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A Hydrogen Gas Concentration Quantitative Detection Technique of Transformer Oil Based on Sound Velocity Measurements

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This paper introduces a quantitative detection technology of hydrogen concentration in transformer oil, which is based on ultrasonic velocity measurements. This detection technique can effectively overcome the influences on final velocity measurement result produced by temperature T, gas adiabatic index γ, number of gas molecules M , and is more suitable for industrial field on-line inspection applications.

1. Introduction

Analysis of the composition and content of the dissolved gas in transformer oil is monitoring the safe operation of the oil-immersed transformer one of the most effective measures. Photoacoustic spectrum method is used to test the power transformer oil gas, which has not consumed the sample, no easily contaminated aging columns and complex pneumatic control systems, high sensitivity, easy maintenance, etc., which is a kind of every the new system is a good application prospects. Using gas chromatography analysis of dissolved gas in oil monitoring oil filled to the safe operation of electrical equipment in our country has more than 30 years of experience in using Chen (2006). And according to the fault characteristics of the gas concentration and distribution proportion, assess and transformer oil latent fault diagnosis.

2. The technical background

In recent years, domestic and foreign manufacturers adopt automatic degasser, auto-sampler, automatic detection technology on the basis of off-line gas chromatography detection technology Tao (2012), launched the transformer fault characteristics of the gas chromatograph on-line detection system, and has been used in large transformer fault on-line monitoring. Pneumatic system is complex, prone to failure, etc. These have greatly increased the system maintenance Hua (2012), maintenance workload and complexity, promotion and application of the system is limited by a certain. Therefore, it is necessary to adopt advanced gas detection principle and technology, developing a new generation of chromatographic column, consumable, simple maintenance and high reliability in the transformer oil gas on-line monitoring system liu (2007), which not only conforms to the current and future technology development direction, and to improve the level of gas in transformer oil online monitoring technology and application level, realize the technology innovation, instead of foreign products, etc.,are also has an important significance.
Fault gases hydrogen gas concentration quantitative detection is an important test indicators based infrared photoacoustic spectroscopy in transformer oil. Since hydrogen gas does not absorb infrared light, therefore, this requires the use of other measurement methods. Currently, hydrogen sensitive sensors are optical fiber sensors, electrochemical sensors, semiconductor sensors, surface acoustic wave sensors, and gas chromatography - atomic absorption spectrometry and mass spectrometry techniques. However, due to varying degrees of device aging, demanding measurement environment, high cost and other questions of the detection technology, which results these technologies applications of fault gases line detection greatly restricted in transformer Jia (2011). According to the principles of physics and thermodynamics, Acoustic wave spread velocity in the gas.

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$$C=\sqrt{\frac{rpV}{M}}=\sqrt{\frac{rpV}{M}} \tag{1}$$

In the above formula: γ- gas adiabatic index; R - the gas constant; T - gas temperature; M - gas molecular weight. hydrogen gas sound velocity is approximately four times in air, the results JKS Wan et al (A novel acoustic sensing system for on line hydrogen measurements) showed that: When the background gas is air, in gas mixed gas containing varying hydrogen volume fractions acoustic wave relative drift of Propagation time and acoustic wave are proportional to the volume fraction of hydrogen; The main factors affecting the measurement accuracy includes changing the background gas composition, which led to changes in the average molecular weight and the stability of the chamber temperature.

At present, Researchers have been proposed hydrogen gas concentration is measured using the photoacoustic signal resonance frequency shift and using acoustic transfer characteristics in the domestic.

The first method: Used photoacoustic signal resonance frequency shift method to detect hydrogen gas concentration, by measuring the photoacoustic signal with the chopping frequency curve fitting, using phase shift amount of photoacoustic signal to measure the concentration of hydrogen gas. But this method, due to the use of photoacoustic pool of resonance, the gas being measured after receiving infrared illuminate, it is difficult to accurately measure the temperature, and the resonance frequency control is difficult, therefore, it is difficult to application in the actual detection device [12].

Second method: using the method hydrogen gas concentration is measured based on the method of sound waves conduction properties , It is assumed that the same measured before and after the hydrogen gas concentration of the air at different temperature corresponding to, i.e., T = T ', and considering hydrogen gas concentration is at a very small amount ,obtained:

$$n=\frac{2\Delta\phi}{\omega x}\sqrt{\frac{rRT}{M}} \tag{2}$$

x —Acoustic wave propagation distance; ω —Acoustic frequency; Δ ϕ —Acoustic wave phase varying amounts

By Equation (2) shows the phase variation Δφ is a function of hydrogen gas concentration n in air, by measuring the acoustic phase change Δφ, the change of hydrogen concentration can be measured. but the phase change Δφ is also the function of temperature T, the gas adiabatic index γ, a Gas molecular weight M, These factors will lead to hydrogen concentration generated error when measuring, especially in the practical application mainly exist the following problems:

(1)To achieve measure air with different hydrogen gas concentrations, temperature of the same before and after the corresponding, i.e., T = T ', with great difficulty in the realization of the technology.

