Motor Exhaust Gas Analyzer MEXA-7000 Series
2. Downsizing and Modular Configuration of Analyzers

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<Abstract>

Based on "the modular configuration of systems," the development concept of the MEXA-7000 series, analyzers are now positioned as sensors for measuring the concentrations of emitted gases, and as emission gas analyzers have undergone unprecedented downsizing (1/4 that of conventional downsizing). Also, "sensors" now can be produced in compact sizes and as maintenance-free as possible.
This paper reports on the features of constant temperature type analyzer modules, and describes the main points in the development of their hardware and the characteristics of heating-type analyzers.

1. Analyzer Module

The motor exhaust gas analyzer module MEXA-7000 series (simply called the MEXA-7000 from here on) is a sensor for measuring the concentration of various gas components. It features centralized displays, compact power supplies and easy operation. It is configured using one-touch operation on a wide range of functions. Figure 1 shows analyzer module of the MEXA-7000. Output from the detector is sent through a pre-amplifier, digitized by a 24-bit A/D converter (ADC), and then passed to the main controller (MCU) over a LAN. The MCU is designed to process all measurement operations. This includes setting measurement conditions, preparing calibration curves, compensating for interference, calibration and result display.

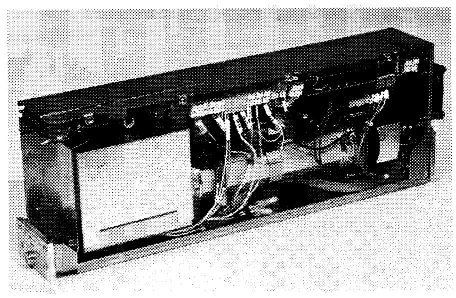


Fig. 1 Analyzer module

2. Features of Analyzer Module

2.1 Smaller Gas Flow by Single-stage Pressure Adjustment System

Due to the smaller overall flow requirements of the system, the flow of each analyzer was reduced. The basic flow of analyzers was reviewed while considering response speed. Until now, analyzers have used a two-stage pressure adjustment system comprising of a main pressure regulator for controlling the pressure of the entire system and pressure regulators for each analyzer. Using this design, many flows were required. The MEXA-7000 uses a one-stage pressure adjustment system comprising only one main pressure regulator, so that the minimum required flow is supplied to each analyzer. **Figure 2** shows the gas flow in the analyzer rack (ANR). The main pressure regulator uses an automatic pressure regulator (APR) for regulating the control valves. The pressure sensor output on the primary side of the control valve is compared with the pressure setting to maintain pressure at a constant value. The APR features reduced pressure fluctuations in flow and outstanding control accuracy and tracking characteristics. **Figure 3** shows the pressure control characteristics of the APR.

The resulting sample flow is reduced to about 1/3 of conventional analyzers.

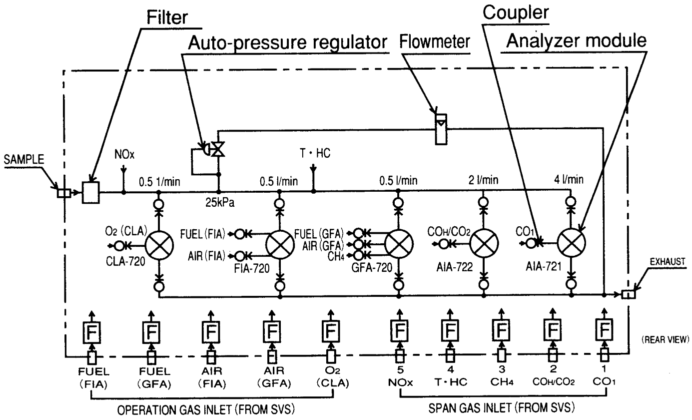


Fig. 2 Gas flow in analyzer rack (ANR)

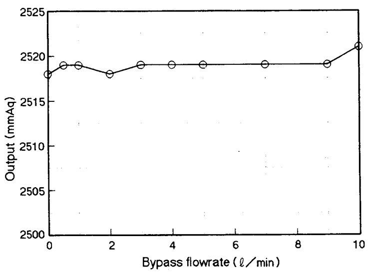


Fig. 3 Pressure control characteristics of automatic pressure regulator (APR)

2.2 Plug-in System

Downsizing of the ANR and smaller flow sampling was achieved by adopting a plug-in type analyzer module. With a "plug-in type module," the rear panel of the module is equipped with a quick-connect mechanism for gas supply and an electrical interface connector to facilitate attachment and detachment from the ANR. (See **Figure 4**.)

