AUTOMATIC VENTILATION SYSTEMS #6249

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1. ABSTRACT

In Japan air cleaners have become popular to improve the indoor air quality. Air cleaners can be automatically controlled by a sensor system. A semiconductor gas sensor is advantageous because of its high sensitivity and reliability. The automatic control system consists of the semiconductor, a power control unit and a microcomputer which contains newly developed software. Furthermore a new gas sensor for auto-damper systems has been developed which can detect diesel exhaust gas.

2. INTRODUCTION

Recently, the awareness in indoor air quality has increased very much in Japan. In addition to conventional temperature and humidity control, people 's interest has shifted to indoor air quality control, where the aim is to detect cigarette smoke, chemical components of building materials,human body and pets odor, dust and pollen.

We have been developing a controller for an automatic air cleaning system to detect the main factors of air contaminations, such as cigarette smoke and dust in indoor air, using a highly sensitive semiconductor gas sensor.

Here we will describe the application of a semiconductor gas sensor for air quality control and the effectiveness of this system. Furthermore, we will explain the recent development of air quality control inside a car's cabin for a more comfortable atmosphere. And our view on future gas sensing technology will be described in the last chapter.

3. OUTLINE OF AIR QUALITY CONTROL SYSTEM USING SEMICONDUCTOR GAS SENSORS

3-1. AIR CLEANER

As shown in FIG. 1, an electronic air cleaner is composed of a screening filter, an ionizer, a dust particle trapping electrode, and an absorption filter. The contaminated air is drawn in by a fan to each section of the filters to remove the dust and odor. After that, the purified air is recirculated. It is preferable to control its operation depending on the degree of air contamination. Before that, it is necessary to know the degree

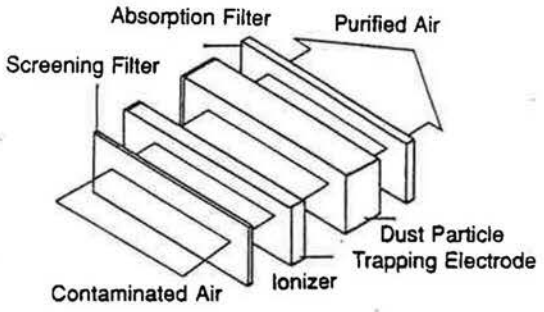


Fig.1 Composition of air cleaning system

of contamination. The sensor used for this purpose should have stability and high sensitivity to components of contaminated air and should be inexpensive for domestic application. A sensor which meets these criteria is a semiconductor gas sensor. The sensor was put to practical use a few years ago and has been used in various appliances. Its application has expanded to air conditioning and ventilation.

3-2. A SEMICONDUCTOR GAS SENSOR

3-2-1. GAS SENSOR STRUCTURE

As an representative of semiconductor gas sensors, a sintered tin oxide gas sensor is described hereunder. Fine particles of semiconductor material mainly composed of tin dioxide are coated around an alumina ceramic tube and sintered to form a gas sensing element. The sensing element is heated at around 400 ℃ by a heater inside the tube. Fig. 2 shows the appearance and configuration. Its housing is compact with a 17 mm diameter and mechanically strong.

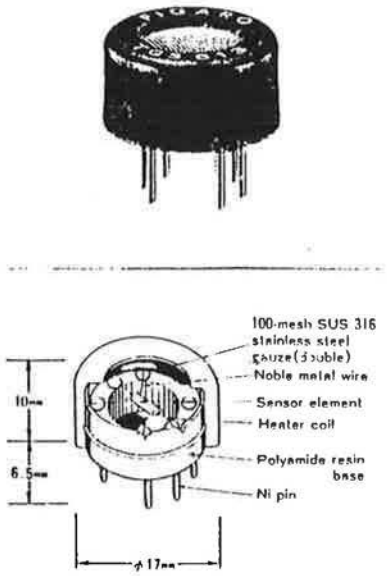


Fig.2 Appearance and configuration

3-2-2. GAS DETECTING MECHANISM

When the sensor is heated to a high temperature, em. 400℃ without the presence of oxygen, free electrons flow easily through the grain boundaries of the tin dioxide(SnO_2) particles. In clean air, oxygen, which traps free electrons by its electron affinity, is absorbed on the tin dioxide particle surface forming a potential barrier in the grain boundaries. This potential barrier(ems in air) restricts the flow of electrons, causing the electric resistance to increase.(Fig. 3-i)) When the sensor is exposed to the air containing reducing gases, em. combustible gases, CO, etc., the tin dioxide surface adsorbs these gas molecules and causes oxidation. This lowers the potential barrier, allowing electrons to flow more easily, thereby reducing the electric resistance. (Fig. 3-ii)) The change of the sensor resistance is converted to output voltage with a simple circuit to know the gas concentration in air.

