Static and Dynamic Tests Performed on a Flat Wagon

Nicolae SANDU[1], Nicusor Laurentiu ZAHARIA[2]

Summary

Today, a wide range of freight wagons is used by railway operators. During the last century, the gondola wagon was the back bone of each freight railway operator due the versatility of such type of wagon. But in the last years because of intermodal necessity a flat wagons are more often used because a 20', 30' or 40' container with goods can be used on ships between continents, on flat wagons from the seaport to a railway station (on main land) and from the railway station to a hypermarket (or end user) with the help of truck. This paper present some of the tests performed at a four axle flat wagon. Based on testing report the wagon was certified (homologated) and putted in service on Romanian Railways.

Keywords: railway; flat wagon; tests, rolling stock; strain gauge

1. Introduction

Before putting in service a railway vehicle, static and dynamic tests are performed for the prototype of the series, according to a testing program. The tests are made in accordance with standards from technical specification of the product. This paper presents only the static and dynamic experimental stress analysis with strain gauges at four axle flat wagon for 20', 30' and 40' container transportation performed at wagon's body, because the bogies of the wagon were Y25 type. The Y25 bogie is standardized bogie, so it wasn't necessary to make tests for bogie's homologation. During homologation procedure other type of tests were also performed (braking tests, vehicle dynamic tests etc.).

Previously the tests, numerical studies with finite element method were performed by the designers of wagon. Those studies were the starting point of some of strain gages locations. The finite element analysis software used by the designers was Ansys. At this moment, the finite element method is widely used all over the world by the designers, but is far to be perfect; because of its limits it is necessary that virtual experiments to be confirmed by real experiments. But still, finite element method is one of the most powerful tools used in design stage or when

[1] Dr, Romanian Railway Authority (AFER), e-mail: sandu.nicolae@afer.ro.
[2] Dr, Romanian Railway Notified Body (ONFR), e-mail: laurentiu@afer.ro.

the necessity to modify the body of the prototype vehicle when some unconformities appear due the testing or because some last moments client requirements. During the years, our observations proved that none of the testing methods (virtual or real) it is not a panacea (a combinations of the methods is recommended), at that moment the real tests are the key (or decision element) to prove the conformity or not of a product with reference documents (standards, technical specifications etc.).

Experimental stress analysis with strain gages for this wagon was performed by Rolling Stock Laboratory of Romanian Railway Notified Body which is one of the four independent from Romanian Railway Authority – AFER according with [1, 2, 3, 7]. The tests were performed as follows:

- Static tests on AFER's static test bench from Bucharest;
- Dynamic ramming (collision) at AFER's Railway Testing Center from Făurei;
- Running tests at AFER's Railway Testing Center from Făurei.

2. The Tests

2.1. Measuring Points and Data Acquisition Systems

A flat wagon had only chassis without end walls, lateral walls or roof. Some flat wagons have wood floor in purpose to transport not only goods in containers but also metal plates, vehicles, or anything railway regulations allow. Other flat wagons are manufactured only for containers transport. In figure 1 is presented the chassis of a flat wagon for container transport.

