H2 - Monitoring System

1. Introduction

The H_2-monitoring system developed by FANP for the containment supervision of NPPs (BWR, PWR and VVER) is equipped with H_2 sensors capable to monitor the local and time distribution of hydrogen concentration after a loss-of-coolant accident.

The areas to be monitored and the positioning of the sensors have to be tailored to the individual requirements of the reactor plant. In German Konvoi PWR plants the hydrogen concentration is monitored in the lower and middle sections of the steam generator compartments and in the dome region of the containment (e.g. picture 1).

The system monitors the hydrogen concentration continuously, without a sampling system and therefore without radiation exposure of the operating personnel.

Sensors are available with measuring ranges of 0 - 10 % and 0 - 30 % (wide range sensor).

The sensors are connected to the signal processing units (gas alarm units) merely by electric cables. Inside containment special LOCA proof cables are used (picture 6).

These cables pass through a number of spatially separated cable penetrations out of the containment to the control rooms where the sensor signals are processed to display the current H_2- concentrations.

2. Principle of design an operation

Picture 2 and 4 show the main components of the system - the signal processing or gas alarm unit and the H2 sensor.

The LOCA-proof H_2 sensor operates on the basis of catalytic oxidation of hydrogen on a heated filament located within the measuring cell of the sensor (picture 5). The atmosphere to be monitored diffuses into this measuring cell through the surface of the sensor consisting of sintered metal.
Within the measuring cell the hydrogen is oxidised on a platinum element. This process is supported by a special catalyst. This chemical reaction causes a temperature increase which results in an increase of the filament resistance. The filament resistance is part of a Wheatstone-bridge which produces a signal corresponding to the hydrogen concentration.
Additional to the H2 concentration the sensor measures the air temperature at the H2 sensor location by means of a resistance thermometer. This resistance thermometer is installed only in H_2 sensors with a measuring range of 0 - 10 %.

For functional testing and calibration of the H2 sensors a test adapter is connected to the sensor and test gas applied directly to this sensor. In areas where access is difficult, the adapter can be mounted permanently and test gas supplied via fixed tubes.

3. Measuring principle

The measuring principle of the H2 concentration bases on sensors of the catalytic combustion type. The filaments which are built into the sensors form one half of a Wheatstone bridge circuit and are heated by current supplied from the gas alarm unit to a temperature best suited for catalytic oxidation. If the sensors come into contact with H2, catalytic combustion takes place at the filament which increases its temperature and, consequently, raises its resistance.

The increased resistance unbalances the bridge proportionally to the concentration of H2 (please refer to pictures 9 - 13).

The voltage signal derived in this manner is used to indicate the H2 concentration on the meter module (central measuring device) of the gas alarm unit and to activate the alarms.

The gas alarm unit FS 16 is always supplied with the meter module and the necessary number of channel cards.

Additional the gas alarm unit produces output signals for the control room (which can also be used as input signals for digital Post Accident Monitoring Systems (PAMS) or Plant Computer Systems (please refer to table 1, example NPP Dukovany).

3.1 Meter Module (central measuring device)

The meter displays the gas concentration at the location of the gas alarm unit. The indication is calibrated corresponding to 0 ... 10 (30) vol.-% H_2.
The meter also displays the set values of the channel selected by operation of the channel READ pushbutton. The number of channel card thus selected is shown on the digital display of the meter module.

3.2 Channel cards (alarm cards)

Each channel of gas detection provides the indication of alarm status, fault condition and allows channel information to be displayed on the meter module. Several adjusting potentiometers allow calibration and set of the alarm levels.

3.3 Fault indication

An open circuit within the measuring bridge (cable or sensor) results in a fault indication in the form of the amber LED lamp on the channel card and the meter module. The power supply of the fault relay will be switched off.

3.4 Test Points for periodic tests

On the front panel of each channel card are located test points which support the accurate determination of the bridge voltage by means of a digital high impedance voltmeter.

During commissioning, the line and insulation resistance should be checked prior to testing the H_2 measuring circuit. Similarly, on completion of the test on the H2 monitoring circuits, a voltage drop measurement should be performed at the sensor outputs of the electronic equipment.

If the Pt 100 measuring circuits are installed during commissioning, the internal and insulation resistance should be tested. Any readings should be checked for plausibility.

4. NPP Dukovany - Structure of the Measuring Channels

During the current upgrading of the I&C systems and installation of a Post Accident Monitoring System (PAMS) 15 of the already existing 16 monitoring channels with a measuring range of 0% ... 10% of H_2-concentration are assigned to the 3 redundancies of PAMS and integrated in the cabinets for the Reactor Vessel Water Level Measurement System (RVLIS). Additionally for each redundancy one new H_2-monitoring channel with a measuring range of 0% ... 20% H_2-concentration will be installed.
In detail the following signals are transferred to the main part of threefold redundant PAMS system in which the H2 monitoring system will be integrated:

Table 1: Signals from H2 monitoring system for 1 PAMS-division

Signal	Signal type	Purpose
H2-Concentration No. 1-6	4 - 20 mA	1 analog signal "H2-concentration (0-20%)" and 5 analog signals "H2-concentration (0-10%)"
Binary No. 1-6	Relay contact	1 signal "First limit value for H2-concentration (0-20%)" 5 signals "First limit value for H2-concentration (0-10%)"
Binary No. 7-12	Relay contact	1 signal "Second limit value for H2-concentration (0-20%)" 5 signals "Second limit value for H2-concentration (0-10%)"
Binary No. 13-18	Relay contact	6 signals "Alarm - electronic fault"

5. Technical data

H_2 Sensor (0 to 10 %), LOCA proof

Type	WS 85
Measuring principle	catalytic oxidation, thermal effect
Measuring range	0 to 10 vol.-% H_2
Measuring accuracy	± 0.25 vol.-% H_2 in the range of 0... 4 vol.-%
	± 0.5 vol.-% H_2 in the range of 4... 10 vol.-%
Design pressure	6 bar
Design temperature	160 °C
Radiation resistance	250 kGy
Dimensions (dia. x h)	110 x 154 mm (without mounting and cable connection)

Resistance Thermometer (inside H_2 Sensor)

Type	PT 100 in four-wire-circuit
Measuring range	0 to 160°C
Measuring accuracy	± 3 K

H_2 Sensor (0 to 30 %), LOCA proof

Type	WS 01
Measuring principle	catalytic oxidation, thermal effect
Measuring range	0 to 30 vol.-% H_2
Measuring accuracy	± 3.0 vol.-% H_2 in the range of 0... 10 vol.-%
	± 2.5 vol.-% H_2 in the range of 10... 30 vol.-%
Design pressure	6 bar
Design temperature	160 °C
Radiation resistance	250 kGy
Dimensions (dia. x h)	110 x 154 mm (without mounting and cable connection)

