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Passenger Car Exhaust Emission

－Trends in Requirements, Control Technology and Exhaust Gas Analysis－

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特別寄稿

Guest Forum

Passenger Car Exhaust Emissions

-Trends in Legal Requirements, Control Technology and Exhaust Gas Analysis-

1. State-of-the-Art

1.1 Legislation

Since the late 60s, air pollution by passenger cars has become an issue of growing public and governmental concern worldwide. So, induced by severe environmental problems in the highly polluted area of Los Angeles the first legal requirements including limit values for passenger car exhaust emissions evolved in 1966. Since then many other countries have followed. At the moment 154 countries around the world -ranging from Austria to Zaire- have exhaust regulations for passenger cars.

Though the approaches of these countries to exhaust legislation were (and in some parts still are) different, today most of them refer to comprehensive standards like the US Federal Test Procedure (Fig.1) or the EC Standard (Fig.2).

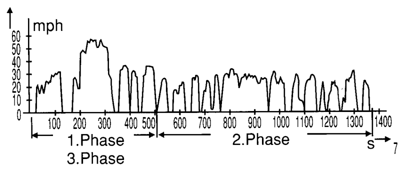

Fig.1 US-driving schedule FTP-75

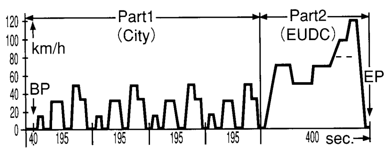

Fig. 2 European driving schedule

1.2 Emission Test Procedure and Equipment

The general outline of the test procedure for official exhaust emission testing (not taking into account any evaporative emissions requirement) thus follows the same schematic. After some preparative action, like e.g. fuelling the car with specific reference fuel and preconditioning, the car has to be parked under defined ambient conditions within a temperature range normally between 20 and 30 deg C for 12 to 36 hours. The start after this period is a cold start. The car then has to be pushed onto a chassis dynamometer simulating all normal road forces, where it has to follow a driving schedule which the government considers representative or from the point of pollution prevention especially important for the country.

乗用車の排出ガス

——排出規制・排出制御技術・排ガス分析の動向——

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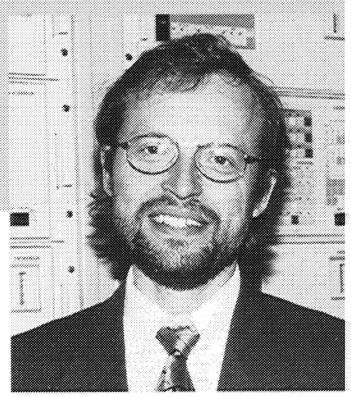
1. 現在の状況

1.1 法規制

ロサンゼルスの大気汚染がきっかけとなり，1966年型車より米国に始まった自動車排ガス規制は，現在では世界154ｶ国で行われている．規制の内容は国ごとに異なっているが，大半はアメリカやヨーロッパ共同体(EC)の試験方法が規範となっている．

1.2 試験方法と測定装置

一般的な排ガス試験は，テスト車を所定の環境条件に置いた後（20～30℃,12～36時間），シャシ・ダイナモ上を規定のモード（図1,2）で走らせて行う．排ガスは定容量試料採取装置



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Born April 12, 1953
1976-79: Assistant at Technical University Clausthal, Germany Research on the emission of hydrocarbons from gasoline engines
1976-83: Employed with Daimler-Benz AG, Stuttgart, Germany, Central Research Department Research on formation, emission and health effects of exhaust compounds from mobile sources
1983- : Employed with Mercedes-Benz AG, Bremen, Germany, Quality Assurance Exhaust Emissions Testing of exhaust emissions from passenger cars for legal conformity of production requirements and for development purposes

While the car is driven on the dynomometer, its exhaust gas is sampled with a CVS (Constant Volume Sampling-system) (Fig.3). There the exhaust gas is diluted with ambient air to prevent water, amounting to roughly 12 to 14% of the exhaust gas volume and thus being one of the most predominant exhaust compounds, from being condensed. In today's conventional CVS-systems the volume of dilution air exceeds the volume of raw exhaust gas by a factor of 8 to 20. The test results are then calculated from the analytical data of the diluted exhaust gas and the dilution air.

