Dynamic behaviour of a car trailer

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Abstract. The most common causes of accidents involving trailer are poor environmental conditions, materials from which trailers are built, inappropriate assembly processes (incorrectly made welds, choosing screws or placing them so that they cannot withstand loads etc.), the inadequacy of the vehicle's speed to the runway quality, the detachment of the trailer from the towing hitch attached to the vehicle, lack of verification of the condition of the trailer (worn tires, the absence of the braking system, damaged of the resistance elements), the resonance of the trailer or the lack of attention of the drivers in traffic. The paper presents the experimental researches performed on a real trailer with one axle attached to a vehicle and driven on a road with and without obstacles. So, the influence of uncontrolled disturbing dynamic effects was analyzed based on acceleration signals recorded during test.

1. Introduction
It is certain that as a dynamic system, during the movement the trailer is subjected to longitudinal movements, which can lead to the rolling motion; transverse movements that lead to pitch and vertical movements that can lead to rotation. All of these vibrations occur and also are transmitted from the vehicle, and when the two systems resonate, the effects can be disastrous. The most common causes of accidents involving trailer are poor environmental conditions, materials from which trailers are built, inappropriate assembly processes (incorrectly made welds, choosing screws or placing them so that they cannot withstand loads etc.), the inadequacy of the vehicle's speed to the runway quality, the detachment of the trailer from the towing hitch attached to the vehicle, lack of verification of the condition of the trailer (worn tires, the absence of the braking system, damaged of the resistance elements), the resonance of the trailer or the lack of attention of the drivers in traffic. In literature review there are some studies about the dynamic behavior of vehicle with or without trailer concerning detailed time response analysis of the vehicle response on an isolated obstacle and analysis of the same quantities of the vehicle response when travelling along the uneven road with defined number of randomly distributed obstacles [1]. Gidlewski and Jemioł analysed [2] the changes in the trajectory course for the pulling vehicle and configuration of vehicles in the combination during passing by the suddenly occurring obstacle, the results being used for the symptoms which signal more and more changes in the location of vehicles which may pose a threat for the trailer movement (e.g. throwing, trailer’s turning over). Hac et al [3] performed analytical model, simulation and road testing to study dynamic response as it is affected by various speed and loading conditions. Some studies proposed
different analytical models of a vehicle-trailer system dynamics which were validated by experimental tests [4]. In previous research, the authors investigated both modal analysis and the real behaviour of vehicle with one axle trailer, in different condition of vehicle’s speed [5, 6].

2. Trailer testing

2.1. The dynamic system
A trailer consists of the following components, shown in figure 1. The two struts (1) are fastened with the beams (2) by welding, forming a rigid frame with the intermediate beams (4). This frame is fixed to the vehicle through connecting bars (5) which are solidarized with L profiles (6) to the beams of the card. For fixing to the vehicle hook, the resistance structure of the semitrailer is provided with a coupling (10) and a longitudinal connection element (3) welded by the bars (5) and the bar (7) transversely positioned, as shown in figure 3. In order to balance the structure during travel, the axle (9) was rigidly secured to the semitrailer frame halfway through the card. The axle (9) ensures that the wheels (8) are fastened (fixed) to the trailer during movement. In order to provide the three support points required during the storage and handling of the semitrailer in the resting state, at the joint between the longitudinal connecting member (3) and the stiffening element (7) it was mounted an additional wheel that can be parked within regular exploitation.

2.2. The instrumentation set-up
The experimental analysis of the dynamic behavior of the semitrailer was carried out on a real structure rented, which was attached to a vehicle running on the roadway around the Transilvania University Research Institute of Brasov. The data acquisition system (shown in figure 2a) consisted of picking up the acceleration signals on the vertical direction, the accelerometers being mounted as follows: an accelerometer at the end of the trailer frame, close to the gripping point of the towing vehicle (figure 2b), and the other two accelerometers on the trailer frame, one on the left and the other on the right side of the trailer (figure 3c). The displacement regime for each analyzed situation consisted in starting from zero speed to a constant march value of the towing vehicle, driving at a steady speed of approximately 40 km/h for about 4 seconds, followed by braking until the assembly vehicle-tow stopped. The test path involved driving, in a straight line, of the runway without obstacles (variant A) and with obstacles known geometric features (variant B). Data processing was done using NI-Labview©-based application.

![Figure 1. The main components of platform used in experimental investigation: a) components: 1-strut; 2 - beam; 3 - trailer – vehicle connecting element; 4 – intermediate beam; 5 - connecting bars; 6 – L profiles of gripping the beams to the connecting bars; 7 – stiffening element; 8 - wheel; 9 – axle; b) the overall sizes of trailer.](image-url)
In the first part of experiments, the test conditions consist of driven car with platform at different speeds (10; 20; 30; 40 km/h) on smooth road without obstacles, in two cases: case 1 - with constant speed; case 2 with slow deceleration, case 3 - acceleration. In another case (case 4), an obstacles putted on road imposed slow deceleration.

