UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica
Más que un estado sólido
https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRONICA
A Case-study Vision

Test bench with wireless control for gasoline injectors

Banco de pruebas con control inalámbrico para inyectores de gasolina

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INFORMACIÓN DEL ARTICULO

Enviado: 25/10/2019
Recibido: 30/10/2019
Aceptado: 12/12/2019

Palabras clave:
Inyector,
Presión,
Control inalámbrico,
Pulsos de inyección,
Limpieza de inyectores,
Sistema hidráulico

Keywords:
Injector,
Pressure,
Wireless control,
Injection pulses,
Cleaning injectors,
Hydraulic system.

ABSTRACT:

Currently, the market for new vehicles in Colombia, particularly in its capital, shows that about 70% is multipoint electronic injection, evidencing the high demand for the injector cleaning service. To this is added the regulations of 2002 that requires the technical and mechanical revision of vehicles conducive to guarantee the operation and emissions within the permissible limits. Therefore, this article describes the design and development of an electromechanical prototype focused on the evaluation and cleaning of injectors in gasoline vehicles. The design obtained from the structural and electronic point of view simulates variables that condition a vehicle in operation: pressure and electrical injection pulses. For the evaluation of the injector tests of: drip, spray and injection flow were used. The results obtained diagnose the spraying and injection flow tests taking as a reference the measurement of the liquid deposited in the measuring pipes.

RESUMEN

Actualmente, el mercado de vehículos nuevos en Colombia, particularmente en Bogotá su capital, muestra que cerca del 70% es de inyección electrónica multipunto evidenciándose así una alta demanda del servicio de limpieza de inyectores. A lo anterior se adiciona la vigencia de la normatividad de 2002 que obliga a la revisión tecnicomecánica de vehículos, conducente a garantizar el funcionamiento y emisiones dentro de los límites admisibles. Por lo anterior, el presente artículo expone el diseño y desarrollo de un prototipo electromecánico enfocado a la evaluación y limpieza de inyectores en vehículos a gasolina. El dispositivo obtenido, desde el punto de vista estructural y electrónico, simula variables que condicionan un vehículo en funcionamiento: la presión y los pulsos eléctricos de inyección. Para la evaluación del inyector se usaron pruebas de goteo, pulverización y flujo de inyección. Los resultados obtenidos diagnostican eficazmente – con un error alrededor de ± 1,5ml - las pruebas de pulverización y flujo de inyección, teniendo como referencia la medida del líquido depositado en los tubos de medición.

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Cite this article as: A. F. Caro-Montes, A. F. Piza-Segura, H. Montaña-Quintero, "Test bench with wireless control for gasoline injectors", Visión Electrónica, vol. 2, no. 2, Spcial edition, 2019 https://doi.org/10.14483/issn.2248-4728

1. Introduction

New vehicles market in Colombia was 175,723 units - registered in the first 9 months of 2018 [1]-; and only in Bogota, circulated about 2,259,568 private vehicles of which 70% were multipoint electronic injection technology, [2]. The above shows the need for an efficient service for cleaning injectors. In addition, there are current regulations given in Article 28 of Law 769 of 2002 (mechanical technical revision of vehicles), which requires these systems to be maintained in good condition in order to guarantee operation and emissions within an admissible range, [3].

On the other hand, in vehicle maintenance, electronic injection is one of the systems that require an ideal calibration; for this, the injectors are carried out a variety of tests that adequately diagnose them; likewise, a cleaning is carried out to guarantee the operation due to the fact that they have a high use frequency: when a car is at 3,600 rpm, the injector is activated 3,600 times in one minute and is subject to performance of other components such as the gasoline filter, which in countries such as Colombia are regularly falsified [4-5]. As a result, machines that meet the requirements described above are in a high cost range - on average close to US$1,000, [6] - so their access is limited for some users and workshops.

According to the above, this problem needs to be investigated so that it leads to implementation of prototypes -affordable- for the corresponding injector maintenance, in order to be an alternative so that the workshops comply with all conditions for an efficient repair of the injection system and its corresponding certification.

This paper is structured as follows: in first part it presents a state of the art as a description of fundamental terms in electronic injection, the reason for injection testing machines, and how other researches elaborated similar prototypes; later it is defined how was elaborated the proposed prototype, from software design to implementation of a functional machine; finally, different tests are carried out performed by the machine (5 injectors) visualizing results to impart a diagnosis; then conclusions are established.

