Webology (ISSN: 1735-188X)
Volume 19, Number 6, 2022

Design And Development Of An Automated System For Examination Of Light-Vehicle Fuel Injectors

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ABSTRACT

Because of the immense growth experienced by the automotive industry in terms of technological development, more and more sophisticated vehicles with higher performance are being created. However, functional failures are emerging even in the most sophisticated new vehicles. The electronic fuel injection system is one of the most prone to failures that lead mainly to loss of vehicle power. Based on this application, the present work deals with the designing and developing an automated system for testing and examination of light-vehicles fuel injectors. Quality function deployment is used as methodology for informational design. Likewise, a reference model-based methodology for development of mechatronic products is applied to systematize the detailed design process. Mechanical, electro-electronic and computational components are presented in detail. Finally, a functional prototype of the product is developed to validate the design concepts and solution principles.

Keywords: Light-Vehicle, injectors, automated system, technological development.

1. INTRODUCTION

The advent of the new industrial revolution, Industry 4.0, is expected to transform the production systems by integrating information and communication technologies and advanced manufacturing systems (Yu et al. 2015). Its main objective is that both companies and consumers take more benefits in terms of the triptych time-to-launch, cost and quality of the new products.

In this context, automotive industry is taking giant steps in the production of new high performance automotive vehicles with sophisticated features such as automatic emergency braking, automatic climate control, and internet connectivity and self-driving. For example, one of most recognized self-driven cars is the Waymo project (Google 2016) being developed by Google, which has the mission to make it safe for people to move around.

Despite this enormous progress, most advanced vehicles are not totally exempt from suffering functionality failures. The problem is that these failures are becoming increasingly difficult to diagnose and treat due to the technological complexity involved in the new cars. Then, new tools and equipment are needed to deal with the various different types of failures that often occur.

In Pamplona city, Colombia, owners of automotive workshops have noted the need to have sophisticated equipment in order to offer a better and complete service to their clients. In addition, this would allow them to attract more clients to their workshops. Nevertheless, they face the inconvenience that such tools and equipments are, de facto, very expensive for their budget. This is the case of the equipment used to examine the vehicle fuel injectors, when the failures occur as a loss of power in the vehicle's engine. Such equipment currently costs around $1,155.00 USD in the market. Too expensive for most workshop owners from Pamplona.

Concerning the above, this work proposes the designing and developing a low-cost automated system for examination of light-vehicles fuel injectors. The system uses solution principles and concepts of mechanical, electronic and software to simulate the real operating conditions of an injector in the examination process. Furthermore, the main objective is to obtain a system with a cost of less than $500 USD from the product development vision.

This work is outlined as follows: the informational design is addressed in section 3; detailed design is presented in section 4; main results are presented in section 5; and, finally the conclusions of the work.

2. INFORMATIONAL DESIGN

Designing the kind of products that involves technological domains such as mechanics, electro-electronics and computation usually it has a complex and interdisciplinary nature; therefore, to adopt structured design methodologies in order to support and systematize decision making during the product development process is recommended (Rodriguez et al. 2017).

A design methodology that considers user's preferences and requirements can be very convenient. QFD is one of the most known and used methodologies to define attributes and/or characteristics of a product based on the user's requirements. In Professor Akao's (inventor of QFD) words, QFD "is a product development method aimed at satisfying the consumer, and then translating consumer demand into goal specifications and key quality assurance points to be used throughout the production phase. ...[QFD] is one way to ensure product quality is still at the design stage" (Akao 2004).

QFD has been successfully applied on the design of different mechatronics products including agriculture automated systems (Sørensen et al. 2010; Riaño et al. 2017), underwater robots (Pasawang et al. 2015), service robots (Pertuz et al. 2014), 3D printers (Rodríguez Gasca et al. 2017), among others. Further detailed information about QFD can be found in (Akao 2004; ReVelle et al. 1998).