**Table 1:** The variants of experimental tests

| Type and position of accelerometers | Studied cases                  | The speed [km/h] |
|------------------------------------|--------------------------------|------------------|
|                                    | Case 1: constant speed         | 10               |
|                                    |                                 | 20               |
|                                    |                                 | 30               |
|                                    |                                 | 40               |
| A (front trailer)                  |                                 |          |
| B (back trailer)                   | Case 2: slow deceleration       | 10               |
| C (one axle)                       |                                 | 20               |
|                                    |                                 | 30               |
|                                    |                                 | 40               |
|                                    | Case 3: acceleration            | 10               |
|                                    |                                 | 20               |
|                                    |                                 | 30               |
|                                    |                                 | 40               |

Figure 2: Presentation of the data acquisition system: a) acquisition system: 1 - laptop; 2 - force transducers; 3 - card acquisition; 4 - cables; b) Accelerometer positioned on the trailer attachment axle of the towing vehicle; c), d) Accelerometers disposed symmetrically on the trailer frame, near the axle, left and right.
3. Results and discussion
The transient dynamic analysis corresponding to the crossing of the vehicle - trailer convoy over an obstacle, were analyzed both the temporal acceleration evolutions as well as their amplitude spectra; the analysis was carried out in two steps, namely: (a) for the entire time interval corresponding to the pre- and post-obstacle movement until the complete braking (stopping the assembly), respectively (b) for the time interval corresponding to the obstacle crossing only for the deck of the trailer, until the convoy stops.

Following experimental marching attempts, in different travel states (starting, constant speed, braking) on a runway path without major flaws and without obstacles, the situation is the following: is the amplitude spectra in the considered range (1-2000 Hz), in which the relevant spectral components are predominantly represented, is roughly composed of two characteristic areas, namely:

- the 1...20 Hz range, which predominantly contains the modal evolutions of the monitored structure (the basic frame of the trailer);
- the 100...1000 Hz range, which contains both the modal evolution of the trailer frame, and the parasitic frequencies, generated by disturbing vibrations of the trailer superstructure (the tank, gripping/fixing elements, auxiliary elements with load protection role, effective load etc.), ie "noise" structural.

From the comparative analysis of the sets of spectral diagrams corresponding to each situation and stages considered in the running tests on unobstructed rolling paths, a series of frequency ranges of the dominant amplitudes resulted. These intervals are presented systematically in table 2. Table 3 presents the values of the spectral components, evaluated on the basis of the data in table 2, taking into account the spectral peaks identified in the corresponding diagrams.

| Table 2: The frequencies domains of dominant spectral components, in Hz |
|---|---|---|
| Steps | Position of accelerometers |
| | A (front trailer) | B (back trailer) | C (one axle) |
| complete | 2; 8-10; 30-40; | 1.3; 3-10; 17-20; | 1.9; 3.5-5; 10.4; 26; 36; |
| | 200-250; 500 | 26; 51; 154 | 212; 8-10; 15; 200; 400; |
| start | 1; 5.5; 8; 20; 80-125; | 1.2-1.3; 4-7.75; 19; | 2; 7.6; 18-31; |
| | 270-280; 575 | 70-88; 112; 850 | 154; 323; 487 |
| displacement | 3; 5; 8-13; 50; 70; 167; 350; 437; 950 | 36; 55; 400; 762 | 84-85; 200; 354; 603-620 |
| | 2; 3.5; 6-8; 55; | 1.2-3.6; 6.8; 8.8; | 1.5-1.7; 4.5; 5.9; 36; |
| braking | 98-110; 230; 650 | 38-39; 50; 384; 710 | 67-73; 105; 477 |

| Table 3: The frequencies of dominant spectral components, in Hz |
|---|---|---|
| Steps | Position of accelerometers |
| | A (front trailer) | B (back trailer) | C (one axle) |
| complete | 22; 10; 34; 216; 500 | 1.3; 7; 26; 154 | 2; 9; 36; 212 |
| start | 5.5; 20; 105; 125; 275; 570 | 2.4; 4.5; 7.8; 19; 112 | 2; 7.5; 25; 154 |
| displacement | 2.9; 11; 72; 166; 340 | 2.5; 4; 6.5; 10; 54 | 3.2; 14; 85 |
| braking | 2.2; 3.6; 6; 8.4; 50; 110; 650 | 1.5; 2.3; 8.8; 50; 710 | 1.6; 4.5 |

In order to facilitate the spectral analysis on different domains of the temporal evolution of the acceleration, on the corresponding diagrams, the time points were marked in which the shock due to the interaction with the tire obstacle was manifested on the front axle, respectively on the rear axle, of the car and on the trailer axle. Also, in order to facilitate the identification of frequencies of the dominant spectral components, on the diagrams corresponding to the amplitude spectra, the maximum points of the respective components were marked. Figures 3, 4 and 5 presents the amplitudes spectrum...
and acceleration for different studied cases. It can be noticed that the dynamic responses on left and write of trailer is symmetric due to symmetric position of accelerometers and lack of additional mass (figure 3) and the first resonant frequency is around 28 Hz for entire structure. Another pick of amplitude is recorded around 7235 Hz for all signals which is due to the vehicle displace with constant speed on road.