2. State of the art

2.1. Injector

The injector is a high pressure solenoid valve that is formed by a cylinder sieved inside; its outlet tip has a nozzle that allows the gasoline pulverization. By means of a coil, a small metallic needle is opened or closed, housed inside. The injector is designed in a conical shape so that the gasoline spray reaches the piston chamber without generating leaks, see figure 1.

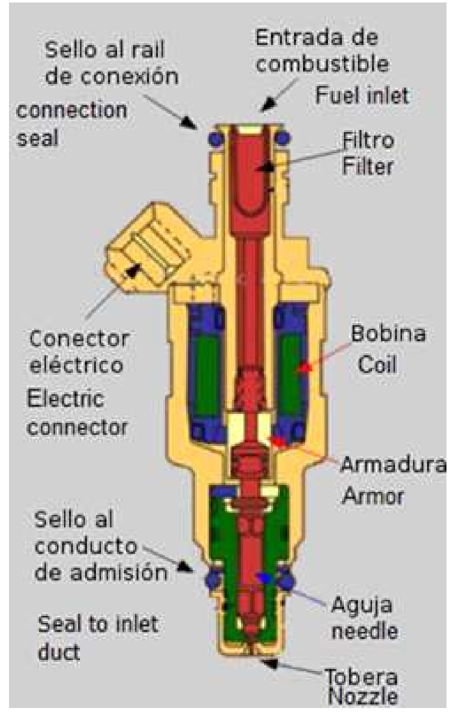

Figure 1. Parts and internal injector scheme. [7]

2.2. Electronic injector system

To generate a mechanic movement from combustion it is required oxygen, gasoline and ignition spark, then are produced explosions that generate movement on the piston system. First known supply system was able to add gasoline in a mechanical way, originating hard gas emissions and a high gasoline consumption; however, due to low quality gasoline supply, this system was replaced by an electronic system that controls everything from a computer (ECU) [5]. In this brand new system the gasoline supply is made by means of an injector that is activated with electronic pulses; so the injector is under various conditions: plugging, flow and a mixture of both, configuring an opening – closure signal.

Because this element has a high use frequency, it can suffer damage – as well as housing gasoline impurities in its interior – producing high failure probability in the proper and general operation of the vehicle.

For these reasons, it was necessary to create machines that simulate the injector conditions to give a diagnosis before and after cleaning. These machines began to generate a high impact due to their efficiency in the car maintenance, so they became essential instruments in automotive mechanics workshops.

As a background, there are recent studies. The project entitled Test bench implementation for electronic control unit of vehicles with electronic injection systems [9], was developed trying to emulate an ECU. With respect to circuits that control the parameters required for test bench, it was tried to obtain signals from all electronic injection systems (Injectors, coils, CKP, TPM, MAP, among others); this is displayed on the oscilloscope when a signal in the vehicle is correct, see figure 2.

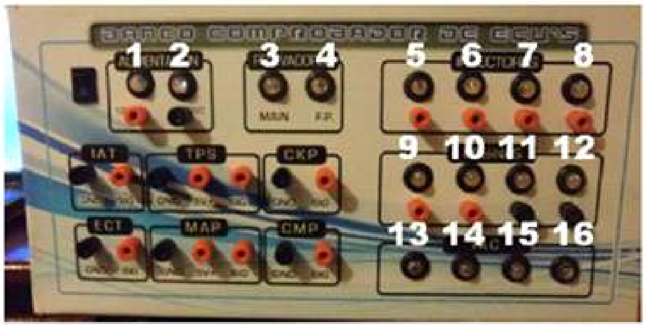

Figure 2. Test stand for electronic vehicle control unit with electronic injection systems. [9].

On the other hand, [10] describes the research that led to the design and construction process of a Wi-Fi activated and controlled gasoline injectors tester; thanks to the versatility of its design, it is possible to activate and control the operation of gasoline injectors in real time under conditions similar to those of a vehicle, [10]. The control and monitoring is developed by means of an interface in LabView of high performance which can carry out tests of any type of brand of gasoline injector, see figure 3.