(2)Although temperature compensation is given in the literature, but the compensation temperature range is very small, if the actual application, it is necessary to carry out more stringent temperature control.

(3)If audio frequency is adapted to measure acoustic wave phase shift, Site environmental noise and vibration will produce very big interference of sound wave signal phase detection, such an approach will affect the stability and accuracy of measurement result.

Therefore, to improve the detection accuracy and stability of the hydrogen gas concentration on the speed of sound, it is necessary online in real time compensation and correction for the temperature T, gas adiabatic index γ, gas molecular weight M. At the same time, to avoid the effects of noise and vibration on-site phase of the acoustic sig

3. The measurement process and principle

3.1 Gas sound velocity and temperature measuring devices

The device consists of a tube prolapse gas chamber and transmitter module and a receiver module mounted on the ends of the tube-type chamber ultrasonic. Precision temperature sensor installed in the tube gas chamber, in the tubular chamber outdoor department there is also the microprocessor, the ultrasonic transmitting/receiving circuits and temperature sensor detection circuit composed of sound velocity and temperature detection unit. Use the device can realize measures of the sound velocity being measured gas indoor and temperature of the gas.

3.2 Detection process

Using of gas sound velocity and measuring device of temperature to measure Sound Velocity Cm measured gas and temperature T;Used other detection methods (such as photoacoustic spectroscopy) to detect the test gas in addition to hydrogen gas concentration X8 and other gaseous components (carbon monoxide, carbon dioxide, methane, ethane, acetylene, ethylene, water vapor, oxygen and nitrogen) concentrations Xi (i = 0,1,2, ... 8).

3.3 Data processing procedure

According to the measured gas temperature T and concentration of known components to calculate the average benchmark gas adiabatic exponent M gamma (T) and the average molar concentration M;

According to the measured Sound Velocity Cm gas and the reference gas equation and the measured Sound Velocity Sound Velocity equation obtained gas contains only hydrogen gas concentration X9 unknown nonlinear equations;

According to the measured velocity Cm, benchmark gas velocity equation and the measured gas velocity equation can be obtained only nonlinear equation containing unknown X9 hydrogen concentration.

Using nonlinear equations to slove hydrogen gas concentration X9, to achieve the concentration of hydrogen gas to be measured quantitatively.

Working principle quantitative detection for hydrogen gas:

Set in the gas being measured components concentration for Xi ppm unit, Gas molar mass of each component Mi kg / kmol, constant pressure heat capacity of each component gases is

$Cp_i KJ / kmol{\bullet}K$ i=0,1,2, …… 9

respectively carbon monoxide, carbon dioxide, methane, ethane, acetylene, ethylene, water vapor, oxygen, nitrogen, and hydrogen.

Cm —Measured gas sound velocity m/s

T —Measured temperature of the gas℃

Among them, Xi(i=0, 1, 2, …… , 7) is a known quantity（Obtained by other detection methods）, The hydrogen concentration X9 is to be detected amount.

When the hydrogen concentration X8 = 0 ppm, According to the law of gas pressure and gas benchmark physical parameters can be calculated the average molar concentration of M, average constant pressure heat capacity Cp and the adiabatic index γ (T)

$$M = \sum_{i=0}^{8} M_i X_i \tag{3}$$

$$C_p(T) = \sum_{i=0}^{8} Cp_i X_i \tag{4}$$

$$r(T) = 1/(1 - 8.314 / C_P(T)) \tag{5}$$

Among them: the nitrogen concentration X8 can be launched according to other gas concentration.

$$X_8 = 1 - \sum_{i=0}^{8} X_i \tag{6}$$

According to gas velocity equation (1) and (3), (5), (6), obtained available benchmark gas velocity.

$$c^2 = \frac{r(T)RT}{M} \tag{7}$$

When the concentration of hydrogen X9 ≠ 0 PPm, Set the average molar concentration of the gas being measured for MH (X9), average constant pressure heat capacity of CpH (T, X9), the adiabatic index for gammaγH (T, X9), according to the law of gas pressure ,there are:

$$M_H(X_9) = \sum_{i=0}^{9} M_i X_i \tag{8}$$

$$Cp_H(T, X_9) = \sum_{i=0}^{9} Cp_i X_i \tag{9}$$

$$r_H(T, X_9) = 1/(1 - 8.314 / Cp_H(Y, X_9)) \tag{10}$$

Wherein: the nitrogen concentration X8 can be exported according to other gas concentration.

