Bulgarian Society for NDT
International Journal "NDT Days"
Volume VI, Issue 1, Year 2023
ISSN: 2603-4018
eISSN: 2603-4646

Research of Inertial Loads Arising in the Fire Truck Tanks Under the Main Motion Modes

Vadim KOVTUN[1], Sergey KOROTKEVICH[1],
Yordan MIRCHEV[2], Vyacheslav LODNYA[3]

[1] University of Civil Protection of the Ministry for Emergency Situations of the Republic of Belarus, Minsk, Belarus, e-mail: vadimkov@ya.ru, korotkevichsergei@mail.ru

[2] Institute of Mechanics of the Bulgarian Academy of Sciences, Sofia, Bulgaria; e-mail: mirchev@imbm.bas.bg, nntdd@abv.bg

[3] Belarusian State University of Transport; Gomel, Belarus; e-mail: lodnja@rambler.ru

Abstract
The operating conditions of fire trucks indicate high operational loading of tank structures. As a result of experimental studies, dependencies that connect the modes of movement of fire trucks on the MAZ-5337 and MAZ-6317 chassis were established. The values of acceleration that occurs under the action of inertial loads in the structures of tanks with a volume of 5, 8 and 10 m^3 were taken into consideration. It has been experimentally confirmed that the modes and operating conditions of fire trucks determine high level of inertial extensions uprising in tank.

Keywords: fire truck tank, motion mode, accelerometer, inertial loads.

1. Introduction

In the production of fire trucks, it is highly important to comply with the increased requirements for the structural strength of the tank itself, which undergoes significant loads when moving [1]. The process of liquid cargo transportation is characterized by large movements of the cargo's mass center in the tank. This is primarily due to the daily operation of fire trucks in the "acceleration", "braking", and "turn" modes. According to statistics, more than 60 % of all fires in our country occur in rural areas, as well as in natural ecosystems, which makes it necessary to carry out the movement of fire trucks on country roads, as well as in the off-road conditions. Under these conditions, tank structures experience significant inertial loads transmitted through the chassis frame and from the transported liquid. Thus, the acting dynamic loads on the tank structure determine the accelerations that cause inertia forces when the fire truck is moving. As a result, there is often a violation of the tightness of tank structures due to the high operational load.

2. Research methods

Nowadays vibration diagnostics is modern and accurate means of condition monitoring of complex technical systems that are exposed to many factors in various operating conditions. These primarily include road transport [2–4]. In general, for the purpose of vibrational condition monitoring of the of machines, the following devices are used: accelerometers, the output signal of which is subjected to the appropriate transformation to obtain the required value; speed sensors, the output signal of which can be integrated to obtain a displacement signal; contactless sensors, the output signal of which is proportional to the relative movement of the moving parts of the machine [5]. Accelerometers are inertial type sensors. Their output signal is proportional to the acceleration of the surface on which they are mounted. The choice of the sensor depends on the conditions of its application.

Contact type sensors are piezoelectric and piezoresistive. They are installed in direct mechanical contact with the structure. Of all the known types of sensors, piezoelectric vibration measuring transducers or accelerometers are the most widely used in the field under consideration [6]. Piezoelectric properties are possessed by many crystalline substances (quartz, ferrotic salt, tourmaline), as well as artificially created and specially electrified piezoceramics (barium titonate, lead titonate). Accordingly, when a crystal is placed in an electric field, elastic deformation will cause an increase or decrease in its length in accordance with the magnitude and direction of the polarity of the field [7]. When acting on the base of the accelerometer, an inert mass reaction force (compressing or stretching) occurs, which causes deformation of the piezoelectric element and generates a charge in it. This leads to polarization after separation of positive and negative charges (Figure 1).