Figure 3. Gasoline injectors tester activated and controlled via Wi-Fi. [10].

Another precedent is found in [8], where an injector tester bank with SCADA control is implemented. The fundamental characteristic is that monitoring of the liquid level is done through artificial vision.
In addition, currently in commercial machines the liquid deposited by injectors in each of the specimens is measured by the consideration that a user can indicate after a simple inspection as a product of direct display. This makes that several prototypes and projects are focused in updates that improve precision of each measurement, as well as in making a better diagnosis of injectors, see figure 4.

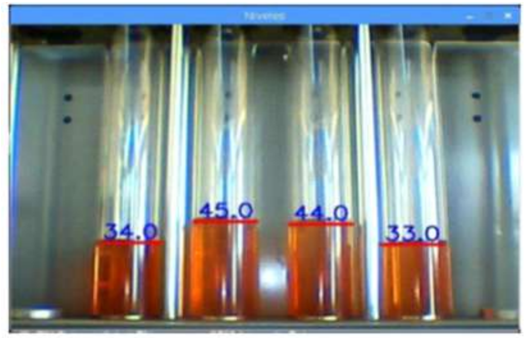

Figure 4. Injector tester with SCADA control. [8].

3. Materials and methods: Design

In this section can be found a description of the structure developed for the proposed machine.
The previous design of the structure is done in a specialized software, figure 5. Then, using aluminum profiles, a frame is built, figure 6, where components are supported with acrylic lids aiming to reduce weight in the final prototype; it must be considered that the support of the glass pipes is made with this same material, but of a higher caliber to absorb the force to be supported.
After this structure, two fundamental systems of the prototype are designed and coupled: the hydraulical and electrical system, each of them from a corresponding operating diagram, as well as the selection and application of the respective tests.
Within the electrical system, it is considered the types of communication of user with the machine: manual and wireless control; and it is satisfied the requirements of operation and selection of the form of liquid measurement.

Figure 5. Prototype design in specialized software. 1) Injectors support rail. 2) Liquid storage pipes. 3) manometer. 4) TFT screen. 5) Keyboard. 6) Base. Source: own.

Figure 6. Aluminium angled skeleton. Source: own.

3.1. Hydraulic scheme and operation

The hydraulic system, figure 7, has a tank where liquid is stored; pressure is exerted by means of a gasoline pump, passes through a filter, and then to a manometer to visualize pressure exerted at the rail point, where it is distributed to the 4 injection points. Inside the return points of the liquid is the pipe drainage, a process that is carried out by means of the activation of electrovalves connected to the tank as shown in figure 7. For some connections, ½" pipe hose fittings are used.

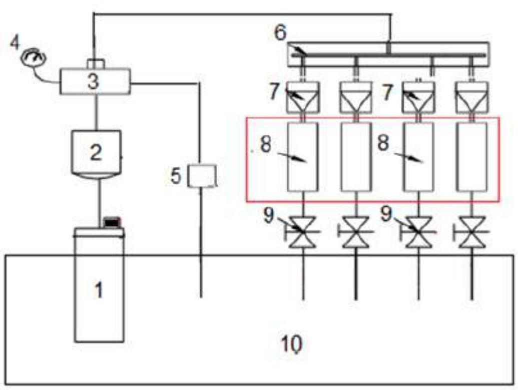

Figure 7. Hydraulic system: 1) gasoline pump, 2) filter, 3) teee,4) manometer 5) return, 6) rail, 7) injectors, 8) measuring pipes, 9) solenoid valves, 10) tank. Source: own.

3.2. Electrical schematic and operation

As previously mentioned, an injector works from a coil that opens a valve (needle). In practice, this solenoid valve is controlled through a low-frequency square signal; to generate these signals, the Psoc5lp microcontroller from Cypress® was used, programmed from Psoc Creator 4.2 software, as shown in figure 8

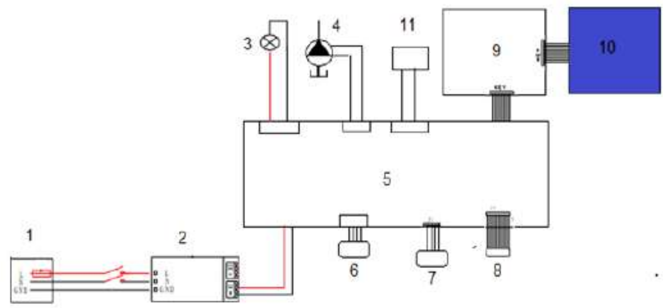

Figure 8. Electrical system: 1) AC power, 2) DC power supply, 3) backlighting, 4) pump, 5) psoc micro controlled system, 6) sensors, 7) solenoid valves, 8) injectors, 9) micro controlled system 2, 10) control panel, 11) wireless communication. Source: own.

