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Summary of Annex A

SUMMARY OF ANNEX A _____ **1**

A. THE COMFORT BENCH _____ **3**

A.1. Description of the bank, the First Road system..... 3

A.1.1. Introduction 3

A.1.2. Overview.....3

A.2. System electronics 4

A.2.1. Test Processor Chassis 498.10.....4

A.2.2. Analog chassis 497.01 5

A.2.3. Closed-loop control 6

A.2.4. Closed-loop operation.....6

A.2.5. Closed-loop response 7

A.2.6. First Road System Control.....8

A.2.7. Function of board 497.14, AC Conditioner 9

A.2.8. Function of plate 498.55, MIOP-II 10

A.2.9. Function of plate 497.26, Dual valve actuator 11

A.3. Hydraulic system..... 11

A.3.1. Hydraulic power source.....13

A.3.2. Hydraulic actuator series 248.....13

A.3.3. Servo valve model 252.25. 14

A.3.4. Servo valve support. 16

A.3.5. Wheel tray. 16

A.3.6. Anti-rotating assembly.....17

A.3.7. XY Positioning System. 17

A.4. Facility capacity 18

A.5. Environmental impact analysis..... 19

REFERENCES _____ **21**

A. The comfort bench

This appendix presents an explanation of the system's components. It also explains the operation and function of each component. Given the complexity of the system and the multitude of components, it was not deemed appropriate to include this information in the project report, as it is useful only to readers who wish to delve deeper into the subject.

A.1. Description of the bank, the First Road system

A.1.1. Introduction

To understand how the desired profile is reproduced on the test bench, it is essential to understand its internal workings. The following section describes the system from a physical perspective, that is, a description of its most important parts, as well as the function of each one.**[A1]**.

A.1.2. General description

The system*First Road*The MTS is a digitally controlled servo-hydraulic vibration testing system. Figure A.1 shows each of the system's major components separately.

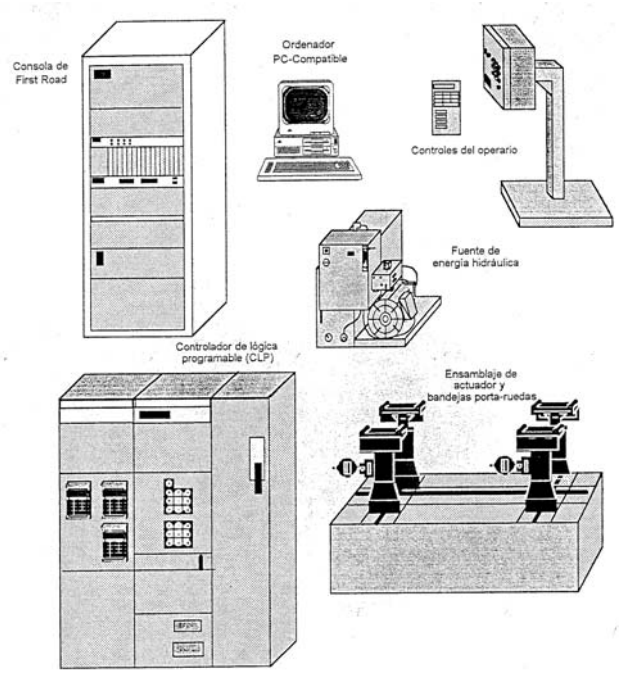


Fig. A.1. Components of the comfort bench

Each system of *First Road* It has four actuators arranged in a rectangle, which are coupled to the tires of different test vehicles. The wheel trays are used to transmit the motion of the actuators to the tires. Each actuator is controlled independently. The dimensions of the wheel trays and their load capacity allow testing of different types of vehicles within certain limits in terms of wheelbase, track, and weight.

In addition, each system *First Road* It has a console for controlling the system by one or more operators, and a hydraulic distribution system that supplies hydraulic power to the assembly. This hydraulic distribution system consists of a power source, or pump, and a hydraulic control cabinet.

A compatible computer is used as a tool for the user to set up, calibrate, and tune the test stand. This computer will be connected to the console. *First Road* through serial data communication connections.

A.2. System electronics

The primary control components on the console *First Road* They are the chassis for the 498 and 497 Series circuit boards and the circuit boards. All actuator movements and many of the system's other functions are controlled by these components.

