

Automation of Mode Driving Operation for Exhaust Gas Measurement

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ABSTRACT

Mode driving is being automated using automatic driving units (robots) with the aim of reducing the number of man-hours needed for the measurement of automobile exhaust gases. Automation using robots offers significant advantages, particularly in high-altitude exhaust gas emissions tests, as it liberates workers from harsh working environments.

This system makes it possible to fully automate all work procedures by constructing automatic cooling fan start/stop systems and automatic hood opening/closing systems, which were issues for full automation with robotic driving under high-altitude conditions. In addition, vehicle speed trace accuracy relative to changes in atmospheric pressure inside the test chamber equivalent to that for driving with a human driver was realized by using separate acceleration parameters for low- and high-altitude conditions and optimizing the control parameters. These changes made it possible to reduce the number of staff and time required for tests and to eliminate tasks in harsh working environments.

1. Introduction

Automobiles are used in a variety of different environments. Consequently, the measurements made to quantify an automobile's impact on the environment are required by regulation to be conducted under a diverse set of modes and environmental conditions. The number of verification tests needed to satisfy these regulations is also increasing. Thus, there is a growing demand for automation of exhaust gas emissions and fuel economy testing in order to reduce the man-hours expended to handle the increasing numbers of these tests.

The demand for automation is of course in part for labor-saving reasons. However, automation is also instrumental in eliminating the need for workers to work in the harsh working conditions involved in working in environmental chambers under such conditions as low temperature, solar radiation and negative pressure and in improving the reproducibility of driving results. Great strides have been made recently in the development of technologies related to automation. The use of an automated driving device (robot) instead of a human being to drive test cars is one extremely effective method of automation. This device is commonly used for vehicle engine endurance testing. It is also used for exhaust gas emissions and fuel economy testing of cars with their air conditioning running. Testing with the air conditioning running takes place in a test room under very harsh working conditions. The temperature is maintained at the very hot temperature of 35°C, with the additional use

of solar radiation devices to simulate the environment of a mid-summer day in California.

The high-altitude exhaust gas emissions test (high-altitude test), conducted at the equivalent of a 1600 m elevation, requires a greater expenditure of man-hours than the low-altitude exhaust gas emissions test (low-altitude test).

The purpose of conventional devices was for the robot to drive in place of a human during driving modes. It was not envisioned that the robot would replace humans when conducting operations other than driving. Consequently, such a device would not provide sufficient advantages for use in high-altitude tests. The reason is that, although humans can easily enter the test room to perform such actions as opening and closing the hood and operating the engine cooling fan during the low-altitude test, this is not the case during high-altitude tests. The robots are not able to perform these operations, and humans cannot enter and leave the test room easily due to the need to acclimatize to the pressure change each time. Thus, there has been no particular benefit in using robots for those tests.

The authors have applied the use of robots to high-altitude testing, and improved the device to fully realize automated testing. This paper introduces the improved device and the robot's high-altitude driving performance.

2. Development aims and target requirements

The high-altitude tests conducted at the equivalent of 1600 m elevation require more man-hours than the low-

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altitude tests. Therefore, we studied methods of replacing human operators with robots in order to improve efficiency of high-altitude test operations and minimize the labor burden. The robots, however, were constructed to replace only the driving function. In the past, the operators of the negative-pressure test room operated the vehicle, turned off the cooling fan, and opened and closed the hood. Therefore, the aim cannot be achieved by robots that simply replace the operators for the driving mode alone. Automating these operations would achieve the objective of raising operational efficiency and reducing the labor burden.

The fundamental requirements came under the following four headings:

- (1) The device is capable of conducting tests in conformance with formal test methods as prescribed by regulation.
- (2) When using the LA4 mode, the robot driving performance is equal in low-altitude and high-altitude testing. In addition, both humans and robots are able to follow the same vehicle speeds.
- (3) Action to avoid danger is to be taken in the case of emergency.
- (4) For practical purposes, the device is generally applicable to all vehicles, not just to certain ones.

The issues that needed to be resolved came under the following four headings:

- (1) Opening and closing the hood and turning the cooling fan on and off in a negative-pressure environment
- (2) Conforming to differences in throttle opening when driving in low-altitude and high-altitude tests
- (3) Setting robot driving performance to be on a par with human performance
- (4) Detecting malfunctions and avoiding danger when malfunctions occur

3. Overview

The conditions were set with the negative-pressure test room at the equivalent of an altitude of 1600 m as the standard. The temperature in the test room is adjusted to within $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$, and the humidity to within $50\% \pm 10\%$. The double roller chassis dynamometer is used.