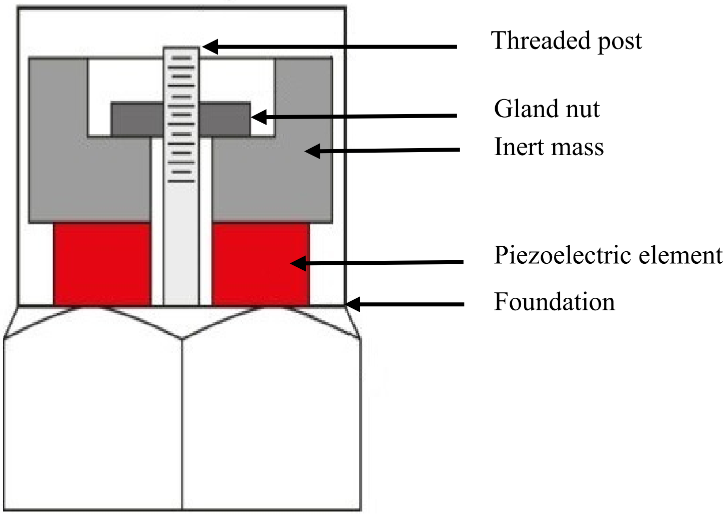


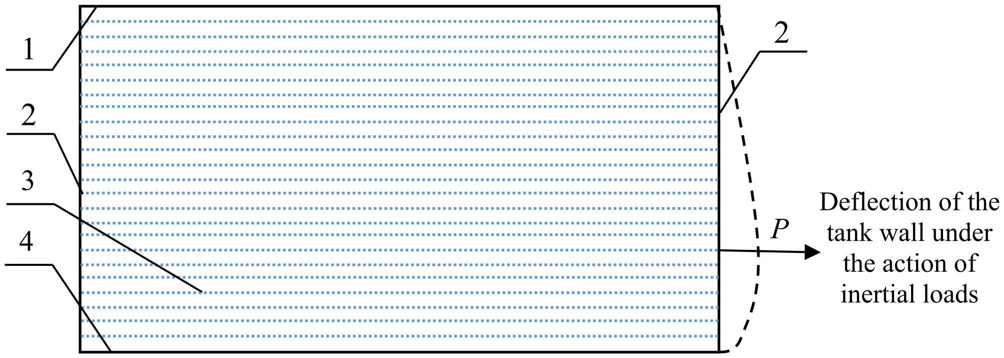
Fig. 1. The structure of the piezoelectric accelerometer

The analysis has shown that the use of piezoelectric vibration measuring transducers (accelerometers) will allow us to estimate the magnitude of the maximum acceleration values arising under the action of inertial loads in the structures of fire truck tanks, depending on different driving modes. Single-component piezoelectric accelerometers of type 352C18 were selected for experimental studies. In accelerometers of the 352 series, piezoelectric ceramics are used as a piezoelectric element [8]. According to the data of the periodic certification of sensors, the error in the conversion factor does not exceed 5 %. The Larson-Davis 2900 noise and vibration analyzer was used to process the data received from accelerometers.

Thus, the aim of the work is an experimental study of the influence of the modes of movement of fire trucks on the inertial loads' level arising in the tank structures. The most common models of tanks with a volume of 5 m^3 of fire trucks on the chassis of MAZ-5337, as well as 8 and 10 m^3 on the chassis of MAZ-6317 were selected as the object of research.

3. The experimental set up and the study results

The experiment was carried out with a fully filled with water tank, which is required by the specifics of fire trucks work. Accelerometers No. 1, 2, 3 were installed outside the tank structure by taking measurements at an equidistant distance from the welds, stiffeners and other structural elements affecting the rigidity of the tank, as well as schemes and models of hydraulic loading [9]. For a comparative analysis of the data obtained, accelerometer No. 4 was installed on the tank's bottom outwardly in the area of the location inside the structure of the cross-section of an equal U-shaped cross-section. According to the presented scheme of hydraulic loading of the tank structure, it is necessary to install sensors on its front and side walls at a height of 1/3 from the bottom of the tank (Figure 2).

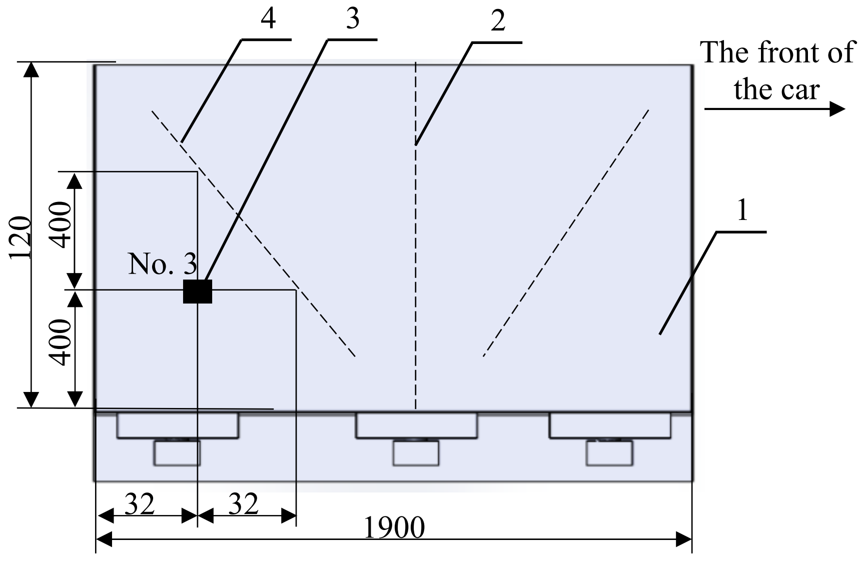


1 – roof; 2 – wall; 3 – transported liquid; 4 – bottom; P – liquid pressure, Pa

Fig. 2. Diagram of hydraulic loading of the fire truck's tank structure under speed conditions