Data for up to ten motion profiles, plus the data required for the system's control functions, are transferred from the PC to the console's electronics, and can be run as many times as desired. This is done through the chassis' RS-232 port. The profile to be run at any given time is selected using the numeric keypad available to the operator.

A.2.1. Test processor chassis 498.10

The Model 498.10 is a multipurpose chassis with seven Motorola VMEbus slots. Each has one of the following circuits:

- 498.34 Processor Board, which is the system manager for the 498 and 497 series electronics.
- Digital Input/Output Board 498.70, which controls the digital inputs and outputs used to connect the First Road console to the operator control panel and hydraulic control cabinet.

- The MIOP-II 498.55 board is the multi-function input/output processor, providing the primary system control functions. It has four separate sections, one for each test stand channel. The MIOP-II also provides analog readout signals to the oscilloscope access panel.

- The 498.04 Clock Module serves two primary purposes. First, it provides a VMEbus clock signal to all circuit boards in the 498.10 chassis. Second, it is equipped with an RS-232 port that serves as the communications system between the PC and the 498.10 chassis.

- Memory card 498.42, permanent system memory used to store data that cannot be altered.

Integrated into the 498.10 chassis is a power supply that provides DC power to all 498 circuit boards. This power supply receives AC voltage from a 3 kVA uninterruptible power supply (UPS) mounted on the bottom of the console. The UPS receives its power from the hydraulic control cabinet via the power entry panel.

A.2.2. Analog chassis 497.01

The Model 497.01 is an 18-slot multipurpose analog chassis, containing the following circuit boards:

- A 497.36 communications board, which provides communication between the PC and the 497.01 chassis via the RS-232 port. On the PC's connection panel, there is a connection point to the RS-232 port on the 497.36.

- A 497.34 board, which serves as an interlock controller for the other circuit boards in the 497.01 chassis.

- Four 497.14 boards serve as signal conditioners for a differential transformation displacement transducer. Therefore, there are four in the system, one per actuator.

- Two 497.26 power boards, each providing control signals to two servovalves. Since each actuator has a servovalve, two 497.26 boards are required.

A power supply located inside the First Road console supplies power to all circuit boards. This power supply receives voltage from the control cabinet.



hydraulic through the mains voltage input panel. The system also has a ventilation unit that provides air circulation within the cabinet, thus preventing excessive temperature increases.

A.2.3. Closed-loop control

Each actuator in the First Road system's test stand is independently controlled with a separate closed-loop function. The primary elements of the First Road system that provide the closed-loop functions are the circuit boards in the 498.10 test processor chassis and the 497.10 analog chassis.

The basic function of what is known as a closed loop is to compare the command signal (the desired response of the actuator) with the feedback signal (the actual response of the actuator) and make instantaneous corrections so that the actual response equals the desired response.

The following diagram (Figure A.2) shows a diagram of a simple servo-hydraulic control loop. The control elements and signals shown in the diagram are for controlling the displacement (position) of an actuator.

