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DESIGN CONSIDERATIONS FOR A MODERN TRAM BOGIE: FROM SHEET METAL TO MULTI-LAYER CARBON FIBER REINFORCED COMPOSITE MATERIAL

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Abstract: *This paper presents the first steps undertaken by a mixed research team in order to validate a modern light-weight bogie frame made of a multi-layer carbon fiber reinforced composite material. An initial design based on the traditional sheet metal fabrication techniques was developed by an experienced team at the Remarul 16 Februarie SA railway depot, which was them redesigned into a model suitable for vacuum molding fabrication technology that is specific for composite materials manufacturing. The structure was analyzed using Finite Element Analysis in ANSYS Workbench.*
Key words: *bogie frame, carbon fiber reinforced composite materials, finite element analysis*

1. INTRODUCTION

The bogie of a railway vehicle is the primary structure that links the weight of the car body and passengers to the wheels and suspension system undergoing repeated loading. The weight of a traditional bogie is approximately 37% of the total vehicle weight in order to ensure enough strength and stiffness. The suspension and damping systems have to absorb vibrations due to uneven railway track. The bogie also ensures that the wheelsets are in correct alignment to meet the requirements of stable running on a straight track and good performance in curves with low track wear.

The use of polymer-based composite materials such as glass fiber reinforced plastic [1-3] or carbon fibers materials have been proposed as replacement for steel in bogie frames [4].

Evaluation of the structural behavior of a bogie frame is usually evaluated through experimental methods based in most cases on strain gauges or fiber Bragg gratings (FBG) sensors, the finite element analysis or hybrid analyses that combine experimental and numerical methods [3-7]. Scaled or full-scale prototypes have been made and tested under static loading conditions. Testing results on scaled bogies [2] or real dimensions [7] have been used to verify the full scale FEA models.

A full-scale bogie was designed to be fabricated from composite materials. The geometry of a composite structure is different from a metallic frame due to manufacturing consideration. The resulting design should fulfill the strength conditions in accordance to those prescribed in case of metal structures. Static performances of the full-scale bogie frame with modified geometry under various static loading condition have been presented in this paper.

2. PROBLEM DESCRIPTION

Modern tram designs must ensure an easy boarding of passengers without climbing stairs, so the floor of the vehicle has to be flush with the curb-stone of the tram shelter. Therefore, the H-style frame of the bogie is redesigned and thus lowered so that the central cross-structure no longer accommodates a single axle between opposite wheels. A modern bogie has individual cantilevered axles for each wheel and the wheels themselves include the drive train (built-in brushless motors). All these transformations were addressed by the partner Remarul 16 Februarie SA, a long established railway depot in Cluj-Napoca specialized in servicing and overhauling locomotives and passenger wagons for the national railway company. Repositioning construction elements is only one aspect of the endeavor, the other major transformation is parting with the traditional fabrication using steel sheet metal and embracing a new light-weight multi-layer structure design like carbon fiber reinforced composite materials. Reducing the vehicle's own mass while keeping the same payload limit for passengers translates into energy savings especially when travelling under-capacity and/or in heavy traffic conditions with frequent starts and stops.

All these represent the core considerations discussed in this paper and they are the first steps in proposing a new design for an urban-friendly energy-efficient tram.

3. CONCEPT DESIGN

The first step was performed at Remarul 16 Februarie SA were the engineers studied the basic geometry and the sub-assemblies that are equipped on a bogie frame and proposed a functional concept (Figure 1) based on their experience in manufacturing using sheets of metal made of steel. This structure served as a reference and, for a while, was used in parallel with the new light-weight composite material frame because they continued to study other accessories and fixtures that have to be attached to a bogie frame such as brackets for electrical wires or hydraulic pipelines.