Gas alarm unit

Dimensions (h x w x d)	266 x 483 x 356 mm
Power Requirement	
DC	24 V nominal (Range of operation: 21.6 V to 32 V)
or	
AC	115 V or 230 V (± 15 %) at 50 to 60 Hz (± 6 %)
Power Consumption	120 W max. for full configuration and maximum cable lengths

Measuring Range Gas concentration	0 to 10 (0 to 30) vol. % of $H2$
Analogue output	0/4 to 20 mA
Relay outputs	
Alarm 1, Alarm 2	Single-pole changeover contact, 2A, 250 V, as NC or NO contacts, energised or deenergised
Master Alarm	double-pole changeover contacts, 4 A, 250 V, as NC or NO contacts, energised or deenergised
Master Fault	Single-pole changeover contact, 4 A, 250 V as NC or NO contacts, energized
Alarm Indicators	High brightness red LEDs
Fault Indicators	High brightness yellow LEDs
Ambient Temperature	0 to 50 °C
Humidity Range	0 to 90 % (relative humidity)

Terminals Screw-type for cross-sections up to 1.5 mm^2 per core

6. References

The H2 monitoring system has been installed in the following nuclear power plants:

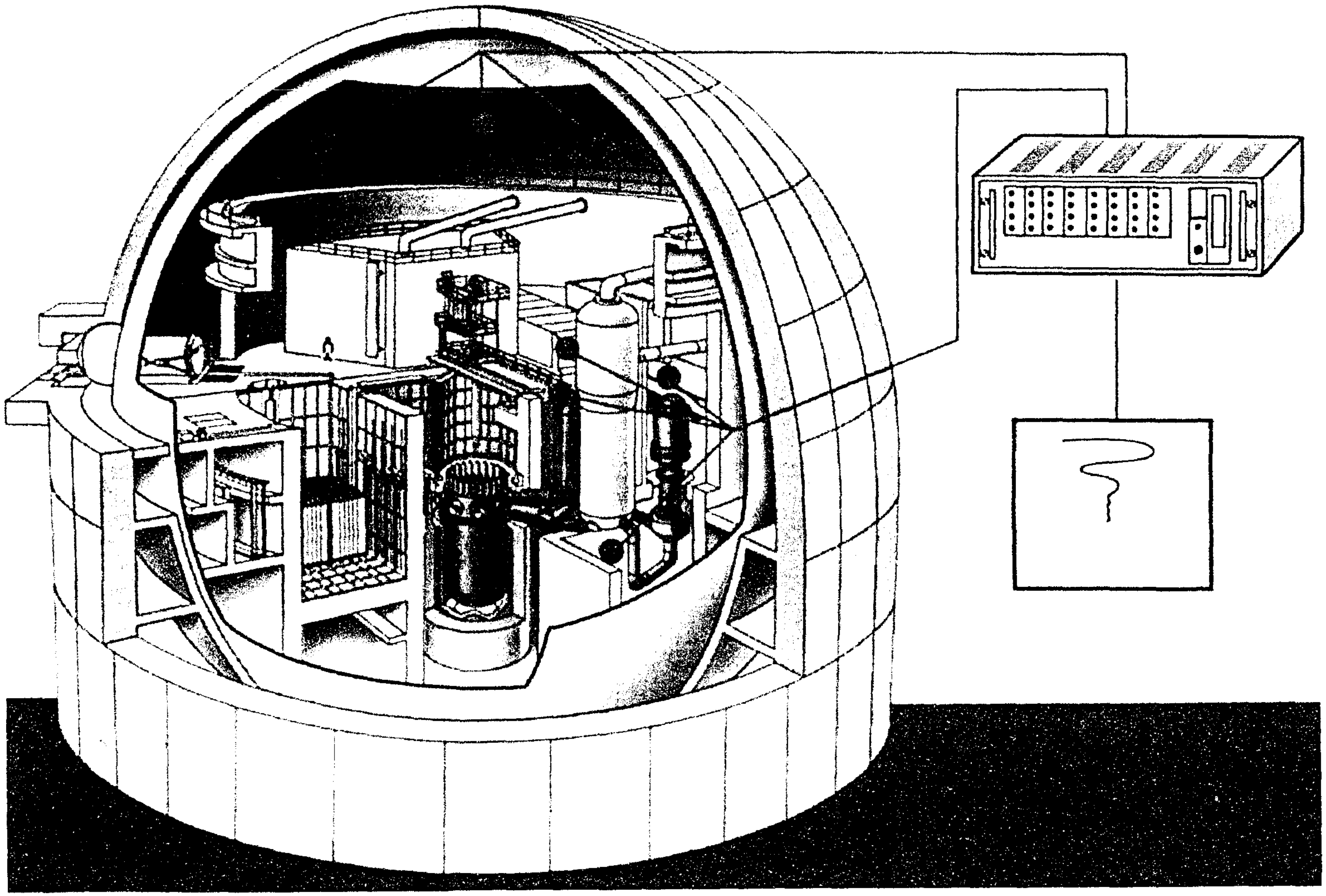
Czech Republic:	Dukovany 1, 2, 3, 4
Finland:	Loviisa 1 & 2
Germany:	Neckar 1 & 2, Emsland, Isar 2, Biblis A & B, Obrigheim, Unterweser
India:	Tarapur
Slovac Republic:	Mochovce 1 & 2
Spain:	Almarez, Cofrentes, Trillo
Sweden:	Ringhals 2, 3, 4
Switzerland:	Beznau 1 & 2, Gösgen
Ukraine:	Zaporozhje 1, 2, 3, 4, 5, 6