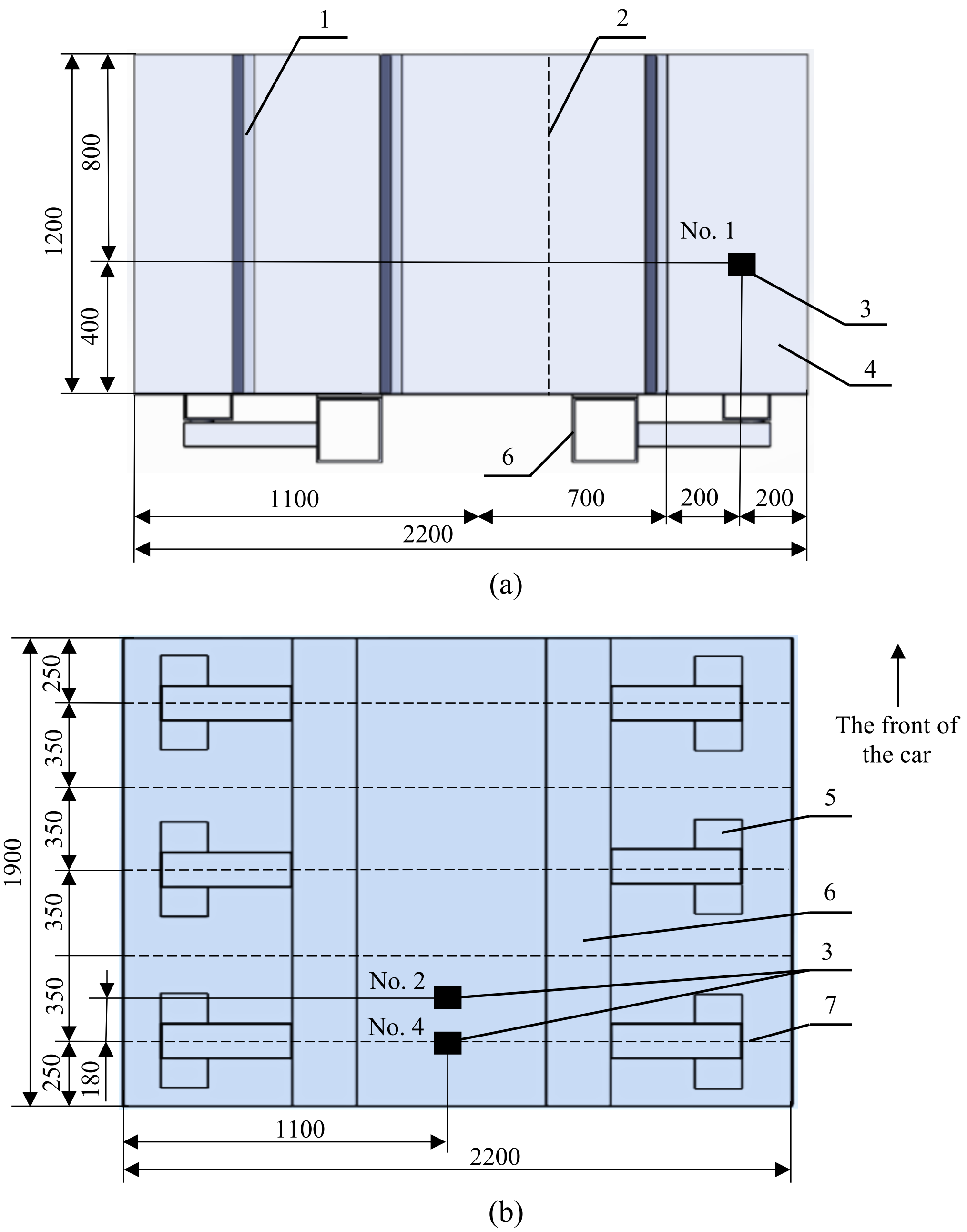
The measuring equipment has been operating at an ambient temperature of 22°C. During the preparation of the Larson-Davis 2900 measuring complex, the zero-acceleration value was set, as well as the variation range of the measured value was found. The tests were reduced to measuring the overall level of acceleration that occurs in the tank structure under various parameters and conditions of fire trucks movement. The following settings were set on the measuring complex: signal averaging – exponential, averaging time 1 second, type of window function of fast Fourier transform – Henning window.