In this work, QFD method is applied to the informational design of the automated system for examination of light-vehicles fuel injectors, described through the following steps:

Step 1: identifying the users

A group of fifteen users formed by expert technicians in automotive mechanics from Pamplona city, Colombia, was identified.

Step 2: defining the user's requirements

Defining the User's Requirements (URs) was based on interview to the users. This survey considered the idea of obtaining a high-performance and low-cost product. In this way, 16 requirements were consolidated and grouped into four categories (Capacity, Operation, Design and Reliability) to facilitate analysis and average. In the QFD language, URs can also be called "WHATs" (Akao 2004). The “WHATs” of the automated system are listed in Table 1.

Table 1: User requirements grouped into four categories.

Categories	**URs (WHATs)**
1-Capacity	1.1-ability to perform several different types of tests on injectors; 1.2-testing fuel pumps; 1.3- that allows to manipulate variables such as RPM and PWM; 1.4- ability to test several injectors at a time.
2-Operation	2.1-easy to use; 2.2-easy to service; 2.3-low energy consumption; 2.4-silent system.
3-Design	3.1-compactness; 3.2-robust structure; 3.3-low weight; 3.4-easy to assemble; 3.5- good appearance; 3.6- low manufacturing and assembly cost; 3.7-low maintenance cost.
4-Reliability	4.1-operation safety;

Step 3: prioritizing user's requirements

In order to prioritize the RUs, it is necessary to attribute to them a relative importance and weight. A Mudge diagram was used, which compares each requirement with its peers, where relative importance is computed as the sum of the score of each UR obtained in the comparison process. Similarly, relative weight is calculated by dividing the relative importance of the UR by the sum of all relative importance.

The result of the analysis with Mudge diagram can be understood through the Pareto diagram shown in Figure 1. According to Pareto diagram analysis, to achieve an 80% compliance of the design, URs with a relative importance above 18 must be strictly complied with. In this way, RUs with their respective weights and relative importance are located on the left side of QFD matrix shown Figure 2.

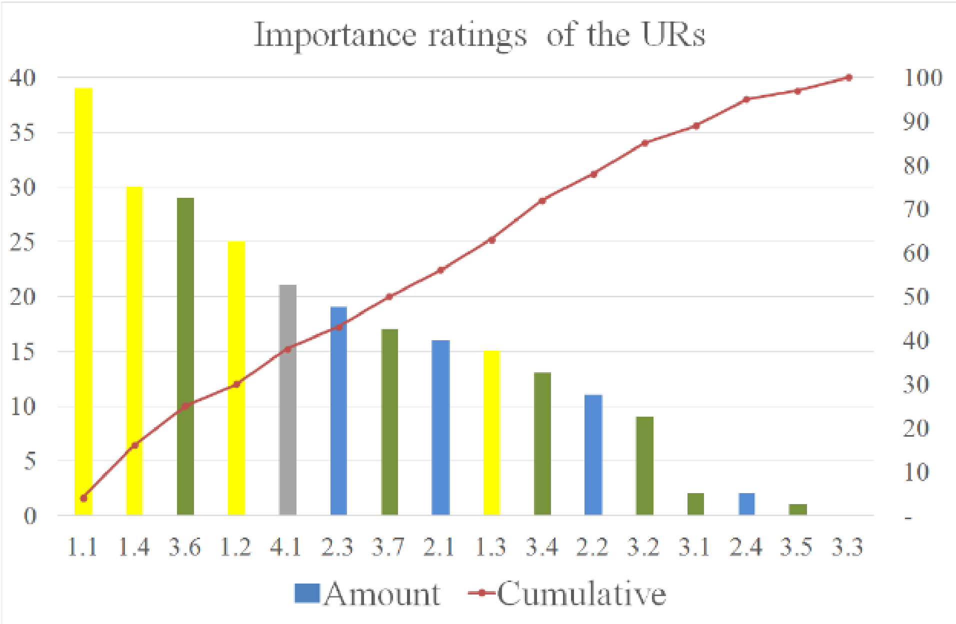

Figure 1. Pareto chart with average importance ratings of the URs.