7. Pictures and Diagrams

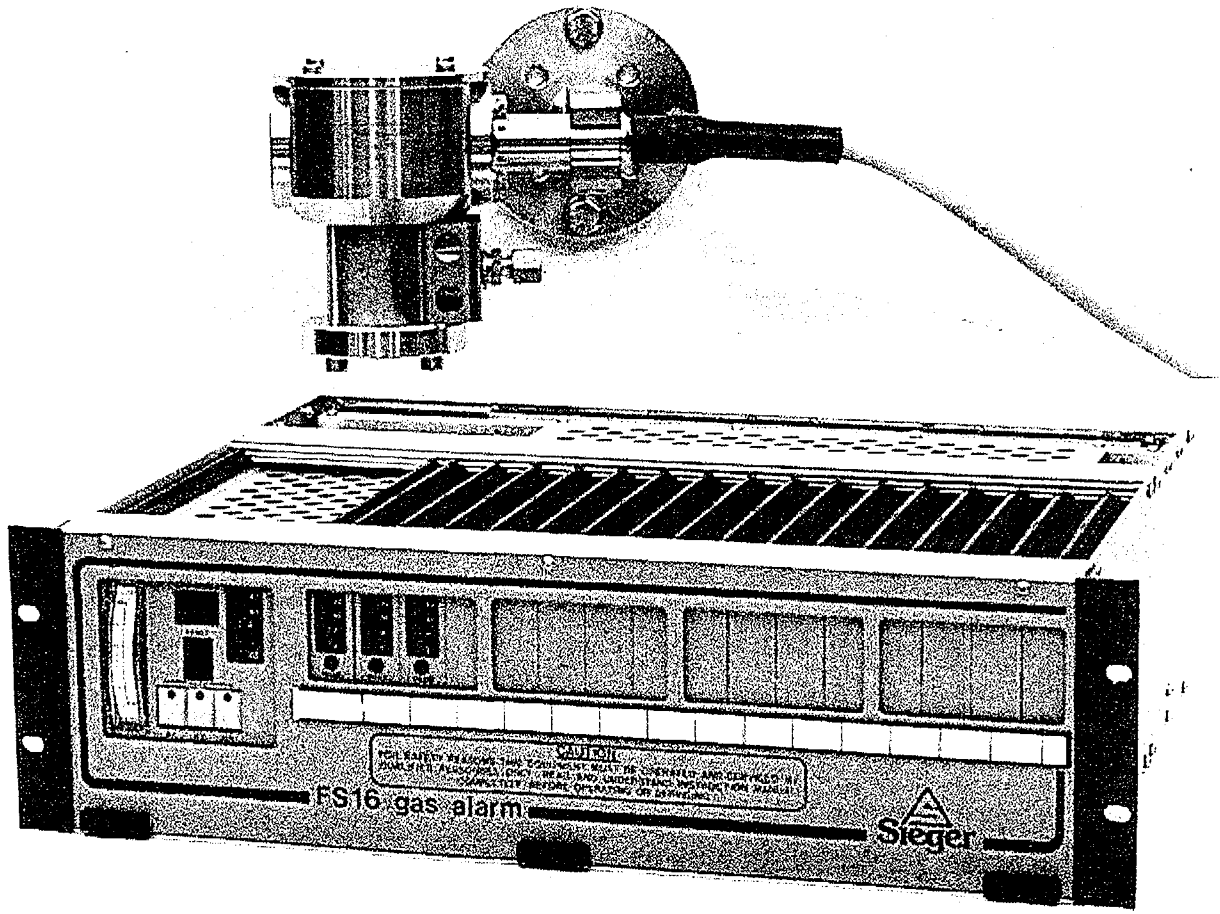
1. Location of H2 sensors in a PWR (example)
2. Components of the Hydrogen Monitoring System
3. Gas Alarm Unit
4. Hydrogen Sensor
5. H2 - Sensor Cross Drawing
6. Schematic Diagram of Hydrogen Monitoring System
7. Principle Wiring Diagram
8. Simplified Connecting Diagram
9. Measuring principle

10. - 13. Wheatstone-Bridge, Explanation of measuring principle

Location of H2 sensors in a PWR (example)