A maximum of five slots for gas supply are available. Sample inlet port ① and exhaust port ⑤ are directly connected by a bus block shared with the ANR, resulting in almost no loss in piping ②, ③ and ④ comprise the operational gas suppling port to be supplied individually to each of the analyzers. Also, the DC drive power suppy and signals are connected by the electrical interface connector.

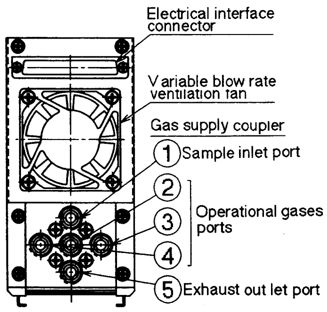


Fig. 4 Rear panel (plug-in type) of analyzer module

2.3 Downsized Common Components and Mass-flow Sensor

Pressure regulators have been downsized to about 1/4 of conventional regulators, while two-way solenoid valves have been downsized to about 2/3 the size. Also, a newly developed thermal flow type mass flow sensor (MFS) is used. The MFS detects the gas flow as changes in temperature on a semiconductor chip. This allows the MCU to monitor the flow of each of the analyzer modules.

3. Analyzer Module Specifications and Key Development Points

Table 1 shows the main specifications of the analyzer modules. The key development points for each of the analyzer modules are introduced as follows.

Model	AIA-721	AIA-722	CLA-720	FIA-720	MPA-720	GFA-720
Measuring Component	CO (L)	CO (H) /CO_2	NO (H) /NO_x	T・HC	O_2	CH_4
Measurement Principle	NDIR	NDIR	CLD	FID	MPA	GC-FID
Measuring Range	0-50~2500ppm 0-100~5000ppm	CO 0-0.5~10vol% CO_2 0-0.5~20vol%	0-10~10000ppm	0-10~20000ppmC	0-1~25vol%	0-5~2500ppm
Repeatability	≦±0.5%FS					≦±1%FS
Zero Drift (≦2℃ of operating temp.)	≦±1%FS/24h (≧100 ppm range) ≦±2%FS/24h (100 ppm> ≧ 50ppm range)	≦±1%FS/24h				≦±1%FS/24h
Span Drift (≦2℃ of operating temp.)	≦±1%FS/24h					≦±2%FS/24h
Noise	≦±0.5%FS	≦±0.5%FS	≦±0.5%FS	≦±0.5%FS	≦±0.5%FS (≧5 vol % range) ≦±1%FS (<5 vol %)	———
Linearity	≦±1%FS or≦±2%RS, whichever is smaller					
Response Time T_{90} • from analyzer inlet	≦2.0s (≧100 ppm) ≦3.0s (100> ≧50 ppm range)	≦1.5s	≦1.5s (≧50 ppm range) ≦2.0s (<50 ppm range)	≦1.5s	≦1.5s (≧5 vol % range) ≦2.0s (<5 vol % range)	Measurement cycle 15±1s
Sample Flowrate	4 ℓ/min	2 ℓ/min	0.5 ℓ/min			
Power Supply	DC24V					
External Dimensions	76 (W) X160 (H) X400 (D)					

Table 1 Main analyzer and specifications

3.1 CO,CO_2 Analyzer:AIA-721,AIA-722

These modules use a non-dispersive infrared gas analyzer (NDIR) that utilizes the infrared absorption of molecules for the analysis of CO and CO_2. Figure 5 shows the basic configuration[1] of the CO gas analyzer (AIA).

The key points in the design for downsizing the NDIR are as follows.

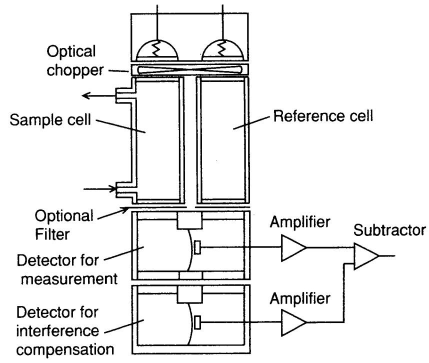


Fig. 5 Operating principles of non-dispersive Infra-red (NDIR) analyzer

(1) Downsizing of optical components and cell dimensions

To allow the analyzer to fit inside the 76 mm (W)×160 mm (H)×400 (D) case, the cell length had to be shortened and components such as the light source downsized. The key point was to downsize components without sacrificing sensitivity. The design was fundamentally reviewed including optical adjustment mechanisms and changes in the signal processing system.

