Accelerated testing of an optimized closing system for automotive fuel tank

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Abstract. Taking into account the legal prescriptions which are in force and the new regulatory requirements that will be mandatory to implement in the near future regarding testing characteristics of automotive fuel tanks, resulted the necessity to develop a new testing methodology which allows to estimate the behaviour of the closing system of automotive fuel tank over a long period of time (10-15 years). Thus, were designed and conducted accelerated tests under extreme assembling and testing conditions (high values for initial tightening torques, extreme values of temperature and pressure). In this paper are presented two of durability tests which were performed on an optimized closing system of fuel tank: (i) the test of exposure to temperature with cyclical variation and (ii) the test of continuous exposure to elevated temperature. In these experimental tests have been used main components of the closing system manufactured of two materials variants, both based on the polyoxymethylene, material that provides higher mechanical stiffness and strength in a wide temperature range, as well as showing increased resistance to the action of chemical agents and fuels. The tested sample included a total of 16 optimized locking systems, 8 of each of 2 versions of material. Over deploying the experiments were determined various parameters such as: the initial tightening torque, the tightening torque at different time points during measurements, the residual tightening torque, defects occurred in the system components (fissures, cracks, ruptures), the sealing conditions of system at the beginning and at the end of test. Based on obtained data were plotted the time evolution diagrams of considered parameter (the residual tightening torque of the system consisting of locking nut and threaded ring), in different temperature conditions, becoming possible to make pertinent assessments on the choice between the two types of materials. By conducting these tests and interpreting the obtained results, it can be created a clear picture of the capacity of closing system of fuel tank to fulfil the functional requirements following the exposure to values of testing parameters significantly above the values that may appear throughout the entire service life of the vehicle. The proposed accelerated testing method shows the main advantage of simulation in a limited time all the situations which may be encountered in a much longer period of time, namely the service life of the vehicle.

1. Introduction

Today, modern automotive are imposed many requirements related to safety, reduced impact on the environment, resources conservation, competitiveness in the global market etc. The primary responsibility for meeting these requirements lies with the designers; they must improve the existing
systems and develop new ones, in accordance with the legal prescriptions more stringent in the field and with user expectations [1,2].

The automotive fuel tank, an integral part of the fuel system, is a complex structure made of plastic, which are imposed a wide range of requirements, because the level of protection afforded by it when an undesirable event occurs (accident, fire etc.) are part of the degree of passive protection offered by the automotive to passengers and other road users. The complexity of this component increased continuously, evolving from a simple container to a complex system for fuel storage and delivery, containing among others the fuel pump and complex closing systems (which provide evaporative emissions reduction).

In order to obtain and validate the optimal solutions of the structure of modern system for fuel storage and supply, it is necessary to know both the legislative requirements related (providing evaporative emissions reduction) and the performance required to be provided by these systems (significant increase of durability and reliability) [3]. In these circumstances, this paper presents the development and implementation of a new testing methodology that allows predicting the behavior of closing system of the fuel tank for a long period of time, by accelerated tests under extreme conditions of assembly and testing.

2. The requirements for fuel tanks and their closing systems

The fuel tanks made of plastics offers major advantages compared to the conventional tanks made of metal. Besides that they can be designed and manufactured in almost any desired shape, using the available space more reasonable compared to those made of metal, they also offer both superior performance for impact and exposure to fire and lighter weight and better resistance to corrosion. The current design also incorporates the fuel delivery module (which includes pump and fuel filter).

The body of this module and most of the components are made of polyoxymethylene (POM), a material that combines superior resistance to fuels and chemicals with good reliability under high temperature, being a good electrical insulator.

In addition, the plastic containers incorporates a valve system that helps to maintain the pressure in the container below the maximum permitted values and, in some cases, incorporates even the automotive carbon canister, to form a complex system for safe storage and delivery of fuel (figure 1).

