Readout
HORIBA Technical Reports

特集　高機能エンジン計測　September 1999 ■ No.19

Mini-dilution Exhaust Sampling System

William M. SILVIS

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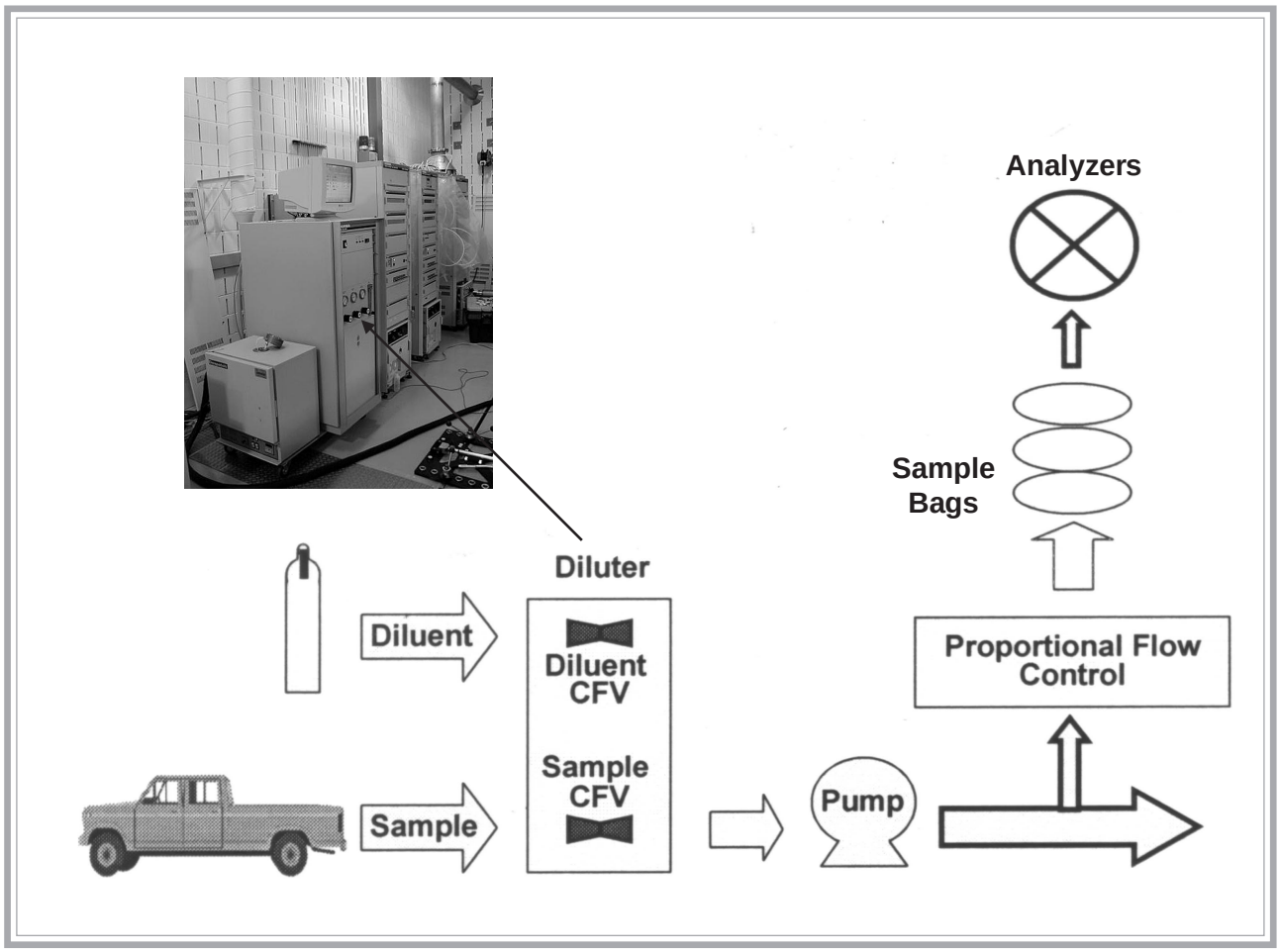
株式会社 堀場製作所

Feature Article
特集論文①

Mini-dilution Exhaust Sampling Systems
ミニダイリューション排ガス装置

William M. Silvis※

(※ Horiba Instruments Inc.)