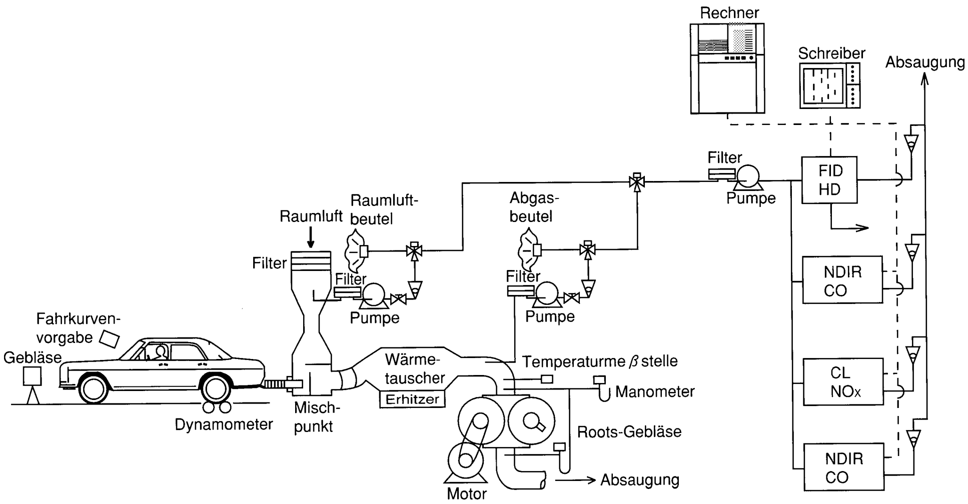

Fig.3 CVS-sampling and analytical system[1)]

(CVS)で水分が凝縮しないように大気で希釈し，排ガス中の各成分濃度を分析する．この分析値と希釈大気の量とから排出された質量を算出する(図3)．

1.3 制御技術

現在，乗用車の排ガス浄化装置としては三元触媒(TWC)が最も普及している．TWCの効率は，空燃比と動作温度によって左右されるが(図4)，次の条件下では極めて有効に働く．

* 閉ループエンジン制御システムを併用して，空燃比を理論空燃比(λ=1)になるような条件で作動させたとき
* TWCの温度が触媒活性温度(light-off temperature:通常200～300℃)に達したとき．

種々の浄化方法の浄化効率を表1にまとめた．

1.3 Control Technology

The legal limits for exhaust components which grew more and more stringent in the course of time and the efforts of the automobile industry to reduce car exhaust emissions led to the development of three-way-catalytic converters (TWC), the system which is now most commonly used for passenger car exhaust purification.

Fig. 4 shows, that the TWC is a very powerful means for exhaust emission reduction provided that

* it is operated together with a closed loop motor management system making sure that the catalytic converter is only confronted with exhaust gas from stochiometric (λ =1) combustion, and
* it has reached its light-off temperature which is -depending on the formulation and age of the TWC- in the range of 200 to 400 deg. C.

The effects of other systems which may be implied in addition to TWCs is shown in Table 1.

	HC	CO	NOx
Raw Emission	100%	100%	100%
+Variable Camshaft Timing	96%	100%	85%
+Exhaust Gas Recirculation	91%	100%	53%
Catalytic Converter	7%	16%	9%
+Secondary Air Injection	5%	8%	4%
+Ignition Adjustment	3%	6%	3%

Table 1 Effect of exhaust gas cleaning systems on emissions

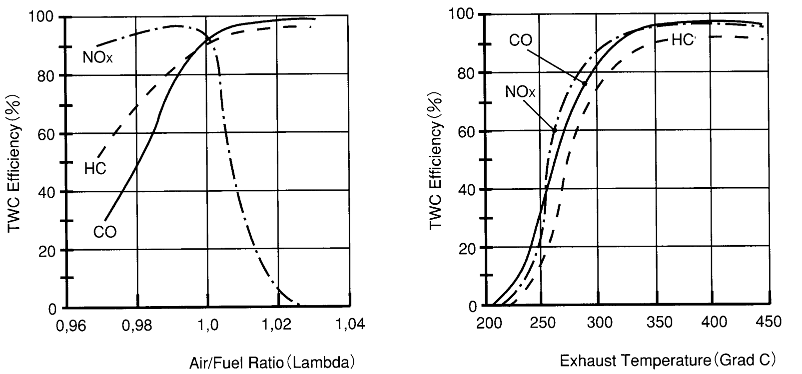

Fig.4 TWC efficiency as a function of the air/fuel ratio of the engine and of the TWC temperature