![Figure 1. Examples of systems for storage and fuel delivery made of plastic.](image)

The attachment system of the fuel pump to the tank module, called "tank closing system", is a major contributor to the total amount of the evaporative emissions system as a whole. For this reason, the efforts to reduce these emissions had to include as essential element the design and development of new
methods and systems, with a much lower permeability, capable of providing a long-term superior sealing and a microscopic hydrocarbon leakage level almost negligible.

To meet the increasingly restrictive regulations on automotive emissions [4], there have been developed many variants, some of the solutions that have provided good results being presented in figure 2 together with the emission level achieved. Out of these, the one shown in figure 2c (KTNA - Kautex-Textron North America) is the one that took place the accelerated tests covered by this research. The basic requirements for these systems are:

- the compression of the gasket must be controlled and maintained between two extreme permitted values (min. 8-10% and max. 25-30%, depending on the material [5]);
- the clamping forces are aligned with each other and pass through, or as close to the center seal;
- the locking system structure and the materials used in the construction of its components, including the gasket seal, must ensure:
  • sealing the system throughout the range of temperatures and pressures to which the automotive is designed to run;
  • the durability and reliability of the system in accordance with the corporate standards and regulations for all fuels presented in the geographical area where the automotive is sold.

### Table 1

| System                      | Emission Level |
|-----------------------------|----------------|
| Mason Jar System            | 25 ... 40 mg/24 hours |
| SAE Cam-Lock System         | 5 mg/24 hours    |
| KTNA Closing System         | 3 mg/24 hours    |

**Figure 2.** The closing systems of the fuel tank.

### 3. Description of KTNA locking system

The KTNA locking system, arose from the need to meet the new requirements stipulated in the regulations regarding emissions [4], contains the following main components (figure 3):

1. lock nut, made from POM type A material;
2. fuel pump flange of the fuel delivery unit;
3. seal gasket, with section "H", made of FKM fluororubber;
4. assembled threaded ring, made of POM type A;
5. tank flange, part of the plastic container body

**Figure 3.** The KTNA closing system, first solution.
By assembling these components it is created a "sandwich" structure which ensures the compression of the seal gasket. After installing the components, the closure of the fuel tank is performed by turning the lock nut to obtain the prescribed installation torque.

4. The KTNA optimized closing system
After carrying out the initial tests on the system in the initial configuration, it was concluded that it meets the LEV III regulations regarding permeability, but does not provide the requirements regarding sealing, durability and reliability [3].

**Figure 4.** Comparison between the initial and optimized system:
1 - alignment of axial force on the gasket seal;
2 - use of a seal gasket with circular section, replacing the one with section "H";
3 - use of FKM GLT elastomer for manufacturing the gasket seal;
4 - changing the material of the components from POM type A to POM G21CP and POM M25;
5 - redesign of the cross-section of the nut;
6 - changing the thread profile of the screw ring and the lock nut;
7 - change the thread pitch of the screw ring and the lock nut;
8 - change the thread end zone to avoid the tension concentrators;
9 - addition of reinforcement elements to the outside of the lock nut.

5. Durability testing methods applied to the optimized closing system
The accelerated test methodology developed allows estimation of the fuel tank closure system behavior over a long period of time, according to the requirements of the regulations LEV II and LEV III [6]. LEV II Regulation provides that this period shall be for 10 years, while for compliance with the requirements of the LEV III Regulation it is necessary to ensure the durability of the system for a period of 15 years. Since the tests on periods provided in the regulations is not a realistic option, it became necessary to carry out accelerated tests under extreme conditions of assembly and testing of the system [6]. The goal of testing is to create meaningful and realistic images on the ability of the fuel tank closing system to meet the functional requirements and after being subjected to stress with parameter values well above those that would be encountered throughout the service life of the automotive in all conditions. The test conditions included: (i) assembling the components of the system at high initial torque, (ii) extreme temperature values and (iii) extreme pressure values. During the experiments there are determined various parameters such as the initial tightening torque, the torque at different points in time during the measurements, the residual tightening torque, the defects occurred (fissures, cracks, breakages), providing leak-free of the system at the beginning and at the end of the test.

