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DESIGN AND CONSTRUCTION OF A TEST FACILITY TO CHARACTERIZE BRAKE-WEAR EMISSIONS

Ronald L. Williams
Environmental Science Department
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General Motors Research Laboratories
Warren, Michigan 48090

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Design and Construction of a Test Facility To Characterize Brake-Wear Emissions

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Ronald L. Williams

Environmental Science Department
General Motors Research Laboratories
Warren, Michigan 48090

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ABSTRACT

A unique brake-wear emission facility has been designed and constructed. The principal components are: a conventional brake test dynamometer, a disc or drum brake-and-wheel assembly, an enclosure tube, and an emission sampling system. Brake emissions can be generated and collected under operating conditions which duplicate the normal range of automobile brake usage. This report documents the test philosophy which motivates this study and details the components of the facility. Typical test data are illustrated and discussed for a series of simulated brake stops.

INTRODUCTION

More than one billion brake linings are currently being used by vehicles in the United States. Every time vehicle brakes are applied, a small amount of this material is worn off and introduced into the environment. Since a major constituent of most brake linings is asbestos, it is of interest to determine how much of the asbestos is emitted into the environment. The possible contribution of brake lining wear to ambient airborne asbestos concentrations has been a subject of recurring discussion among brake manufacturers, auto makers and regulatory agencies for the past ten years.

To determine the amount of asbestos emitted from brakes, it is necessary to determine the total quantity of material emitted, the fraction which becomes airborne, and its asbestos content. The simplest sampling technique is to brush out some of the dust retained in a drake drum,[1] but this gives no information about the quantity or composition of the emitted airborne dust. Two more-sophisticated approaches have been reported. Anderson et al.[2] collected dust from an airstream blown past a test brake on a dynamometer but could only estimate the fraction of the total dust which they collected. Jacko et al.[3] put a shroud around the brake assembly of an automobile to confine the emissions during on-road testing. However, the shroud itself could dramatically change the fraction of airborne emissions. Clearly, a better approach to emissions sampling is required.

DESIGN CONSIDERATIONS

Definitive brake-emission testing requires the use of full-size, production brakes because laboratory or bench-scale test apparatus cannot adequately simulate the conditions experienced by vehicle brakes in normal use. Both disc and drum brakes should be tested because they are mechanically distinct and may have distinguishable emission characteristics. Brake-emission testing also requires that all the particulate and gaseous wear products be sampled in a manner which permits quantitative analysis. The most logical approach to emission recovery is to encapsulate an entire brake-and-wheel assembly.

The airstream which passes over a vehicle brake performs two functions. It cools the brake by convection between brake applications, and it carries away some of the wear products. While details of the flow pattern past a brake in normal service are largely unstudied, the essential functions of the airstream could be simulated by controlled air flow parallel with the brake assembly.

The test conditions should be variable over the full range of normal brake use. For any given friction material, one would expect emissions to depend on mechanical parameters, such as speed, load, pressure, deceleration, and the interval between brake stops. Each of these parameters must be controlled and monitored. For a basic understanding of brake emissions, one should study the chemical and mechanical processes as they occur at the friction interface, although few techniques are available that permit such a study. Temperature comparisons in the bulk materials, either in the brake lining or in the drum, can be used as a design criterion to determine how closely simulation tests approximate actual brake use.

CONSTRUCTION AND CAPABILITIES

A unique brake-wear emission facility was constructed which meets all the design requirements. Each of the main components will be described in sufficient detail to document our approach and to provide a ready reference for reporting emission results.

Variable Speed Drive

The brake and wheel assemblies were driven by a 30-kW General Electric D.C. drive motor capable of accelerating the assemblies to preselected speeds up to 100 km/h, with controllability to $\pm$ 0.1 km/h (600 $\pm$ 0.5 RPM).

Variable Inertial Load

To provide the inertial load appropriate to the brake, a variable-mass flywheel was mounted on the drive train. A set of 18 plates, each 6.35-mm thick x 1.02-m diameter, may be bolted to a solid wheel (38 mm x 1.02 m) providing an inertial load variable from 30 to 115 kg·m^2 in steps of 5 kg·m^2. This provides the loading appropriate for testing front and rear brakes for vehicles between 1250 kg and 2500 kg. When not in use, the flywheel plates can be unbolted and stored on the assembly without uncoupling the drive train.