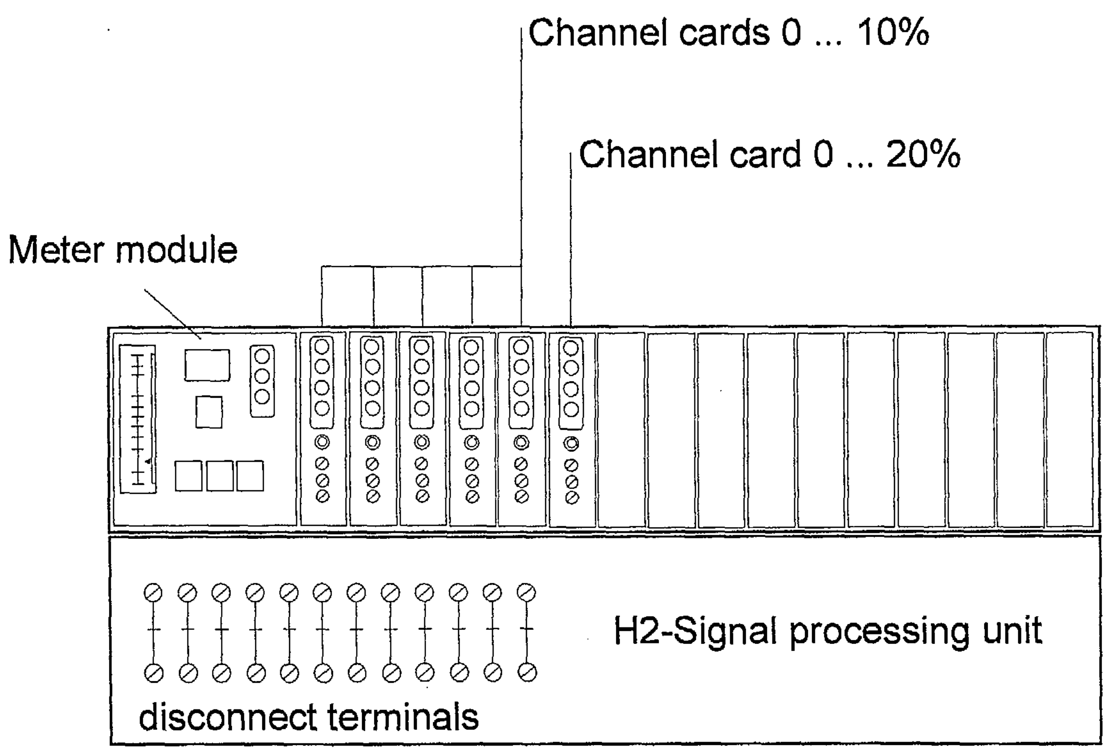


Components of the Hydrogen Monitoring System

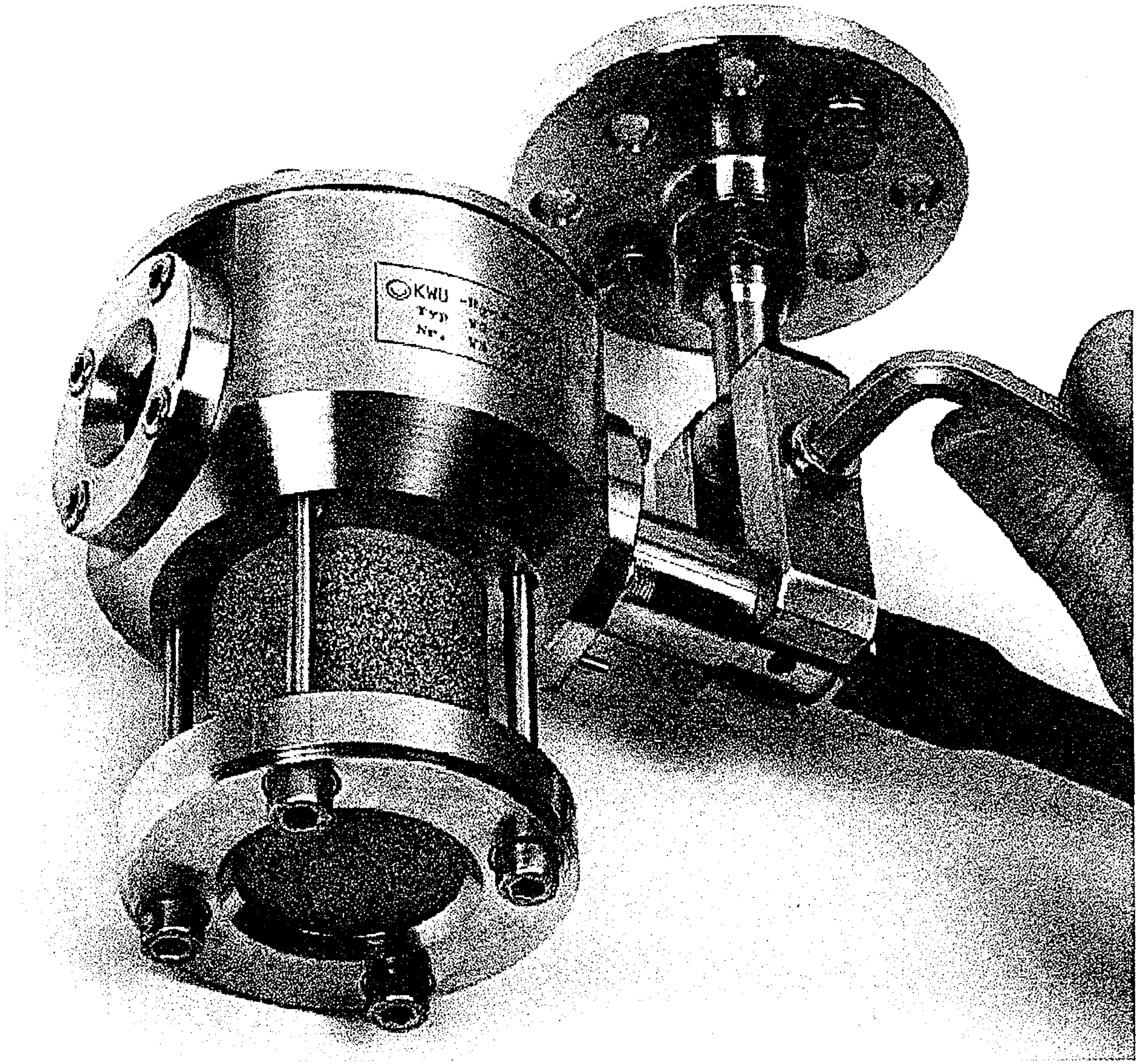


FRAMATOME ANP