要旨

従来の自動車排ガスの測定方法はCVS法に基づいており、公的な規制文書にも記載されている。本法は排ガスの全量を希釈した後に, その一部分を定量的にサンプリングする手法である。この程, この順序を入れ替えることにより, 排ガス計測の性能を向上させることが可能となった。ULEV 車からの排出ガス濃度を考慮すると, ミニダイリュータは非常に興味深い排ガスのサンプリング装置である。本稿ではミニダイリュータの動作原理および最新の測定結果について紹介する。

Abstract

Traditional methods for sampling vehicle exhaust are based on the constant volume sampler (CVS) technique, as described in government regulations. This method dilutes the entire exhaust output from the vehicle, then takes a proportional sample for measurement. Reversing this process by sampling first, then diluting, offers new opportunities to improve the quality of this measurement. This is especially interesting considering the emissions levels from ULEVs. This paper describes the operation of and presents results from a “mini-dilution” system based on this principle.

1. MINI-DILUTERS

Mini-diluters are a new class of devices that avoid CVS limitations by reversing the order of the diluting and sampling of exhaust gases (see **Figure 1**).

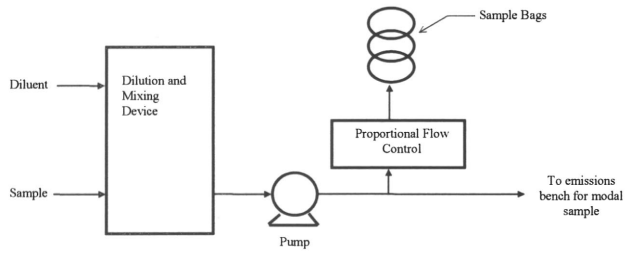


Fig. 1 Mini-diluter block diagram

CVSs dilute all vehicle exhaust at a variable dilution ratio, then take a proportional sample. The Mini-diluter takes a small sample of exhaust gas, then accurately dilutes it at a known dilution ratio. Since a smaller volume of diluent is needed, a dry, contaminant-free gas can be used. Two advantages are the higher, more easily measured concentrations and the lack of background contaminants. Also eliminated are separate, error-prone collection and analysis of the contaminants in ambient dilution air.

Table 1 Increased concentrations using a mini-diluter

Modern Vehicle Typical Bag Concentrations

Test Phase	Mini-diluter		CVS			
	P1	P2	P1		P2	
	Sample	Sample	Sample	Ambient	Sample	Ambient
HC	34.6	2.1	11.8	2.3	2.7	2.3
CO	728.5	1.8	247.7	0.4	0.6	0.4
NOx	52.2	1.5	17.7	0.0	0.5	0.0

Table 1 illustrates the concentrations expected on the FTP phases 1 and 2 from a Mini-diluter and compares them with concentrations for a standard CVS, with fixed flow at 9 m^3/min. Note that the CVS sample bags have much lower concentrations than Mini-diluter sample bags. Additionally, CVS Phase 2 sample concentrations are nearly the same as the ambient bag levels, rendering an accurate measurement more difficult. Mini-diluter sample concentrations for Phase 2 are high enough to measure with the analyzer ranges used today.

Two important technical challenges face the Mini-diluter. Its dilution ratio must be accurately known and stable, and the sampling rate over a test period must stay proportional to the vehicle's strongly varying raw exhaust flow.

There have been several devices described in the literature that use the Mini-dilution technique.[2,3,4] Described below are the principles of Mini-diluter operation that we developed[1,2], using critical flow venturis to provide an accurate and stable dilution ratio. Also presented are results from vehicle tests comparing this Mini-diluter to a CVS.

2. CFV TYPE MINI-DILUTER

The features of the CFV type Mini-diluter illustrated in **Figure 2** are listed below.

- Two small CFVs establish a stable dilution ratio, one for the diluent and a smaller one for the sample gas.
- A differential pressure regulator. The reference port connects to the sample inlet, and regulator action maintains equal pressure at both the diluent and sample orifice inlets.
- Heated lines and an oven prevent sample condensation before dilution. The oven also maintains the same temperature at both orifice inlets.
- A mass flow controller sends flow to sample bags in proportion to vehicle-exhaust flow.