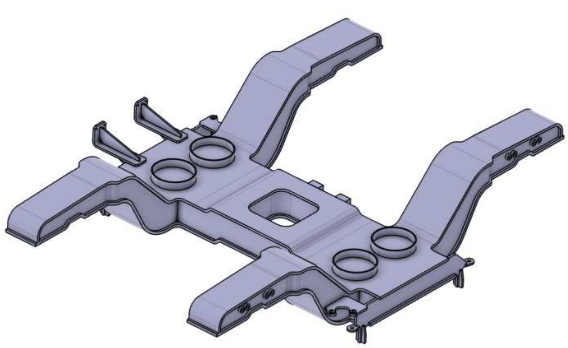

Fig. 1. Steel sheet metal design concept of the bogie frame

This model was then edited using the Catia computer aided design software solution and a mid-surface shell type structure was extracted. Of course, the resulting model has corners, sharp edges and other small radius geometrical details that are not suited for the fabrication using multi-layer fiber reinforced composites that involve mold vacuuming. Therefore, the model was edited even more to eliminate such features and a preliminary solutions (Figure 2) was proposed for the bogie frame structure.

Fig. 2. Shell (mid-surface) model of the bogie frame

4. LOAD CASES

The European standard EN 15663 - Railway applications – Definition of Vehicle Reference Masses defines the masses and reference weights for passengers and exceptional payloads due to heavy baggage and overcrowding. The values for our case study are presented below:

Table 1

Tram masses for bogie structural analysis

Mass	Symbol	Value [kg]
Vehicle in running order	M_V	~60000
Vehicle body	m_1	48000
Bogie mass without any spring masses	m_b	~8000
Primary spring mass	m_2	~4000
Exceptional payload	P_1	(60+170*1.8) * 70=25620
Normal service payload	P_2	230*70=16100

The European standard EN 13749 – Railway applications. Wheelsets and bogies. Method of specifying the structural requirements of bogie frames, depicts the coordinate system (Figure 3)

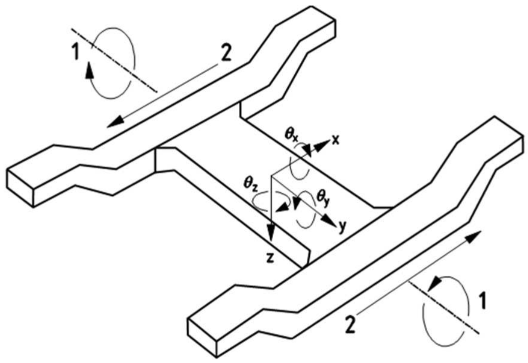

Fig. 3. Standardized coordinate system for bogie frames

The first appendix of this norm contains definitions and classifications accord to which our structure falls under B-II category – bogies for inner and outer suburban passenger carrying vehicles, powered and un-powered and thus has to withstand the following loads:

4.1 Normal service loads

- Vertical forces

$$F_{z1} = F_{z2} = F_z / 2 = (M_V + 1.2P_2 - 2m_b)g / 4$$
$$\cong 39 kN / wheel$$

- Transverse forces

$$F_{y1} = F_{y2} = (F_z + m_b * g)/8 \cong 7.3 kN / wheel$$

- Lozenging forces

$$F_{x1} = 0.05(F_z + m_b * g) \cong 4.9 kN / wheel$$

- Twist loading – the load corresponding to a 0.5% twist of the track – it is therefore dependent on the stiffness of the structure and it is determined as the reaction force for an imposed displacement of 9mm in the vertical (z) direction given a 1800mm span between wheel axles.

$$F_t \cong 3.3 kN / wheel$$

4.2 Exceptional load case

- Vertical forces

$$F_{z1} = F_{z2} = F_z / 2 = (M_V + P_1 - 2m_b)1.4 g / 4$$
$$\cong 54.6 kN / wheel$$

- Transverse forces

$$F_{y1} = F_{y2} = (10^4 + (F_z + P_1))g / 12$$
$$\cong 26.3 kN / wheel$$

- Lozenging forces

$$F_{x1} = 0.1(F_z + m_b * g) \cong 12.9 kN / wheel$$

- Twist loading – the load corresponding to a 0.5% twist of the track – it is therefore dependent on the stiffness of the structure and it is determined as the reaction force for an imposed displacement of 9mm in the vertical (z) direction given a 1800mm span between wheel axles.

$$F_t \cong 8.5 kN / wheel$$

5. FINITE ELEMENT ANALYSIS

Due to the symmetry of the structure as far as the geometry, supports and loads are concerned the model prepared for numerical analysis was defined using a symmetry plane (Figure 4) as well as face mapping criteria for better performance and faster solution. The resulting mesh has 19000 nodes and a growth rate of under 1.2, meaning that no connected elements differ as far as the area is concerned by more than 20%.