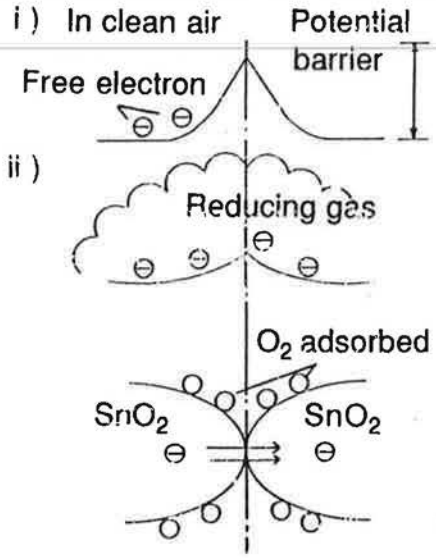


Fig.3 Scheme of principle

3-2-3. CHARACTERISTICS OF GAS SENSORS

One of the advantageous characteristics of the semiconductor gas sensor is its high sensitivity to low concentration gases. Fig. 4 illustrates the relationship between the gas concentration and sensor resistance in logarithmic scales. It implies a large change in sensor resistance even in low gas concentrations. The components of very low gas concentrations are typical sources of indoor air contamination. That means the semiconductor gas sensor is suitable for the detection of indoor air contaminations. Long term stability is another important characteristics of the sensor to be used for air quality control. Fig. 5 shows typical long term stability characteristics of the semiconductor gas sensor. The sensor resistance maintains stable values in clean air and in low concentration gases, which shows the semiconductor gas sensor is reliable for air quality control systems.

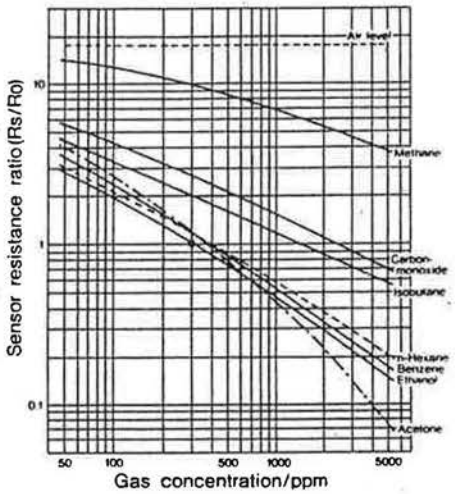


Fig.4 Typical sensitivity characteristics of semiconductor gas sensor

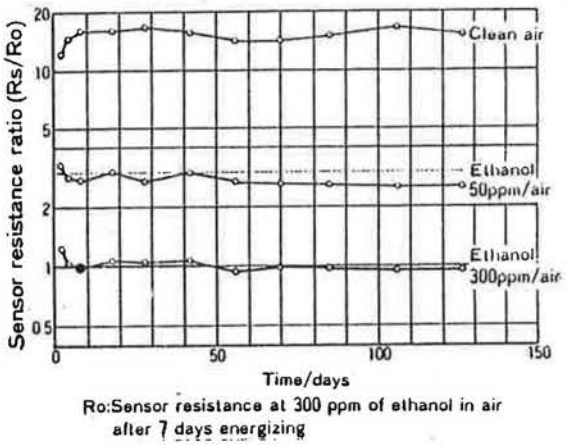


Fig.5 Typical long-term stability of semiconductor gas sensor

3-3 AIR QUALITY CONTROL METHOD

3-3-1. STRUCTURE OF CONTROL UNIT

We have developed a control unit combined with a semiconductor gas sensor and a microcomputer to realize the automatic control of an air purifier and a ventilation fan. The gas sensor unit model AM-800 manufactured by Figaro Engineering Inc. is an example of a control unit. Fig. 6 shows the structure.