**Figure 3:** Acceleration and amplitude spectrum recorded on vertical direction, on the trailer attachment axle of the towing vehicle and on the symmetric trailer frame, case 1.

**Figure 4:** Acceleration and amplitude spectrum recorded on vertical direction, on the trailer attachment axle of the towing vehicle and on the symmetric trailer frame, case 2.
Figure 5: Acceleration and amplitude spectrum recorded on vertical direction, on the trailer attachment axle of the towing vehicle and on the symmetric trailer frame, case 3.

Concerning the experimental tests performed on a roadway path with rigid obstacle, compared to the rigidity of the running system (of tires), the analysis was performed both individually and comparatively, on the charts corresponding to the amplitude spectra of the recorded accelerations for each situation. To facilitate the spectral analysis on distinct domains of the acceleration time evolution, on the corresponding diagrams, were marked the moments of time when the shock due to the interaction with the obstacle of the tires manifested on the front axle, respectively on the rear axle of the vehicle and on the deck of the trailer (figure 6). Also, in order to facilitate the identification of frequencies of the dominant spectral components, on the corresponding charts to the amplitude spectra, the maximum points of the respective components were marked.

Figure 6: Acceleration and amplitude spectrum recorded on vertical direction, on the trailer attachment axle of the towing vehicle and on the symmetric trailer frame, when passing over obstacle at a speed of 20 km/h.

Observations regarding the distribution of spectral zones with significant amplitudes manifestation, previously performed for marching tests on the runway path without obstacles, are also valid when moving over obstacles. From the comparative analysis of the global signal spectra,
respectively of the "cut-out" ones, for each monitoring situation (A, B, C), it results that, in the case of the exclusive excitement of the trailer, the values of the essential frequencies are lower than in the case of global analysis of the whole signal. A possible explanation for this is given by the difference between the rigidity of the excitation transmission paths - through the hook (high stiffness), respectively by the tires (low stiffness).

It is also noted that, in the case of exclusive trailer excitation, there is an amplification of the upper spectral zone (with frequencies greater than 100 Hz) compared to the global situation. The justification for this is supported by the following: namely, although the bandwidth of the shock transmitted by the hook is greater than that of the shock transmitted by the trailer tires, the intensity of the latter is clearly superior, and this aspect leads to excitement and to the higher vibration modes of the trailer structure (it must be take into account that the dominant frequencies of the entire analyzed spectra, and therefore in the upper area, are lower in the case of the exclusive excitement of the trailer).

4. Conclusions

This experimental study has two significant components, namely: a component that relates to the assessment of the dynamic effects induced during operation, in the structure of a one axle trailer, respectively, a component that falls under what is called Operational Modal Analysis (OMA), with the role of determining the modal evolutions of the analyzed structure. Thus, from the point of view of the first component, the results obtained are particularly useful, providing relevant information on the dynamics of the trailer and its effects on the safety and integrity of the transported load, on the potential sources generating loss of functional capacity, on the vibro-acoustics pollution level in the environment, on the dynamic effects induced in the base vehicle (towing vehicle) etc. On the other hand, from the point of view of the second component, this study provides relevant informations, at least qualitative, regarding the modal evolution of the monitored structure (the basic framework of the trailer) and constitutes at the same time, the initial stage of a detailed modal analysis, possibly Experimental Modal Analysis (EMA) type, with controlled excitations and acquisition/processing simultaneously of both excitation, as well as the dynamic response, performed directly on the structure being analyzed. These results are general in nature, being obtained by the cumulative analysis of the three diagrams that make up the set corresponding to each stage / situation. The separate analysis of each set of spectral diagrams highlights both common elements and some differences, regarding the values or frequency ranges of the dominant amplitudes. This fact is justified by the following aspects, namely: constructive (longitudinal / transverse) asymmetries of the resistance structure (base frame) of the trailer; the potential existence of defects in the structure of the trailer's resistance due to the duration and / or the inadequate mode of operation; the asymmetrical distribution of the elements that make up the trailer tank on its basic frame; profile differences (transverse) of the tread, so that the kinematic excitations on each wheel of the trailer are different during the march; deviations from the perfectly straight path while moving the convoy on the road; deviation from the central position (in the longitudinal plane of symmetry of the trailer) of the monitoring equipment and its operator, during the actual tests; the position of the acceleration transducers on the monitored structure, relative to the maximum and minimum points corresponding to the own modes of the respective structure (with reference to the own modes excited mainly during each experimental situation).

The identification of frequencies corresponding to the own mode’s of the trailer's resistance structure is hampered by the interference in the spectral composition of the parasitic modes specific to the other structural elements in the trailer configuration. The predominant evolution of certain vibration modes of the resistance structure is dictated (and at the same time limited) by the type and the excitation characteristics, as well as by the configuration of the monitoring system (the number of transducers, their type of mounting, the position and the directions monitored etc.).
5. References

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