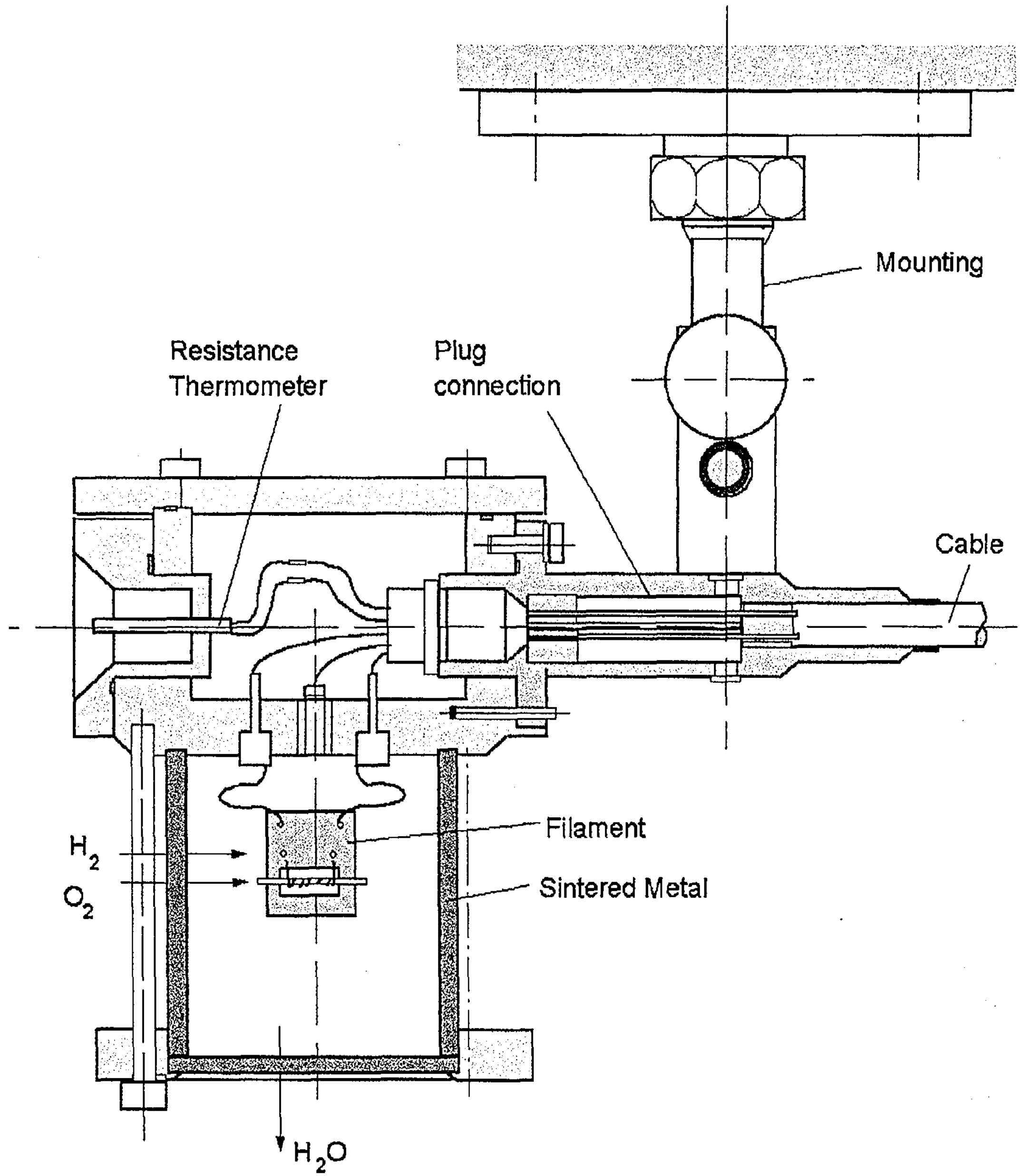
Gas Alarm Unit



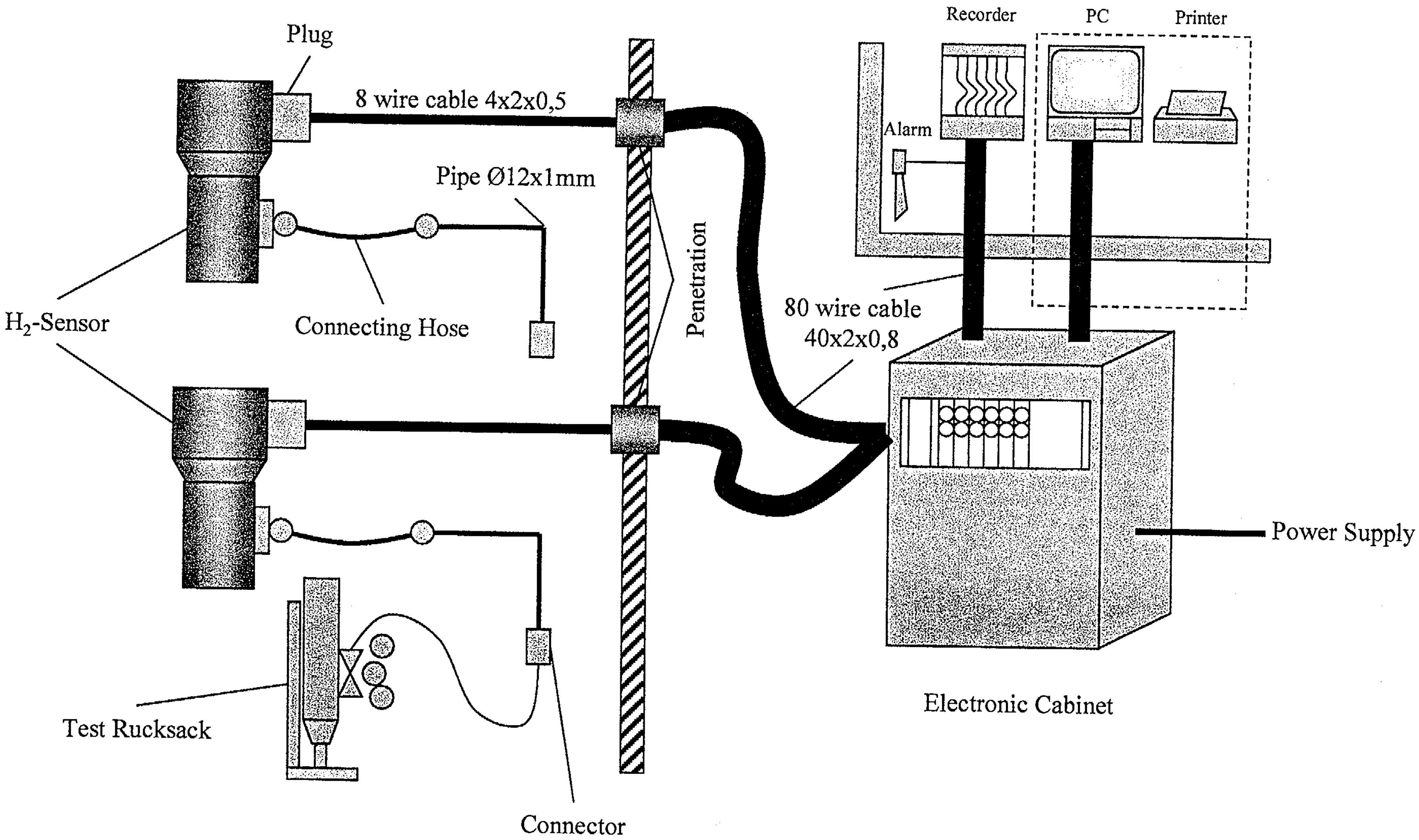
Hydrogen Sensor



