THE EFFECT OF EXHAUST SYSTEM

BACKPRESSURE ON HC, CO, AND NOx EMISSIONS

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Abstract

The exhaust systems of three light-duty passenger cars and one light duty truck were altered and the vehicles were tested for exhaust emissions using the Federal Test Procedure. To determine the effect of the alterations on backpressure, exhaust system pressure was measured for four of the five tests run on each vehicle. When the catalyst was replaced by a straight, unrestricted pipe, two of the four vehicles exceeded the Federal standard for NOx emissions, one exceeded the standard for CO, and all vehicles exceeded the standard for HC. When dual exhaust systems were installed in place of the single exhaust systems all vehicles failed NOx.

I. Introduction

Purpose

The purpose of this report is to present the results of a test program conducted at the Virginia Testing Laboratory for the Field Operations and Support Division (FOSD). The test program involved measurement of exhaust pressure during Federal Test Procedure (FTP) testing of in-use vehicles. The purpose of the program was to (1) determine the impact of a decrease in exhaust system backpressure on HC, CO, and NOx emissions from vehicles with and without backpressure-actuated EGR systems, and, (2) separate the effects [on emissions] of the following:

(1) the restriction to flow caused by the catalytic converter, and,

(2) the combined effect of the catalytic material and the restriction to flow caused by the catalytic converter.

The effects on exhaust emissions of the converter restriction and the catalytic material plus the converter restriction can be separated by determining the emissions with the catalyst in place and the emissions with the catalyst replaced by a restriction which simulates the restriction caused by the converter but which employs no catalytic material. For this program, a gate valve was used to simulate the restriction caused by the converter.

Objectives of the Test Program

The objectives of the program were to: (1) obtain measurements of the exhaust pressure at a point upstream of the catalytic converter, and at that same point with the catalyst replaced by (a) a straight, unrestricted pipe, and, (b) the catalyst and original exhaust system replaced by a dual exhaust system equipped with a muffler on each exhaust pipe, and (2) determine the effect of these changes [(a) and (b)] on the FTP measured HC, CO, and NOx emissions of the vehicles.

II. Description of Test and Maintenance Sequence

This test program involved FTP testing of three passenger cars and one van. A description of the vehicles is given in Attachment I. Five FTP's were run on each vehicle. The exhaust system on each vehicle was altered prior to every test except the first two tests. Each vehicle underwent the same alterations. The configuration for each vehicle for each test was as follows:

M-1	as received configuration
M-T1	as received configuration with pressure transducer installed
M-2	converter removed and straight pipe [fitted with a gate valve] installed; gate valve partially closed to simulate catalyst backpressure.
M-3	straight pipe installed; gate valve in wide-open position
M-4	dual exhaust system installed; muffler in each pipe; transducer installed

For vehicles 119/0001, 119/0004, and 119/0005 catalytic converter inlet pressure was measured and recorded throughout the exhaust portion of the second FTP (i.e., that portion of the M-T1 test (as received configuration with pressure transducer installed) which involves sampling the exhaust, as opposed to other portions of the FTP such as preconditioning, fueling, etc.). This was done so that the difference in pressure between the M-T1 test (as received configuration with pressure transducer installed) and M-3 test (catalyst replaced by gate valve - gate valve in wide-open position) could be determined. See Figure I for the location of the pressure transducer for each test. For the M-2 tests (catalyst replaced by partially closed gate valve) and M-3 tests on vehicles 119/0001, 119/0004, and 119/0005, the pressure was measured at the same point as it was for the second test, but the converter was not present. For the last test the pressure was measured on both sides of the dual exhaust system and in the same relative position (relative to the chassis of the vehicle) as it was for the second test.

For vehicle 119/0003, exhaust system pressure was measured in a straight section of pipe downstream from the left bank of cylinders but upstream from the "Y" connection where the exhaust from both banks of cylinders meet (see Figure I). This was done because a sufficient length of pipe did not exist between the "Y" connection and the inlet to the catalyst. It was believed that a true reading of the pressure of the stabilized exhaust flow from both banks of cylinders would not have been obtained had a measurement been made at the converter inlet.

Pressure transducers in two different pressure ranges were used. These ranges were 0-1.25 psi and 0-3.2 psi. The 3.2 psi transducer was used because the 1.25 psi transducer was damaged after exposure to pressures higher than 1.25 psi. Attachment II shows the pressure range of the transducer used for each test.