Electrical circuit generates a square signal variable in frequency and pulse width at the users convenience and the tests selected, by means of equation (1) the working frequency is related to the revolutions per minute of a vehicle, in order to obtain which frequency is driven at certain revolutions.

$$F = \frac{Rpm * 1Hz}{60Rpm} \tag{1}$$

Subsequently and because the PWM (pulse-width modulation) that is going to work has changes of both frequency and period (2); for adjustment of the signal applied to the injector the frequency is related to a value that refers to the period and that microcontroller can understand in bits -table 1-, also taking into account the controller speed.

$$T = \frac{1}{F} \tag{2}$$

Frequency (Hz)	T.period(ms)	R period value(Bits)
60	16	191
65	15,38	183
70	14,2	170
75	13,3	159
80	12,5	149
85	11,7	140
90	11,1	132
95	10,5	125

Table 1. Relationship between frequency, period and values to implement in PSOC. Source: own.

From this relation a graph is made, figure 9, where a linear relation (3) is obtained and will be executed from the microcontroller when necessary.

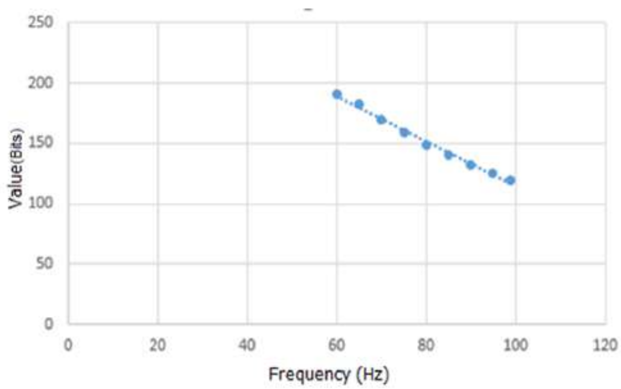

Figure 9. Frequency ratio graph with values to be read by the microcontroller. Source: own.

$$R = -1.8707F + 301.56 \tag{3}$$

R is the Bits value F is the frequency

After obtaining the signal that is intended to apply to injectors, is needed an electrical coupling capable of providing this signal at a level of voltage and current with which the injector is operated -figure 1- with this same circuit is driven the pump that supplies fuel from the tank.

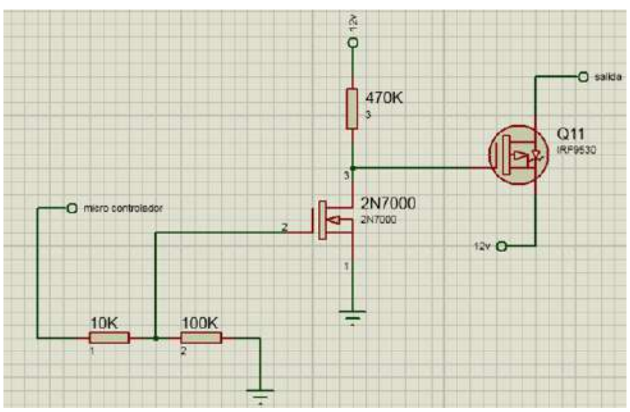

Figure 10. Circuit schematic, managed with power MOSFET for the injectors control. Source: own.

On the other side, the prototype consists of two types of operation: manual and remote (wireless), both connected by serial communication.

- **Manual Operation**

This type of machine operation is controlled from an ATmega328P microcontroller, programmed on the Arduino® platform. A TFT screen is operated for visualization; the operation of this screen is given by a keyboard where the user can select three types of test (drip, spray and injection flow) from this same keyboard is manipulated the test draining, start and pause of tests, figure 11.