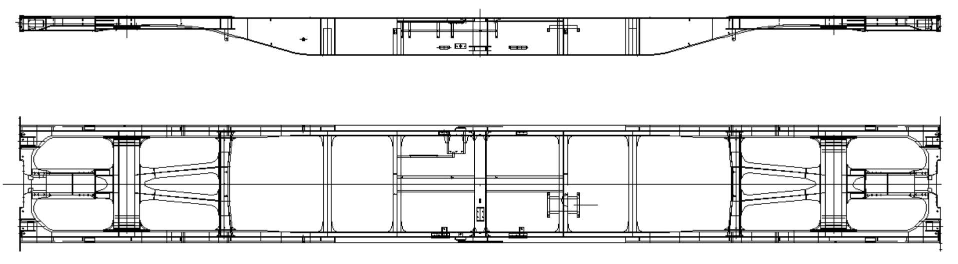

Fig. 1. The chassis of a flat wagon

As data acquisition systems we used HBM Centipede 100 for static tests and HBM MGCplus and HBM Spider8 for dynamic (ramming and running) tests. For this project we used only 30 channels for strain gauges of the HBM Centipede 100 amplifier; the maximum number of our static data acquisition system is 180 (strain gauges, load cells etc., fig. 2). For other projects, at dynamic tests a large number of channels of MGCplus and Spider8 were used (maximum 54). The data acquisition interface was made by AFER in HBM Catman 4.5 software. The number of measuring points for a project depends of the complexity of the vehicle's body, if the body has symmetry planes etc. The strain gauges and accessories (bonding material, protective coating) were also from HBM [4]. For freight wagons in some documents [3] there are indications regarding the type of strain gauge (120 Ω electrical resistance and 10 mm measuring base). In purpose to measure deflections and deformations at static tests, high and deformation roll gauges were mounted (fig. 3) for horizontal deformations (a-a', b-b', c-c') and vertical deflections (1-1', 2-2', 3-3').

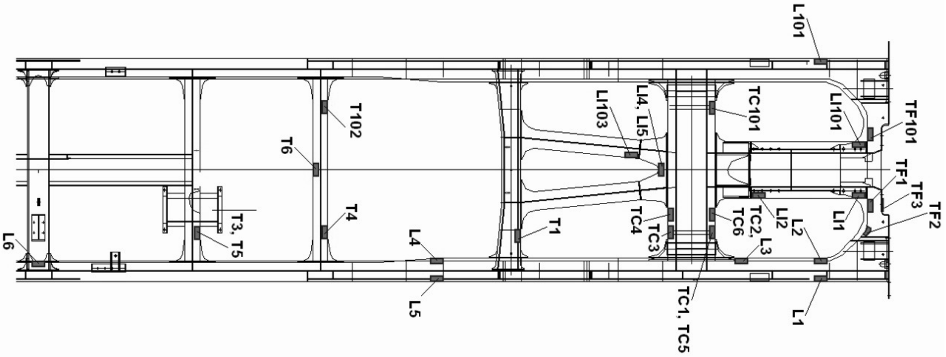

Fig. 2. Measuring points (strain gauges) position

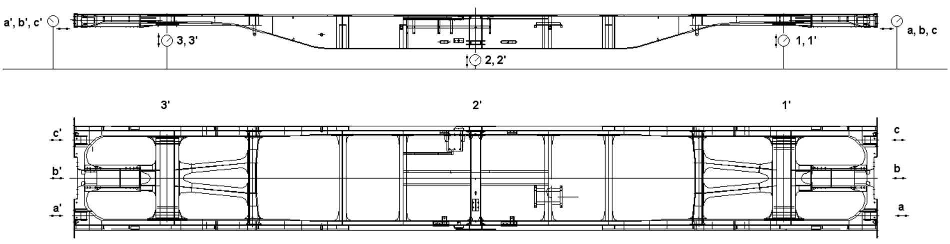

Fig. 3. Deformation roll gauges positions

2.2. Static Tests

Static tests with strain gauges at the wagon's body were performed on AFER's static test bench from Bucharest. In figure 4 is presented AFER's static test bench for railway vehicles from Bucharest.

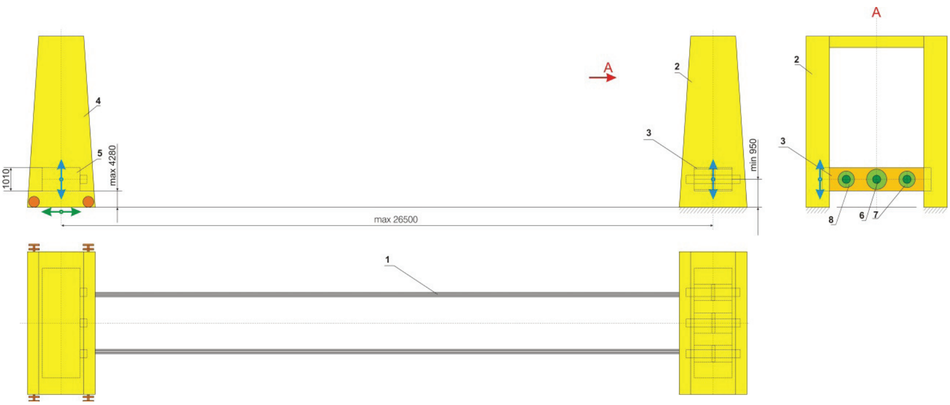

Fig. 4. AFER’s static test bench: 1) railways (1435 mm gauge), 2) fixed frame, 3) hydraulic cylinders beam, 4) mobile frame, 5) resting beam, 6) central hydraulic cylinder, 7) hydraulic cylinder, 8) hydraulic cylinder