Quick-Coupling Drive Hub

To avoid artificial distortion or misalignment of the brake components, the drive shaft was fitted with a hub to engage with the wheel lugs. The hub has five holes on a 12.7-cm bolt circle with rubber-centered bushings. The test wheel is slip-coupled to the hub. This permits the testing of complete brake assemblies of both disc and drum type. Near the drive hub, the drive shaft is fitted with a set of eight silver slip-rings (Electra Minature, Inc., #20007-48) to facilitate measuring and recording temperatures from rotating parts during tests. The slip-rings are connected to binding posts located inside the test enclosure, just behind the drive hub, by wires routed through the hollow center of the drive shaft.

Slide Base, Slide Fixture, and Torquemeter

A special base was fabricated to support a sliding fixture to which a Himmelstein MCRT 6-02T (15-3) torquemeter is attached. Torque signals to 1700 N·m are conditioned by a Himmelstein 8000 A/2 calibrator, and are read out on digital panel meters on the operator's console. The torque signals are also used to control the antiskid modulator for constant-deceleration brake stops. The signals may also be recorded on strip-chart recorders. The torquemeter is fitted with an adapter hub with a common bolt circle to allow quick exchange of preassembled brake and wheel assemblies. The slide fixture is aligned with the centerline of the drive shaft to allow the assembled test wheel and torquemeter to be slip coupled into the drive hub. The slide fixture is operated by a Saginaw ball screw and is held in position by a locking gib.

Brake and Wheel Assemblies

Front hub and knuckle assemblies lubricated with Sunplex 872 E.P. grease are mounted to a torque tube by a special fixture using tapered adapter bolts to replace the standard ball joints. The other end of the torque tube mates with the torquemeter.

Rear axle, hub, and drum assemblies use a different torque tube which also mates with the torquemeter. The modified production axle is supported inside the torque tube by cone-and-roller bearings at each end. A production axle seal is used to seal the outside bearing. A second seal is located behind the outside bearing, and a sight-glass is mounted in the torque tube to allow the use of production axle lubricant, if desired. This cavity is vented to the outside of the test enclosure to prevent degassing interference with HC measurements during tests. For testing to date, Sunplex 872 E.P. grease has been used instead of production axle lubricant for both sets of bearings. This was done to prevent inconsistencies with tests conducted with front disc brakes where Sunplex 872 E.P. grease is always used.

Brake System

The brake system uses an air-actuated Wagner Electric AF-840 Air Hydraulic Power Cluster (18 cm x 4.5 cm x 6.5 cm stroke) having a 15:1 pressure ratio and maximum pressure of 10 000 kPa. This Wagner power cluster is a commonly available production assembly used on 11-Mg trucks. The system uses production brake lines and fittings, and brake fluid.

Air is supplied by the building air supply system to a 30-L portable air tank. Brake air pressure (pedal pressure) up to 700 kPa is controlled by a Moore 42-100 regulator. Both air pressure and brake line hydraulic pressure are read out on guages and on digital panel meters on the operator's console through Bell and Howell (4-393-0001) pressure transducers. The transducer output may also be recorded on strip-chart recorders.

Many of the components described thus far are shown in Figure 1.