Step 4: selected design parameters

This step consists of deploying the URs to design parameters (DPs), which represent physical concepts of the product that can be better understood by the designer. This stage is the first decision making on the design of the product.

DPs were selected based on the experience of the design team and literature review. The 16 selected DPs are listed in Table 2 and placed on top of the QFD matrix in Figure 2. A desired tendency is also established for each DP, which can be crescent, decrescent or target as shown in Figure 2. In QFD language, DPs are usually called "HOWs" (Akao 2004).

Table 2: Design parameters grouped in four categories.

Categories	**DPs (HOWs)**
1-Capacity	1.1-number of possible tests; 1.2- pressure measurement; 1.3-control system; 1.4- number of injectors that can be tested.
2-Operation	2.1-user driver-interface; 2.2-modular design; 2.3-power supply; 2.4-noise level.
3-Design	3.1-system dimensions; 3.2-resistent materials; 3.3-total weight; 3.4-number of parts; 3.5- beautiful design; 3.6- overall cost; 3.7-maintenance cost.
4-Reliability	4.1-compliance with machine safety standards;

Step 5: relationship between URs and DPs

The process of identifying relationships between URs and DPs is performed subjectively by the designer. The degree of relationships is set to three levels as follows: strong relation = 9, medium relation = 3, and weak relation = 0. As a result of this analysis, URs scores are obtained on the right side of the QFD matrix in Figure 2.

It is observed that the requirements including “low manufacturing and assembly cost”, “low maintenance cost”, “ability to perform several different types of tests on injectors” and “compactness” with scores 105, 66, 52 and 52 , respectively, are the most influenced from the selected DPs. Meanwhile, lowest relationship URs according to this analysis was “easy to use” and “noise level” with scores of 24. Further detailing of this analysis is reported in a previous work (Rangel et al. 2016).

Step 6: design parameters correlations

Correlations between DPs are located on the ceiling of QFD matrix in Figure 2, where each DP is compared to its peers. The correlation degree can be: positive (+) or negative (-). A positive correlation implies that an increase in a DP results in a positive effect on its pair. On other hand, if correlation is negative, a satisfactory balance is sought between the DPs being compared.

The overall cost of the system is affected by the design solutions selected to guarantee a machine with robust structure, ability for testing several injectors at a time and performing many types of test, among others requirements. Therefore, it is necessary to seek a balance between these DPs. Similarly it happens with the maintenance cost, since expensive solutions imply high maintenance costs. In this case, equilibrium can be treated by selecting components solutions and manufacturing processes of low cost without affecting the quality and performance.

