A Proposal of an Effective Compensation Method for IR Lamp Deterioration in NDIR Type Capnograph Systems

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Abstract: This paper proposes the effective compensation method for the IR lamp deterioration in NDIR capnograph system. The newly designed optical chamber with two IR lamps and an electronic hardware for controlling lamp intensity have been implemented. After applying the proposed optical chamber and reference lamp control circuit to the NDIR type capnograph system, it is identified that the proposed method can compensate the lamp deterioration effectively.

1. Introduction

Most capnograph systems that can indirectly determine the partial pressure of carbon dioxide in the blood of a patient are based on NDIR (non-dispersive infrared) absorption technology[1]. As such an NDIR gas analyzing method requires an optical absorption chamber composed of IR(infrared) source and detecting sensor[2][3]. The commonly used IR sources are platinum filament lamps which produce a visible ray and a broad IR band. But light emission of the lamps can be mainly affected by filament deterioration because of the limited lifetime of the lamps. The unwanted reduction of IR light can lead wrong measurements of CO_2 gas concentration. For the correction of the IR lamp deterioration, the applied voltage of the lamp should be increased so that the sensor output signal show a constant amplitude for the reference gas, for example, N_2 gas. But the increased voltage applied to the lamp can accelerate the decay of lamp performance and life time.

In this paper, to compensate effectively for the lamp deterioration, the newly designed optical chamber with two IR lamps and an electronic hardware for controlling intensity of IR lamps have been proposed. Two IR lamps consist of a main lamp with a fixed voltage source and a reference lamp with a variable one controlled by microprocessor. After applying the proposed optical chamber and reference lamp control circuit to the NDIR type capnograph system, it is identified that the proposed method can compensate the lamp deterioration effectively.

2. The Compensation Method for IR Lamp Deterioration Using Two Sources

2.1 Conventional compensation method using one IR lamp

The CO_2 gas in the optical chamber absorbs the 4.3μm wavelength component radiated from an IR source. The reduced component can be represented as a function of the CO_2 gas concentration and optical chamber length using Beer's law. As in Fig 1.(a), in the conventional optical chamber structure with chopped IR radiation, the related sensor output signal component, U_{out}, can be represented as follows.

$$U_{out} = \alpha I_l e^{-kcl_l} \cdot u \quad (1)$$

where α is a sensitivity, I_l is an initial intensity of radiation, k is a proportional constant, c is CO_2 gas concentration, l_l is a distance from lamp to detector, and u is a function that becomes one when a lamp is active and otherwise zero. Since the initial intensity of radiation is related directly the sensor output signal in the eq. (1), it should be constant and stable for the reliable measurement of CO_2 gas concentration. The IR lamp, however, has the limited lifetime and undergo the deterioration inevitably as lamp driving time goes by.

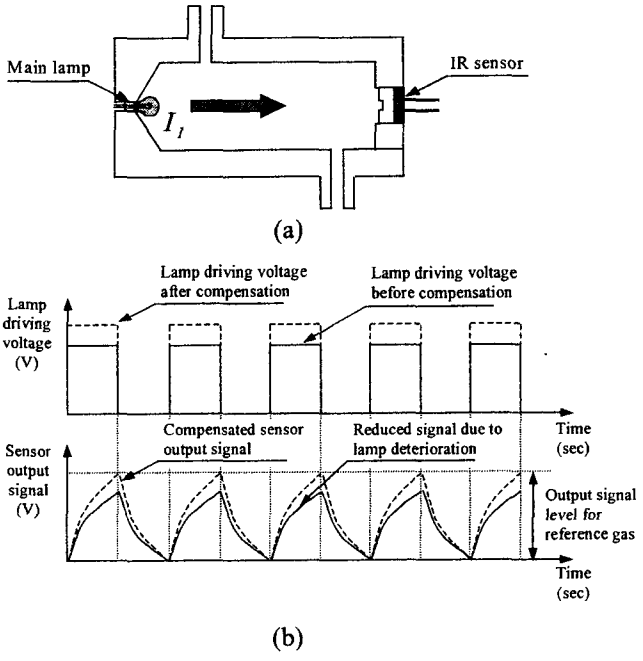


Fig. 1. (a) The structure of conventional optical chamber with one IR lamp and (b) its time diagrams about lamp driving voltages and sensor output signal