The durability tests included in the test program which will be presented in this paper are: (I) the test of exposure to temperature with cyclical variation and (II) test of continuous exposure to elevated
In these two tests it was evaluated the behavior of a total of 16 systems optimized for closing the fuel tank, having the gasket seal made of FKM fluoro-elastomer with circular cross section, the lock nut and screw ring being made of POM M25 or POM G21CP for each half of the systems tested. Each of the two tests included a total of 8 tanks assembled, respectively by 4 systems in each category, the torque being measured during tests. The samples that were chosen to conduct the tests were dimensionally controlled and their compliance was validated. The durability criteria chosen to tie the results was the higher value of the residual tightening torque, in conditions of fulfillment the fuel tank sealing requirements.

5.1. The test of exposure to temperature with cyclical variation
This test consisted of alternating exposure of the 8 container closure systems simultaneously at temperatures between two extremes, namely: - 40 °C and + 80 °C. Therefore, the systems have been introduced for 456 hours in two thermal chambers which ensured the temperature conditions mentioned. The two thermal chambers have been placed at a short distance from one another, in order to minimize the time necessary to transfer the containers from one temperature to another. After starting the test, the first measurement of the residual tightening torque was performed at the end of the first 240 hours of testing, the following two measurements are made at 48 hours after each previous measurement.

5.2. The test of continuous exposure to elevated temperature
The total duration of the test was 480 hours and consisted of exposing the tanks at a constant temperature of + 80 °C, in order to evaluate the maximum effect of creep and relaxation of the material on the component structure and the residual tightening torque. In this test we used a single thermal chamber capable of allowing the conditioning of the 8 systems. After the test, the first torque measurement was performed at the end of the first 240 hours of testing, the following measurements were performed at 48 hours after each previous measurement.

6. Results and discussion
The results of the test of exposure to temperature cycling variation are shown in Figure 5.
The graphical evolution of the residual tightening torque is influenced by the fact that at each measurement the lock nut has been rotated by about 0.5° - 1.5°, which introduced an additional factor in the variation of torque values. Given that this affected all the 8 systems in a relatively similar manner, the information obtained is representative for the long-term durability assessment of the optimized closing system and for the comparison of the two POM materials analyzed.

The checks for leaks carried out at the end of the tests according to ECE R34 at a pressure of 30 kPa and at three different values of temperature [7] confirmed that the sealing properties were maintained during measurements and the sealing requirements are met successfully in all the 8 cases. Based on these results, it can be concluded that for this test the tanks equipped with closing systems whose components were made of POM G21CP material gave better results compared with those having components made of POM M25.

The results of the continuous exposure at high temperature test are shown in figure 6.

![Figure 6. The variation of the residual tightening torque over exposure to high temperature for 480 hours.](image)

In this case, the form of graphs is influenced by the fact that on each measurement the lock nut is rotated by about 0.5° - 1.5°, which introduced an additional factor in the variation of torque values. Based on the results for the residual tightening torque is found that tanks equipped with closing systems with components manufactured of POM G21CP material gave better results compared with those having components made of POM M25.

At the end of the test it was done the fuel tanks leaks check and there were tested and inspected the components of the system to detect the potential areas for cracks and / or stress. It was found that all the 8 tested systems meet the sealing requirements stipulated in ECE R34 [7] without the structure of components show signs of degradation.

7. Conclusions

After closure of a cycle of durability assessment tests of the fuel tank closing system, the results indicated that the systems made of POM G21CP repeatedly showed a residual tightening torque greater than that of the systems made of POM M25. As a result, the option for the POM G21CP material became clear both for the lock nut and for the threaded ring.

By analyzing the results obtained during these tests, it appears a clear picture on the capacity of the fuel tank closing system to fulfill the functional requirements after exposure to the test parameter values well above the values that may occur throughout the entire automotive service life. The main
advantage of this method of accelerated testing is that during a relatively short time (480 hours) it is simulated the requests that may be encountered in a longer period of time during the automotive service life (10-15 years).

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