ミニダイリューション排ガス採集装置

1．ミニダイリュータ

ミニダイリュータ(MD)は,排ガスの希釈とサンプリングの順序を変えることによって定容量試料採取装置(CVS)の限界を越えることができる新しいタイプの装置である。

CVSでは全排ガスを一旦希釈し,希釈排ガスの流量に比例させてサンプリングする。一方,MDでは少量の排ガスを採取し,一定の率で希釈する。MDは希釈量が少ないため,水分及び不純物濃度が非常に低いゼロガスが使用できる。MD は CVS に比べ次の利点がある。

・濃度が高く高精度の測定が可能
・バックグラウンド中の不純物影響を無視できる
・バックグラウンド測定が省略できる

FTP の Phase 1,2 での CVS とミニダイリュータとのガス濃度の比較を**表１**に示す。MD では , Phase 2 のサンプル濃度で充分に測定可能である。

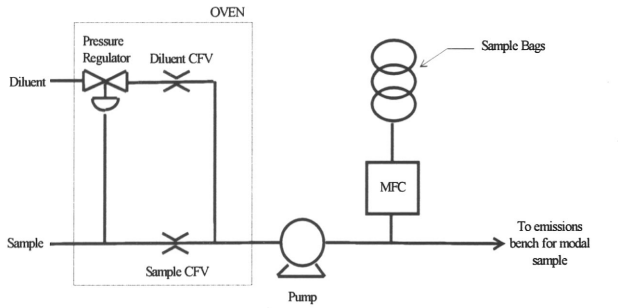


Fig. 2 CFV type Mini-diluter block diagram

3. THEORY OF OPERATION

Fundamental constant for the diluter component

The operation of the CFVs in the diluter portion of the device is described by the principles of sonic flow through nozzles. The diluent and sample CFVs determine a fixed dilution ratio. The action of the diluter can be characterized by the ratio of these flows, *K*.

From the continuity of the flow

$$Q_{md} = Q_{N_2} + Q_{samp} \quad \cdots (1)$$

$$K = \frac{Q_{N_2}}{Q_{samp}} \quad \cdots (2)$$

$$Q_{md} = (1+K) \cdot Q_{samp} \quad \cdots (3)$$

Proportional Sampling

The object of a bag sampler and analytical system is to calculate the grams of a pollutant emitted over a test interval. The diluting portion of the sampler dilutes the sample by the factor *K* so that:

$$[P]_{sample} = \frac{[P]_{raw}}{(1+K)} \quad \cdots (4)$$

Filling a sample bag at a flow rate proportional to the exhaust-flow rate ensures that:

$$n_{bag} = \alpha \cdot n_{ex} \quad \cdots (5)$$

The action of collecting the sample gases in a bag integrates these quantities. At the end of a test phase or bag-filling interval, the concentration in the bag can be represented as:

$$[P]_{bag} = \frac{\int_0^{505} \frac{[P]_{raw}}{(1+K)} \cdot \alpha \cdot n_{ex} \cdot dt}{\int_0^{505} \alpha \cdot n_{ex} \cdot dt} \quad \cdots (6)$$

K and α are constant, so they can be taken out from under the integral and we can write:

$$\rho \cdot [P]_{bag} \cdot V_{tp} \cdot (1+K) = \rho \cdot \int_0^t \frac{n_p}{n_{ex}} \cdot n_{ex} \cdot dt = \rho \cdot \int_0^t n_p \cdot dt = grams_p \quad \cdots (7)$$

This is the desired result: the grams from the test are obtained by multiplying the concentration in the bag by the total exhaust volume collected over the test phase and applying a constant dilution factor.

4. TEST RESULTS

The Mini-diluter's performance has been evaluated in several laboratory-test programs. The Mini-diluter was connected in series with a CVS system to obtain results from both samplers during the same emissions test.

Table 2 compares the weighted FTP results from a battery of tests conducted at the SAAB Technical Research Center. It shows the differences between Mini-diluter and CVS, expressed as a percentage of the CVS result.

Clearly, the results from the Mini-diluter and the CVS are substantially the same.