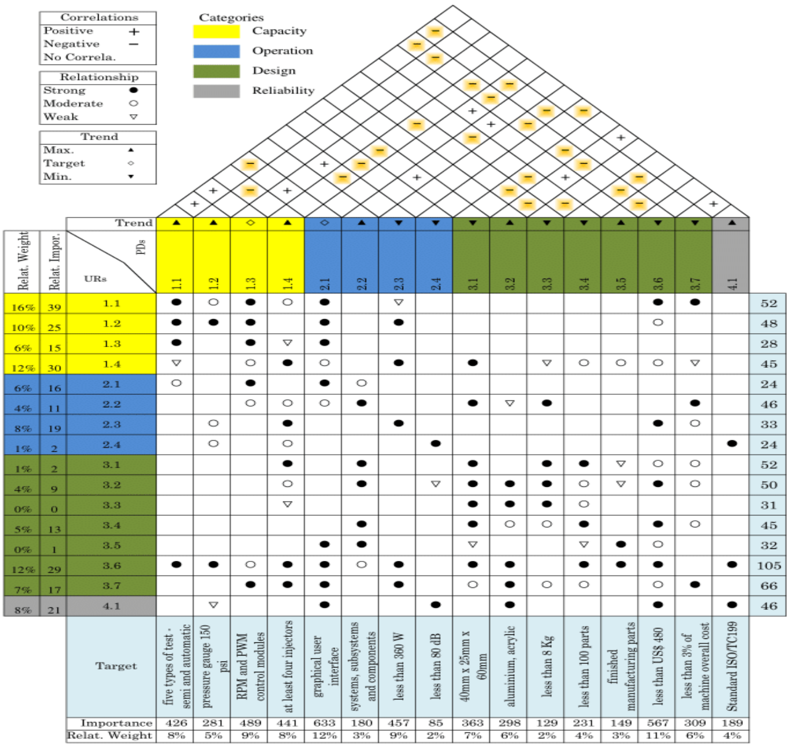

Figure 2. Analysis of the relationships between URs and DPs.

Step 7: defining goal specifications

As result of applying the QFD method, a set of goal specifications are obtained, which are placed on the lower side of QFD matrix in Fig 2. So, main goal specifications defined for the system being proposed are: five types of test –semiautomatic and automatic modes-; pressure gauge of 150 psi; RPM and PWM control modules; testing at least four injectors at a time; graphical user interface; systems, subsystems and components; power supply of 110-220 V 350 W; noise less than 80 dB; overall size of 400x250x600 mm3; aluminum and acrylic structure; weight less than 8 kg; less than 100 parts; finished manufactured parts; overall cost less than $480 USD; maintenance cost less than 3% of overall cost; and, compliance with ISO/TC199 standard.

3. DETAILED DESIGN

The reference model presented in Figure 3, well-known as “V model” under the industrial guide VDI 2206 (Gausemeier & Moehringer 2003), was proposed by the German Association of Engineers in 2000. It aims to provide a structured methodology to support the design of mechatronic systems in a systematic way.

This methodology can be understood as a specific reference model for the development of mechatronic products. However, it is not intended to replace existing models, but aims to complement models focused on an individual domain (mechanical, electronic or computational), even if the generic character models.

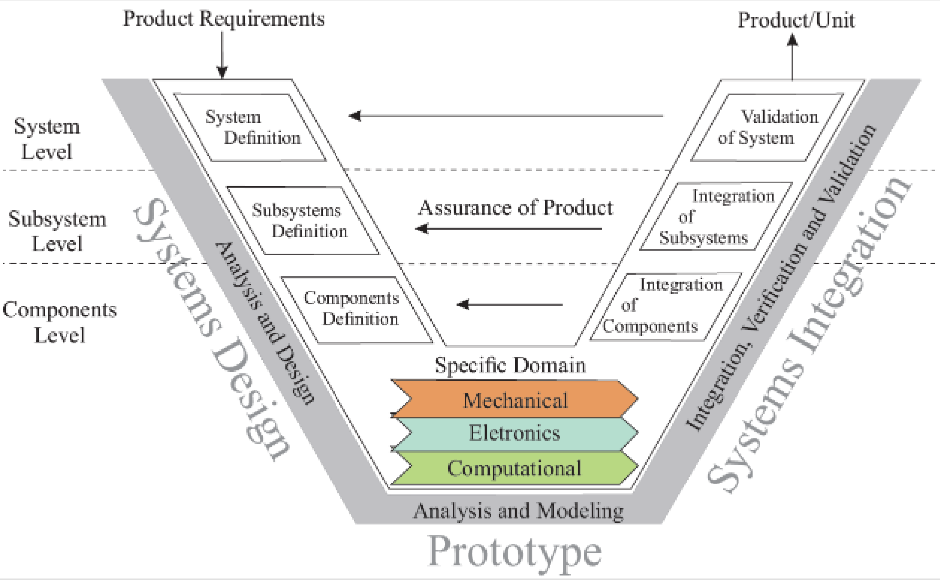

Figure 3. VDI model for development of mechatronic products (Gausemeier & Moehringer 2003).