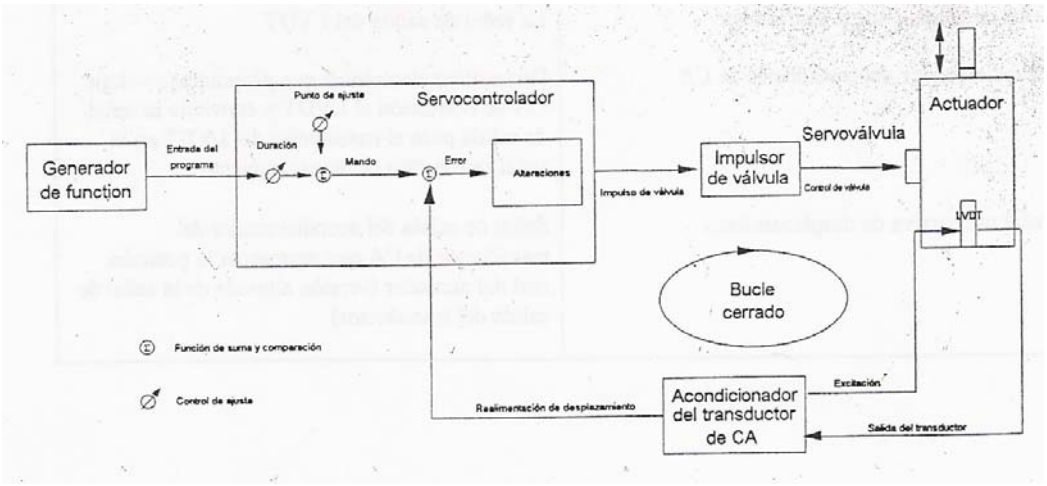


Fig. A.2. Closed loop diagram

A.2.4. Closed-loop operation

When the command and feedback signals are equal, the error signal is zero and the loop is at rest, the actuator is motionless and in the command position. If the command signal changes, the error signal is no longer zero, the polarity of the

error signal is determined by the command signal which may be greater or less than the displacement feedback signal.

From everything discussed so far, it's clear that the error signal is proportional to the difference between the command and the feedback. This error signal, when non-zero, triggers a series of actions in the loop, which cause the actuator to move toward the new command position. As this happens, the displacement feedback signal approaches the command signal, causing the error signal to decrease as the actuator moves.

When the displacement feedback signal equals the command signal, the error signal is zero and the actuator stops, returning the loop to its resting state.

The process described so far explains how a closed loop reacts to a simple change in the control. The control started at a static level and changed to another static level. That is, the actuator started in a static position (without movement) and then changed to another static position and stopped.

If the control were to alternate between two levels repeatedly, and the changes were instantaneous and in equal time intervals, the closed loop would be operating with a rectangular wave. In addition to operating with static and rectangular wave controls, the closed loop is capable of operating with sinusoids, triangular (ramps), and arbitrary waves.

A.2.5. Closed-loop response

The closed-loop response is defined as its ability to detect and react to changes. Many factors affect the loop's response, the most important of which are:

- Command dynamics
- Hydraulic system responsiveness
- Responsiveness of the electronic servo controller system.

Since the drive is used to drive a closed loop and is not actually part of it, and since the response of the hydraulic equipment is fixed, the most important factor in determining the loop's response is the servo controller's electronics. Furthermore, since the response of the servo controller's electronics is much faster than that of the hydraulic equipment, it can be adjusted to match the response of the hydraulic equipment. It can be said that the servo controller's electronics



The system is tuned to produce an optimal loop response, ensuring that the loop accurately replicates a wide range of waveforms, amplitude and frequency of the controller.

The process of adjusting the servo controller's electronics to achieve optimal loop response is known as "loop tuning." This process basically involves adjusting the tuning controls that alter the error signal, converting it into the valve drive signal.

The closed loop of the system *First Road* It has functions for:

- Convert the transducer output signal into a displacement feedback signal that represents the actuator position.
- Alter the error signal and convert it into the valve drive signal by introducing proportional, integral and derivative functions.
- Generate the valve control signal with the valve drive signal by means of inputting a conditioning oscillation signal and a balanced valve voltage.

These functions and their associated electronic elements (of those discussed in points A.2.1 and A.2.2) are described below.

A.2.6. System control *First Road*

The following schematic (Figure A.3) shows a simplified block diagram of the closed-loop function of the system *First Road*. As can be seen, the functions of the system *First Road* They include controls used to tune the loop by altering the error signal. They also have specific transducer conditioner and valve driver functions that alter the valve drive and transducer output signals and convert them, respectively, into valve servo control and displacement feedback signals.