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2. 法規制の動向

環境問題の高まりとともに排ガス規制を強化しようとする動きがあるが，いずれも現在の排出抑制技術の限界に挑むものである．

カリフォルニア州で新たに可決された排ガス規制（表2）では，車/エンジン/燃料を一体として捕らえ，高度な診断システムの搭載を義務付けている．また，蒸散ガス規制が強化され，試験方法が変更され，炭化水素による光化学スモッグが規制対策の焦点となっている．これに伴い，炭化水素の定義が変更され，最大許容限度も大幅に削減される見込みで，スモッグを形成する各成分が測定・評価の対象となる．

ECでも新たに規制（表3）が強化され，今世紀末までには米国の規制レベルと同程度になる見込みだが，現在の技術水準では達成は難しい．

2. Trends in Legal Requirements

In recent years, facing severe environmental problems and/or political pressure from the public several governments felt the need to push forward very stringent new automotive emission regulations, which for example are both legislated in the US and proposed in Europe and which challenge the limits of current emission control technology.

So for example California passed a new complex framework of exhaust requirements, which do not only regard fuel and car/engine as an integrated system , require sophisticated on-board-diagnosis systems, enforce strict limits on evaporative emissions and alter test procedures but also focus on the smog forming potential of hydrocarbon emissions. Consistently the definition of "hydrocarbons" was altered and the maximum tolerable amount of hydrocarbons emitted has been and will be further drastically reduced over the years to come. No longer are they regarded as a sum value. A whole variety of components has to be measured and evaluated individually for their smog forming potential.

Parallely to the USA the European Community, too, introduced new requirements and tightened its emission standards. By the end of this century both requirements can be considered equivalent, and cannot be met with today's state-of-the-art-technology. Table 2 shows the emission standards California[2] and Table 3 shows the emission standards Europe[2] (These tables are attached on the last page of this report)

3．排出の制御技術の動向

排ガスは始動時に主に発生するため，自動車メーカでは触媒の活性化時間の短縮に努力してきた．図5に触媒搭載車の炭化水素の排出特性を示す．

ULEV (Ultra Low Emission Vehicle) やEuropean stage II standardへの対応策は，エンジンの始動から触媒の活性温度に達するまでの時間を20秒以内に押さえることである．現在，受動的・能動的の両面からの次のような技術開発が行なわれている．

(1) 受動的な対応策

＊点火時期，クランクシャフト・タイミングなどによるエンジン管理

＊空気噴射や排ガス再循環方式 (EGR) の補助装置

＊触媒の組成と装着位置の最適化

＊触媒の前の排気管を断熱

＊前置触媒 (pre-catalyst)

3. Trends in Control Technology

Since most of the emissions are generated in the cold start portion of the driving cycle, the auto manufacturer's development efforts have primarily directed to reducing the time necessary to achieve catalyst activity.

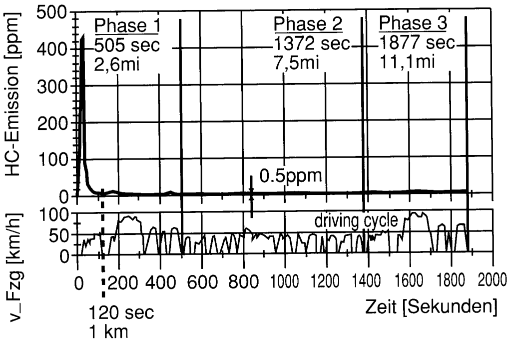

Fig .5 Emission of hydrocarbons during an FTP-test of a car with catalytic converter

To cope with ULEV or European stage III standards it is currently believed that the catalytic converter has to reach its light-off-temperature at least 20 seconds after the start of the cold engine.
The development efforts have encompassed improvements to passive technologies like

* engine management, with e.g. ignition timing, crankshaft timing
* supplementary systems, like e.g. air injection, EGR
* catalyst formulation and position in the exhaust duct
* heat insulation of the exhaust pipe in front of the catalyst
* precatalysts and to development of new active systems like e.g.