From a macro perspective, the starting point of model V is the definition of a design task for an individual mechatronic product. Therefore, a set of product requirements are established for the project task being executed, which will represent a reference target for validation of the future product.

An extended description of this model can be found in (Gausemeier & Moehringer 2003).

In this work, V model is used on the development process of the automated system for examination of fuel injectors to describe each of mechanical, electro-electronics and computational domains.

Mechanical design

Detailing the mechanical structure of the automated system being developed is presented in Figure 4. It made basically by a main structure and a substructure for mounting injectors. Main structure is made of acrylic plastic with an ergonomic elongated pyramidal shape achieved by using hot forging process, with two cover plates screwed on each end.

On top of previous one, substructure for mounting injectors is assembled, which consists mostly of two bracket pieces and one support plate that passes through two steel linear guides. Primary and secondary brackets are made of fused aluminum having internal cavities for fuel circulation.

The test tubes together with their respective valves are fixed between the primary bracket and the support plate. Likewise, injectors that will be tested are hooked between the support plate and the secondary bracket, which is mobile to facilitate placement and removal of the injectors.

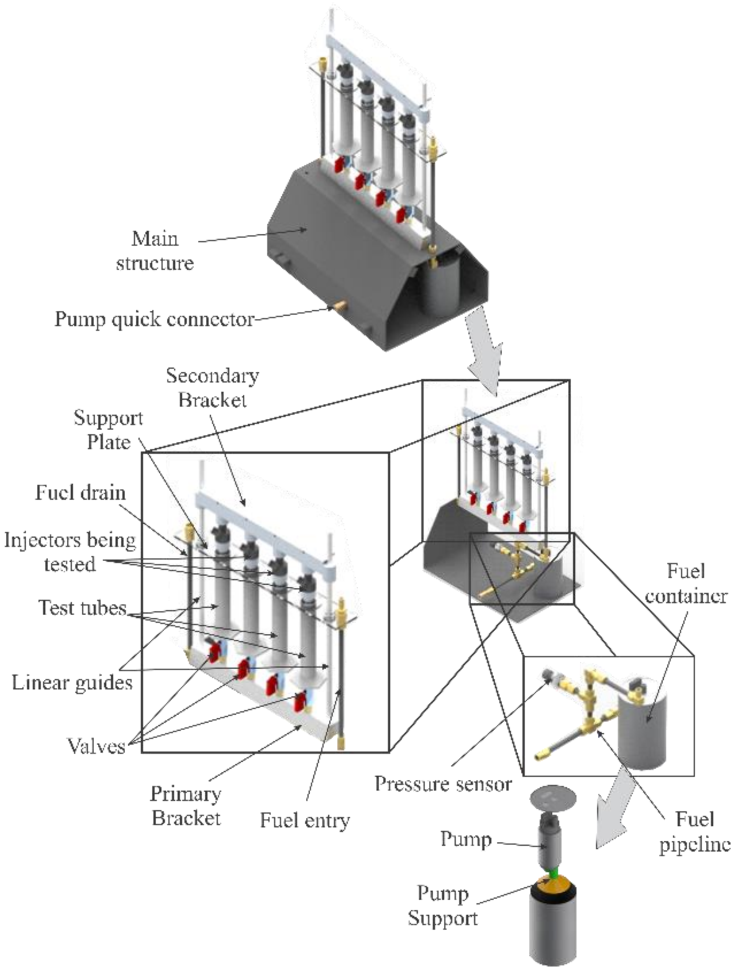

Figure 4. Detailing the mechanical structure.

The fuel reaches the injectors through the inlet pipe from the pump and returns to the container through the outlet pipe. Injectors receive the activation signal from the electronic system described in following subsection.

In addition, a quick connector is available on the front side of the main structure, where a pump can be attached to be tested. Fuel pressure, received by the pump, is measured through the electronic pressure sensor connected to the circulation pipe of the fuel.

Finally, all mechanical components are assembled together on the main structure as shown in Figure 4.