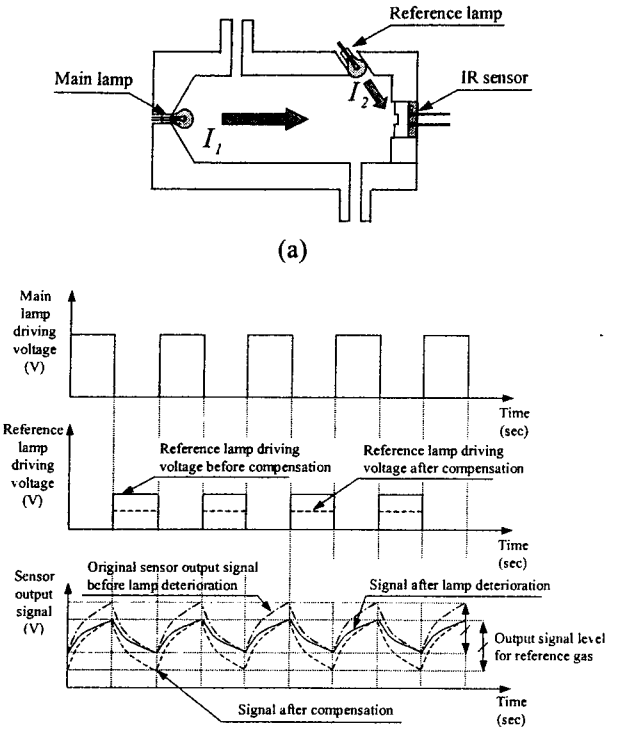


Fig. 2. (a) The structure of a newly designed optical chamber with two IR lamps and (b) its time diagrams about lamp driving voltages and sensor output signal

To compensate the reduced initial intensity of radiation, like a Fig. 1.(b), the applied voltage to the IR lamp must be increased so that the sensor output signal has the constant amplitude corresponding to the output level of CO_2 free gas. Unfortunately, the raised voltage accelerates the decay of lamp performance and lifetime and results in the increasement of power dissipation.

2.2 Proposed compensation method using two IR lamps

But the newly designed optical chamber with two IR lamps, like a Fig. 2.(a), enables IR detector produce the output signal component being proportional to the different intensities between main lamp and reference one. Two lamps operate in phase difference of 180 degrees with different driving voltages each other. And the deterioration process of the main lamp proceeds more fast than one of reference lamp because the driving voltage of main lamp is higher than that of reference. So the deterioration problem of IR lamps occurred severely in a main lamp and the decay of reference lamp radiation is very slight compared to that of main lamp. If the compensation process for a deteriorated IR lamp proceeds for N_2 gas, the sensor output signal component can be represented as following equation.

$$U_{out} = \alpha [(I_1 - \Delta I_1) e^{-kcl_1} \cdot u + I_2 e^{-kcl_2} \cdot (1 - u)]$$
$$= \alpha [(I_1 - \Delta I_1) e^{-kcl_1} - I_2 e^{-kcl_2}] \cdot u + \alpha I_2 e^{-kcl_2} \quad (2)$$

where I_1 and I_2 are initial intensities of radiation from main and reference lamp respectively, ΔI_1 is a reduced amount of radiation intensity of maim lamp, and l_1 and l_2 are distances from each lamp to detector. If the intensity of reference IR lamp, I_2, is reduced into $I_2 - \Delta I_1 e^{-kc(l_1 - l_2)}$ by changing the applied voltage, the decayed component by a main lamp deterioration can be removed as following equation.

$$U_{out} = \alpha [I_1 e^{-kcl_1} - I_2 e^{-kcl_2}] \cdot u + \alpha [I_2 e^{-kcl_2} - \Delta I_1 e^{-kcl_1}] \quad (3)$$

If a narrow bandpass filter centered at lamp chopping frequency is used, the compensated sensor output signal can be extracted in eq.(3) without the affection by the IR lamp deterioration. Additionally, this compensation method is more advantageous in the view of life time and power dissipation of IR lamp than the conventional method since the applied voltage to main lamp is fixed and that of reference lamp becomes lower as the deterioration process goes further.

3. The designed optical chamber and lamp driving hardware

The optical chamber using two IR lamps has been designed and implemented like a Fig. 3.(a). The lamps are IRL 715 of PerkinElmer Inc. and the IR sensor is PbSe photoconductive detector of Calsensors Inc. with 4.3μm optical bandpass filter. The reference lamp positions nearby