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(2) 能動的な対応策

＊エンジン始動時の冷えた状態で発生する炭化水素を一旦吸着し，触媒活性温度に達した後に再び放出するような吸着剤(adsorber)

＊エンジン始動後急速に触媒を昇温させるバーナー（図6）

＊触媒を電気的に加熱するヒータ

4. 排ガス分析の動向

このような規制の動きに対し，排ガス分析装置には次のような対応が求められている．

＊排ガス中の各成分濃度の低下に対応できる測定範囲の低濃度化．

＊CVSによる排ガス希釈率の最適制御：希釈し過ぎると微量成分の検出が困難になり，逆

* adsorbers, which adsorb the hydrocarbons during cold engine operation and release them after the catalyst has reached its operating temperature,
* burners to quickly increase the catalytic converter temperature after cold start,
* electric heater systems which increase the TWC-temperature by means of electric power

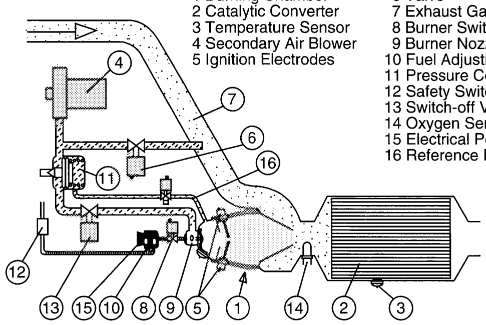

Fig.6 Burner system [3)]

4. Trends in Exhaust Gas Analysis

As far as Passenger car exhaust gas sampling and analytical systems are concerned the new regulations mean

* lower measurement ranges for the lower concentration levels of the exhaust compounds,
* a better control of the exhaust gas dilution during the CVS-Test, as with higher dilution the concentration levels of the components to be detected drop and thus are more difficult to detect and with lower dilution the danger of water condensation increases,

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に足りないと水分が凝縮する．

＊希釈用空気の清浄化：大気中には各種成分とくに炭化水素が排ガスと同程度含まれており，生の大気では正確な測定が困難になる．

＊アルデヒドや個々の炭化水素など，従来は排ガス試験の対象になっていない新たな成分の分析技術の開発．

5. おわりに

新たな排ガス試験基準が検討されている中，各国政府は個別に対応してようとしている．資源に限りがあることが明白な今日，国際市場で活躍する自動車メーカは，明確で世界的に統一された指針を求めている．この指針に向かって自動車技術の発展を集中させて行けば，環境保全が図れるであろう．　（抄訳　編集部）

* cleaning of the dilution air, as ambient air contains all compounds present in automotive exhaust and especially as far as hydrocarbons are concerned in concentrations close to those in exhaust gas. The closer the gap between these two concentration levels is and the more fluctuations there are in the ambient air concentrations, the more difficult it is to achieve correct exhaust results.
* analytical tools have to be applied for new compounds so far unknown in conventional exhaust emission testing, like e.g. aldehydes and individual hydrocarbons.

5. Final Remarks

In some new and very complicated legal requirements for the emission test procedure there is a clear danger to be seen that the governmental emphasis might be laid more on specific, national and procedural aspects than on environmental protection. In a world where it is obvious that mankind's resources are limited car manufacturers on the international market need clear and throughout the world uniform guidelines so they can concentrate their efforts on progress in car technologies with real benefits for the environment rather than on a broad variety of different procedural requirements, where it is hard to realize, what they are useful for.