A flowchart showing the test sequence is shown in Attachment III.

Following the M-T1 test (pressure transducer installed) on each vehicle a series of steady state tests were run. The purpose of the steady states was to measure the catalytic converter inlet pressure (gauge pressure) so that this pressure could later be approximated using a gate valve in place of the catalytic converter. The steady state tests are a means of finding an adjustment of the gate valve which should cause the pressure sensed by the EGR backpressure transducer to be similar to that pressure sensed when the catalytic converter is in place. Other means, such as running accelerations representative of the accelerations in the driving cycle, or running complete LA-4's (an LA-4 is phases 1 and 2 of the EPA Urban Dynamometer Driving Schedule (UDDS)) at different gate valve adjustments, could have been used. The steady states were run on a dynamometer and involved operating the engine at several constant speeds (20, 40, and 60 mph or 20, 40, and 55 mph). The speeds were chosen to cover the range of speeds in the UDDS. The reason that the 55 mph steady state was used for vehicle 119/0001 was because the pressure at 60 mph was off-scale with the 1.25 psi full-scale range transducer. The output of a pressure transducer exposed to the catalytic converter inlet pressure was recorded on a stripchart. (A metal tube approximately 12 inches in length was placed between the hole in the exhaust pipe at the inlet to the converter and the pressure transducer so that the hot exhaust gases would not damage the transducer.) Attachment IV shows the steady state speeds at which each vehicle was run and the average gauge pressure measured during each steady state.

The restriction to flow of the catalytic converter was simulated, by means of a gate valve, for one test on each vehicle. Pipes were attached to the inlet and exit of the gate valve and the assembly was installed in place of the catalyst.

Following the M-2 maintenance (catalyst replaced by partially closed gate valve) a second series of steady state tests were run. The gate valve was adjusted so that the average pressure as read from the stripchart approximated, as closely as possible, the pressure recorded during the steady states conducted after the M-T1 test (pressure transducer installed). The gate valve was adjusted so that the average pressure was similar for as many of the steady state speeds as possible (see Attachment IV). It was assumed that this adjustment of the valve should cause the pressure sensed by the EGR back-pressure transducer to be similar to that pressure sensed when the catalytic converter was in place.

III. Discussion of Results

A. Summary of Results

With one exception, the objectives of the test program were met. This exception was that complete pressure data was not obtained for the M-4 test (dual exhaust system installed) on vehicle 119/0004.

For all vehicles, pressure was less for the M-3 test (converter replaced by unrestricted pipe) than for the M-T1 test (as received). Also, pressure was less for the M-4 test than for the M-3 test. (See the attached pressure traces.)

For all vehicles, HC and CO emissions increased when the catalyst was replaced by an unrestricted straight piece of pipe. NOx emissions increased for vehicles 119/0001, 119/0003, and 119/0004. The emission results are given in Attachment V.

B. Comparison of As-Received and Post M-2 Tests (Gate Valve Installed)

M-2 FTP (catalyst replaced by partially closed gate valve) NOx emissions for vehicles 119/0001 and 119/0003 increased from the as-received values (M-1 and M-T1). This is not what would be expected assuming that the partially closed gate valve simulates the restriction of the catalyst. Since the catalyst produces some NOx, and it is assumed that exhaust gas recirculation would occur on vehicles 119/0001 and 119/0003 at the same times as with the catalyst in place, it would be expected that NOx emissions would decrease from the as-received values. The increase is greater than the maximum ± 33% (for NOx) test-to-test variability cited in the literature[1] and could be due to the fact that the gate valve does not correctly simulate catalyst backpressure under all engine operating conditions.

M-2 FTP (catalyst replaced by partially closed gate valve) NOx emissions for vehicle 119/0004 decreased from the as-received values as expected. NOx emissions for vehicle 119/0005 stayed approximately the same. NOx would be expected to stay the same or decrease for this vehicle (119/0005).

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[1]Wiplove K. Juneja, David D. Horschler, and Harold M. Haskew, "A Treatise on Exhaust Emissions Test Variability", SAE Paper 770136.

C. Don Paulsell and Ronald E. Kruse, "Test Variability of Emission and Fuel Economy Measurements Using The 1975 Federal Test Procedure", SAE Paper 741035.