In purpose to test many types of railway vehicles (freight wagons, passenger cars or locomotives) the bench test can be adapted according with each vehicle geometry. For example, from the point of view of the length of the vehicle the mobile frame (5) can be translated parallel with the railways. Depending of the buffers height measured from the upper face of the railways, the beam with hydraulic cylinders and the resting beam can be moved up or down. In purpose to create compressive forces on buffers, the hydraulic cylinders (7) and (8) are used. For tensile or compressive force at coupler level, central hydraulic cylinder (6) is used. Due the action of the hydraulic cylinders on the wagon’s body is necessary the resting beam in purpose to create the reactions.

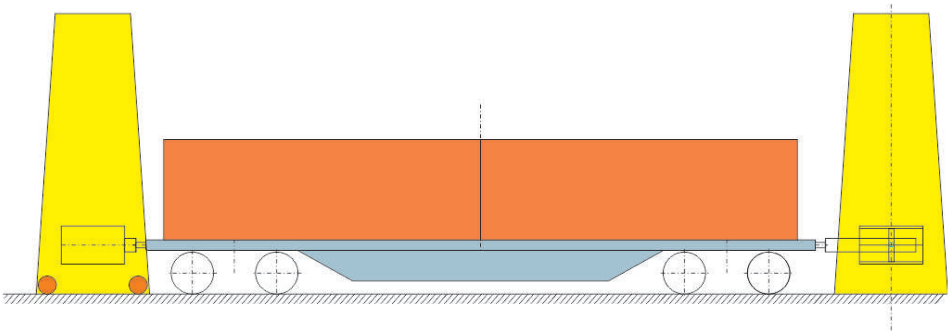

Fig. 5. The flat wagon positioned on AFER’s static test bench

For a freight wagon as it is the flat wagon (fig. 5), next static tests must be made according with [1, 2, 3, 7]:

Horizontal forces:

- tensile test at couple level with 1500 kN,
- compressive test at couple level with 2000 kN,
- compressive test on buffer's axe with 2 x 1000 kN,
- compressive test on buffers at 50 mm below bufers's axe level with 2 x 750 kN,
- diagonal compresive test with 400 kN;

Vertical loads:

- vertical load test (V1) which simulate three 20' length containers and with mases of 18 t, 34 t and 18 t,
- vertical load test (V2) which simulate three 20' length containers and with mases of 34 t, 2 t and 34 t,
- vertical load test (V3) which simulate three 20' length containers and with mases of 23,3 t, 23,3 t and 23,3 t,
- vertical load test (V4) which simulate two 20' length containers and with mases of 35 t and 35 t,
- vertical load test (V5) which simulate two 20' length containers and with mases of 36 t and 30,31 t,
- vertical load test (V6) which simulate one 40' length container and mass of 3 t;
- vertical load test (V7) which simulate two 30' length containers and with mases of 34 t and 34 t,
- vertical load test (V8) which simulate two containers, 30' length first and 20' length the other and masses of 34 t and 34 t,
- vertical load test (V9) which simulate two containers, 40' length first and 20' length the other and masses of 34 t and 27,2 t,
- vertical load test (V10) which simulate two containers, 40' length first and 20' length the other and masses of 11,62 t and 34 t;

Combined loads:

- tensile test at couple level combined with vertical load V1,
- compresive test at couple level combined with vertical load V1,
- compresion buffer's axe test combined with vertical load V1,
- compressive test on buffers at 50 mm below bufers's axe combined with vertical load V1.

The above vertical loads are presented also in figure 6. The vertical loads were created using vertical hydraulic cylinders. On wagon's floor there are many container corner lockers in purpose to allow different configurations of containers (see fig. 6). The vertical cylinders were positioned so that all the loads from figure 6 to be created. For example for V1, V2 and V3 loads, 6 pairs of vertical cylinders were used. The position of each cylinder was above the corner locker.