Figures 3 and 4 show the installation locations of four accelerometers on the walls and bottom of the tank structure with a volume of 5 m^3 of fire trucks on the MAZ-5337chassis.



1 – side walls; 2 – T-joint of the breakwater and the side wall;
3 – location of accelerometer No.3; 4 – internal stiffeners

Fig. 3. Layout of accelerometers on the side walls of a 5 m^3 fire trucks tank on the MAZ-5337 chassis (all dimensions in mm)



1 – stiffeners; 2 – T-joint of the breakwater and the front wall;
3 – location of accelerometers No.1, 2 and 4; 4 – front walls; 5 – bracket; 6 – stringer;
7 – U-shaped cross-section profiles inside the tank

Fig. 4. Layout of accelerometers on the front walls (a) and bottom (b) of a 5 m^3 fire trucks tank on the MAZ-5337 chassis (all dimensions in mm)

To conduct the research, the following parameters and conditions characterizing the features of the movement modes of fire trucks to the place of fire occurrence were determined: mode No. 1 – movement along a straight section of an asphalted road at a speed of 50 ± 2 km/h; mode No. 2 – driving on a dirt road of category VI-b with a permissible speed of 20–30 km/h [10]; mode No. 3 – driving on a straight section of paved road at a speed of

50 ± 2 km/h, followed by slowing down the engine to a speed of 10–15 km/h to enter the left turn by 90°; mode No. 4 – acceleration from a standstill on a straight section of paved road to a speed of 30 ± 2 km/h and emergency braking to a complete stop of fire trucks (Figure 5).

Experiments in each mode of movement of fire trucks were carried out with a repetition of 3 times. A total of 12 measurement cycles were carried out. The length of the test sections for mode No. 1 was 850–900 m; for mode No. 2 – 480–500 m; for mode No. 3 – 280–300 m; for mode No. 4 – 100–110 m.

(a) (b) (c) (d)

Fig. 5. Investigation of acceleration values arising under the action of inertial loads in the construction of a tank with a volume of 5 m^3 of fire trucks on the MAZ-5337 chassis when driving in mode No. 1 (a); mode No. 2 (b); mode No. 3 (c); mode No. 4 (d)

Figure 6 shows an example of the recorded results of the maximum acceleration values, arising under the action of inertial loads in the structure of a 5 m^3 fire trucks tank on the MAZ-5337chassis, which were obtained by accelerometer No. 2 after data processing by the Larson-Davis 2900 measuring complex.

The obtained experimental data were processed in accordance with GOST R 8.736-2011 [11] and [12]. The arithmetic mean of the obtained maximum acceleration values is taken as the measurement result, in which corrections have been previously introduced to exclude systematic errors. The table shows the maximum values of acceleration arising under the action of inertial loads in tank structures with a volume of 5, 8 and 10 m^3 under the studied modes of movement of fire trucks on the MAZ-5337 and MAZ-6317 chassis after processing experimental data.

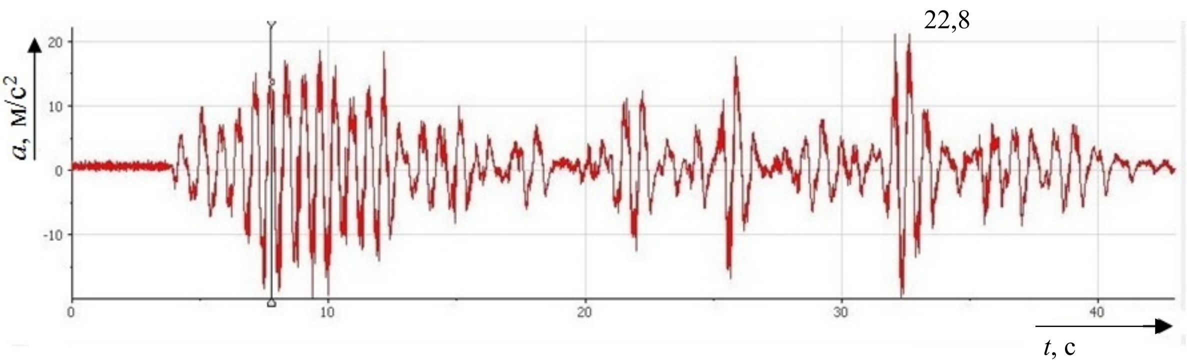


Fig. 6. The dependence of the acceleration values arising on the time of fire trucks movement on a dirt road of category VI-b with an allowable speed of 20–30 km/h, recorded by accelerometer No. 2