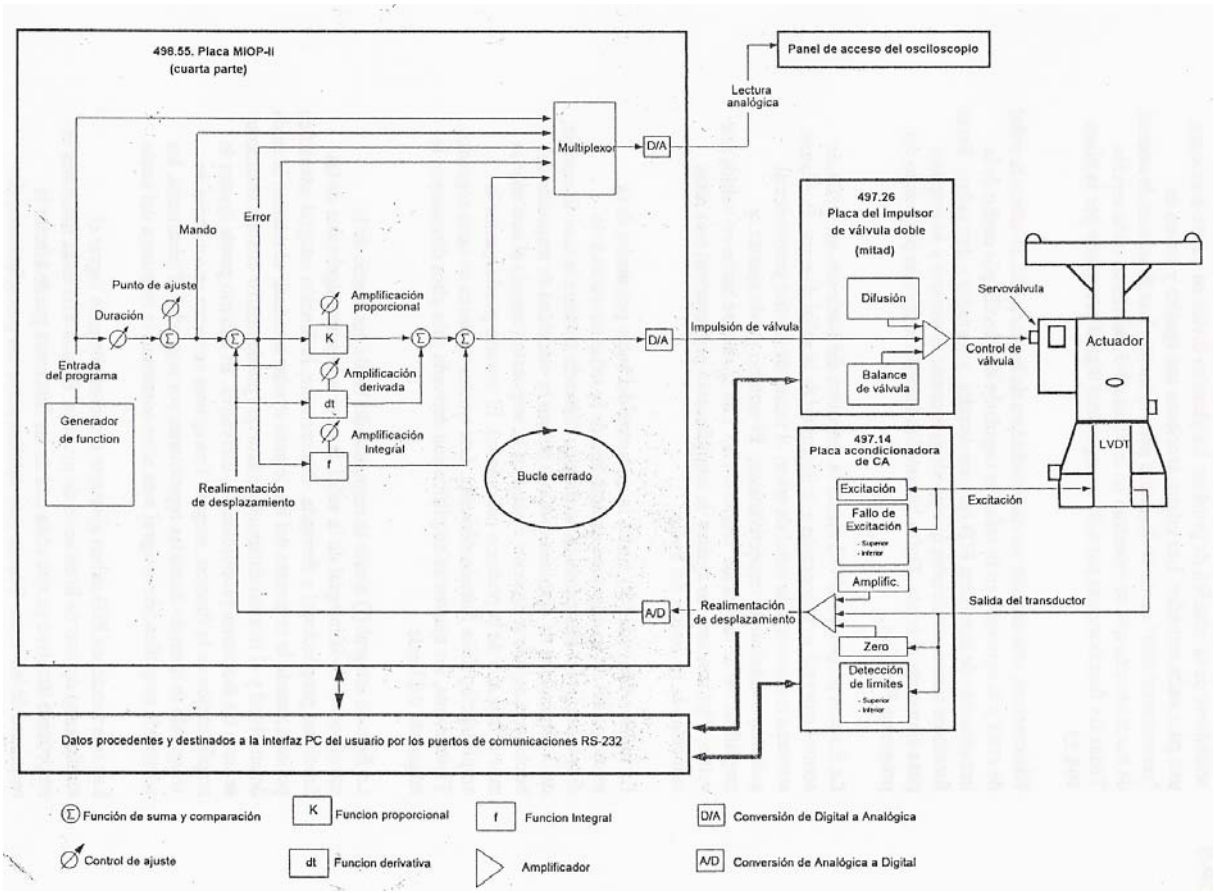


Fig. A.3. Closed-loop control functions

The three main elements of the system electronics in closed-loop function are:

- Plate 497.14, AC Conditioner
- Plate 498.55, MIOP-II
- Plate 497.26, Dual Valve Impeller

A.2.7. Function of plate 497.14, AC Conditioner

There is one 497.14 board for each actuator in the system, for a total of four. The input to this board is the transducer output signal from the actuator's LVDT. One of the outputs is an AC drive voltage that goes to the LVDT. The other output is the displacement feedback signal that goes to board 498.55, MIOP-II.

The 497.14 board converts the transducer output signal into the displacement feedback signal by introducing a zero offset voltage and an amplification factor (also a voltage). Both voltages are used for calibration and are programmed using the installation's tuning program.

The amplification factor voltage is used to alter the transducer output signal so that the displacement feedback signal represents the actuator position (direction and distance) in engineering units of measurement per volt.

The zero offset voltage is used to alter the transducer output signal so that the displacement feedback signal is zero at the desired actuator position (typically mid-travel).

The AC excitation voltage to the LVDT can also be programmed by the person in charge of controlling the installation. The excitation voltage level and phase values are adjusted using the installation's tuning program.

The 497.14 board also provides upper or lower excitation failure detection and upper and lower travel limit detection. Interlock signals are generated by the 497.14 board when one of these limits is exceeded, that is, when for any reason one of the actuators exceeds its travel limits.

