

Evaluation of the safety quality of automotive pyrotechnic articles following their exposure to triaxial vibrations with predetermined thermal conditioning cycles

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Abstract. Pyrotechnic articles fall into the field of dangerous products, Risk Class 1 - explosives, thus requiring the assurance of their security quality in order to make them available on the market. The family of pyrotechnic articles also includes pyrotechnic articles for vehicles. The main types of pyrotechnic articles intended for vehicles are: actuators (triggers), airbag gas generators, airbag modules, igniters, micro gas generators, semi-finished products and seat belt pretensioners safety. Since pyrotechnic articles for vehicles are only used in the composition of security devices in vehicles, they must meet the essential security requirements, being subjected to trials and tests based on harmonized standards for this field. The paper highlights the results of the experimental tests that were obtained using the latest generation specialized equipment intended for the determination of the triaxial vibration parameter and under conditions of variable temperature with predetermined cycles, in order to evaluate the security quality of pyrotechnic articles intended for automobiles (pyrotechnic actuator for automotive use, seat belt pre-tensioner) included in category P1.

1 Introduction

INCD INSEMEX Petroșani is the only Research and Development Institute in Romania with constant concerns and results in the field of explosives security, and internationally, INCD INSEMEX has a notified body at European level (NANDO 1809), which certifies explosives for use civil as well as pyrotechnic articles, in the family of which also includes automotive pyrotechnic articles, that are part of security devices in vehicles [1].

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Romania has seen a particular dynamic in terms of ensuring the safety quality of pyrotechnic articles for vehicles, offered through harmonized standards, both in terms of their number and in terms of the level of detail of the technical requirements. The requirements that must be respected, as well as the acceptance criteria for each type of pyrotechnic articles in the automotive industry are specified in parts 4 to 10 of the reference SR EN ISO 14451:2013, and the test methods are established in part 2.

Given that in practice products from the automotive industry are subject to vibrations, which are very difficult to avoid and impossible to eliminate, as well as cyclical temperature variations, in order to evaluate the quality of security, these products are tested during the certification, process by their exposure to triaxial vibrations with predetermined thermal conditioning cycles according to the applicable references [2,3].

The paper highlights the results of the experimental tests that were obtained, using state-of-the-art specialized equipment, following the exposure to triaxial vibrations with predetermined thermal conditioning cycles of the following two constructive types of pyrotechnic articles intended for vehicles, namely: seatbelt pretensioners and pyrotechnic actuators, both of which fall into the P1 category (see Figure 1).



a. seatbelt pretensioner



b. pyrotechnic actuator

Fig. 1. Constructive types of pyrotechnic articles intended for vehicles

The subject addressed in the work is of particular importance in terms of harmonizing the level of technical competence existing at national level with the international profile performance, regarding the compliance with the specific security requirements of pyrotechnic articles intended for automobiles from the perspective of verifying and ensuring the preservation of their integrity, after testing them by exposure to vibration and in various predetermined temperature conditions, according to the applicable references [4,5].

2 Considerations on the methodology for carrying out vibration and temperature tests specific to pyrotechnic articles for automotive use

Taking into account the requirements of Directive 2013/29/EU transposed by Decision of the Romanian Government no.1102/2014 respectively the Technical Norms to Law 126/1995 in order to assess the security quality, pyrotechnic articles for automotive use are subject to vibration and temperature testing to determine their ability to withstand conditions of triaxial vibration and variable temperature.

The test method that is applied is one standardized at European level applying the harmonized standard SR EN ISO 14451-2:2013 Pyrotechnic articles for vehicles – Part 2: Test methods.

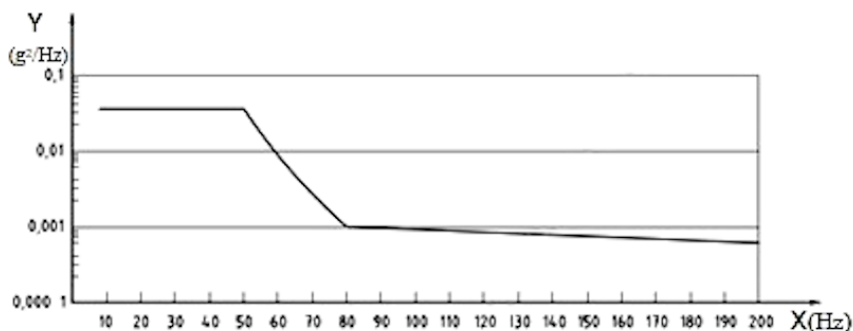
The principle of the test method consists in the fact that, pyrotechnic articles intended for automobiles will be tested under vibration and temperature variable conditions, using

specialized equipment for mechanical conditioning on the three axes, respectively for thermal conditioning, with preset 24h cycles. Thus, for the vibration test, after the appropriate fixation of the pyrotechnic article on the vibrating table of the equipment, a random vibration is applied the values of which are in accordance with Table 1 and Figure 2 [6].