Martin Fock, Karl-Heinz Lies, and Laszlo Pazsitka, "Critical Study of the United States Exhaust Emission Certification Test - Error and Probability Analysis", SAE Paper 750678.

Douglas Berg, "Survey of Sources of Test Variability in the 1975 Federal Test Procedure", internal EPA report, August, 1978.

R.D. Lawrence, "Emission Data Variability", internal EPA memo to R. E. Harrington.

M-2 FTP HC and CO emissions increased, in part, because of the absence of the catalyst.

C. Comparison of As-Received and Post M-3 Tests (Unrestricted Pipe)

M-3 FTP (unrestricted pipe) NOx emissions either increased from or remained approximately equal to the as-received values. These trends are expected. Increases are expected because of higher combustion chamber temperatures and pressures. Higher temperatures and pressures would exist because of a decreased amount of residual gas in the cylinder as the piston would be free to expel more burned gases on the exhaust stroke, due to the decreased backpressure. It is also believed that the greater NOx increase for vehicles with positive backpressure EGR valves (as compared to those with negative backpressure EGR valves) is due to the positive backpressure EGR valves being affected to a greater degree by changes in backpressure than the negative backpressure EGR valves.

D. Comparison of M-2 and M-3 Tests (Gate Valve Installed vs. Unrestricted Pipe)

It would be expected that M-3 NOx values would be greater than M-2 NOx values. For vehicles with backpressure controlled EGR this was expected because of decreased amounts of residual gases and decreased EGR, both impacts due to decreased backpressure. For vehicles without backpressure controlled EGR a NOx increase is expected because of the decrease in residual gases. Even though the gate valve does not exactly simulate the catalyst backpressure, a NOx increase is expected because backpressure dces decrease. NOx increased for two vehicles, decreased for one vehicle and remained the same for one vehicle. Test-to-test variability and the backpressure effect (i.e., decreased amounts of residual gases and decreased EGR (where applicable) due to decreased backpressure) are possible reasons for the difference in NOx.

M-3 FTP (unrestricted pipe) HC and CO emissions decreased from their M-2 FTP values for vehicles 119/0001, 119/0004, and 119/0005, HC emissions for vehicle 119/0003 decreased, and CO emissions for vehicle 119/0003 increased. (The non-rounded CO emissions for the M-2 and M-3 FTP's on vehicle 119/0003 were 11.591 and 12.131, respectively. Both of these values round to 12, which is the number shown in Attachment V.) The reason for the CO increase for vehicle 119/0003 is unknown. The HC and CO decrease for vehicles 119/0001, 119/0004, and 119/0005, and the HC decrease for vehicle 119/0003 could be attributed to a decreased throttle opening due to decreased backpressure or more complete burning due to the decreased amount of residual gas in the cylinder.

E. Description of Dual Exhaust System Test

The last test on each vehicle was run with the vehicle equipped with a dual exhaust system. A pressure measurement was made on both sides of the dual exhaust system (see Figure I). (For vehicle 119/0004, no stripchart recording of the pressure was obtained for the the right bank of cylinders. This might have been due to plugging of the hole in the exhaust pipe where the pressure was measured.) Except for the second "hill" (that portion of the driver's trace between the second and third idle periods) of test 5535 (the M-4 test on vehicle 119/0005) the two pressures measured were approximately equal in each case. The reason that the pressures measured for the second hill of test 5535 were not approximately equal is unknown.

F. Comparison of M-3 and M-4 Tests (Unrestricted Pipe vs. Dual Exhaust System)

M-4 FTP (dual exhaust system installed) NOx emissions increased from their M-3 FTP (unrestricted pipe) values. Possible reasons for the increase are reduced EGR caused by reduced backpressure, and higher combustion chamber temperatures and pressures, which are in turn due to less residual gas in the cylinder. The reasons stated above related to varying increases based on the presence of a positive or negative backpressure EGR valve also apply to the comparison of these two tests (M-3 and M-4).

M-4 FTP (dual exhaust system installed) HC and CO emissions increased from their M-3 FTP (unrestricted pipe) values for two vehicles and decreased for one vehicle. For the fourth vehicle M-4 FTP HC emissions increased and CO emissions remained approximately the same. HC and CO increases could be attributed to (1) a richer mixture due to decreased amounts of recirculated exhaust gas in the cylinder, and/or, (2) decreased oxidation of unburned mixture in the exhaust manifold, due to less residence time in the manifold.
HC and CO decreases could be attributed to higher combustion chamber temperatures and pressures.