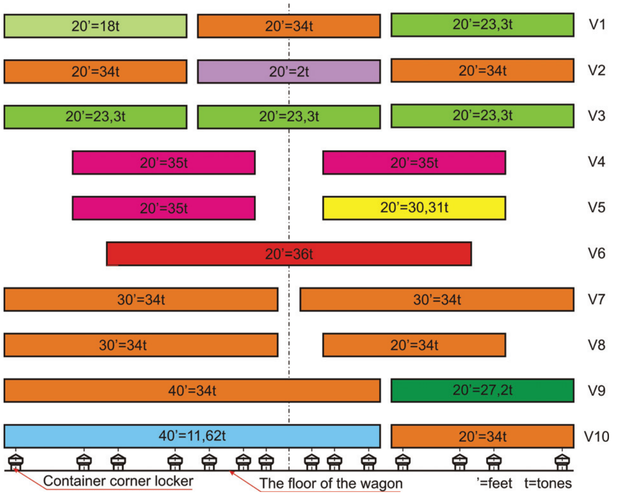

Fig. 6. Different types of containers that can be transported with this type of flat wagon

Tests objectives for static tests was to calculate stress in each measuring point based on strain measured by strain gauge. For stress calculus, Hooke's law is used [5, 6]:

$$\sigma = E \cdot \varepsilon \tag{1}$$

where σ is the stress, E is Young modulus and ε is measured strain.

The stress in each measuring point must be smaller than the permissible stress according with [3] or with EN 12663-2:2010.

2.3. Dynamic Ramming Tests

Ramming (collision) tests simulate shock due sorting in marshaling yard. Shocks with empty wagon and loaded wagon were performed. This paper present only loaded wagon ramming. The tests were performed at Faurei Railway Testing Center (fig. 7) on collision line (fig. 8). Faurei Railway Testing Center it is owned by AFER and provide proper railway infrastructure to perform vehicle dynamics tests (on large ring, small ring and twisted track), braking performance test (on large ring) and strength structure dynamic tests (on collision line) or strength structure running tests (on large ring). Due Center's facilities, the necessary preparation operations of the vehicles can be done also in Faurei Railway Testing Center.

Fig. 7. Faurei Railway Testing Center

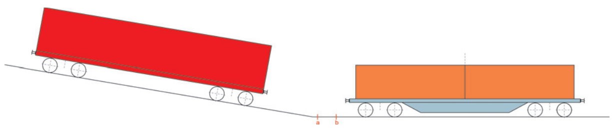

Fig. 8. Ramming of the loaded wagon

Collision objective's tests were measuring of strains during all the tests and observation of cumulate residual strain's trend.

The tests were performed as follows:

- The flat wagon was loaded at maximum axle load 22,5 t,
- The tested wagon, was placed on a straight and level line was rammed by a ramming wagon fitted according with ERRI B12/RP17 report, chapter 3.1 (fig. 8),
- 40 impacts were done at medium speed V = 7,00 km/h; during impacts maximum and residual strains were measured. With the help of Microsoft Excel, the trend of cumulated residual strains ε_{rc} was observed,
- Status of wagon's body during and after the impacts was continuosly observed.

Cumultated residual strains ε_{rc}, after 40 impacts must be smaller than 2‰. During tests no visible deformations of wagon's components were observed.

2.4. Running Tests

Running test for Sgns wagon was performed according with B12/RP17 report, chapter 3.2 [3]. The Sgns wagon is the version of Sgs wagon which a common wagon all over Europe; the letter „n" means that axle load is 22,5 t. The test was done with maximum circulation speed for loaded wagon (100 km/h) and maximum load, on railways between Caracal and Craiova stations because in that period the large ring of Faurei Railway Testing Center was in a refurbishment process.