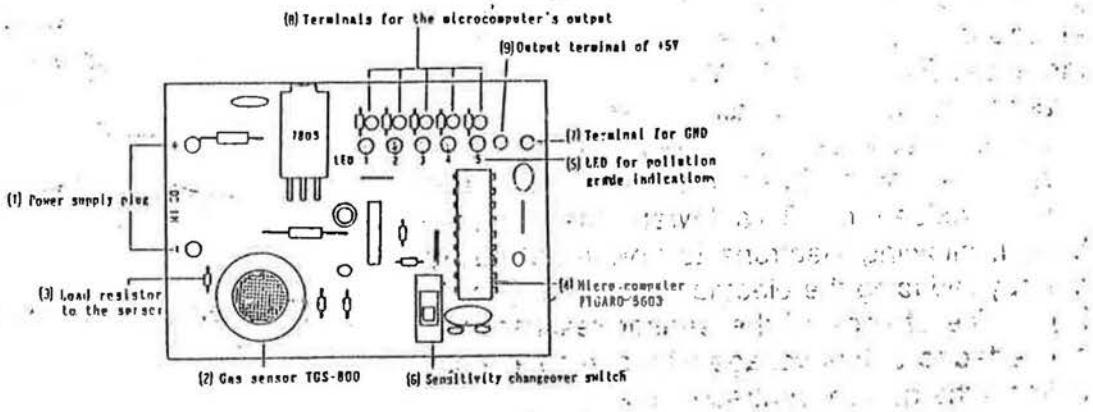


Fig.6 Structure of control unit AM-800

A gas sensor, a microcomputer and a power control unit are mounted on a printed circuit board , equipped with terminals for output voltage and LED to indicate the degree of air contamination.

3-3-2 MICROCOMPUTER BASED CONTROL

In contaminated air, there are traces of gas below several ppm concentration level. Even in this low gas concentration range, a semiconductor gas sensor is sensitive to a certain extent. As the sensor's sensitivity is very high, the resistance shows a slight and slow change over a period of time even in clean air due to the influences of ambient temperature and humidity changes as shown in FIG. 7. It is difficult to detect gaseous contaminants of low concentration by comparing to a fixed reference value because the resistance change in low concentration range is rather small while the resistance always has some fluctuation.

To solve this problem, we have developed a computer software that picks up relatively rapid changes in the sensor's resistance that will appear in slow fluctuation of the sensor resistance, and recognizes it as a response to air contaminants. This software has already been used for commercial applications. We call this algorithm the successive renewed reference value method, and will explain it below using FIG. 8.

The first period T1 in FIG. 8 is the initial transitional time that appears when the power is first supplied to the sensor heater. The sensor resistance at the end of period T1 is registered as a reference value(A), which is used as a reference value during period T2. The reference value is renewed thereafter at predetermined times T.

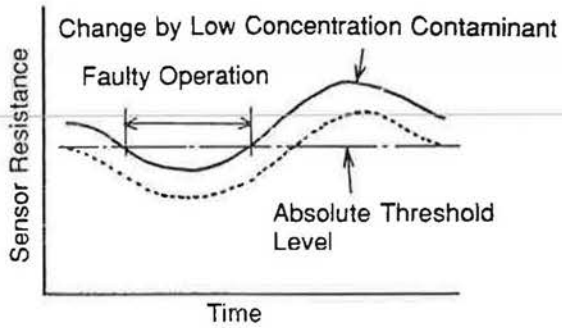
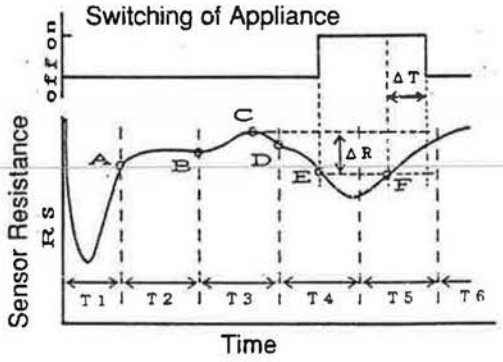


Fig.7 Fluctuation of semiconductor gas sensor resistance in indoor air



T1:Initial transitional time
T2=T3= =Tn=T : Renewal time

Fig.8 Concept of the successively renewed reference value method

The reference value to be used for the next period is not necessarily the sensor resistance at the end of the previous period such as T2, T3,.., but the highest resistance in the last period is chosen as the reference value for the next period. For example, value C in period T3 (between point B and point D) is chosen for period T4. When the sensor resistance ratio between the current value and the reference value becomes greater than the predetermined value (delta R) at point E for instance in FIG. 8, then the controller will start an air quality control system.