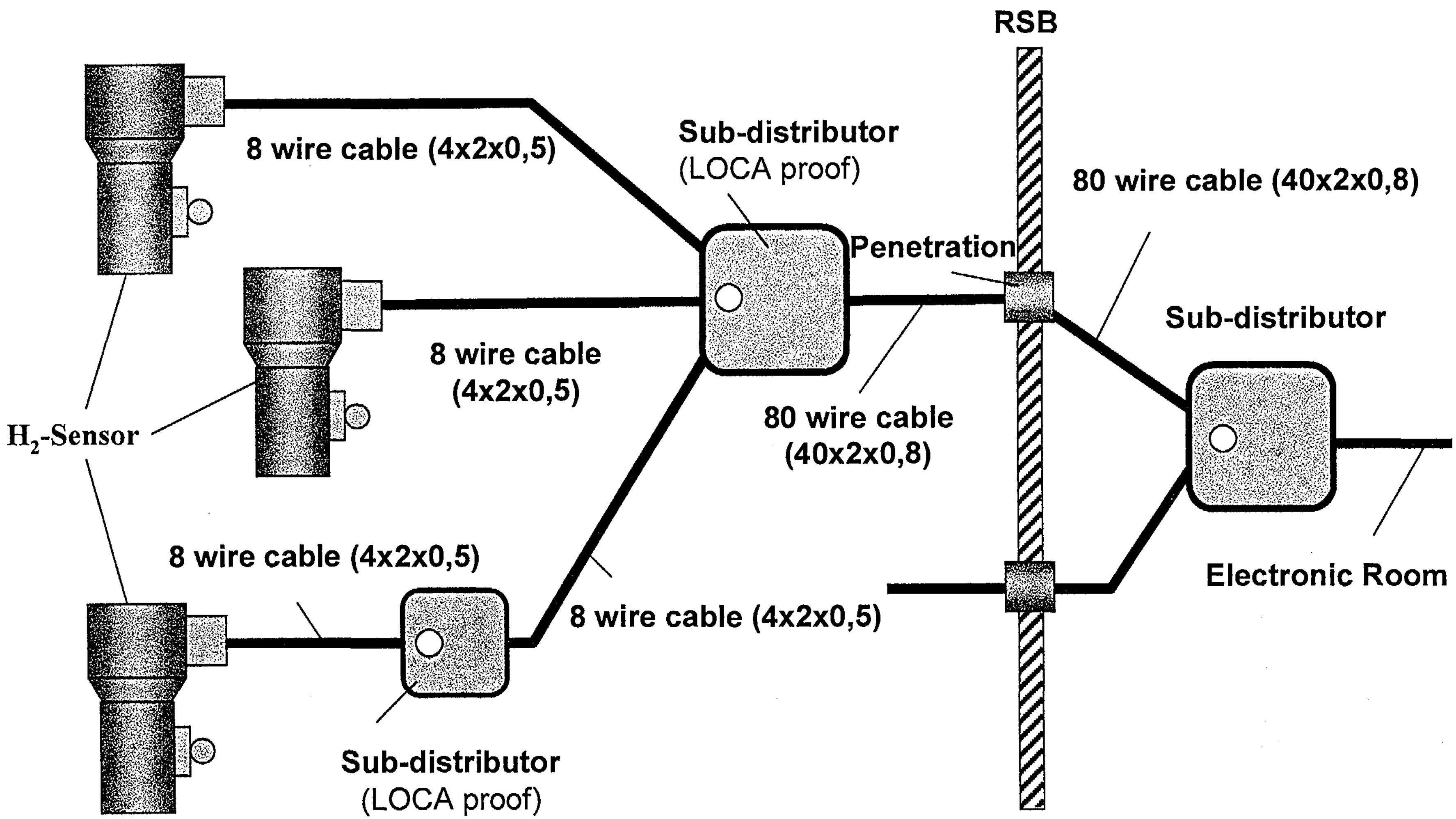
H_2 - Sensor
Cross Drawing



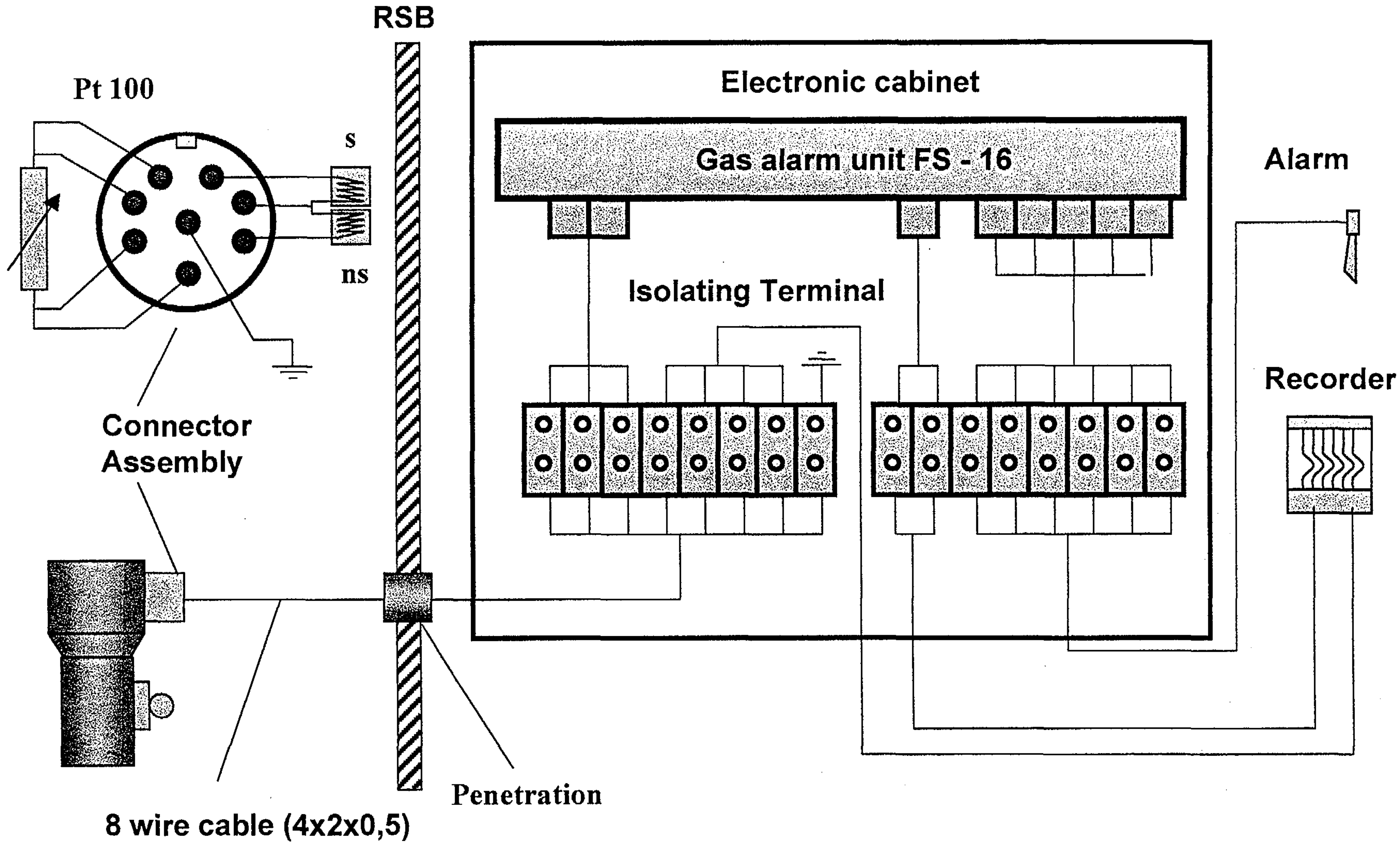
Schematic Diagram of Hydrogen Monitoring System