This system communicates through the serial communication protocol with the Psoc microcontroller -figure 8- that will execute manual control commands.

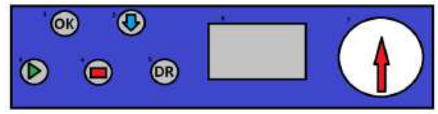

Figure 11. 1-Selection (OK), 2-Move in menu, 3-Play, 4-Stop, 5-Draining, 6-TFT Screen, 7-Manometer. Source: own.

- Remote Operation

This machine control block is designed for Android, it communicates with the microcontroller through Bluetooth making a serial port emulator. The application has a home screen, figure 12, indicating connection status and a main menu with four selection options (connect, test, help and exit).

Figure 12. Main interface screenshot. Source: own.

When connection is made, machine and mobile device are linked via Bluetooth, then the final connection is made from the App.

In the main menu there is an option of tests where the same tests of manual opeation are shown together with an added test -figure 13- (vehicle in operation) that consists of a frequency management of the injectors from the phone accelerometer.

In this test it is sent in an information packet that is then processed in microcontroller 2; in this packet it is sent the value obtained from the accelerometer in its vertical axis, as shown in figure 14.

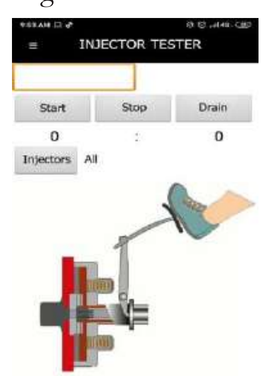

Figure 13. Added vehicle test interface running from the application. Source: own.

Figure 14. Application information packet. Source: own.

- **Level measurement:**

Liquid level measurement in pipes is important in injection and spray flow tests. With the liquid level it can be known if there is an equilibrium in the injector operation; it can also be known if the injector is expelling more than the allowed amount, table 2, which causes a malfunction or an emission of highly polluting gases.

Vehicle cylinder(cm^3)	Consumption(ml)
1.000-1.900	20-25
2.000-2.800	30-35

Table 2. Liquid quantity allowed in injection flow test according to engine cylinder. Source: own.

For liquid measurement, a float-type level sensor was implemented -figure15- equipped with an encoder barrier sensor, a float, and a segmented bar. By means of the same one can give a quantity value of liquid that is deposited in the pipe, in order to give a diagnosis of the injector that is in test.

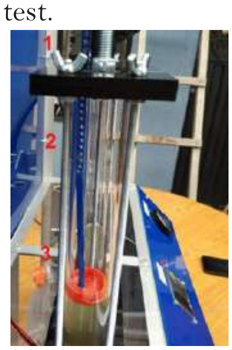

Figure 15. Float type level sensor: 1-Encoder, 2-segmented bar, 3- float. Source: own.

4. Tests and results

The prototype is capable of simulating conditions of a vehicle in operation; for this reason, through a series of test pipes, the piston chamber can be represented to be able to visualize the amount of liquid consumed by injectors, and in the same way with sensors the same value can be obtained. A hydraulic system distributes the liquid uniformly for each one of the injectors exerting the same pressure in each one; this, in turn, can be variable in a test evaluating one of the injector characteristics.

4.1. Tests

4.1.1. Leakage

In this test, the injector is subjected to variable pressure from manual operation -figure 17-, or wireless -figure 16- starting from 30 Psi for 120 seconds in order to observe the injector plugging. For this, the injector being tested should not drip to pass the test; if it drips, the injector is not plugging properly and may be leaking.

The test was applied to five different injectors in order to classify them in three states: approved, checked and damaged.

This test was performed on the same injectors 5 times to see if behavior varied when the plugging test was applied more than once, results are shown in Table 3. It was concluded that only one injector leaked after a second test; on the contrary, the other injectors had the sme behaavior.

Figure 16. Leak test interface in application. Source: own.

	Test 1	Test 2	Test 3	Test 4	Test 5	Status
Injector 1	0	0	0	1	0	Approved
Injector 2	2	2	1	2	1	Check
Injector 3	1	1	1	2	2	Check
Injector 4	0	1	0	0	0	Approved
Injector 5	4	3	1	3	2	Damaged

Table 3. Injector status according to drip number. Source own

Figure 17. Leak menu in manual control. Source own.