Test objective was stress measuring in the chassis and comparing of recorded values with the allowable limits from ERRI B12/RP 17 report [3]. The steps for the test were:

1) Measuring of static component σ_{st} of the stress during wagon's loading;
2) Recording of stress variations (dynamic components) $\Delta\sigma_{+}$ and $\Delta\sigma_{-}$ from wagon's body during circulation with 100 km/h. The measuring devices were putted in one of the locomotive's cabin so that the running speed monitoring was easy to do;
3) Maximum and minimum stress values calculations based on expressions [1, 5]:

$$\sigma_{\max} = \sigma_{st} + \Delta\sigma_{+} \tag{2}$$

$$\sigma_{\min} = \sigma_{st} + \Delta\sigma_{-} \tag{3}$$

4) Medium stress calculation:

$$\sigma_{m} = \frac{\sigma_{\max} + \sigma_{\min}}{2} \tag{4}$$

5) Stress's amplitude calculation:

$$\sigma_{v} = \frac{\sigma_{\max} - \sigma_{\min}}{2} \tag{5}$$

For that test, during static component σ_{st} of the stress's measuring Centipede 100 measuring device was used and during running test MGCplus measuring device was used in purpose to measure dynamic components $\Delta\sigma_{+}$ and $\Delta\sigma_{-}$. Numerical processing of data was made after the test with Microsoft Excel.

Stress amplitudes σ_{v} were compared with those from Goodman – Smith diagrams from annex F.3 of ERRI B12/RP17 report [3]. The admissibility condition is:

$$\sigma_{v} =\leq \sigma_{vadm} \tag{6}$$

The above steps are showed in figure 9.

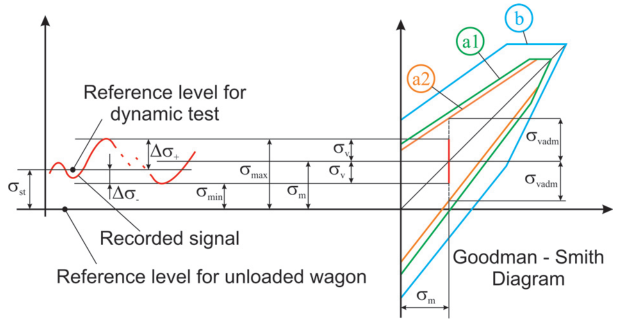

Fig. 9. Graphic representation of running test

3. Results

1. The stress measured for static tests were smaller than permissible stress for all measuring points.
2. For dynamic tests (impact tests) in figure 10 are presented the recorded shock for collision number 40 recorded by TF1 strain gauge and TF101 strain gauge.
3. The sample rate of the measuring devices was 200 Hz without filters. The measuring device MGCplus can record with a maximum sample rate of 19 000 Hz, but for railways applications during time, it was concluded that a 200 Hz sample rate it is enough. The diagrams from figures 9 are made in Catman 4.5 data acquisition software.

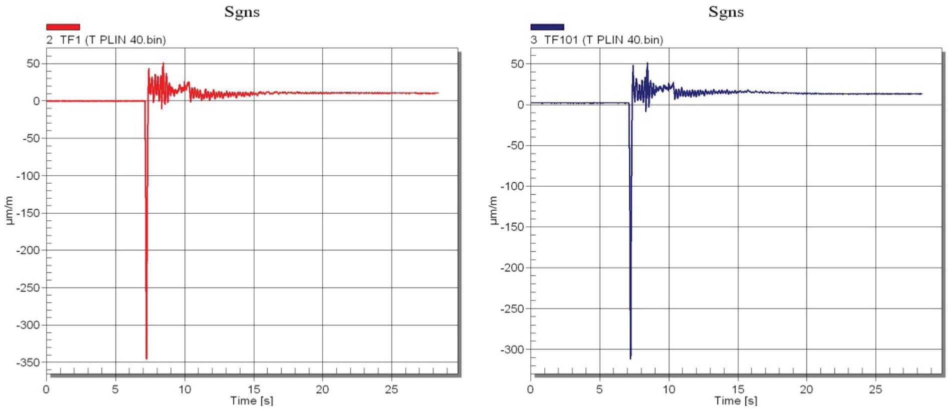

Fig. 10. Strain diagram for TF1 and TF101 strain gauge for shock number 40

In figure 11 is presented a sample from the signal recorded during running test for TF1 strain gauge.