MD には次の技術要素が重要となる。

・希釈率が常に一定であること

・バッグへの採取流量は全排ガス流量と比例すること

２．臨界流(CFV)タイプの MD

CFV タイプ MD には次のような特徴がある。

・二つの CFV により希釈率が安定である

・差圧レギュレータで希釈ガスとサンプルガスの入口圧を同じに保つ

・加熱配管とオーブンにより水分の凝結を防ぎ , ガス温度を一定に保つ

・マスフローコントローラで排ガス流量に比例した流量でバッグへサンプリングする

３．動作原理

CFVの動作はノズルを通過する音速流体の理論で記述される。希釈後のガス流量(Qmd), 希釈ガス流量(Q_{N_2}), サンプルガス流量(Qsamp)は,**(1)**～**(3)式**で表される。サンプルの希釈率は流量比(K)によって**(4)式**で,バッグへ採取されるサンプル流量は**(5)式**で表される。従って,車輌試験終了後のバッグ内の濃度は**(6)式**で表され, これを

Table 2　BMD/CVS as percentage of measured value

Vehicle	Ei18	TLEV		
Test #	HC	CO	NO_x	CO_2
1114	1.9 %	-0.3%	-1.9%	1.5 %
1129	-3.1%	-0.8%	0.8%	-0.5%
1138	-0.1%	0.0%	0.5%	-1.4%
1143	-1.4%	1.0%	4.5%	0.3 %
Ave	**-0.7%**	**0.0%**	**1.0%**	**0.0 %**
SD	2.1	0.8	2.7	1.2

Vehicle	Ei11	LEV		
Test #	HC	CO	NO_x	CO_2
1115	-0.1%	-0.7%	0.8%	-2.2%
1131	-1.6%	3.2%	2.2%	-1.7%
1140	-1.2%	-0.8%	1.8%	-1.8%
Ave	**-1.0%**	**0.6%**	**1.6%**	**-1.9%**
SD	0.8	2.3	0.7	0.2

Vehicle	EI79	LEV		
Test #	HC	CO	NO_x	CO_2
1117	5.7%	-1.0%	0.7%	-1.3%
1139	0.3%	0.0%	2.7%	-0.3%
1144	-0.5%	-1.0%	3.2%	-0.3%
Ave	**1.8%**	**-0.7%**	**2.2%**	**-0.6%**
SD	3.4	0.6	1.4	0.6

5. CONCLUSIONS

The Mini-diluter offers advantages over conventional CVS samplers:

- Less dilution is used because the diluent is dry, resulting in higher bag concentrations.
- The diluent contains very low levels of background contaminants, so no ambient sample bags are required.
- Exhaust sample is collected through a heated line and diluted to a non-condensing condition, so contaminants are not lost in mixing Tees, ductwork, or coolers.

Test results confirm that Mini-diluter measurements correlate well with the CVS method.

References:

1) Silvis, W. M., “Mini-Dilution Sampling Systems for Vehicle Exhaust Emissions Measurement,” Autotest ’96, 1996.
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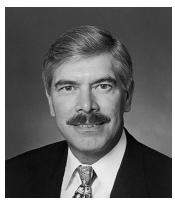
3) Yoda, Kimikazu, and Kenichi Uchida. “A New Proportional Collection System for Extremely Low Emission Measurement in Vehicle Exhaust,” SAE 1999-01-1460, International Spring Fuels & Lubricants Meeting & Exposition, Dearborn, Michigan. 1999.
4) McLeod, J., et al, “A Sampling System for the Measurement of Pre-Catalyst Emissions from Vehicles Operating Under Transient Conditions.” SAE 930141, 1993.



William M. SILVIS

Director
Technical Applications Div.
Horiba Instruments Inc.

書き換えた**(7)式**によって排出量を求めることができる。

４．試験結果

CVS の前段に MD を接続することにより , 両者のデータを同時に採ることができた。

表２はSAABテクニカルリサーチセンタで得られたFTPでの試験結果である。これらの試験により,CVSとMDとが同等であることを確認できた。

５．結論

以上まとめると , MD は従来の CVS システムよりも以下の点が優れている。

・乾燥ガスを希釈に使うため , 希釈率を最低限に押さえ , バッグガスを高濃度に保つことができる
・ゼロガスの不純物が非常に少ないため , 希釈空気の採取および測定が不要となる
・加熱サンプリングのため , 水分の凝縮が生じず , 配管内やクーラに被測定成分が付着しない

以上の結果 , ミニダイリュータ法と CVS 法の間には充分な相関関係があることを確認した。

(抄訳 エンジン計測開発部　中谷　茂)