Table 2 summarizes the main improvements and compares differences with conventional models.

Item	AIA-72X series	Conventional model
Ligh Source	58 (W) X40 (H) X30 (D)	60 (W) X60 (H) X32 (D)
Cell Length	200mm	250mm
Chopper	Chopper motor	Chopper/motor separated type
Positional Adjustment	No (processed by mechanical tolerance and signal processing)	Yes (mechanical adjustment by chopper)
Light Intensity Adjustment	Adjustment of light source applied voltage	Adjustment by light shield
Signal Processing	Synchronous rectifying system	Absolute rectifying system

Table 2 Main improvement of NDIR

(2) Improved maintainability

Figure 6 shows the output characteristics of a pneumatic NDIR detector employing an absolute rectifying system and synchronous rectifying system. With the absolute rectifying system, as the output characteristics exhibit inflection (an area demonstrating no response to changes in light intensity), an optical phase shift must be provided by adjusting the optical axis and light intensity. On the other hand, with the simultaneous rectifying system used in the MEXA-7000, optical phase shift in principle is not required. This is advantageous for downsizing the analyzer and for increasing its maintainability.

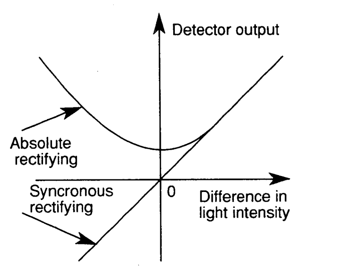


Fig. 6 Output characteristics of pneumatic detector

3.2 THC Analyzer: FIA-720

In the analysis of total hydrocarbons (THC), molecules are burned in a hydrogen flame, and the resulting ion current is measured. This method is referred to as the flame ionization analysis method (FIA).

The following points of the FIA analyzer were modified.

(1) Downsized detector

On the FIA-720, the sensor has been reduced to 1/2 the size of conventional models. (Figure 7)

The problem of reduced sensitivity that accompanies the downsizing of the detector has been solved by optimizing the flow of the fuel (H_2/He) and combustion air. Furthermore, sufficient linearity can be obtained in the 10 to 10,000 ppmC range.

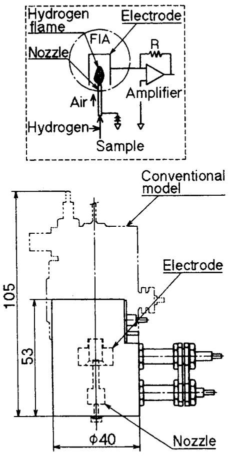


Fig. 7 Flame ionization detector

(2) Integrated sensor and operational amplifier

Generally, micro-signals from the detector are easily influenced by noise caused by vibration of the signal cables and electromagnetic induction. On the FIA-720, the operation amplifier and drive circuits are integrated into the detector and pre-amplifier board. Noise and drift are considerably reduced by further temperature control.

(3) Atmospheric pressure compensation

On the FIA-720, zero drift and span drift can be caused by changes in the atmospheric pressure. On the FIA-720 and FMA-720, fluctuations in atmospheric pressure are compensated by the MCU using an atmospheric pressure sensor. This has resulted in improved stability over prolonged use. (Figure 8)

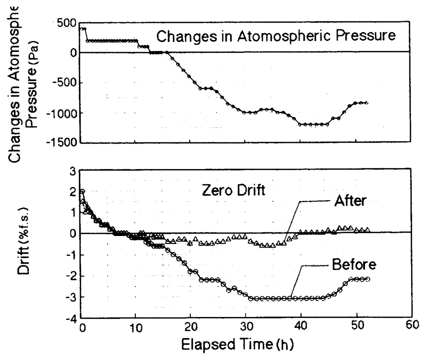


Fig. 8 Effect of atmospheric pressure compensation of FIA-720

Atmospheric pressure compensation is performed for each of the analyzers.