Table 1 - Frequency characteristics at RMS of 1,34 g

Frequency (Hz)	Power spectral density (g^2/Hz)
8	0,035
50	0,035
80	0,001
200	0,0005

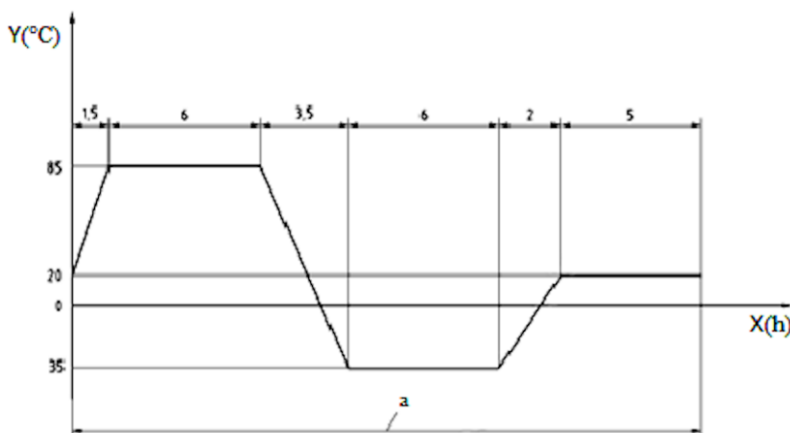
Vibration requests, as well as those characterized in Figure 2 are applied to the tested products, successively along each of the three main axes.



Legend: X - Frequency (Hz);
 Y - Power spectral density (g^2/Hz)

Fig. 2 Vibration test

For the temperature test: the pyrotechnic article is placed in the climatic chamber in which the temperature will be variable, this changing according to the graph in Figure 3, in predetermined cycles of 24h.



Legend: X - time, expressed in hours (h)
 Y - temperature, expressed in degrees Celsius ($^{\circ}C$)
 a - Duration of one cycle: 24h

Fig. 3. Temperature cycle

The specific quality system of the Explosive Materials and Pyrotechnic Articles Testing Laboratory, within the INSEMEX Petroșani Testing Laboratory Group, also includes the RENAR accredited test procedure (PI-98) for verifying the functioning of pyrotechnic articles, including of those with car destination [9,10].

2.1 Synthetic presentation of the technical test infrastructure

In order to determine the ability of pyrotechnic articles intended for automobiles to withstand vibration conditions, according to the applicable reference SR EN ISO 14451-2, a specialized equipment was used to determine the parameters of triaxial vibrations with programmable cycles type TS20LS3-340 with the following main components: the sliding mass subassembly and the power amplifier (Figure 4) [11].