4. APPLICATION TO AIR CLEANERS

4-1. USE FOR AIR CLEANERS

As shown in Table, the air cleaner market has grown in three fields in Japan; domestic, business and automobile use. The typical contaminants to be eliminated are cigarette smoke, odor and dust particles. The operation of air cleaners used to be controlled manually or by a timer in the early stages of its market growth. From the time a control system using a semiconductor gas sensor was developed, automatic control type air cleaners have increased their market share.

4-2. DETECTION TARGET

Gaseous components in cigarette smoke and odor are primary components of air contamination that can be detected by a semiconductor gas sensor. FIG.9 illustrates an example of gas composition in cigarette smoke. Hydrogen and carbon monoxide contained in cigarette smoke are among those detectable by a semiconductor gas sensor. As the gas sensor used for air cleaners is more sensitive to hydrogen than to carbon monoxide or alcohol, it implies that hydrogen gas can be used as an index of gas components of cigarette smoke.

Table 1. Use of air cleaner and objects detected by gas sensor

Use		Objects
Domestic use	Living room Reception room Bed room	Cigarette smoke Cooking odor Human body Pet odor
Business use	Shop Office Meeting Reception room Hospital	Cigarette smoke Alcohol etc.
Automobile use	Cabin (Outside)	Cosmetics Engine exhaust gas

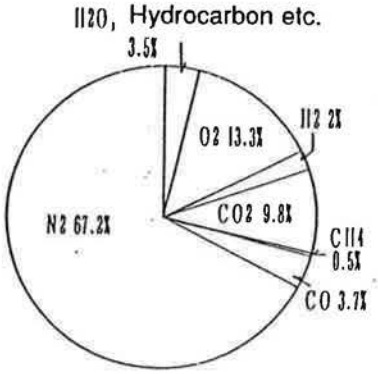


Fig.9 Gaseous components of cigarette smoke

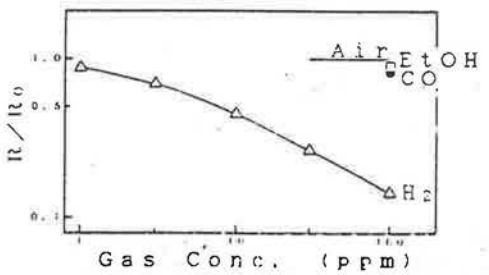


Fig.10 Gas sensitivity of air cleaner sensor (TGS 800R)

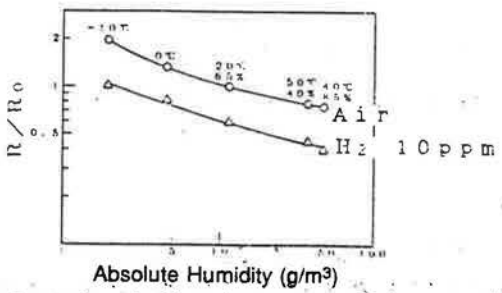


Fig.11 Dependency on humidity and temperature Ro=Rs(AIR) at 20 ℃ 65% (TGS 800R)

The sensor resistance in clean air or in gas of low concentration shows some fluctuation caused by absolute humidity change in normal room air. The sensor responses to cigarette smoke and those to hydrogen in a low concentration range are compared in FIG. 12. After 0.8 of cigarette was smoked in a closed room 4.1 m^3 capacity, the change ratio of the sensor resistance (Rs) from its base level in clean air was measured to be about 0.6 with good repeatability. This change ratio is equivalent to the response to around 18 ppm hydrogen. If the same amount of cigarette is smoked in 24.6 m^3 room, the concentration of cigarette smoke will be around 3 ppm in terms of hydrogen concentration. And the resistance change ratio is around 0.8. The successive renewed reference value method described in the previous section is used for detecting this small sensor resistance change in normal room air where the resistance fluctuates with ambient temperature and humidity change shown in FIG.11.