3.3 O_2 Analyzer: MPA-720

The accuracy required in engine control has increased in recent years. There has been a stronger demand for a high sensitivity measurement in the 1 vol% range for oxygen detectors used in air-fuel ratio (A/F) measurement. Magnetic pressure type oxygen analyzers utilize the susceptibility of oxygen in comparison to other gas components. The operating principle of these analyzers is as follows. A magnetic field is applied on the gas cell and the pressure difference caused by collection of oxygen in the sample at a magnetic pole is sensed by a capacitor microphone. For this reason, the magnetic pressure method is disadvantageous in that mechanical vibration is transmitted to the microphone and noise is generated.

Until now, HORIBA has used a bi-polar double-cell system for the oxygen detector in the measurement of exhaust gas to remove the influence of vibration. (Figure 9)

However, the MEXA-7000 uses a newly developed single-cell magnetic pressure type oxygen detector that uses one pole and a differential condensor microphone. This eliminates the influence of vibration and has resulted in a miniaturized oxygen detector with the same or higher sensitivity of conventional detectors. (Figure 10)

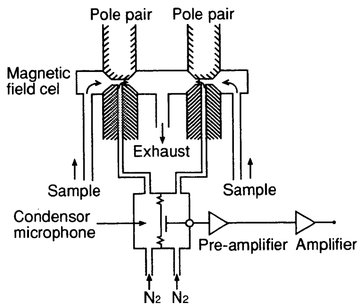


Fig. 9 Bi-polar double-cell magnetic pressure type oxygen detector

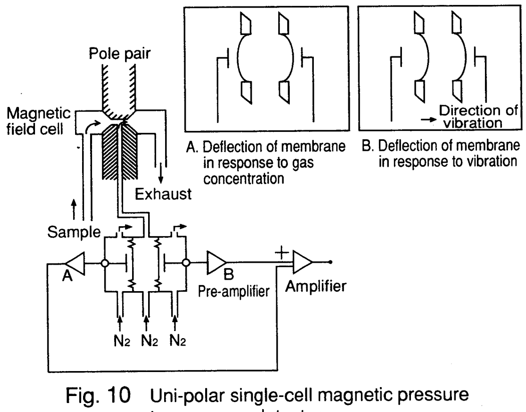


Fig. 10 Uni-polar single-cell magnetic pressure type oxygen detector

3.4 NOx Analyzer: CLA-720, CLA-750

Chemiluminescent analysis (CLA) utilizes the chemical reaction between NO and O_3. This process emits light in the 800 to 2500 nm range when it returns to a ground state. ($NO+O_3 \rightarrow NO_2^*$, $NO_2^* \rightarrow NO_2+h\nu$)
One problem exists in that the amount of emitted light is reduced at high gas densities, and the sensitivity drops (quenching). Until now, the pressure of the chemical reaction chamber was reduced to about 0.1 kPa in the measurement of low-concentration NOx. This posed many problems including the maintainability of the vacuum pump used for reducing the pressure.

With the CLA-720, we studied hardware and software carefully. We were able to achieve a minimum concentration range of 10 ppm by an atmospheric pressure system. A maximum concentration range of 10,000 ppm was also achieved. Now, high-concentration NOx can be measured as in the case of exhaust gas emitted from gas turbine engines. Figure 11 shows an example of output in the 10 ppm range. In addition, vacuum analyzers (minimum concentration range 1 ppm) are also available for measuring lower concentration gases such as in low emission vehicles (LEV).

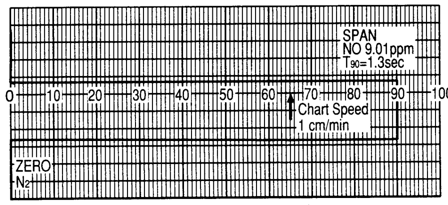


Fig. 11 CLA-720 (NOx: 10ppm range) output example

(1) Higher sensitivity of atmospheric pressure CLD

The key points resulting from increasing sensitivity are as follows:

① Increased sample flow
② Improved light condensing efficiency
③ Optimized reaction chamber structure

(2) Reduced noise and drift

The following three points were modified to reduce noise and drift:

① Thermal noise by cooling of the photodiodes is reduced.
② Spike noise caused by time-sharing output signals is reduced.
③ Out put drift is prevented by temperature control of the operational amplifier.

(3) Modified NOx converter

On the CLA, a converter is required for converting all NOx in the exhaust gas (mainly NO_2) to NO. NO_2 reacts with carbon in the converter and is converted to NO, and the resulting NO reacts with O_3 to emit light. ($NO_2+C \rightarrow NO+CO$)

With the CLA, we reviewed the NOx converter to lower its operating temperature. This has eliminated the risk of aromatic hydrocarbons causing a side reaction in the converter and blocking the pipes. Furthermore, the sample is preheated before it is introduced to the catalyst, resulting in improved reaction speed and reduced amount of catalyst.