The control unit for the robot is installed in the control room, with only the mechanical unit installed in the vehicle. This mechanical unit is constructed presupposing use under other environmental conditions, with a heater warming unit to make it capable of trouble-free operation even when left at temperatures as low as -25°C . The mechanical unit is shown in Fig. 1, and installed in a vehicle as shown in Fig. 2.

The previous method of conducting tests with human drivers required two people in the test room and two others in the control room for safety reasons. This was done so that an extra person would be available to help if the driver's physical condition deteriorated in the negative pressure environment. Two people would be present in the control room so that one person could enter the test room to help in case of an emergency, while the other person could operate the equipment. When testing with a robot, the test room is unmanned, and one person is sufficient in the control room because of no possible human emergencies in the test room.



Fig. 1 Mechanical unit



Fig. 2 Mechanical unit with vehicle

It requires some time for human beings to acclimatize their bodies to the pressure when going from the control room into the test room under negative-pressure conditions. Consequently, entering and leaving the negative-pressure test room takes 12 minutes each way. This 12 minutes is required at an altitude of 1600 m, and still higher elevations require correspondingly longer times. This situation is outlined in Fig. 3 and Fig. 4. This requirement for additional time and personnel increased the required man-hours before testing was automated.

A U.S. model ULEV Accord with an automatic transmission was used as the test vehicle.

The matter of selecting a standard for the robot operating accuracy was a subject for discussion. The driving style

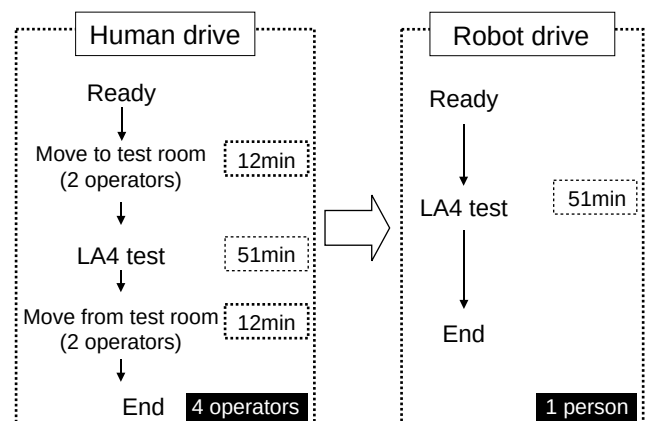


Fig. 3 High altitude test schedule

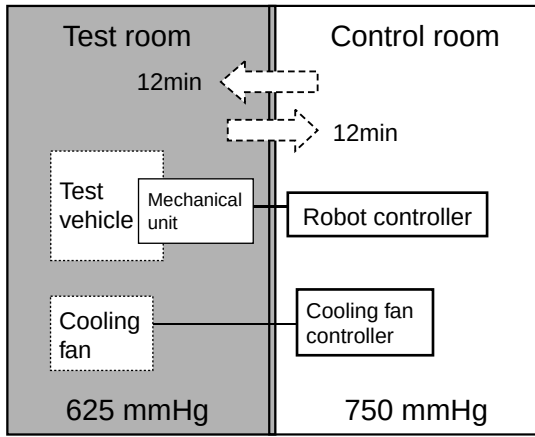


Fig. 4 Test room layout

was eventually based on a driver with three or more years of experience in testing. However, there are individual differences in driving according to the driver. Some drivers follow the benchmark speed exactly while others continuously predict the future and smoothly follow the preceding vehicle. Therefore, an ordinary driving style was selected as the standard.

4. Issue-resolution measures

4.1 Issue 1: Changing of the device

The high-altitude testing requires the engine to be stopped for a 10-minute period (soak), which is an obstacle in the conventional test system. The LA4 mode shown in Fig. 5 has three driving modes: cold transition (CT), cold stabilized (CS), and hot transition (HT). A soak is mandated between the CS and HT modes. At the start of the soak period, the engine is stopped, the hood is closed, and the engine cooling fan is turned off. When the soak ends, the engine is started, the hood is opened, and the engine cooling fan is turned on.