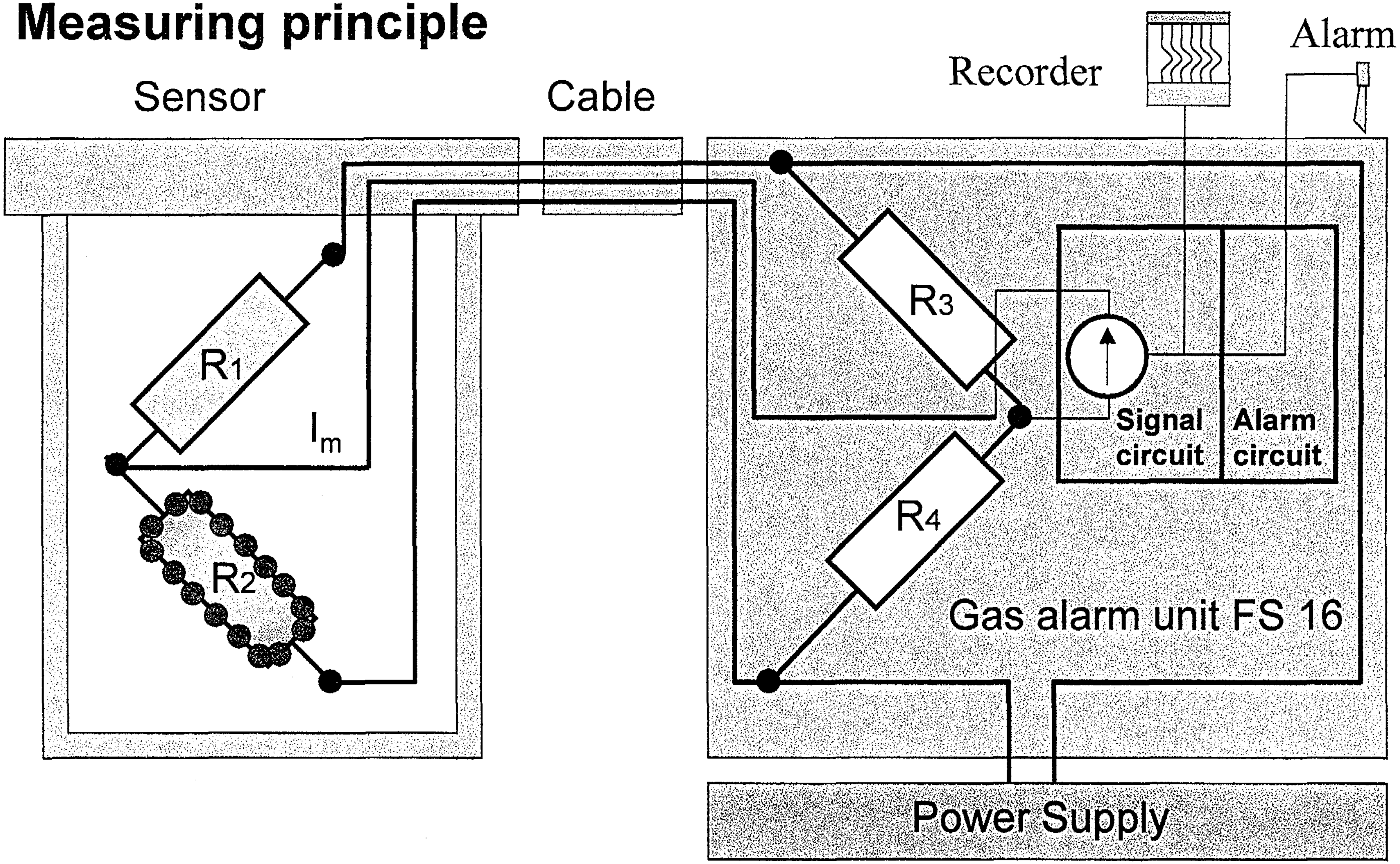
Principle Wiring Diagram



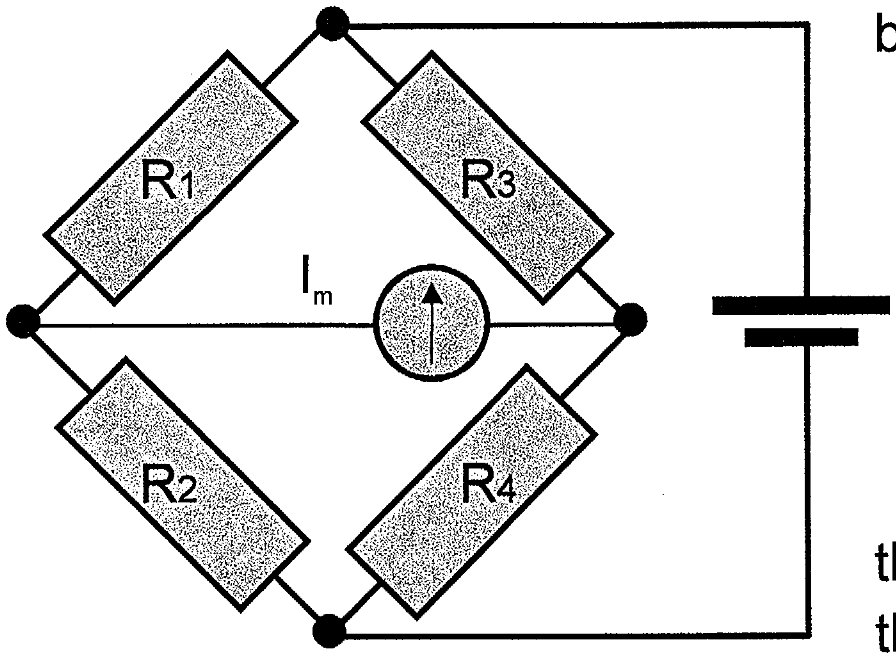
Simplified Connecting Diagram



Measuring principle



Wheatstone-Bridge



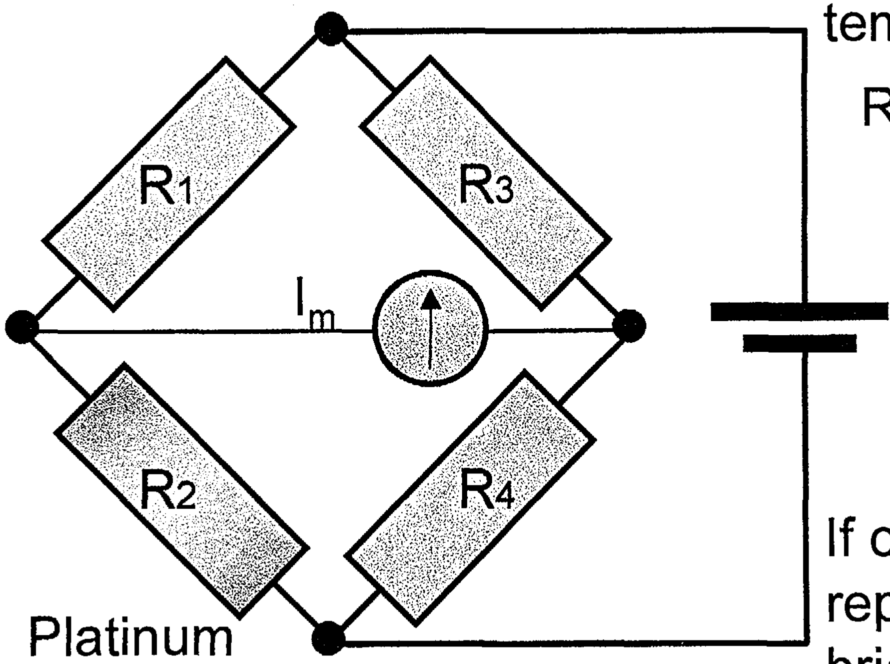
If in a Wheatstone bridge the ratio between the resistors is 1 to 1