In addition to this signal processing method, the software contains functions listed in fig.13 to prevent faulty operation and to match the operation of an appliance in the same way a human would react to polluted air. There is one problem which can't be fully solved in detecting air contaminants by a semiconductor gas sensor. In detecting cigarette smoke by a semiconductor gas sensor, hydrogen is a main component to be detected as mentioned above. When contaminated air is purified through an air cleaner, particles and odor components in the smoke are trapped in the air cleaning filters. But hydrogen and CO gas can`t be removed by the air cleaner, so the sensor resistance keeps a low value even if the air seems clean .
In order to match the air cleaner`s operation to match human reaction, the software adopts an idea called "saturation judgment" by using a timer. (Fig.14) Air cleaners with these functions have been commercialized since 1986 and have increased in number year by year.

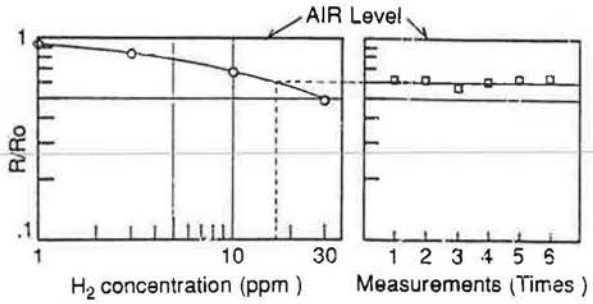


Fig.12 Sensitivity to hydrogen and cigarette smoke (TGS 800)

1. Noise

Averaging sampling values

Delay after switching fan operation (Switching noise)

2. Wind

Delay after switching fan operation (Sensor output change)

3. Sensor trouble

Sensor output trouble (Short, Cutoff etc.)

Fig.13 Functions to prevent faulty operation

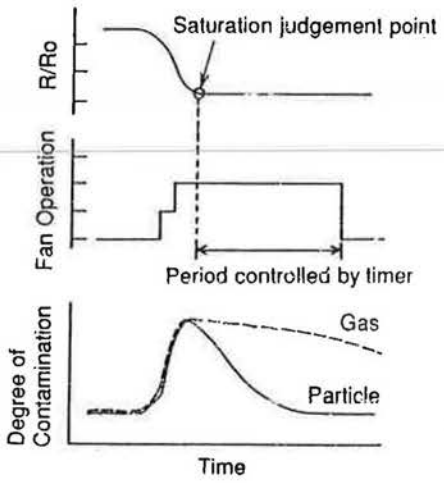


Fig.14 Concept of saturation judgement

5. APPLICATION FOR AUTO-DAMPER SYSTEM

5-1. CONCEPT OF AUTO-DAMPER CONTROL USING A SEMICONDUCTOR GAS SENSOR

Recently there has been public awareness in air quality control in automobile cabins as well as in houses and offices. In the car' cabin it is important not only to purify the air inside but also to control the outside air from entering the cabin. So far the damper control is manually operated by the driver. (Fig.15) In the auto-damper control system, opening and closing of the damper is controlled by a microcomputer according to the purity of the outside air judged by the gas sensor. Moreover this system can be combined with a car air-conditioner and an air cleaner, so that a more comfortable environment inside an automobile is realized.