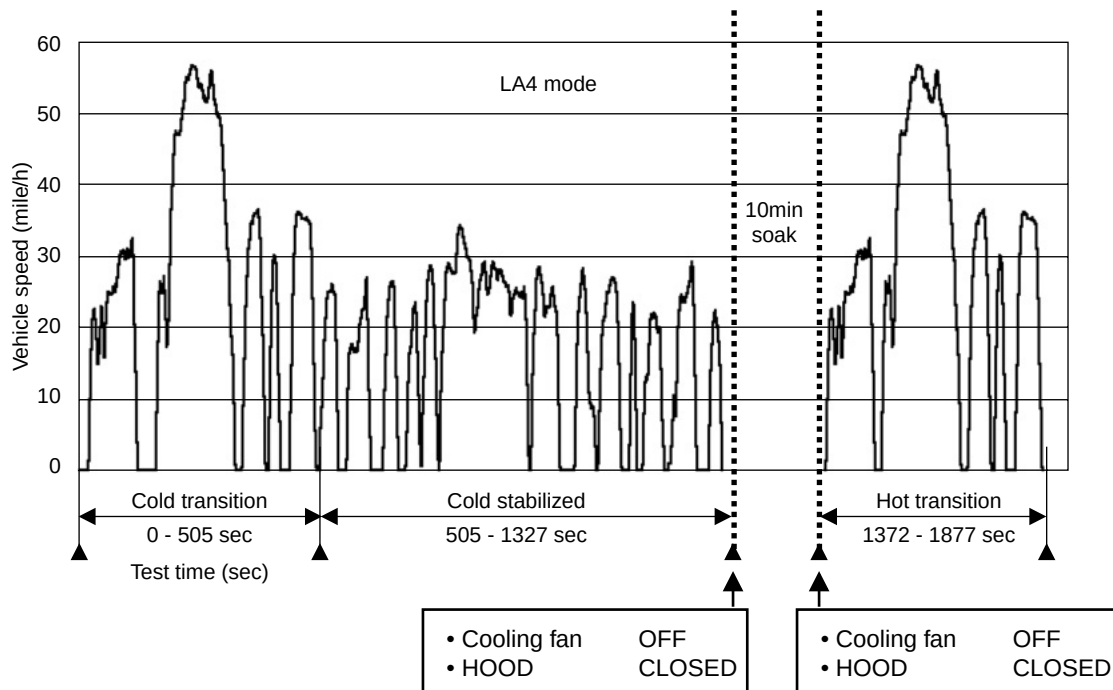


Fig. 5 LA4 test mode

These operations were conventionally carried out by the driver, which means that the high-altitude test as conducted previously could not be performed unmanned.

Fig. 6 shows a comparison between the measurements of exhaust gas emissions with the hood open and closed during the soak period in the LA4 mode. When the hood is open, the NO_x emissions tend to increase. This means that the NO_x emissions values will end up differing during formal tests. This happens because the temperature changes in the catalyst and the exhaust pipe.

An even greater difference than that occurring due to the hood being opened and closed appears in the exhaust gas emissions when the engine cooling fan is not turned off during the soak. This occurs because the engine cooling wind blows directly on the exhaust pipe as far back as the catalyst; thus lowering the catalyst temperature.

As the opened and closed condition of the hood has a significant effect on exhaust gas emissions, full automation by robot cannot be achieved unless this operation is also included as part of the automated test procedure. The

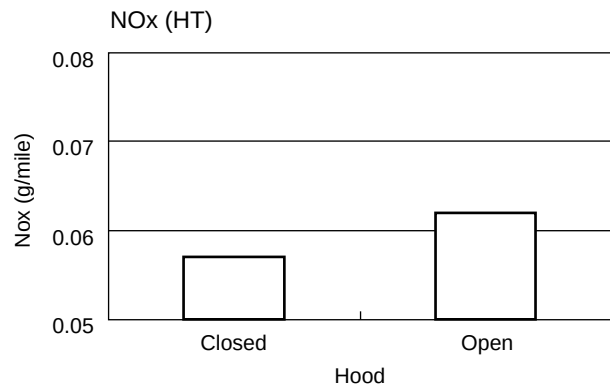


Fig. 6 Comparison of emissions with the hood open and closed (LA4 HT)

required operation is opening and closing the hood during the soak. Therefore, a wire rope was attached to the front edge of the hood, and a reel was installed at the ceiling to reel the rope in and out and thereby raise and lower the hood. This device is shown in Fig. 7. The device was taught the hood open position in advance, and an upper torque limit was set in order to prevent the vehicle itself from being lifted up in the case of a malfunction.

The switch for the engine cooling fan is mounted in the test room. Therefore a branch extension of the switch to the robot was installed to synchronize switching the fan on and off with the robot operation. The device for opening and closing the hood was linked to the robot in the same way.