A.2.8. Function of plate 498.55, MIOP-II

The system consists of a 498.55 MIOP-II board used to control the test station's four actuators. The board is divided into four identical sections, one for each actuator, each containing the closed-loop control functions explained in the previous sections.

Basically, a servo-controller section on the 498.55 board alters the error signal and converts it into the valve drive signal by inputting PID (proportional, integrated, and derivative) functions. These functions have amplitudes that can be programmed using the system's tuning program on the system's computer.

The proportional (K) function adjusts the loop response with a control factor that is proportional to the magnitude of the error signal. As the error signal increases or decreases, the proportional control factor increases or decreases, respectively. Typically, higher proportional gain settings increase the loop response.

The derivative function (dt) adjusts the loop response by introducing a component derived from the displacement feedback signal. Basically, the

The derivative function anticipates the rate of change of displacement feedback and reduces the loop's response speed to help prevent overshoot (when the actuator moves beyond the handle position). Higher derivative amplification values slow the loop's response.

The integral function (f) adjusts the loop response by introducing the integral of the error signal to the algebraic sum of the proportional and derivative functions. Basically, the integral function periodically boosts the loop response to help minimize the amplitude rolloff and dynamic phase delay that can occur when only the proportional and derivative functions are used. Higher integral boost values increase the loop response.

PID function tuning should be done to achieve optimal operation of the installation. This process is iterative since each of the functions can affect the response of the others.

A.2.9. Function of plate 497.26, Dual valve actuator

The system consists of two 497.26 boards, which are used to control the four actuators. Each board is divided into two identical sections, each providing the valve control functions of a servo valve. The input for each section is the valve drive signal from the 498.55 board. The output is the valve control signal to the actuator's servo valve.

The 497.26 board converts the valve drive signal into the valve control signal by means of inputting a conditioning oscillation signal and a balanced valve voltage.

The conditioning oscillation signal is a low-amplitude, low-frequency sine wave added to the valve's drive signal. This helps prevent servo valve settling by minimizing the effects of friction and valve spool inertia. The frequency of the conditioning oscillation signal is 50 Hz, and its amplitude is adjusted using the system's tuning software.

A.3. Hydraulic system

The First Road system's hydraulic system provides the power needed to simulate road surfaces in a vehicle—in other words, the power to move the actuators, which in turn drive the suspension's vertical motion.



Each system*First Road*It has four actuator assemblies and a hydraulic power source. The hydraulic power that moves the actuator assemblies comes from a hydraulic distribution system.

Figure A.4 shows an illustration of a hydraulic actuator assembly, which is composed of the following parts:

- Hydraulic power source
- Series 248 actuator with hydrostatic bearings.
- Servo valve model 252.25.
- Servo valve support with accumulators.
- Wheel tray.
- Anti-rotation assembly.
- XY positioning system



Fig. A.4. Hydraulic actuator

The most important characteristics and function of each component of a hydraulic actuator assembly will be discussed below.

A.3.1. Hydraulic power source

The MTS Model 510.30 Hydraulic Power Pack (Figure A.5) employs a variable volume pump to provide up to 1.57x10^{-3}m^3/s (*25 gal/m*) and power a test station. Accumulators are used to satisfy short-duration peak flows that cannot be met with the pump's average flow rate. The maximum recommended system pressure is 21 MPa (3000 psi).



Fig. A.5. Hydraulic power source

A.3.2. Hydraulic actuator series 248.

The MTS Series 248 hydraulic actuator is a high-power, two-point linear displacement actuator. It consists of hydraulic bearings and an LVDT. The Series 248 actuator has a maximum travel of ±25 mm and a maximum nominal force of ±20 kN. Normal operating pressure is 21 MPa (3000 psi) and is supplied by the hydraulic distribution system.

An LVDT integrated into the actuator measures piston displacement and provides an analog electronic signal representing the piston position (direction and distance from mid-stroke). The signal is wired to a Model 498.14 AC Conditioner Board in the First Road console, where it is used for closed-loop control of the actuator's displacement. The LVDT's supply voltage is supplied by the board.

498.14. The following figure (figure A.6) shows the sectional view of the 248 series actuator with its main parts, such as the piston (*piston rod*), hydraulic bearings (*hydraulic bearings*) responsible for maintaining the position of the piston when subjected to lateral loads, and the LVDT which provides information on the position of the actuator at all times.

