High temperature humidity sensor for detection of leak through slits and cracks in pressurized nuclear power reactor pipes, *Sensors and Transducers Jr.* Vol. 77, Issue 3, 2007.
- [16]. H. Shibata, M. Ito, M. Asakura, K. Waltanabe, A digital hygrometer using a polyimide film relative humidity sensor, *IEEE Trans. Instrum. Meas.* 45 (2) (1996) 564-569.
- [17]. P.J. Schubert, J.H. nevin, A polyimide-based capacitive humidity sensor, *IEEE Trans. Electron devices* ED-32 (1985) 1220-1223.