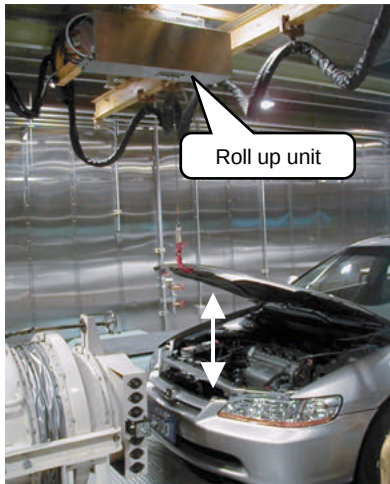


Fig. 7 Automatic hood open-close system

4.2 Issue 2: Differing air densities due to altitude

Differing air densities at low and high altitudes mean that the throttle opening will be significantly different even for identical driving operations. The robot is programmed with a standard acceleration value that is based on the engine output and throttle opening. If the vehicle is accelerated at high altitude using the standard throttle opening for low altitude, the desired acceleration will not be obtained because the lower air density reduces engine output (acceleration). In order to obtain the same acceleration at a high altitude, the throttle must be set to open farther than at low altitudes. Using the standard low-altitude acceleration value at a high altitude will have a negative impact on driving performance and exhaust gas emissions values because efforts to follow the set vehicle speed will be impeded.

It is necessary, therefore, to teach the device the separate throttle openings for low and high altitudes in advance, and to manage the low-altitude and high-altitude data separately. This method eliminated the difference in exhaust gas emissions figures between low and high altitudes that occurred with the robot driving.

Fig. 8 presents comparisons for fuel economy at low altitude and high altitude and fuel economy with human and robot vehicle operation. The discrepancies that arise from the differences when operating at low and high altitudes were studied with reference to differences in fuel economy. However, the differences between results with human drivers and robot drivers were extremely small at both low and high

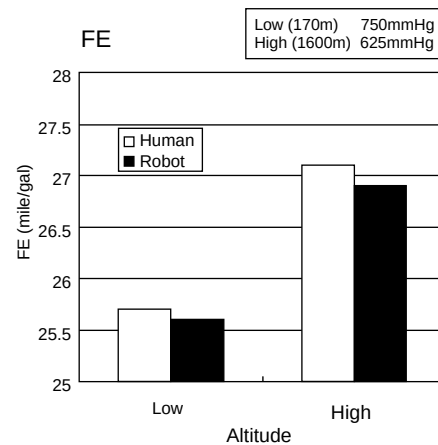


Fig. 8 Comparison of low and high altitude FE for human and robot vehicle operation

altitudes. This confirmed that the device poses no difficulties from the standpoint of practical application.

4.3 Issue 3: Individual variations in following set vehicle speeds due to drivers

Individual variations in following the set vehicle speed occur with different drivers. The regulations prescribe a certain acceptable margin with respect to the standard speed, so that following a speed within that range poses no difficulty. However, variations in vehicle speed trace affect exhaust gas emissions and fuel economy, making it necessary to impose some kind of driving standards. Consequently, the standard selected specifies a driver who has three or more years of experience in testing and the ability to follow the set vehicle speed. Operation of the throttle is an important element in the ability to follow a set vehicle speed. Driver throttle operations can be grouped under three general types.

The standard of a driver who has ordinary speed trace abilities will be defined here as the standard trace. When following the vehicle speed, some drivers will be slow and others will be quick in operating the throttle relative to the deviation between the target vehicle speed and the current target vehicle speed. The former type will be defined here as the slow trace, the latter as the quick trace, and the type in between those two as the standard trace.

We decided to set the robot to have vehicle speed trace abilities equivalent to the standard trace. The speed following control constant for the throttle was adjusted accordingly.

The details of the adjustment are explained here. When the control constant causes a sluggish response to keeping the target speed within the acceptable margin of the vehicle speed range, driving with that control constant constitutes the slow trace setting. Conversely, when the control constant causes a sensitive response that very quickly brings the vehicle to the target speed, driving with that control constant constitutes the quick trace setting. The control constant that lies between those two constitutes the standard trace setting. The standard vehicle speed prescribed by the test method is defined as the trigger speed. Fig. 9 shows a comparison of different vehicle-speed trace performance. This is a comparison of vehicle-speed trace performance within the 55 to 65-second period of LA4 mode initiation. The line

that shows relatively little variation from the trigger speed represents the quick trace. For further comparison of throttle operation, Fig. 10 shows the intake manifold pressure. It is apparent that frequent application of the throttle for the quick trace is a wasteful activity. The slow trace performs future projection for driving with as little throttle application as possible, so there is less waste in throttle operation. Consequently, for the purposes of speed trace performance and throttle operation, the standard trace was set between those two, and it was decided to use the standard trace in the standard control constant for robot operation.