IV Conclusions

It can be concluded that, for the vehicles tested, exhaust system pressure decreased when the catalytic converter was removed and an unrestricted replacement pipe was installed. NOx emissions for every vehicle equipped with a dual exhaust system exceeded the NOx standard.

In order that restrictions used in future test programs simulate as closely as possible the restriction of the catalyst, we would attempt to use as the restriction a catalyst containing no active catalytic coating on the ceramic substrate.

Attachment I

Vehicle Descriptions

Vehicle Control No.	119/0001	119/0003	119/0004	119/0005
Model Year	1979	1979	1979	1978
Manufacturer	Ford	GM	GM	GM
Model	Econoline 150 (van)	Buick Electra Limited	Chevrolet Caprice S.W.	Monte Carlo
Engine Disp.	351 cu. in.	350 cu. in.	350 cu. in.	305 cu. in.
No. of Cylinders	8	8	8	8
Engine Family	5.8W "D" (JX150)	940J4U	910L4	810Y2
VIN	E14HBEC4916	4X69X9H453297	1L35L9C110551	1Z37U8B496656
Trans. Type	Automatic	Automatic	Automatic	Automatic
Air Cond. (Yes/No)	Yes	Yes	Yes	Yes
EGR Valve Type	Integral backpressure transducer; positive pressure	Integral backpressure transducer; positive pressure	Integral backpressure transducer; negative pressure	Vacuum modulated