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

$$1 = 1$$

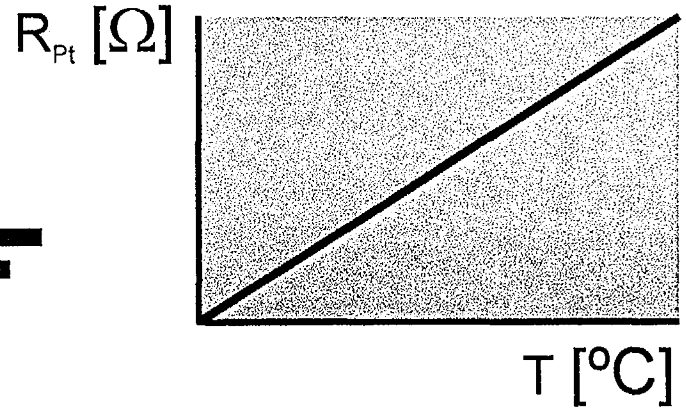
then the bridge is balanced and the bridge current is $I_m = 0$.

Wheatstone-Bridge



$R_2 = f_{(T)}$

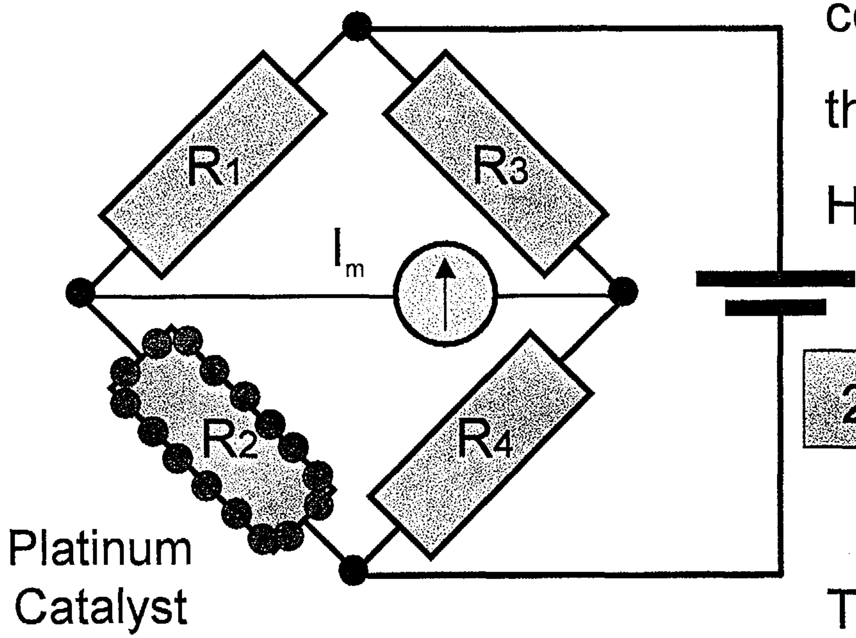
Platinum (Pt) changes its resistance in a linear manner depending on the temperature.

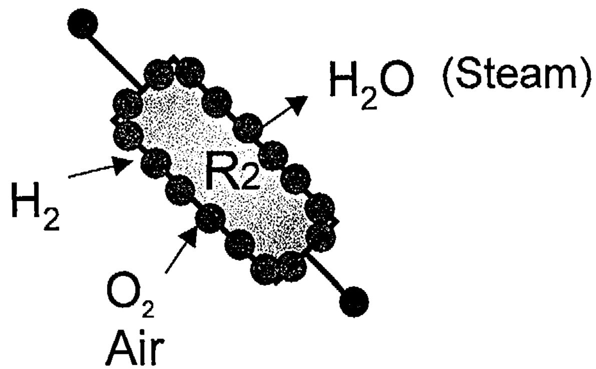


If one of the bridge resistors is replaced by a Pt-resistor then the bridge current also depends on the temperature in a linear manner.

$I_m = f_{(T)}$

Wheatstone-Bridge





If additionally the plate (Pt) resistor is covered with catalytic material then the following reaction takes place after H_2 occurs at the sensor location.

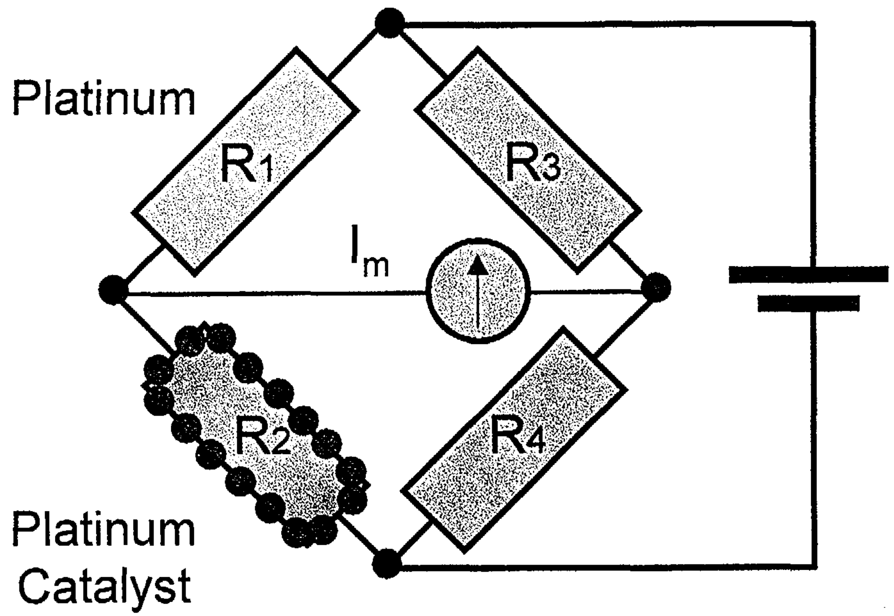
$$2H_2 + O_2 \Rightarrow 2H_2O + \text{heat disposal}$$

The heat disposal causes a change in

- temperature
- resistance of R2
- bridge current I_m

Therefore the bridge current is proportional to the H_2 concentration.

Wheatstone-Bridge



If additionally the bridge resistance R1 is replaced by a Pt-resistor then the bridge current no longer depends on the temperature of the environment at the sensor location. It only depends on the H_2 concentration.

$$R_1 = f_{(T\text{-surrounding})}$$
$$R_2 = f_{(T\text{-surrounding})} + f_{(T\text{-hydrogen combustion})}$$

I_m is therefore proportional to the H_2 concentration