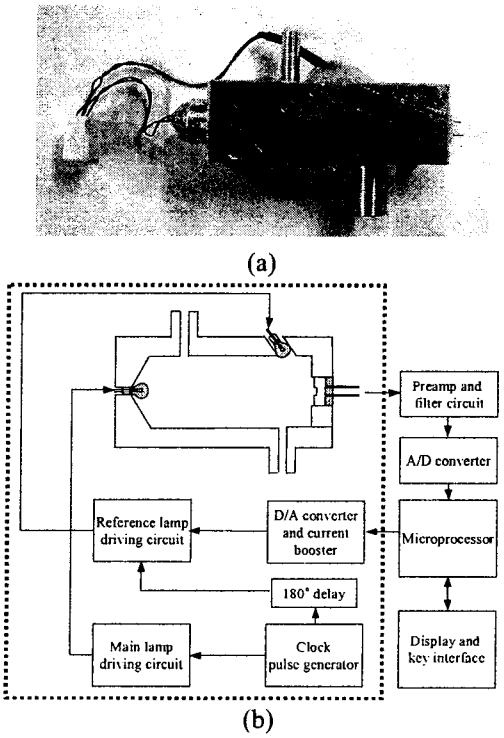
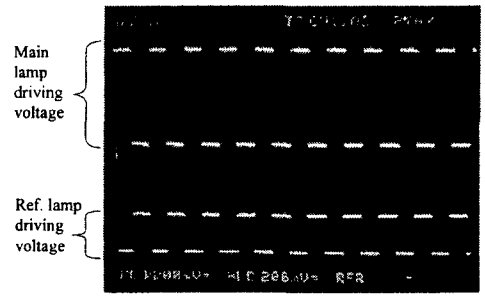
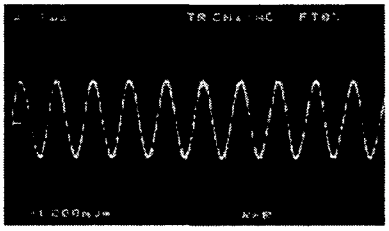


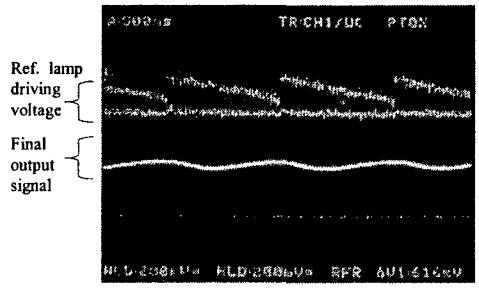
Fig. 3. (a) The implemented optical chamber using two IR lamps and (b) a block diagram of lamp driving and lamp intensity control circuit



(a)



(b)



(c)

Fig. 4. (a) The lamp driving voltages in the implemented optical chamber and (b) the compensated sensor output signal passed through a narrow bandpass filter and (c) the final output signal according to the variation of reference lamp voltage

the sensor so that the IR absorbtion by the reference lamp is less than that by the main lamp. The dotted line part in Fig. 3.(b) shows a block diagram of lamp driving and lamp intensity control circuit. The intensity of main lamp can be adjusted by users' manual operation. And the intensity of reference lamp can be adjusted automatically by the compensation process in the program of microprocessor. The compensation process controls the voltage of reference lamp so that the level of final ouput signal voltage for N_2 gas is a constant value.

4. Experiment and discussion

The implemented optical chamber and lamp driving and intensity control circuit have been adopted in a NDIR type capnograph system which had been developed by our research team. Fig. 4.(a) shows lamp driving voltages applied in the implemented optical chamber and Fig. 4.(b) is the compensated sensor output signal passed through a narrow bandpass filter. And Fig. 4.(c) shows the variation of final output signal according to the variation of reference lamp driving voltage.

Table 1. Compensation result of the final output signal and reference lamp voltage according to the change of main lamp driving voltage

Main lamp driving voltage(V)	6.00	5.90	5.80	5.70	5.60	5.50	5.40	5.30	5.20	5.10
Ref. lamp driving voltage(V)	2.50	2.70	2.52	2.35	2.22	2.12	1.88	1.69	1.41	1.22
Final output signal voltage(V)	2.40	2.39	2.39	2.40	2.39	2.41	2.40	2.40	2.39	2.40

To demonstrate the proposed compensation method for IR lamp deterioration, the variation of voltage applied to the reference lamp has been measured when the voltage of main lamp is decreased purposely for the simulated lamp deterioration. As shown in Table 1, the reference voltage is changed and the final ouput signal goes to the constant level for the N_2 gas though the main lamp intensity is decreased. In this way, it is verified that the propesed method can compensate the main lamp deterioration effectively.

5. Conclusion

In this paper, an effective compensation method for IR lamp deterioration has been proposed using the newly designed optical chamber with two IR lamps and the an electronic hardware for controlling the applied voltage of the lamp. Two IR lamps consist of a main lamp with a constant voltage source and a reference lamp with a variable one controlled by microprocessor. After applying the proposed optical chamber and reference lamp control circuit to the NDIR type capnograph system, it is verified that the proposed method can compensate the lamp deterioration effectively.

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