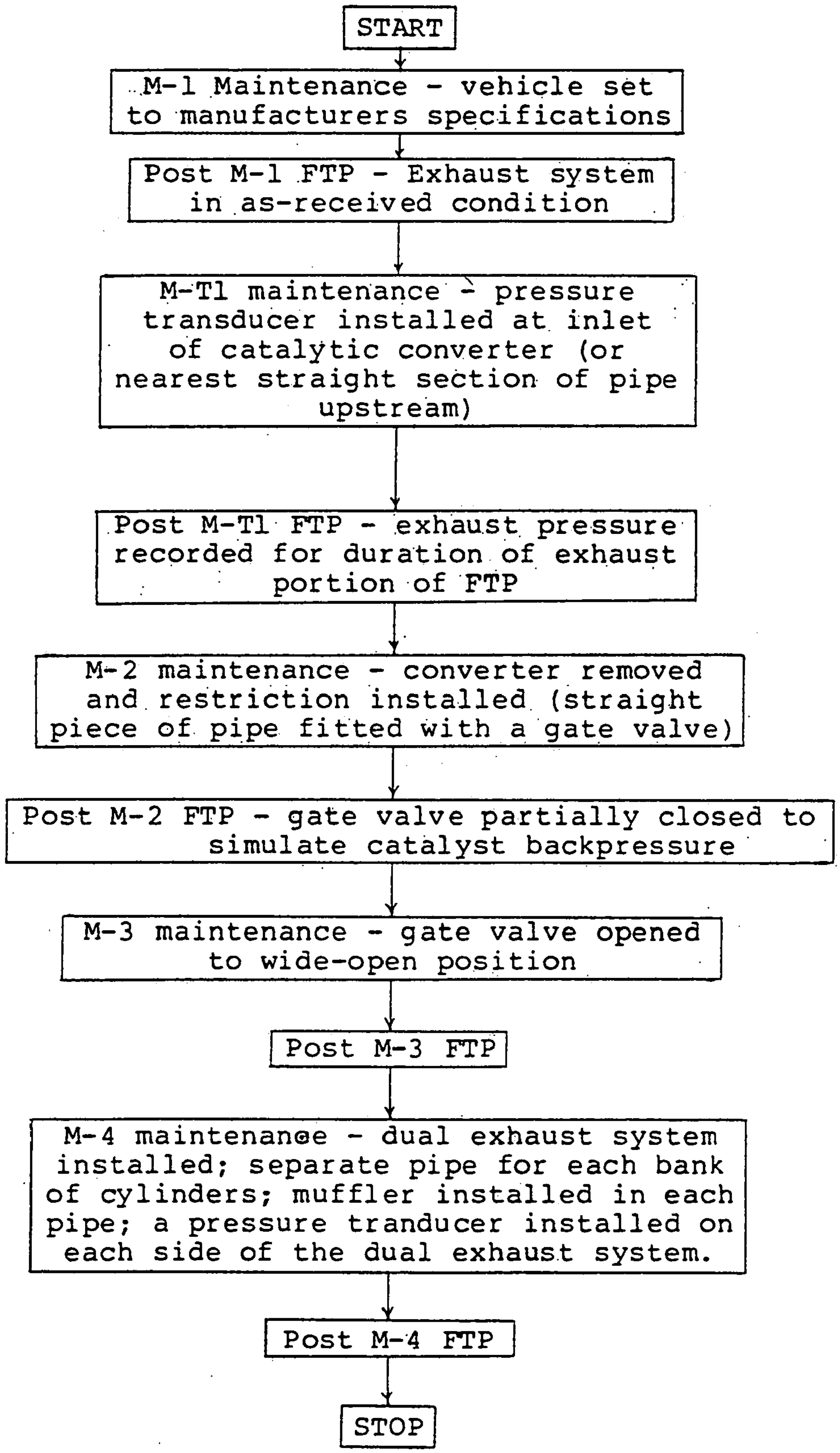
Attachment II

Pressure Range of Transducer(s) Used for Each Test

(Ranges are given in pounds per square inch (psi).)

	Vehicle			
Maintenance	119/001	119/0003	119/0004	119/0005
M-T1	0 - 1.25	0 - 3.2	0 - 3.2	0 - 3.2
M-2	0 - 1.25	0 - 3.2	0 - 3.2	0 - 3.2
M-3	0 - 1.25	0 - 3.2	0 - 3.2	0 - 3.2
M-4 (2 transducers used)	0 - 3.2	0 - 3.2	0 - 3.2	0 - 3.2

Attachment III
Test Sequence



Attachment IV

Average Gauge Pressures Measured During Steady State Tests and Approximate Ranges of Difference in Backpressure Between M-T1 and M-3 Tests

Vehicle	Column A Gauge Pressures (in "H_2O) Measured During Post M-T1 FTP Steady States (with catalyst)[1]	Column B Gauge Pressures (in "H_2O) Measured During Post M-2 Maintenance Steady States (with restriction)[1]	Column A Minus Column B (Δ)	Approximate Ranges of Difference in Backpressure Between M-T1 and M-3 Tests (in "H_2O)[2]
119/0001	3.32	3.50	-0.18	2.1 to 6.9
	12.59	13.26	-0.67	
	31.21	31.31	-0.10	
119/0003	1.34	1.34	0.00	1.8 to 4.4
	4.44	3.58	+0.86	
	16.77	15.10	+1.67	
119/0004	2.68	2.24	+0.44	3.5 to 8.9
	12.50	15.97	-3.47	
	33.58	45.95	+12.37	
119/0005	1.79	1.79	0.00	1.3 to 8.0
	7.14	7.14	0.00	
	17.74	25.66	-7.92	

[1]The gauge pressures given correspond to 20, 40, and 55 mph, respectively (e.g., 3.32 "H_2O corresponds to 20 mph, 12.59 "H_2O corresponds to 40 mph, and 31.21 "H_2O corresponds to 55 mph) for vehicle 119/0001, and 20, 40, and 60 mph, respectively, for all other vehicles.

[2]For all vehicles, the difference in pressure sometimes exceeded the upper limits of these ranges. The upper limits shown were given to represent an average over the entire driving cycle. Including the large differences between some pressure peaks would give a larger range which would not be typical of the overall driving cycle. For vehicles 119/0003, 119/0004, and 119/0005 only a small difference (.44 "H_2O) in idle period pressure could be seen on the stripchart recordings. This is partly due to the fact that transducers of a larger range (larger than what was used on vehicle 119/0001) were used on these vehicles.

Emission Results
(Emissions are given in grams/mile. Failing values are underlined)