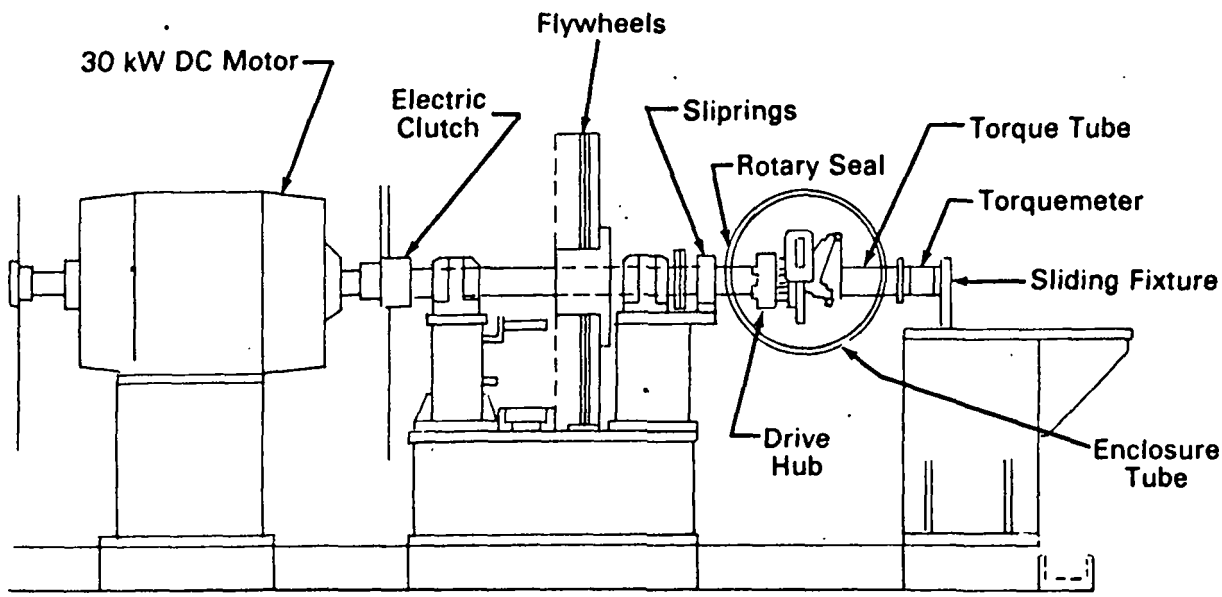


Figure 1. A Descriptive Sketch of the Brake-Emission Test Dynamometer.

The brake is actuated by a solenoid valve in the air supply line between the tank and the hydraulic power cluster. The brake solenoid may be actuated manually by a switch on the operator's console or by an automatic programmer. The programmer may be set for 1 to 10 000 replicate cycles of five variably timed events. The five events may be used to start and stop the drive motor as well as to apply the brake, allowing the test cycles to be automatically repeated.

The brake may be applied in either of two operating modes. For constant pressure stops, the brakeline pressure is preset for up to 7000 kPa. Once actuated, constant pressure is applied throughout the stopping event. The torque, and consequent deceleration, may vary. For constant deceleration stops, the brakeline pressure is preset, but the brake is actuated through an Oldsmobile True-Track Anti-Skid modulator assembly, which drives a torque signal comparator to keep the braking torque at a constant value. Figure 2 is a descriptive sketch of the brake system showing most of its components.

Brake and Wheel Enclosure

The brake and wheel assemblies are enclosed in a 0.45-m diameter x 1.8-m long 16-gauge steel tube. The power shaft and drive hub protrude through the wall. The shaft is fitted with a rotary seal. The end flanges of the tube have O-ring seals. Flush-mounting double panels, also fitted with seals, may be removed to provide access for clean up after testing and for exchange of brake and wheel assemblies.

The inlet end of the tube is fitted with a transition section from a 0.6-m x 0.6-m Cambridge 1AT-1000 absolute filter (rated 37 m^3/min, tested with 31 m^3/min at 1.6 mm Hg). The outlet end of the tube has a 0.66-m-long transition to 0.20-m diameter with an O-ring flange compatible with a portable, isokinetic particulate-sampling unit.

To maintain a smooth interior surface, all seams and grooves were filled, and both the inside and outside surfaces were coated with polyurethane