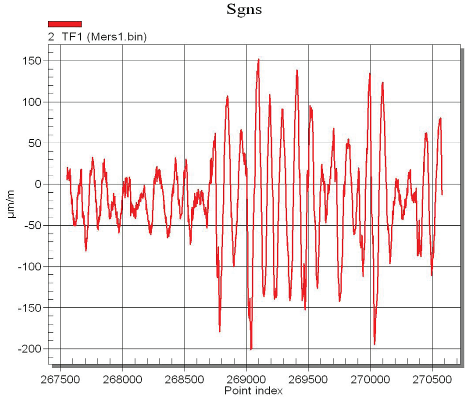

Fig. 11. Sample from recorded signal, TF1 strain gauge

4. Conclusions

For static tests no permissible stress exceeding or visible residual deformations were observed.

After the dynamic tests (ramming and circulation) it was concluded that the wagon is in accordance with the conditions from reference documents.

After the tests, based on testing reports the wagon's homologation (certification) was made. This type of wagon is putted in service and carry containers on Romanian Railways.

Experimental stress analysis with strain gauges offer accurate measured results of an existing stress from a wagon's body when external forces are applied. Because is non destructive measuring method, the test can be repeated. The accuracy of measuring devices is extremely high and it is validated by calibration with special calibrator devices or precision resistors. The experimental results can be also used in purpose to validate finite element analysis results or as feedback for numerical model.

Literature

1. EN 12663-1: 2010 Railway applications – Structural requirements of railway vehicle bodies – Part 1: Locomotives and passenger rolling stock (and alternative method for freight wagons).
2. EN 12663-2:2010 Railway applications – Structural requirements of railway vehicle bodies - Part 2: Freight wagons.
3. ERRI B12/RP17: Programme des essais à châssis et superstructure en acier (apte à recevoir l'attelage automatique de choc et traction) et à leur bogies à châssis en acier.
4. Hoffman K.: *An Introduction to Measurement using Strain Gages,* Hottinger Baldwin Messtechnik GmbH, Darmstadt, 2005.
5. Manescu T.S et al.: *Notiuni fundamentale de rezistenta materialelor,* Editura „Eftimie Murgu" Orizonturi tehnice, ISBN 973-8286-79-4, Resita, 2008.
6. Manescu T.S. et al.: *Notiuni fundamentale de rezistenta materialelor and teoria elasticitatii,* Editura „Eftimie Murgu", ISBN 978-973-1906-67-6, Resita, 2010.
7. UIC leaflet 577 Wagon stresses.

Statyczne i dynamiczne badania wagonu – platformy

Streszczenie

Operatorzy kolejowi korzystają z wagonów towarowych różnego typu. W ostatnim stuleciu podstawowym typem taboru kolejowego każdego operatora przewozów towarowych był wagon odkryty, cechujący się wszechstronnością zastosowań. W ostatnich latach, coraz szerszym użyciu są wagony – platformy, które spełniają wymagania transportu intermodalnego. Na takich wagonach w morskim transporcie międzykontynentalnym przewozi się dwudziesto, trzydziesto i czterdziesto stopowe kontenery towarowe, które po wyładowaniu w porcie są dostarczane do stacji kolejowych na lądzie i samochodami ciężarowymi do placówek handlowych lub innych odbiorców końcowych. W artykule przedstawiono wyniki badań czteroosiowego wagonu platformy. Na podstawie wyników tych badań wagon był certyfikowany (homologowany) i przekazany do eksploatacji na Koleje Rumuńskie.

Słowa kluczowe: koleje, wagon-platforma, badania, tabor kolejowy, czujnik tensometryczny

Статические и динамические испытания железнодорожных вагонов-платформ

Резюме

В настоящее время железнодорожные перевозчики используют широкий спектр грузовых вагонов. Вагон-гондола, в связи со своим универсальным характером, был в течение последнего столетия основным типом вагона для каждого железнодорожного перевозчика грузов. Но в последние годы в связи с интермодальными перевозками всё чаще применяются вагоны-платформы, так как 20’, 30’ и 40’ контейнеры с грузом можно перевозить на судах между континентами, на железнодорожных вагонах-платформах от порта до железнодорожной станции (на материке) и от железнодорожного вокзала до гипермаркета (или конечного пользователя) при помощи грузовика.

Ключевые слова: железная дорога, железнодорожный вагон-платформа, исследования, железнодорожный подвижной состав, тензометрический датчик