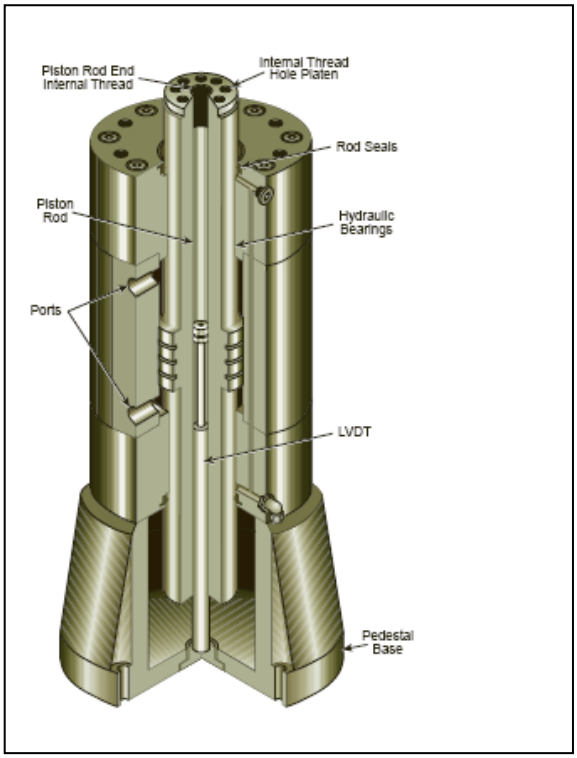


Fig. A.6. Sectional view of an actuator

A.3.3. Servo valve model 252.25.

The Model 252.25 servo valve (Figure A.8) is a proportional, bi-directional flow control valve, with a nominal flow value of $8.2 \times 10^{-4} m^3/s$ (*13 gal/s*), which controls hydraulic flow through both sides of the actuator. It operates in response to an electronic analog signal to control the servo valve.

Servo control is provided by a Model 497.26 dual-valve actuator board on the First Road console. The polarity and magnitude of the servo control signal are determined by a closed-loop displacement control function provided by the First Road console.

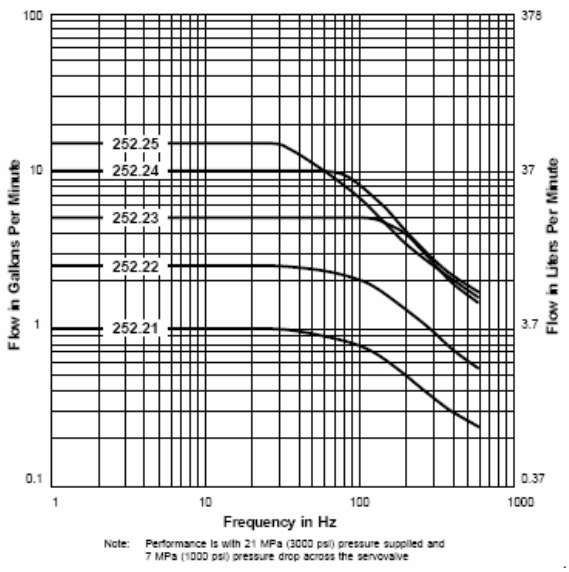


Fig. A.7. Servo valve characteristic of an actuator (*)

(*): SI units 1 gallon = $3.78x10^{-3}m^3$



Fig. A.8. Servo valve of an actuator

A.3.4. Servo valve support.

The servo valve bracket provides the mounting for the servo valve and the hydraulic pressure and return accumulators. It also provides the fluid flow path between the servo valve and the hydraulic pressure and return lines coming from the HPS, and between the servo valve and the actuator.

Mounted on the sides of the servovalve bracket are two hydraulic accumulators (Figure A.9). One is for the hydraulic pressure line and the other is for the hydraulic return line. The pressure-side accumulator provides short-term compensation for flow demand and dampens hydraulic shocks that occur during servovalve transitions. The return-side accumulator dampens hydraulic shocks. Both accumulators can be seen in the following figure (Figure A.9).



Fig. A.9. Accumulators of one of the actuators

A.3.5. Wheel tray.