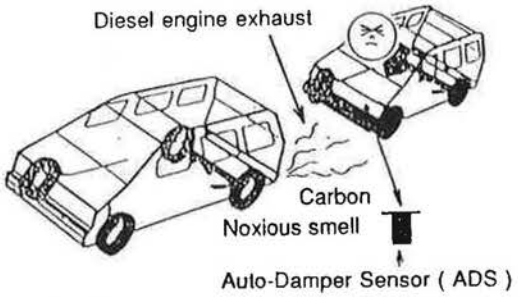


Fig.15 Concept of auto-damper system

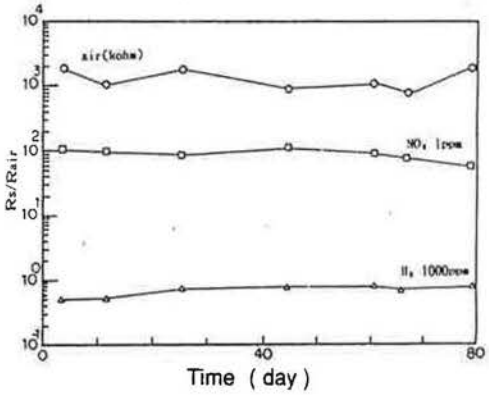


Fig.17 Long-term stability

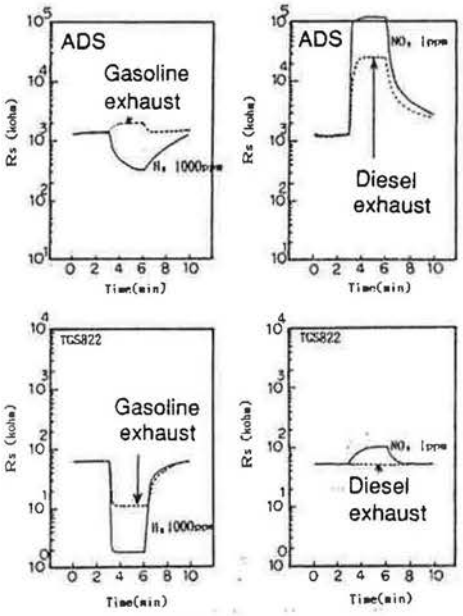
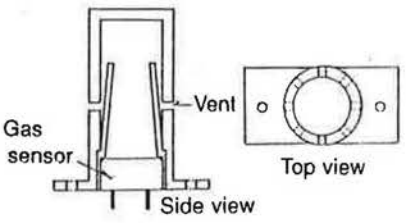
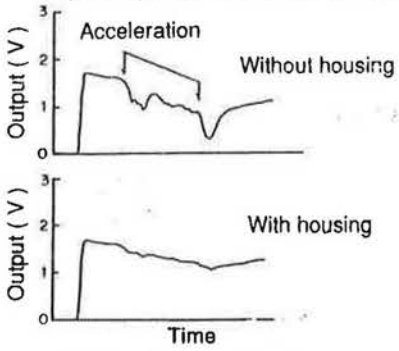


Fig.16 Gas response



i) Configuration of sensor housing



ii) Effect of sensor housing

Fig.18 Investigation of sensor housing

5-2. SENSOR FOR AUTO-DAMPER SYSTEM

The objective gases to be detected by a sensor for an auto-damper system are exhaust gas from gasoline and diesel engines. The multi-purpose sensor (TGS 822) which has a high sensitivity to ethanol, hydrogen and CO can fully detect

gasoline engine exhaust gas. But it can't respond to a diesel exhaust gas. Actually we feel uncomfortable when we are driving behind a diesel automobile, especially against black smoke and noxious smell when starting and climbing a slope. NOx is main component to be detected for a diesel engine exhaust gas as a result of various experiments. Furthermore the concentration level is very low under 1 ppm. The new sensor which can detect the above has been developed. Response curves to gasoline and diesel engines' exhaust gas of a multipurpose sensor (TGS 822) and a newly developed sensor for a diesel engine exhaust gas (ADS) are shown in fig. 16. TGS 822 shows a large response to a gasoline exhaust gas and ADS does to diesel exhaust gas. For an auto-damper control sensor, stability of sensor resistance and gas sensitivity are important characteristics. The long-term stability of this new sensor is stable enough as shown in fig. 17.

5-3. HOUSING OF SENSOR

The auto-damper sensor is affected by wind when the automobile is running. As one of the measures to the adverse wind effect , an outside housing covering the sensor has to be installed. As a result of various investigations, the shape of the housing as in fig. 18-i) is effective to avoid fluctuation of sensor signal by a wind. (Fig.18-ii)) In a design of such housing, diminishing adverse wind effect and also keeping quick response has to be considered.

5-4. MOUNTING TEST OF SENSOR TO AUTOMOBILE

The sensor unit for an auto-damper system is mounted in the front of an automobile and tested in actual running mode. The sensor output signal, presence of a diesel vehicle and a feeling of bad smell and black smoke by the occupants are recorded in fig. 19. The sensor output signal shows a delicate change. But by differentiating this signal, the sharp peaks apparently appear. Large peaks correspond to the presence of a diesel vehicle and also odor and black smoke. So the newly developed sensor for an auto-damper system is suitable to the application of controlling opening and closing the auto-damper by detecting outside pollutants.