Fig. 11 presents the relationship between vehicle speed trace performance and exhaust gas emissions figures.

Vehicle speed trace performance has little effect on exhaust gas emissions figures. In terms of fuel economy, quick trace causes a 0.6% degeneration, but standard trace produced stable results for both fuel economy and exhaust gas emissions.

The control constants we determined were also used for verification with vehicles other than the Accord. The results showed that the requirement for vehicle speed following was satisfied using the determined control constants.

The following vehicles were confirmed to raise no issues when tested with this control constant:

- (1) NSX with a six-speed transmission (MT and AT)
- (2) Legend with a four-speed transmission (AT)
- (3) S2000 with a six-speed transmission (MT), also verified using the push-button starter
- (4) Civic with a five-speed transmission (MT and AT), also continuously variable transmission (CVT)
- (5) Insight (hybrid vehicle) with a five-speed transmission (MT and AT), also with CVT

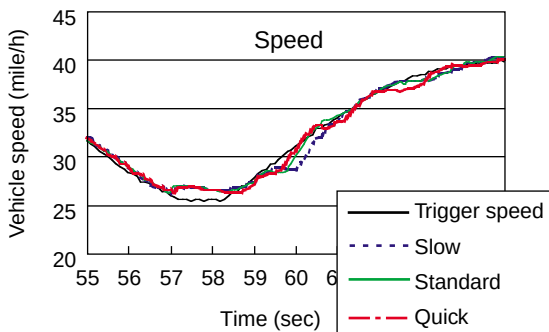


Fig. 9 Vehicle speed trace

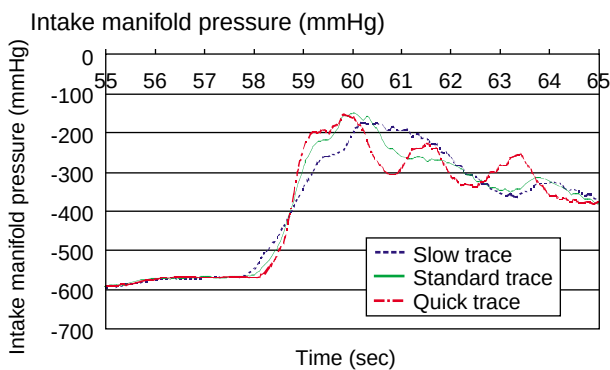


Fig. 10 Intake manifold pressure

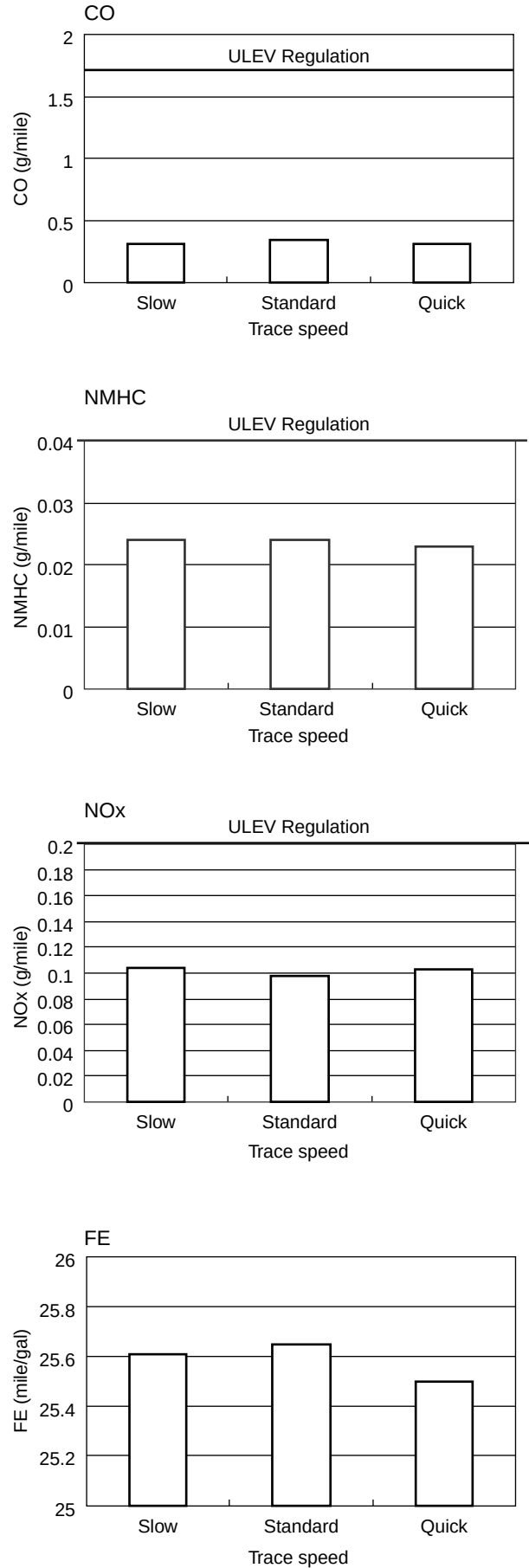


Fig. 11 Comparison of emissions and FE for slow, quick, and standard trace speeds

4.4 Issue 4: Countermeasures for malfunctions

The device is intended for use in unmanned testing in the test room. It is necessary, therefore, to install monitors to detect tire blowouts or other vehicle malfunctions that may occur. Consequently, vehicle position monitoring sensors were installed to monitor vehicle behavior in the vertical and longitudinal directions for malfunctions. Engine speed is also monitored, and malfunctions are identified by the engine stopping or exceeding a set speed. The control room is notified by an alarm when a malfunction occurs, and an emergency stop function is activated to prevent accidents.

5. Effects

5.1 Eliminating highly burdensome work

The use of robots to replace the workers who drive and manage operations in the negative-pressure test room has eliminated the need for those workers to conduct tests in an environment that imposes a heavy work burden. Making the transition to a high altitude in a short time can have a negative effect on the human body. Engine developers have been requesting the elimination of testing that required them to enter the negative-pressure environment of the test room.

5.2 Labor savings

Safety measures for high-altitude testing formerly required the presence of two workers in the negative-pressure test room and two workers in the control room, so that the work standards mandated four workers in all. The use of robot driving, however, has made it possible for a single worker to conduct tests. A single test can now achieve a personnel reduction of three workers.