Vehicle Control No.	119/0001				119/0003				119/0004				119/0005			
EGR Valve Type	Integral/Positive				Integral/Positive				Integral/Negative				Vacuum Modulated			
Maintenance	HC	CO	NOx	FE	HC	CO	NOx	FE	HC	CO	NOx	FE	HC	CO	NOx	FE
M-1 - as received	0.4	3.6	1.8	12.2	0.9	7.7	1.9	16.6	0.6	6.5	1.2	13.9	0.5	6.6	2.0	17.5
M-T1 - As received exhaust pressure measured throughout exhaust portion of FTP	0.4	3.6	1.6	12.1	0.7	8.0	1.9	16.4	0.6	6.1	1.2	13.8	0.5	5.7	1.9	17.8
M-2 - Catalyst replaced by partially closed gate valve	2.2	29	2.9	12.2	2.4	12	2.7	16.9	4.9	11	1.1	13.7	2.4	14	1.9	18.5
M-3 - same as M-2 except gate valve fully opened	1.9	21	2.5	13.1	2.2	12	3.0	17.0	4.0	9.1	1.4	14.4	2.1	11	1.9	18.7
M-4 - dual exhaust system installed; one muffler in each exhaust line; no catalyst.	2.3	31	5.2	12.5	2.4	13	5.0	16.3	3.7	7.4	2.2	15.7	2.2	11	2.1	18.4

Emission Standards (g/mile)

	HC	CO	NOx
1978	1.5	15	2.0
1979	1.5	15	2.0

Attachment VI

Integral Exhaust Pressure Modulated EGR Valve - Positive Control Pressure - Description of Operation

Exhaust pressure modulated EGR uses a transducer responsive to exhaust pressure to modulate the vacuum signal to the EGR valve. The vacuum signal source is a port above the throttle valve. The transducer is located within the EGR valve. Under conditions when exhaust pressure is below the control value, the transducer diaphragm spring is expanded against the transducer diaphragm and causes the vacuum signal to be reduced by the air bleed. No EGR is obtained under these conditions. Under conditions when exhaust pressure is above the control value, the transducer diaphragm spring is compressed and the air bleed is closed, causing the valve to open if the vacuum signal is strong enough.

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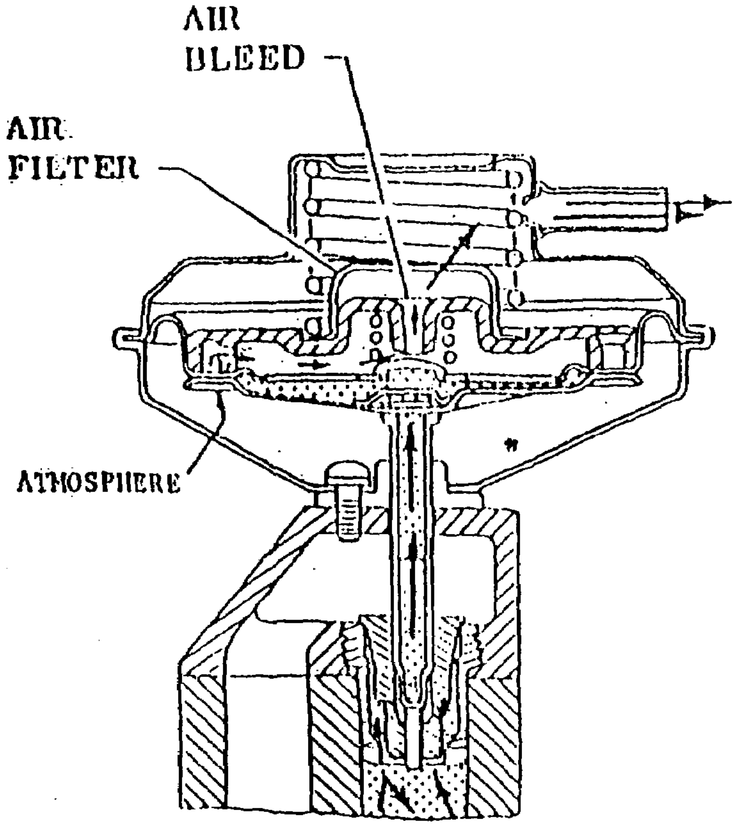
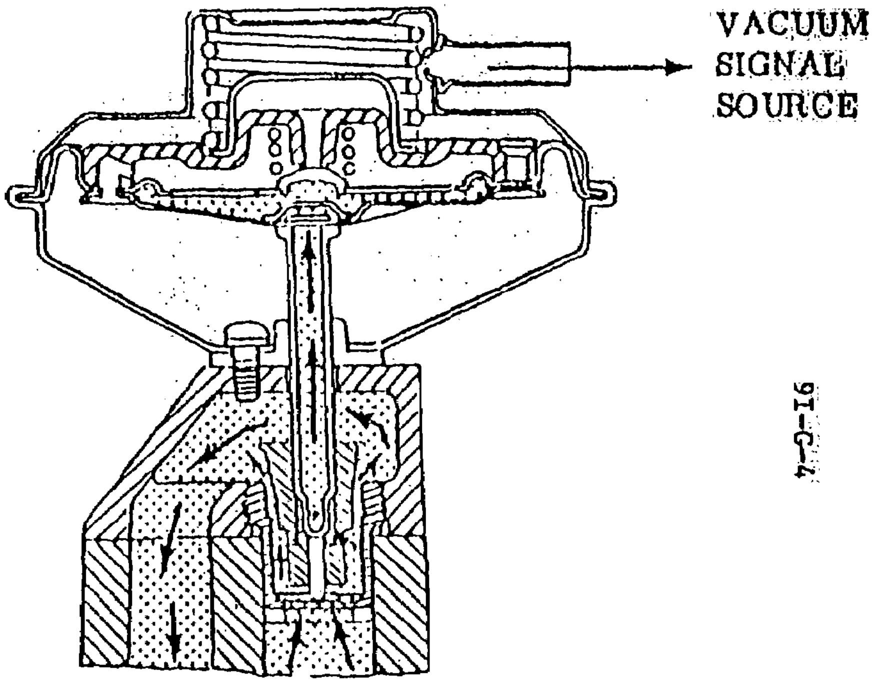
INTEGRAL EXHAUST PRESSURE MODULATED EGR