$$X_8 = 1 - \sum_{i=0}^{7} X_i - X_9 \tag{11}$$

According to gas velocity equation (1) and (8), (10), (11), gas velocity can be measured.
From (7), (12), there is

$$C_m^2 = \frac{r_H(T, X_9)RT}{M_H(X_9)} \tag{12}$$

$$\frac{M_H(X_9)}{M} = \frac{r_H(T, X_9)C^2}{r(T)C_m^2} \tag{13}$$

Obviously, (11) containing only unknown parameter X8 (hydrogen concentration) equation, equation (11) using the numerical solution of nonlinear equations, you can get the X8 hydrogen concentration from the gas to be measured.
By using the above detection:
(1) Eliminating the direct effect of temperature T for solving results of equation (11);
(2) The calculation method used benchmark gas adiabatic index γ (T) and measured gas adiabatic index γH (T, X8), eliminating the temperature and group concentration affects parts of the adiabatic index;
(3) We calculated an average molar concentration of the reference gas M and MH average molar concentration of the test gas, eliminating the impact of changes in the concentration of the components of the average molar concentration of gas.

4. Specific implementation

Composition of test system used for the implementation of the case:

4.1 The gas velocity and temperature measuring devices
The gas chamber of this device is made of brass, the length L may be measured at 5cm - 15cm resolution according to sound velocity;
The device velocity and temperature measurement unit, high-speed microprocessors and ultrasonic transducer drive circuitry, high-precision temperature detection circuit that detects sound velocity with a resolution of 0.01m / s, temperature detection resolution of 0.02 ℃.

4.2 The data processing unit
The unit adopts the embedded PC. The unit can be through the RS - 485 communication interfaces to read the sound velocity and temperature measurement unit, measurement data of photoacoustic spectrum measurement unit, and complete relevant calculation is given according to the invention the detection principle.

4.3 Implementation example 1
Using nitrogen as the background gas, standard gas sample for testing.
Each component concentration of Standard sample gas are: hydrogen H2－250.1ppm, Carbon monoxide CO－250.1ppm, Carbon dioxide CO2－1013.6ppm, Methane CH4－50.3ppm, Ethane C2H6－50.4ppm, Acetylene C2H2－50.0ppm.
Table I shows the test results at different temperatures.

Table I: Test results at different temperatures

Detection No.	Measured gas temperature℃	Measured gas velocity m/s	Hydrogen concentration ppm
1	12.26	344.25	275.3
2	12.82	344.57	235.8
3	13.66	345.09	255.6
4	13.98	345.28	228.5
5	14.60	345.66	267.1
6	15.16	345.99	259.9
7	16.62	346.88	279.6
9	17.90	347.61	247.7
The average hydrogen concentration			256.2

From Table II, when the temperature changes in the range of 12--18 ℃, and the hydrogen gas concentration measurement Mo (2005) of the average absolute error is 250.1-256.2 = 6.2 ppm parts per million, the maximum absolute error is 279.6-250.1 = 29.5 ppm.
According to maximum absolute error of test results of the implementation example I and example II, the minimum detection concentration of hydrogen detection can reach 20.5 + 29.5 = 50 ppm.

5. The technical improvement of system reliability and stability

5.1 The anti-jamming ability of the hardware system

Because the system needs to be installed near the transformer, the working environment is poor QI (2009). Therefore, in the photoacoustic detection unit, ultrasonic sound velocity measurement unit and high precision temperature and the hardware design of pressure testQu (2010), The measures to be used for the system of power supply, communication interface, I/O interface and hardware such as shell and wires, at the same time on the software system adopts the door dog, software trap and data redundancy protection technology XU(2011), further improves the system security, reliability, stability, environmental adaptability, and electromagnetic compatibility.

5.2 Improve the reliability and stability of the software system

Because this system integrating subsystems such as manufacturing, to reduce the correlation between each subsystem and the coupling, in the overall design of this system, which adopts the modular design method, the structure and the system function is optimized, the system is divided into sample collection separation of oil and gas control subsystem, photoacoustic spectrum detection subsystem and ultrasonic hydrogen detection subsystem, each subsystem is connected by MODBUS field bus [Yu (2008)] to a main control unit composed of embedded PC, formed a distributed measurement and control system, and through the main control unit to complete the task scheduling and coordination of each subsystem.
Through the above task scheduling mechanism, making the control of the system testing process is more flexible and convenient [Yong (2014)], especially in the subtask state return mechanism, can be effective to control the process of monitoring, to accurate positioning of system failure, improve the stability and maintainability of the system.

6. Conclusion

Through the implementation of this project, we have developed systems on several major fault gas detection index basically reached GB / T 7252-2001 "transformer oil dissolved gas analysis and judgment Guide" minimum detection standards. Through on-site commissioning and operation, the accumulation of data, improved data processing method, improved the detection accuracy of the system, simplifying system calibration. The software also needs to be further improved and perfected.

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