5.3 Time savings

It previously required a total of 24 minutes for the tester to enter and leave the test room in order to make the transition from low-altitude to high-altitude testing. Elimination of the need for this time has made it possible to cut the time needed by 30%. There was no way to reduce the time required to enter and leave the negative-pressure test room by ingenuity or effort, but automation has made it possible to increase the number of tests conducted in one day.

5.4 Other effects

Advances made in exhaust gas purification performance in recent years have narrowed the difference between concentrations of emissions in the atmosphere and in exhaust gas. A major part of total exhaust gas emissions across the measurement modes is now made up of the highly-concentrated emissions that occur in launches immediately after engine start-up, before the catalyst is activated. Automated testing by robot provides superior reproducibility of driving immediately after engine start-up. This has improved the accuracy of exhaust gas emissions measurement and enhanced the value of the data.

6. Conclusion

The replacement of drivers by a robot for high-altitude

testing and automation of the operations of opening and closing the hood and turning the cooling fan on and off have eliminated the need for human labor in negative-pressure environments. The device deals with driving performance by changing between low-altitude and high-altitude data, and achieved vehicle-speed trace performance by optimizing the control constant. Test results have shown that there is no difference between manned and unmanned testing.

Consequently, the device has enabled the elimination of workers from work that imposes a heavy burden. It provides labor savings and time savings, which has significantly improved operational efficiency. This has also brought improved reproducibility of exhaust gas emissions and fuel economy and enhanced the value of measurement data. For the future, we intend to develop further expanded applications for improving test efficiency and for testing under even harsher environmental conditions.

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References

- (1) I. Inoue, et al.: Development of an Automatic Driving System Using Prediction Control and Applications for Emissions Testing, Ono Sokki Technical Report, No. 12, p. 29–33 (1999)
- (2) S. Noguchi, et al.: Automatic Driving System for Chassis Dynamometers, Horiba Technical Report Readout, No. 6, p. 63–66 (1993)
- (3) Y. Ogawa: Automatic Driving System for Chassis Dynamometers, Kansai Branch Symposium of the Society of Instrument and Control Engineers, October 1998
- (4) T. Wolfgang, et al.: Investigations on Robot Drivers for Vehicle Exhaust Emission Measurements in Comparison to the Driver Strategies of Human Drivers, SAE Paper 982642

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