A wheel tray (Figure A.10) is used to connect the wheels of the vehicle under test to the test stand actuators. It consists of a welded structure and stops that ensure the wheels do not move laterally, which could cause an accident. This welded structure has a flat top surface and is bolted directly to the piston rod of each actuator.

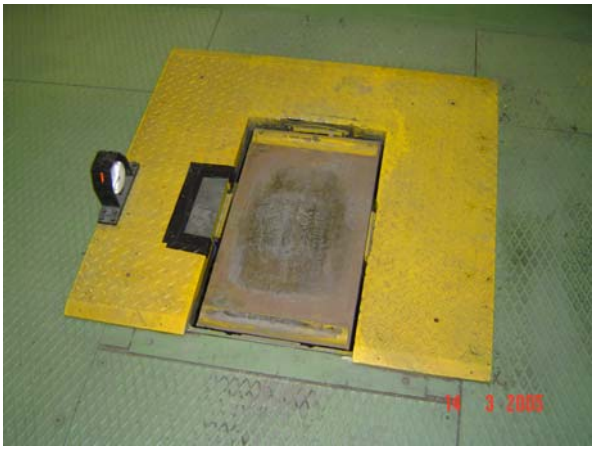


Fig. A.10. Wheel tray

A.3.6. Anti-rotating assembly.

This assembly uses two tie rods and a welded box-shaped structure to anchor the ends of the wheel tray to the stationary actuator cylinder, preventing the wheel tray from rotating. Without this system, the actuator piston and wheel tray would be free to rotate in any direction.

A.3.7. XY positioning system.

The First Road system features an automatic XY positioning system (Figure A.11) for the actuator assemblies. This system allows the wheelbase and track measurements of the vehicles to be tested at the facility to be entered into the computer controlling the facility. These measurements are stored on the computer and subsequently downloaded to the First Road console (a maximum of 10). By selecting the desired vehicle at any given time on the console, the wheel platforms move automatically.



Fig. A.11. Detail of the control system (left) and positioning mechanism (right)

A.4. Facility capacity

All profiles intended to be used in the installation must be within the limits established by the manufacturer, which are obviously determined by the capacity of each of the installation's components. These limits have already been discussed in the previous points and are shown below in a graph (Figure A.12) with the operating limits.