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2) N.N.,"Exhaust Emissions - Standards, Regulations and Test Procedures for Passenger Cars", Mercedes-Benz AG, Dep. EP/CZ, July 1995 (in preparation)

3) A. Schürfeld, G. Härtel,"Brennersystem zur schnellen Aufheizung von Abgaskatalysatoren", 14th. Internationales Motoren symposium, Vienna (1993), VDI-Fortschrittsberichte 12, 1982,VDI-Verlag, Düsseldorf (1983)

Passenger Car Exhaust Emission Regulations—USA
california (ARB) and Sect.177 States

Fuel	Standards	Vehicle Useful Life [miles]	THC [g/m]	NMHC [g/m]	OMHCE [g/m]	OMNM HCE [g/m]	NMOG [g/m]	CO [g/m]	NOx [g/m]	PM [g/m]	HCHO [g/m]
Gasoline	Tier 0	50 000 (full useful life)	0,41	0,39	-	-	-	7,0	0,4	-	-
	Tier 1	50 000 (half useful life)	-	0,25	-	-	-	3,4	0,4	-	-
		100 000 (full useful life)	-	0,31	-	-	-	4,2	0,6	-	-
Diesel	Tier 0	50 000 (full useful life)	0,41	0,39	-	-	-	7,0	0,4	0,08	-
	Tier 0/Option 2	100 000 (full useful life)	-	0,46	-	-	-	8,3	1,0	0,08	-
	Tier 1	50 000 (half useful life)	-	0,25	-	-	-	3,4	0,4	0,08	-
		100 000 (full useful life)	-	0,31	-	-	-	4,2	0,6	-	-
	Tier 1/Option 2	100 000 (full useful life)	-	0,31	-	-	-	4,2	1,0	0,08	-
Methanol/Ethanol (Alcohols) (13)	Tier 0	50 000 (full useful life)	0,41	-	0,39	-	-	7,0	0,4	0,08	0,015
	Tier 1	50 000 (half useful life)	-	-	-	0,25	-	3,4	0,4	0,08	0,015
		100 000 (full useful life)	-	-	-	0,31	-	4,2	0,6	-	-
	Tier 1/Option 2	100 000 (full useful life)	-	-	-	0,31	-	4,2	1,0	0,08	0,015
All Fuels	TLEV Transient Low Emission Vehicle	50 000 (half useful life)	-	-	-	-	0,125	3,4	0,4	-	0,015
		100 000 (full useful life)	-	-	-	-	0,156	4.2	0,6	0,08	0,018
	LEV Low Emission Vehicle	50 000 (half useful life)	-	-	-	-	0,075	3,4	0,2	-	0,015
		100 000 (full useful life)	-	-	-	-	0,090	4,2	0,3	0,08	0,018
	ULEV Ultra Low Emission Vehicle	50 000 (half useful life)	-	-	-	-	0,04	1,7	0,2	-	0,08
		100 000 (full useful life)	-	-	-	-	0,055	2,1	0,3	0,04	0,011
Electricity	ZEV Zero Emission Vehicle	No durability requirements Useful Life not defined	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Electricity/Internal combustion engine	HEV-Type A/B/C Hybrid Electric Vehicle	Specific durab.requirements 100 000 (full useful life)	-	The internal combustion engine must meet one set of standards as indicated above,but not the Tier 0 standards.							

Additional Requirements

Requirement	Model Year 1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
OBD II	OBD I		(21)		100%							
Enhanced Evap Procedure	(Current Test Procedure)			10%	30%	50%	100%					
Cold Temperature CO					100% from MY 1996 on							
50° F-Test			Applicable to TLEV,LEV, and ULEV vehicles									

Table 2 Emission standards California[2)]

Passenger Car Exhaust Emission Regulations
European Union

Effective	MVEG-A Testcycle	Certification Standards[g/km] NMHC	NOx	HC+NOx	CO	Partikel
1/93	EURO 1 Diesel	–	–	0,97	2,72	0,14
1/93	EURO 2			0,5	0,2	
	Diesel IDI-Motoren	–	–	0,7	1,0	0,08
	Diesel DI-Motoren			0,9	1,0	0,10
1/2000	EURO 3*	0,05	0,14	0,14	2,2	
	Diesel	0,05	0,40	0,40	1,0	0,05

*proposal Germany

Table 3 Emission standards Europe[2)]