3.5 CH_4 Analyzer: GFA-720

The measurement of CH4 is based on the gas chromatograph method. This shares the same hardware as the FIA-720. For the GFA-720 we have developed a new compact 10-way valve comprising a combination of a pipe flow pattern and compact two-way solenoid valves. This selector valve contributes to the analyzer's compact size and maintainability.

4. Heating Analyzer Unit

4.1 Features

(1) Continuous 3-component measurement (CH_4/NHMC/THC)

The heating type FIA analyzer unit (OVN) incorporates a maximum of two analyzers and is used mainly for the measurement of exhaust gas emitted from diesel engines. This was in response to requests for continuous measurement of CH_4 in exhaust gas and non-methane hydrocarbons (NMHC) emitted from vehicles that recently have come to use low-pollution fuels such as natural gas. One of the analyzers on the FIA measures THC, while the other is used as a continuous CH_4 analyzer that uses the cutter method. This method uses a non-methane cutter (NMC) catalyst for selectively burning NMHC. Computing the two FIA outputs enables continuous measurement of three components CH_4, NMHC and THC.

(2) Addition of NOx analyzers

In addition to the heating type FIA, a heating type CLA is incorporated in the heater analyzer unit. Also, the sampling pumps have been integrated into a single pump. Two methods are used for directly sampling gasoline and NOx in the diesel engine exhaust gas at high temperature. The first is a dry method whereby the section up to the NOx converter is heated to remove moisture in the sample gas by an electronic cooling dehumidifier. The second is a wet method whereby the section up to the NOx converter is humidified. Either of these methods can be selected.

4.2 Specifications

Table 3 shows the main specifications of analyzers that can be mounted on the heating analyzer unit. Table 4 shows the possible combinations of analyzers.

Model	FIA-725	FIA-721H	CLA-720M	CLA-755
Measuring Component	T・HC	T・FHC/CH_4	NO/NO_x	NO/NO_x
Measurement Principle	H・FID (heating oven)	H・FID/NMC (heating oven)	Normal temperature/pressure (dry) (heating up to converter)	Heated/reduced pressure (wet) (heating up to analyzer)
Measuring Range	0-10~50000ppmC		0-10~10000ppm	
Repeatability	≦±0.5%FS			
Zero Drift	≦±1% FS/24h (≦±2℃ of operating temp.)			
Span Drift	≦±1% FS/24h (≦±2℃ of operating temp.)			
Noise	≦±0.5%FS		≦±1%FS	
Linearity	≦±1%FS or ≦±2%RS, Whichever is smaller			
Response Time (T_{90})	≦1.5s	≦1.5s (THC) ≦3.0s (CH_4)	≦2.0s (≧50 ppm range) ≦2.5s (<50 ppm range)	
Sample Flowrate	0.5 ℓ/min		1 ℓ/min	
Power Supply	AC100 240V (overseas specification)			

Table. 3 Main functions heating analyzer unit (OVN)

Model No.	On-board Analyzer			
	FIA-725 T・HC	FIA-721H T・HC/CH_4 (NMC)	CLA-720M Dry Atmospheric Pressure NOx	CLA-755 Wet Reduced Pressure NOx
OVN-720	○			
OVN-721		○		
OVN-722	○	○		
OVN-723	○		○	
OVN-724	○			○
OVN-725		○	○	
OVN-726		○		○
OVN-727	○	○	○	
OVN-728	○	○		○

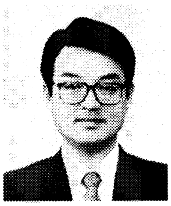
Table. 4 On-board analyzer of heating analyzer unit (OVN)

5. Analyzer Self-diagnostics

The signals from the analyzer modules are transferred to the MCU which identifies trouble or error. If the MCU identifies an error, it generates an alarm to aid maintainability. Furthermore, the FIA, CLA and GFA are provided with a dummy input generating circuit as a self-diagnostic function to enable judgment of errors in the electrical system.

<Literature>

1) Readout－HORIBA Technical Reports－ No.6, p.55-61 (1993).



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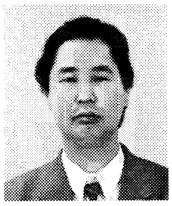

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