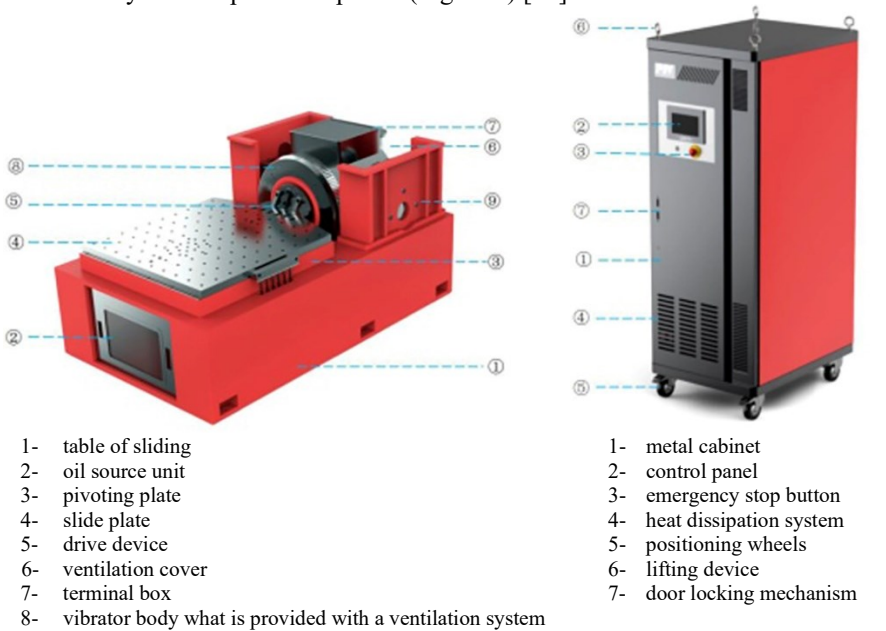


Fig. 4. Specialized type TS20LS3-340 equipment

The interface of the control and verification system of the power amplifier allows the setting of system parameters through the interface of operation and that of defects verification (Figure 5).

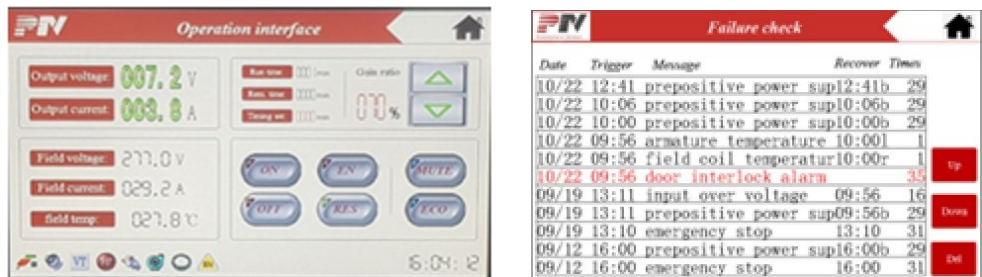
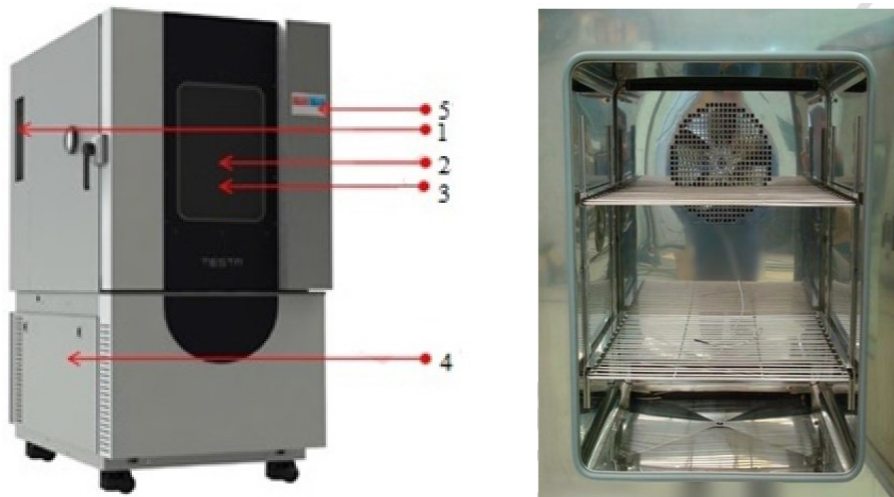


Fig. 5. Power amplifier control system interface

The TS20LS3-340 type equipment allows the programming of vibration cycles, the acquisition, analysis and processing of data/information obtained in the type of tests, with the help of a controller, to which are connected to ensure the technical facilities of data processing, both the vibration sensor(s) and a high-performance PC, through which the equipment is programmed and is possible visualization and storage of test reports.

In order to determine the ability of pyrotechnic articles in the automotive industry to withstand temperature conditions with predetermined cycles, in accordance with the applicable standards, a specialized equipment was used for conditioning pyrotechnic articles at controlled temperature and humidity type TESTA CT-TT (Figure 6) [12].