Positive Control Pressure Valve



EXHAUST PRESSURE BELOW
CONTROL VALUE



EXHAUST PRESSURE ABOVE
CONTROL VALUE

4-G-16

Attachment VII

Integral Exhaust Pressure Modulated EGR Valve - Negative Control Pressure - Description of Operation

The negative control pressure EGR valve, like the positive control pressure valve, uses a transducer, and a vacuum signal source located above the throttle valve. When either a positive pressure (a pressure above atmospheric pressure) or a negative pressure (vacuum) of small magnitude (small enough that the transducer diaphragm spring holds the transducer diaphragm tight against the bleed hole) exists at point A, the bleed hole is closed and EGR occurs if the vacuum signal is strong enough. When a negative pressure of sufficient magnitude exists at point A (as occurs when the valve is open and intake manifold vacuum causes the pressure at point A to drop) the transducer diaphragm spring is compressed and the bleed hole is open causing the vacuum signal to be reduced and EGR to be cut off.

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INTEGRAL EXHAUST PRESSURE MODULATED EGR
Negative Control Pressure Valve

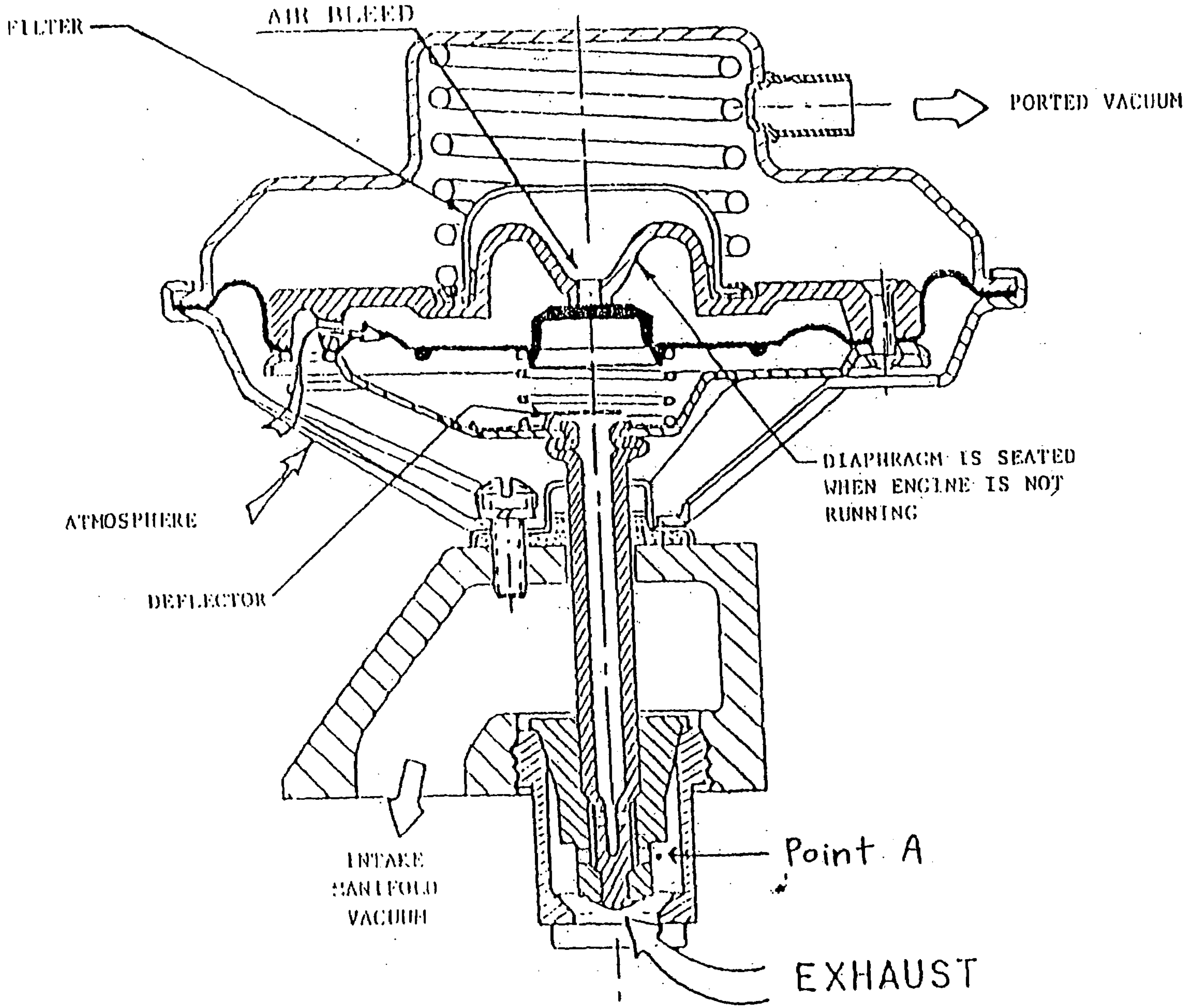
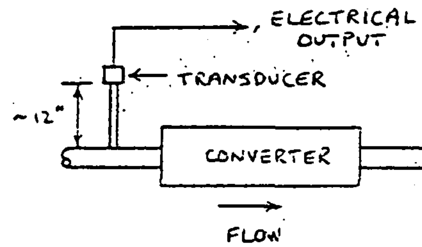
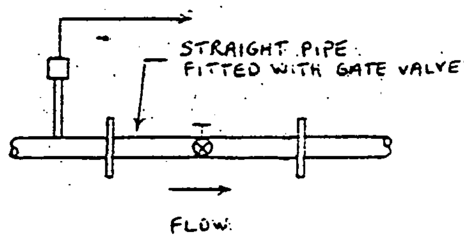
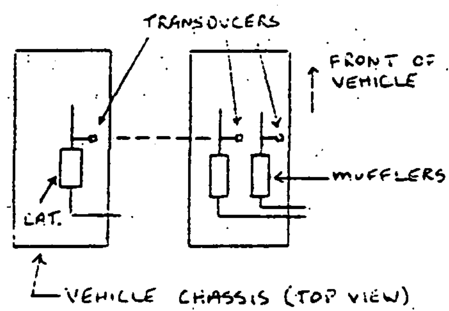
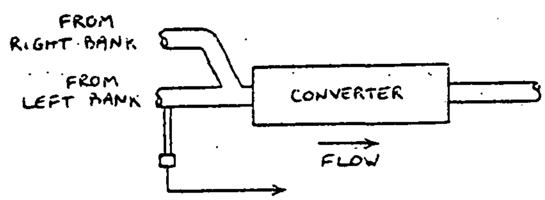
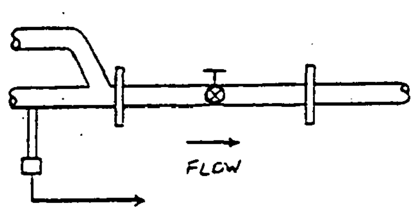


Figure I.

Location of Pressure Transducer for Each Test

Vehicle	Test	Location of Pressure Transducer
119/0001, 119/0004, 119/0005	M-T1	
119/0001, 119/0004, 119/0005	M-2, M-3	
119/0001, 119/0004, 119/0005	M-4	
119/0003	M-T1	
119/0003	M-2, M-3	
119/0003	M-4