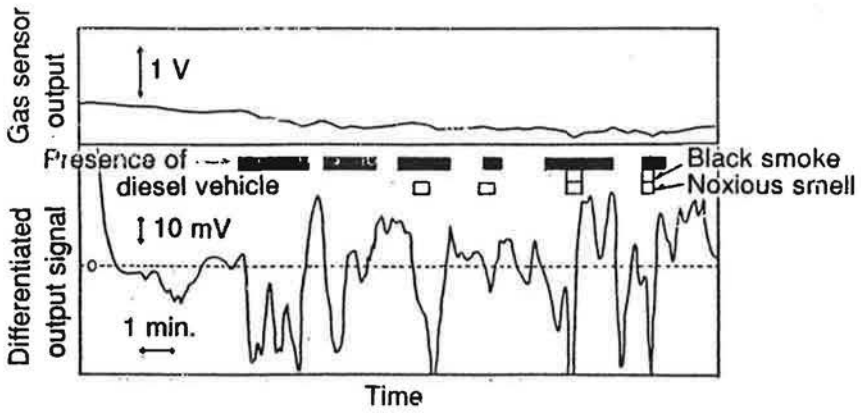


Fig.19 Mounting test

6. DIRECTION OF AIR CONDITIONING CONTROLLING SYSTEM USING GAS SENSOR

6-1. TREND OF DEMAND

In Japan the sales amount of air cleaners has increased year by year as in fig. 20. Sales for business use and automobile use will increase compared to that for domestic use. Especially the market of auto-damper system is expected to increase as shown in fig. 21. In addition an application of a gas sensor system for total air conditioning control in buildings is one of the most important future developments.

6-2. ADVANCEMENT OF SENSORS

So far the main object to be detected by a semiconductor gas sensor in an air cleaning system has been cigarette smoke. Furthermore automobile exhaust gas and various odor components need to be detected. Especially a CO2 gas sensor will have a large demand and many methods have been investigated to develop a CO2 sensor in Japan. In addition to gaseous components, detecting particles, for instance, pollen and dust by optical type sensors is becoming important. In the future air quality sensors such as gas sensors and particle sensors will be combined with not only conventional temperature and humidity sensors but also light, wind velocity, radiation and human presence sensors. And such combined sensor system will perform important functions to realize more comfortable indoor air quality.

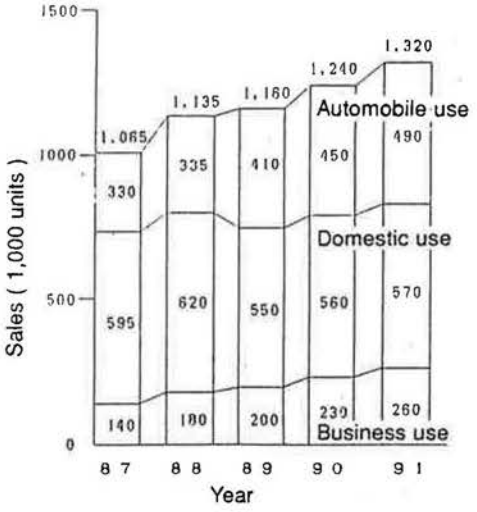


Fig.20 Market of air cleaner in Japan

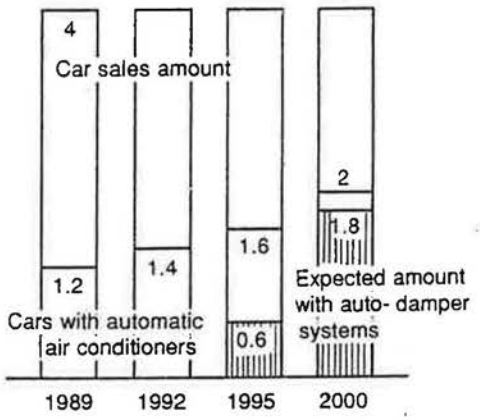


Fig.21 Expected market size of auto-damper system from automatic air conditioner (million)