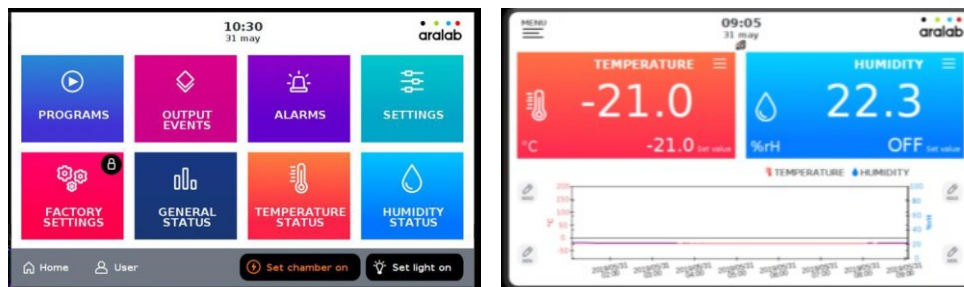
- 1- electrical panel
- 2- access door to the climatic chamber
- 3- test chamber
- 4- mechanical compartment
- 5- climatic chamber controller

a. general view

b. test chamber

Fig. 6. Climatic chamber type TESTA CT-TT

The climatic chamber intended for the precise control of the ambient conditions of temperature and humidity, allows the adjustment of the control, the definition of alarms, the real-time display of process variables and the implementation of programs by means of the Climaplus 9822 controller equipped with a programming touch screen (Figure 7).



a. the access buttons for the controller areas

b. displaying the conditions in the climate chamber

Fig. 7. Interface of the Climaplus 9822 controller

By means of a MODBUS TCP™ network, the controller communicates with a remote computer, making it possible to: acquire data in the computer, in real time; sending the test

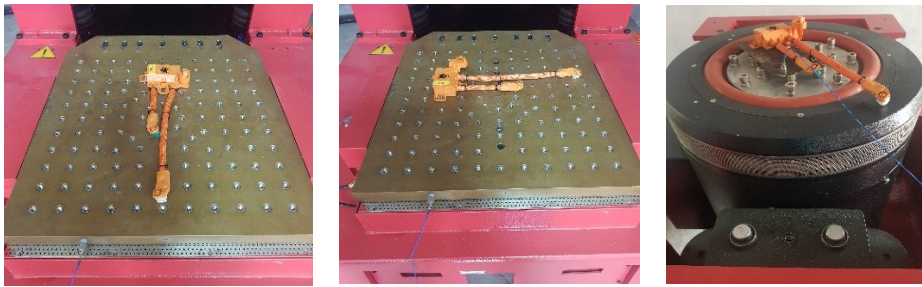
programs from the computer to the climatic chamber and downloading the stored programs from the controller to the computer.

2.2 Carrying out experimental tests, using specialized equipment type TS20LS3-340 and TESTA CT-TT to carry out the vibration and temperature test of pyrotechnic articles intended for vehicles

In order to test with the TS20LS3-340 equipment respectively TESTA CT-TT, by exposing to triaxial vibrations with predetermined cycles of thermal conditioning of pyrotechnic articles intended for automobiles, tests were carried out in laboratory conditions of an actuator pyrotechnic and a seatbelt pretensioner device that are part of the P1 category.

According to the work procedure PL-12 with the name "Work procedure regarding the use of specialized equipment for determining vibration parameters, type TS20LS3-340" for carrying out vibration tests on pyrotechnic articles intended for automotive use in the P1 category, proceed as follows:

- Fix the pyrotechnic article and the accelerometer on the vibrating table (by a suitable method), ensuring the correct transmission of the vibration load, on each of the 3 main axes (Figures 8, 9).



a. horizontal vibration (X axis) b. horizontal vibration (Y axis) c. vertical vibration (Z axis)
Fig. 8. Fixation of pyrotechnic actuator in view of exposure to vibrations



Fig. 9. Fixation of seatbelt pretensioner in view of exposure to vibrations on the X, Y, Z axes

- Check the connection of the controller with the computer and with the vibration sensor (accelerometer) that was previously fixed on the sliding plate. The vibration sensors used to measure the vibrations produced with this equipment can be IEPE/ICP type voltage output, with a sensitivity of 100 mV/g, or with capacitive type output with a sensitivity of 10 pC/g when subjected to mechanical vibrations [11].

The programming of vibration cycles with values of frequency and spectral density of power, RMS limit and test duration, according to the requirements, is carried out by means of the CRISTAL Instruments controller, whose software makes it possible to connect the computer to the vibration equipment (Figure 10).