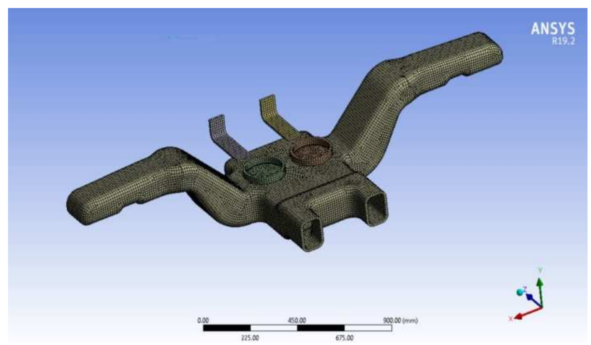

Fig. 4. Resulting mesh for the half model

The finite element analysis results for the normal load case are shown in Figure 5.

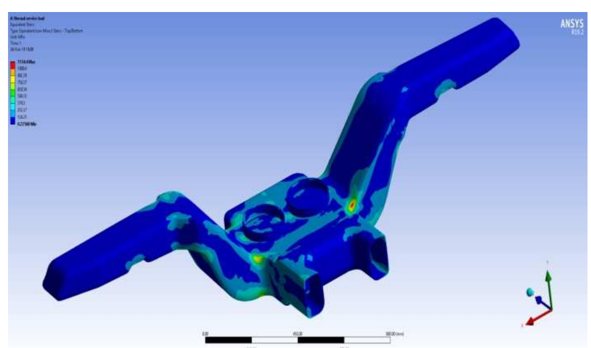

Fig. 5. Stress levels for normal service loads

Figure 6 shows the results for the exceptional load case. The material determined after several runs of the simulation is PR-UD CS 600/1250 FT109 35 (Fibertype SGL Carbon Sigrafil C30 T050) consisting of 10 layers of carbon fiber weave totaling 6.5mm thickness. Considering that the preliminary sheet metal model was designed using 12mm thick steel we get an 85% reduction in mass for the bogie frame.

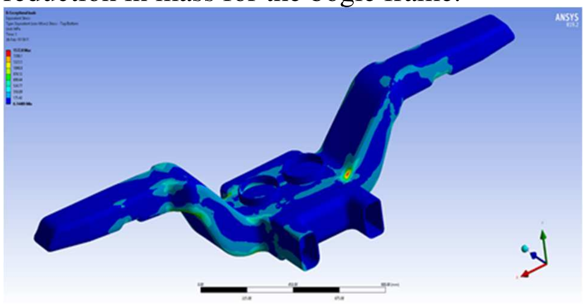

Fig. 6. Stress levels for exceptional service loads

The stress values are under 900MPa for the majority of the structure's surface in both cases (which is well under half the Ultimate Tensile Strength of the material - 1900MPa) with minor stress concentration phenomena that give maximum values of around 1100MPa. We will try to address these issues in future models by modifying the radius or adding patches of extra carbon fiber layers locally.

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Considerente de design pentru un boghiu modern de tramvai: de la semifabricate din otel la material compozit multistratificat, ramforsat cu fibre de carbon

Rezumat: *Aceasta lucrare prezinta primii pasi ai unei echipe mixte de cercetatori spre validarea unui concept modern de rama de boghiu usoara fabricata din material compozit multistratificat, ramforsat cu fibre de carbon. Un design initial specific tehnologiilor de fabricatie din semifabricate metalice din otel a fost dezvoltat de o echipa a depoului Remarul 16 Februarie SA ce a fost ulterior reproiectat obtinand un model compatibil cu tehnologia specifica fabricarii structurilor din material compozit utilizand vacuumarea in matrita. Structura a fost analizata prin metoda elementelor finite utilizand ANSYS Workbench.*

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