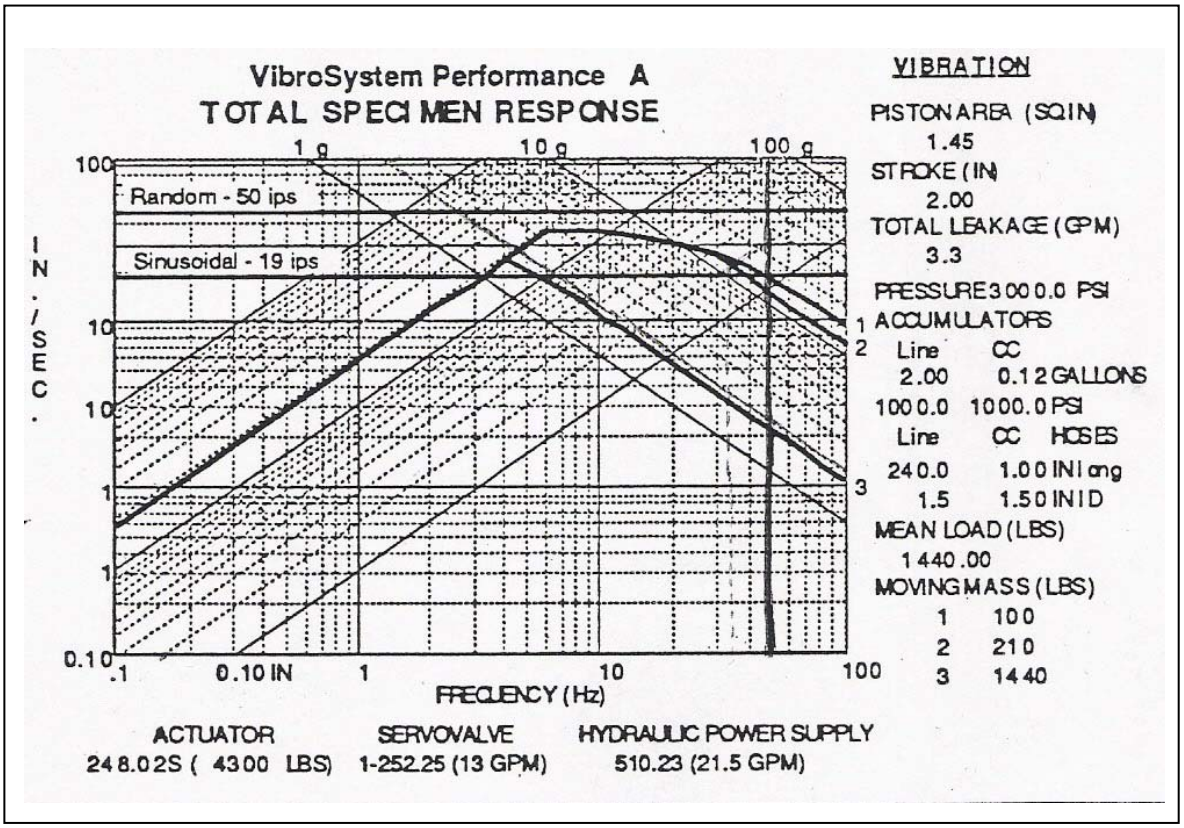


Fig. A.12. Detail of the control system (left) and positioning mechanism (right) (*)

(*) Units in SI

1 lbs = 1 pound = 0.453 kg

1 GPM = 1 gallon per minute *1 gallon = 3.78x10^{-3}m^{3}*

1 SQIN = 1 inch^{2} *1 inch = 25.4 mm*

1 PSI = 6.9x10^{3}Pa

The graph (Figure A.12) shows three performance curves for the system using three different moving masses. The graph obviously shows the operation of one of the channels (actuators).

1. Actuator only
2. Actuator + unsprung masses
3. Actuator + complete vehicle quarter

Curve 1 shows the maximum values that the signal reproduced by the test bench can reach, which are applied to the vehicle through the tire. Curves 2 and 3 only apply at frequencies where the vehicle and unsprung masses are coupled to the actuator. Generally, at frequencies above 2 Hz for the vehicle and 12 Hz for the unsprung masses, these masses do not follow the movement of the actuator and assume static loads. The lines marked 1, 2, and 3 will therefore be the maximum values that the installation can reproduce under these weight conditions on each of the actuators.

From curve number 1 we can therefore deduce the maximum installation values, which will be:

- Maximum acceleration: 147.15 m/s_2
- Maximum speed: 0.9 m/s
- Maximum displacement: 50 mm
- Frequency range: 0 – 100 Hz

A.5. Environmental impact analysis

In this type of installation, the power source is primarily electrical, which drives the hydraulic pump. Therefore, waste generation is practically zero, reducing the waste generated by the oil change required by the manufacturer.

This is where the waste collection plan comes into play, ensuring complete control of the entire process, including the extraction of the liquid, its handling, and its subsequent packaging for collection by specialized companies.



In addition, the installation is periodically inspected by the Nissan Motor Ibérica maintenance department to detect any leaks of the oil used to operate the cylinders. To prevent such leaks, the manufacturer's specifications for the pipes or hoses that carry the oil from the pump to each of the actuators are strictly followed.

Each and every hose in the system is inspected and replaced as specified by the manufacturer, thus preventing leaks or fluid losses. Furthermore, in the event of a spill, Nissan Motor Ibérica has a protocol in place to stop the spill and collect all the fluid, thus preventing possible leaks or accidents.

In addition to the above, which refers to physical waste, it is also worth highlighting the noise pollution produced by the pump's operation.

This pump is located directly below the bench, so the noise it produces is noticeable to bench users. This noise pollution makes it necessary to wear protective headphones while the pump is on, or in other words, while tests are being performed. In this regard, the Occupational Safety Department, together with the Maintenance Department, have decided that starting in 2007, the bench will be connected to the central power source of the technical center's laboratory, thus eliminating the pump. This will both improve noise pollution and allow noise detection work in vehicles, something that until now was practically impossible due to the noise generated by the pump.

References

[A1]: MTS SYSTEM CORPORATION. Nissan MTS Job Number 307.11 System reference, Minneapolis, Minnesota, 1991.



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