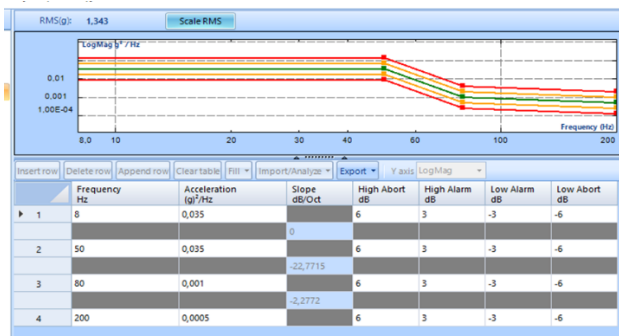
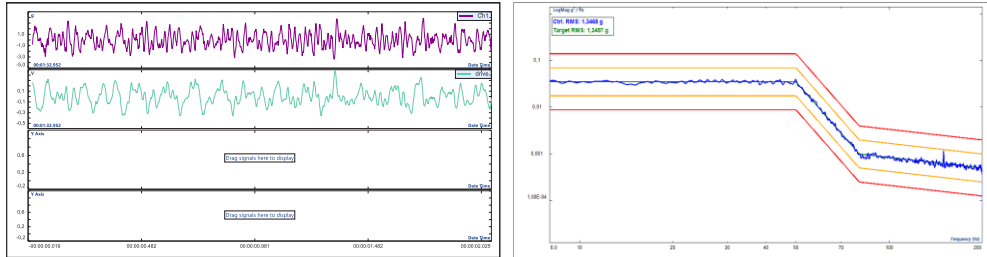


Fig. 10. Vibration test profile (setting frequencies and power spectral density)

By means of the interface of the control system of the power amplifier, the setting of the system parameters is carried out (amplification according to the test conditions). The vibration test program is launched, the execution of which is monitored on the computer (Figure 11).



a. accelerometer response

b. compliance with the established profile

Fig. 11. Compliance with the established profile

After completing the vibration exposure test for 24 h on each of the 3 axes, the program automatically saves the test report.

In order to carry out the tests in variable temperature conditions of P1 category automotive pyrotechnic articles, in order to carry out in good conditions the activity of using the climate chamber, was developed and implemented in the quality system of the Department of Security of Explosives and Pyrotechnic Articles, work procedure PL-06 with the name "Work procedure regarding the use of the climatic chamber for testing in variable conditions of temperature and humidity of pyrotechnic articles", according to whom, is done like as follows:

- The pyrotechnic article is placed on the metal shelf inside the climate chamber. Attach the mobile temperature sensor to the body of the pyrotechnic article to be tested (Figure 12).



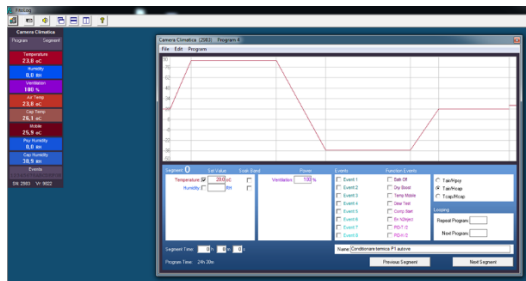
a. pyrotechnic actuator



b. seatbelt pretensioner

Fig. 12. Preparation for the variable temperature test of pyrotechnic articles

- By means of the computer connected via the network to the controller of the climate room or using its touch screen, the test program is carried out, on program segments according to the graph in Figure 3, for the two types of pyrotechnic articles intended for automobiles, category P1. For each program segment, the user can set the temperature value and the time duration of the segment (Figure 13).



a. Via computer with FitoLog 9000



b. Using the controller's touch screen

Fig. 13. Configuration the segments of test program

- The test program is launched, the period of one cycle being 24 hours, during which all the values read by the sensor inside the chamber and the mobile sensor attached to the product subjected to thermal conditioning are recorded in a FitoLog Wiew 9000 file. After the completion of the temperature test, the graphs regarding the temperature values obtained during the program segments can be viewed, both inside the climate chamber and at the level of the tested product (Figure 14).