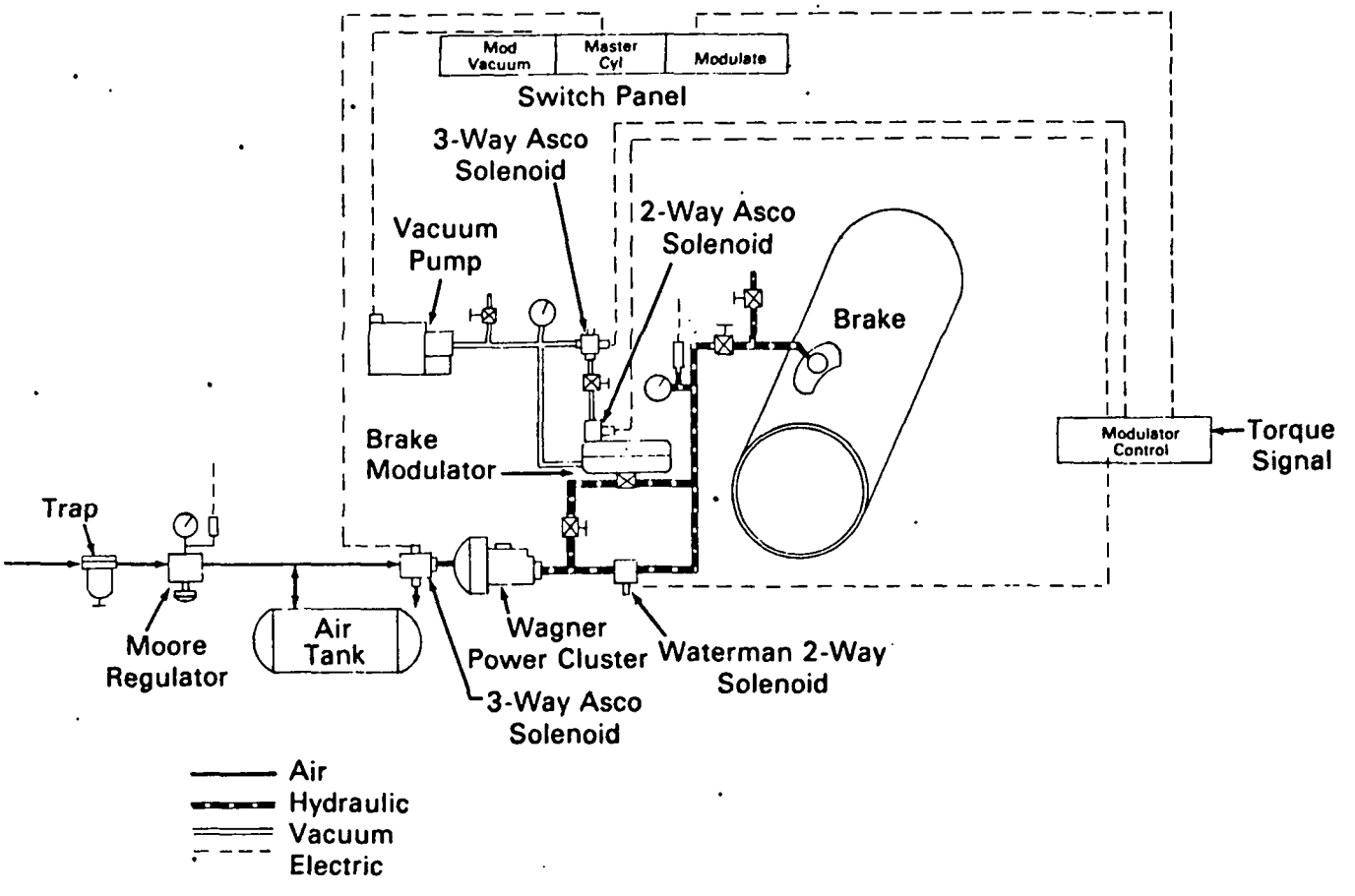


Figure 2. A Descriptive Sketch of the Brake System Used in Emission Studies.

paint. The inside surface is white to allow better cleanup after tests, and the polyurethane surface allows the use of solvents, if necessary.

ILLUSTRATED OPERATION

To illustrate the test data generated by the brake-wear emission facility, ten brake stops from a test series are displayed in Figure 3. Simultaneous recorder traces of wheel speed, brake torque, disc temperature, and HC concentration in the enclosure tube are shown. One brake cycle was completed every 120 seconds. The wheel was accelerated from rest to a preset speed. One second after the power to the drive motor was turned off, the brake was actuated. The brake torque rose rapidly and followed a J-curve pattern, characteristic of constant pressure stops. Apparently a small amount of fade occurred, but as the wheel speed approached zero the tendency to seize overrode the fade effect and the brake torque rose during the final three or four revolutions of the wheel. This effect is shown clearly in the brake stop at the right, which was recorded at 60 times the normal chart speed. The wheel speed decreased nonlinearly, reflecting these torque variations.

In addition to the speed and torque traces, Figure 3 shows the temperature of the brake disc as measured by a thermocouple embedded in the edge of the disc. During the brake stop the temperature rose rapidly. The disc then cooled at a slow rate until the wheel was restarted for the next cycle. While the wheel was rotating the temperature fell rapidly until the brake was applied again. The final parameter monitored in this test was the HC concentration in the enclosure tube with no air flowing through the tube. The HC trace shows a stepwise increase of gaseous hydrocarbons generated from the brake pad. The time-constant for detecting the changes in HC was several seconds as shown by the expanded test cycle at the right.