4.1.2. Pulverization

In this test, a signal graduated by the user, figure 18, is applied to the selected injectors, under a constant pressure, in order to visualize the amount of liquid that pulverizes each one of the injectors and thus give a diagnosis.

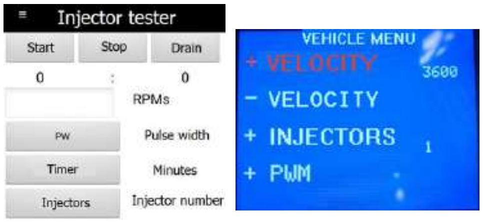

Figure 18. Pulverization test interface from application and manual machine operation. Source own.

For the same amount of time injectors must expel a similar level of liquid in pipes; for the injectors being tested there should not be a range greater than 10% in each amount of liquid, see table 4; likewise, the way the liquid is expelled from an injector should be pulverized and not fractionated, see figure 19, as can happen in a dirty injector.

Figure 19. Injector in pulverization test. Source: own.# injectorQuantity (ml)

# injector	Quantity (ml)
1	40
2	43
3	50
4	30

Table 4. Liquid quantity supplied by each pulverizarion test injector - Data provided by prototype. Source: own.

4.1.3. Injection flow

For this test the injectors that user wishes to use are fully open for a short period of time, with constant pressure, in order to observe the behavior of the injectors when they are open, and ensure that there is no clogging or excessive consumption as shown in Table 2 and Figure 20. The interface can be used to operate this test from manual operation and wireless operation.

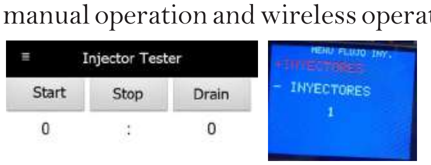

Figure 20. Injection flow test interface in application and in manual machine operation. Source: own.

In this test two indicators are taken into account which are fundamental to give a injector diagnosis: the injector after test must not produce dripping, and depending on the vehicle engine cylinder -table 2- the injector must expel a maximum amount of liquid; with these measured values, one can know the injector quality individually to determine the excess consumption -figure 21- or the approved consumption in the range -figure 22-. The test was carried out five times on injectors (table 5), and it was evident that these vary acceptably their behavior in tests; in the same way, with these data it is reviewed if the injector is approved or needs cleaning.

Figure 21. Liquid quantity deposited by an overconsuming injector Source: own.

Figure 22. Liquid quantity deposited by an injector in good condition. Source: own.

	Test 1		Test 2		Test 3		Test 4	
# injector	Quantity	Rear leakage	Quantity	Rear leakage	Quantity	Rear leakage	Quantity	Rear leakage
1	45 ml	YES	43 ml	YES	43 ml	YES	42 ml	YES
2	22 ml	YES	24 ml	NO	22 ml	YES	20 ml	NO
3	20 ml	NO	21 ml	NO	22 ml	NO	20 ml	NO
4	10 ml	NO	11 ml	NO	9 ml	NO	11 ml	NO
5	32 ml	YES	33 ml	YES	29 ml	YES	28 ml	YES

Table 5: Injection flow test to 5 injectors with parameters of liquid quantity - Data given by prototype - and leakage after test. Source: own.

5. Conclusions

Injectors are fundamental elements in a gasoline vehicle injection system, therefore they need an effective calibration and cleaning to avoid: high consumption of gasoline, excessive emission of gases, or simply a general malfunction of the vehicle.

In order to solve this need, a functional prototype was developed for diagnosis of gasoline vehicle injectors, by means of sensors that make it possible to produce a level value within an error range ± 1.5ml with respect to the scale of the measuring pipes. This demonstrates the usefulness of this method at an accessible level.

The prototype was made by combining and coupling two functional designs: the one that led to a hydraulic system, and an electronic one, capable of simulating variables of a vehicle in operation such as pressure, and injection pulses.

The wireless communication guarantees a good operation so that the prototype has two types of control, and with them modify parameters of each test, in this case: dripping, pulverization, and injection flow.

It is necessary to handle each of the tests with a fluid that is adequate for proper behavior of injectors, because the fluid density test can influence; likewise, use solenoid valves with sufficient force to drain the liquid tester.

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