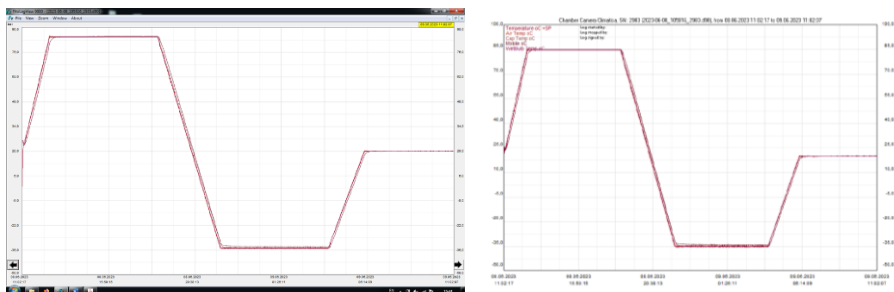


Fig. 14. Graphs of temperatures obtained during the test

By viewing the graph in Figure 3 and the graph recorded by the FitoLog 9000 software, it is possible to check whether the conditions imposed according to the applicable standard were respected, during the temperature test.

3 Expressing and evaluation of results

According to the applicable standard for products in the automotive industry, for the purpose of evaluating security quality, tests on the ability of pyrotechnic articles for automotive use to withstand vibration and temperature conditions will be done for each batch of products, and the number of samples within the batch, which will be subjected to tests, will be established according to the reference.

The results obtained from the tests to determine the resistance to vibrations and temperature are recorded in the table in the Register of primary records (located at the test point) and later must be recorded in the Test Report, in which additionally provided the following information, both for pyrotechnic actuators (triggers) and for safety belt

pretensioners: whether or not initiation occurred during the tests; if there was a leak of the pyrotechnic composition during the tests; whether they functioned correctly according to the product specification in the functional test.

Results obtained from vibration and temperature tests of pyrotechnic articles for vehicles, category P1 of the type of pyrotechnic actuators and safety belt pretensioners, using specialized equipment type TS20LS3-340 respectively the climate chamber type TESTA CT-TT, are shown in Table 2.

Table 2 - Results of the test on the determination of resistance to vibration and temperature

Constructive type	Mass of product before the test (g)	Initiation during vibration test (Y/N)	Initiation during temperature test (Y/N)	Mass of product after the test (g)	Loss of pyrotechnic composition (g)
Pyrotechnic actuator	618.62	N	N	618.62	-
Seatbelt pretensioner	548.48	N	N	548.48	-

In order to certify these constructive types of automotive pyrotechnic articles, according to the requirements and acceptance criteria of the applicable referentials, there must be no initiation during the tests and no leakage of the pyrotechnic composition from the product under test [7,8].

Considering the results of the tests regarding the determination of the resistance to vibration and temperature of the pyrotechnic actuator (trigger) and the seat belt pretensioner it can be appreciated that in both situations there was no loss of mass, and no initiation during vibration and temperature tests.

According to the test matrices of the harmonized European standard SR EN ISO 14451 parts 7 and 9, the samples that have been subjected to the vibration and temperature test if they passed the test, are subsequently tested to function and they must operation correctly, according to the product specification.

Based on the technology presented regarding the evaluation of the security quality of pyrotechnic articles for automotive use, in terms of resistance to vibration and temperature conditions, following the results obtained after exposure to triaxial vibrations with predetermined cycles of thermal conditioning of the tested products, both for the pyrotechnic actuator as well as for the seat belt pretensioner, it can be stated that they meet the security requirements for ensuring their quality, in order to make them available on the market.

4 Conclusions

The subject addressed in the paper is of particular importance in terms of harmonizing the level of technical competence existing at national level with the international profile performance, regarding the compliance with the specific security requirements of pyrotechnic articles intended for automobiles, from the perspective of verifying and ensuring the preservation of their integrity, in follow their testing by exposure to vibrations and in various pre-set temperature conditions according to the applicable references.

The conditioning process of the pyrotechnic articles intended for vehicles, which must be carried out by the vibration equipment and the climate chamber, as well as the subsequent verification of their behaviour during operation, are very important, because based on the results obtained, the shelf life of the products is established, an essential aspect in their safe use.

The use of specialized equipment to determine the ability of pyrotechnic articles to withstand vibration and temperature conditions has as a first result the shortening of the time necessary to carry out the tests and also the provision of relevant and credible informational support provided by this equipment, to the competent authorities with attributions in the field of automotive products.

The test programs in laboratory conditions regarding the vibration and temperature testing of products from the automotive industry, using the specialized equipment type TS20LS3-340 and TESTA CT-TT have highlighted the fact that the results obtained allow a better interpretation of them, allowing the analysis and evaluation in order to ensure the quality of security, which means a safer market for automotive pyrotechnics.

Acknowledgements

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