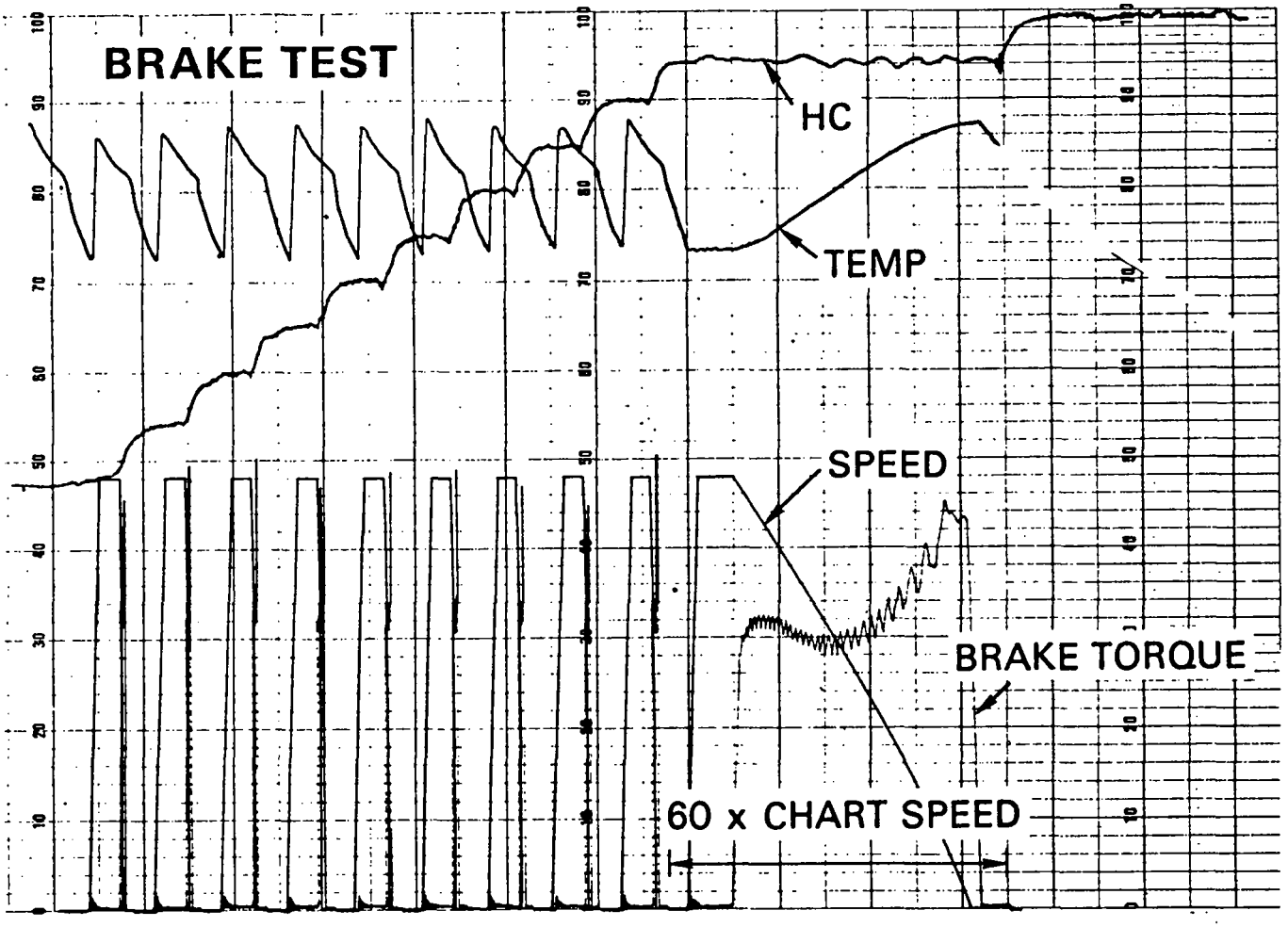


Figure 3. An Illustration of Test Data Generated by the Brake-Wear Emission Facility.

The principal application of this facility will be for the characterization of brake-wear emissions. Gaseous and particulate products can be measured for a variety of friction materials and a wide range of operating conditions. Emissions can be collected for laboratory analysis. Using this facility, a systematic study will be conducted to determine the asbestos fiber content of the material worn from automobile brakes.

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