Electro-electronic design

A simplified connection diagram of the electro-electronic system is shown in Figure 5. This system uses a controller based on Arduino technology, specifically the reference board Arduino Mega 2560. The advantages of using Arduino include an open technology, affordability, easy to use and compatibility with lots of electronic modules for different applications.

Power drivers used to control the injectors are of commercial reference TB6560, which is based on Toshiba's TB6560 integrated circuit, it is mainly used in stepper motor control handling loads up to 3A maximum. This driver has a built-in heat-sink that ensures excellent heat dissipation for its components and, driver combines quality and high performance.

On the other hand, a 12 V relay module is used to deal with the pump load and a pressure sensor SKU237545 for output pressure measurement.

A screen touch module, 2.8” TFT LCD display, has been chosen for graphic user interface, since it brings fascinating features in terms of visualization of graphic components and tactile handling. In addition, there are free code libraries available on the web that allow easy handling of that screen touch module with Arduino technology controllers.

Finally, switched power supply capable to work at voltages 110-220 V, delivering a 12 V voltage and 20 A current on the output.

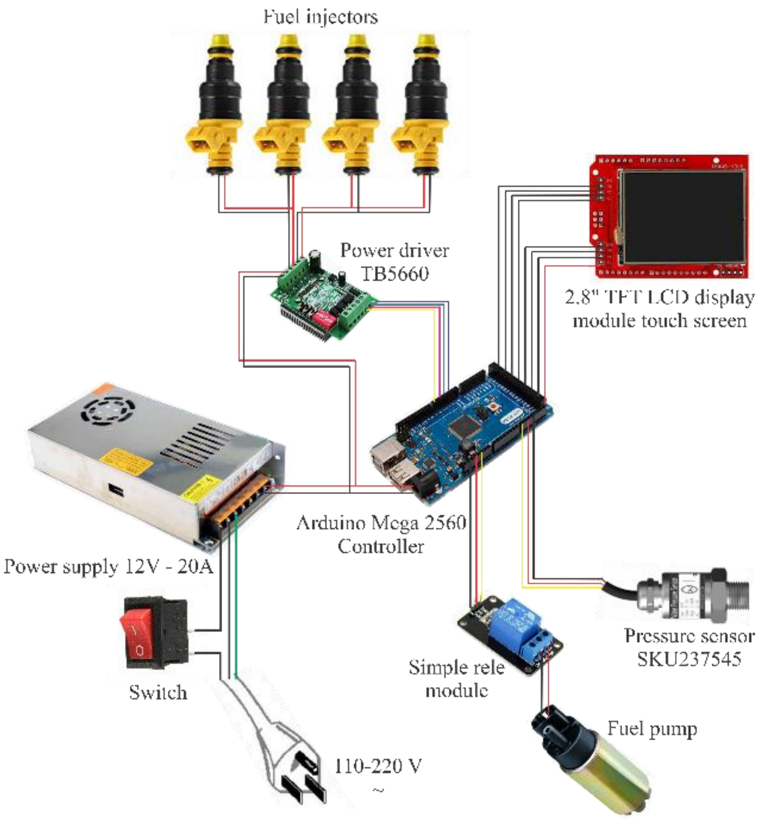

Figure 5. Electro-electronic schema.

4. CONCLUSIONS

The designing and developing a low-cost automated system for examination of light-vehicles fuel injectors was presented in this paper.

Using reference methodologies for product development allowed systematizing the design and development process in this work. QFD served as a guideline for decision-making to generate and select engineering concepts and solutions throughout the design of the automated system proposed. The main requirement of a product with cost of less than $500 USD was achieved.

A prototype of the automated system was developed to validate the design concepts and functionality. Currently, this prototype is being tested and used in RANCARS automotive workshop at Pamplona city, Colombia.

ACKNOWLEDGEMENTS

The authors would like to thank the financial support of RAN-CARS auto shop and University of Pamplona.

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