Table. Maximum acceleration values a_{max} (m/sec^2) recorded in tank structures during fire trucks tests

Motion mode	Tank volume and fire trucks' chassis model		
	5 м^3 chassis МАЗ-5337	8 м^3 chassis МАЗ-6317	10 м^3 chassis МАЗ-6317
Mode No. 1	7,4 ± 0,7	9,2 ± 0,8	10,8 ± 0,9
Mode No. 2	22,3 ± 1,7	24,6 ± 1,8	25,2 ± 1,9
Mode No. 3	17,9 ± 1,4	18,1 ± 1,5	19,4 ± 1,5
Mode No. 4	15,8 ± 1,2	22,7 ± 1,7	22,9 ± 1,8

The results obtained indicate that the magnitude of inertial loads arising in tank structures largely depends on the driving modes of fire trucks. Thus, when fire trucks are moving along a dirt road of category VI-b with an allowable speed of 20–30 km/h, the highest acceleration values were recorded, which amounted to 22.3 m/s^2 for fire trucks with a volume of 5 m^3 on the MAZ-5337chassis; 24.6 m/sec^2 for tanks with a volume of 8 m^3 on the MAZ-6317 chassis and 25.2 m/sec^2 for tanks with a volume of 10 m^3 on the MAZ-6317 chassis.

4. Conclusions

Experimental studies of the general level of acceleration occurring in tank structures under various modes of fire trucks movement were carried out using the Larson-Davis 2900 measuring complex and piezoelectric accelerometers 352C18. As a result of testing and data processing, dependences were obtained linking the parameters (speed, acceleration, braking, turning) and conditions (type of road surface) characterizing the features of the modes of movement of fire trucks on the chassis of MAZ-5337 and MAZ-6317 with the values of acceleration arising under the action of inertial loads in the structures of tanks with a volume of 5, 8 and 10 m^3. The results of experimental studies have shown that the modes and operating conditions of fire trucks determine the high load of tank structures. The obtained results can be used for further strength calculations using finite element modeling software products.

References

1. Vysotskiy M., Pleskachevsky Yu., Shimanovskiy A. Dynamics of truck and rail tanks. Minsk, Belautotractorbuilding Publ., 2006, 320 p.
2. Liguori, A. Study of Tank Containers for Foodstuffs / A. Liguori, A. Formato, A. Pellegrino, F. Villecco // Machines, 2021, Vol. 9, pp. 1–21. DOI: 10.3390/machines9020044.
3. Orlov D., Makhov V., Katsan I. Diagnostics of vibrations of vehicle assemblies by the method of wavelet analysis of the boundaries of a focused optical image. Engineering Bulletin of the Don, 2014, No. 3, pp. 1–14.
4. Hajdu, F. Examination of chaotic vibrations during operation of a fire truck / F. Hajdu, R. Kuti // MAC-EITAI. Prague, 2018, pp. 163–170.
5. Shock and vibration measurements. Characteristics to be specified for seismic pick-ups. GOST R 8042-2002 – Introduced. 01.04.08. – M.: Inter-State Council for Standardization, Metrology and Certification, 2002, 8 p.
6. Kostyukov N., Naumenko A. Fundamentals of vibroacoustic diagnostics and monitoring of machines. Textbook. Omsk. Publishing house of OmSTU, 2011, 360 p.
7. Yanchich V. Piezoelectric sensors of vibration and shock acceleration. Textbook. Rostov-on-Don, 2008, 77 p.
8. Vibration converters of the company GLOBALTEST [Electronic resources]. Available at: https://globaltest.ru/product/preobrazovatel-vibroskorosti-av02-01-0-8/ (accessed 02 september 2023).
9. Kovtun V., Korotkevich S., Zharanov V. Computer simulation and research of the stress-strain state of fire tank truck structures. Journal of civil protection, 2018, Vol. 2, No. 1, pp. 81-90. DOI: https://doi.org/10.33408/2519- 237X.2018.2-1.81.
10. Roads: Building codes 3.03.04-2019. – Introduced. 26.12.19. – Minsk: Ministry of Construction and Architecture, 2020, 55 p.
11. Multiple direct measurements. Methods of measurement results processing. Main principles. GOST R 8.736-2011. – Introduced. 13.12.11. – M.: Federal Agency for Technical regulation and metrology, 2011, 23 p.
12. Grebennikova V. Methods of mathematical processing of experimental data. Textbook: method. manual. Yekaterinburg. Ural Publishing House, 2015, 124 p.