Considerations on studying the loads on the motor bogie frame

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Abstract. One of the elements of the load-bearing structure of the railway vehicles is the bogie. This element is allowing the link between the chassis on which the vehicle box and the rolling elements (axles, wheels) by means of the suspension elements. Depending on the type of vehicle where the bogies (motors vehicle or towed vehicle - wagon) are used, its static and dynamic loads differ. On motors vehicles, the axle drive system additionally loads the vehicle structure (bogie or chassis) into there are fixing points. Depending on the type of drive system used, the distribution of the forces and moments generated by the drive equipment at the axles is different. For the case of the LE 060 EA locomotives, which is mostly used by the Romanian railway operators, the drive system is individual, with the suspended electric motor and the semi-suspension reducer (supported on the axle and connected to the bogie frame). This paper aims to analyse the load rating of the bogie frame, taking into account the type of drive system used to transmit the traction force to the motors axles of the vehicle. In this respect, it was modelled in 3D format at scale 1:1, the bogie frame of the LE 060 EA locomotives.

1. Introduction
The railway train running along a track is one of the most complicated dynamical Systems in engineering. [1] A locomotive is a railway vehicle that provides driving power for the train. [2] The studying of the dynamic behaviour and traction performances of locomotives is decisively related to the properties and features of the component parts of these locomotives; because almost all the locomotive parts participate in the traction process. Of these parts we mention: locomotive compartment, bogie, suspension systems and wheel-sets. [3]

In motorized railway vehicles, the drive system (electric traction motors, mechanical gears, drive axles) is fixed to the bogie frame and rests on the drive axle. This causes additional stresses for the two elements depending on the size of the traction forces. In order to dimension the constructional elements of these elements it is necessary to determine the torques and forces that appear as well as the application points.

The mode of application of the loads entered due to the engine torque as well as their value depends on the type of axle drive. Depending on the position of the axle in the bogie and the direction of travel, it is possible for the drive unit to be in front of or behind the axle. [4]

The LE 060 EA locomotive has two bogies of three axles each. The axle drive system is individual for each axle.

The traction electric motors are fixed to the bogie frame (suspended) and the gearboxes are semi-suspended (rests on the axle and is connected to the bogie frame by means of a rod). This type of drive is encountered in the case of medium or large power vehicles. [4]
In stationary regime (the vehicle is stationary) on the bogie there are a series of permanent forces coming from the weight of the components that are attached to it (traction motors, gearbox, body, etc.).

The main axle drive scheme is presented in figure 1. [4]

Based on the equilibrium conditions of the axle and the gear housing (figure 2), the following equations can be written: [4]

\[ R_C = P_t = F_o \cdot D / 2 \cdot r_2 \]  \hspace{1cm} (1)

\[ V : \quad R_{B_V} - P_t \cos \gamma + R_A \cos \theta = 0 \]
\[ H : \quad R_{B_H} - P_t \sin \gamma - R_A \sin \theta = 0 \]
\[ \sum M_{B=B'} = 0 : R_A l_1 = P_t (l_1 + r_2) \]  \hspace{1cm} (2)

**Figure 1.** Axle drive scheme for LE 060EA locomotive [4].

**Figure 2.** Balance of the forces at the axle and the reducer level [4].

The values of the actual forces acting in points C, B’ and B’’ are the reactions taken with changed sign. [4]
\[
\begin{align*}
P_{C\ V} &= -\left( R_{C\ V} \right) = -\frac{F_0 D}{2r_2} \cos \gamma \\
P_{B\ V} &= P_{B'\ V} = R_{B\ V} = \frac{F_0 D}{2r_2} \left[ \cos \gamma - \left( \frac{1}{i} \frac{r_2}{4} \cos \theta \right) \right] \\
P_{C\ H} &= -\left( R_{C\ H} \right) = \frac{F_0 D}{2r_2} \sin \gamma \\
P_{B\ H} &= -R_{B\ H} = -\frac{F_0 D}{2r_2} \left[ \sin \gamma + \left( \frac{1}{i} \frac{r_2}{4} \sin \theta \right) \right]
\end{align*}
\]

Since the B’ and B” points and the axle bearings of the gear housing are very close, PBV and PBH can be assumed to operate at the O≡C point (figure 3). The action Cm on the bogie frame is represented by the force of the point E, PE (figure 4). [4]

\[
P_{\alpha} = P_{c\alpha} + P_{b\alpha} = -\frac{F_0 D}{2r_2} \left( \frac{1}{i} \frac{r_2}{l_1} \cos \theta \right) = -\frac{F_0 D}{2l_1} \left( \frac{1}{i} \frac{r_2}{l_1} \cos \theta \right) = -\left(R_{A} \right) = \frac{F_0 D}{2l_1} \left( \frac{1}{i} \frac{r_2}{l_1} \cos \theta \right) = P_{E} \\
P_{\alpha} = P_{c\alpha} + P_{b\alpha} = -\frac{F_0 D}{2r_2} \left( \frac{1}{i} \frac{r_2}{l_1} \sin \theta \right) = -\frac{F_0 D}{2l_1} \left( \frac{1}{i} \frac{r_2}{l_1} \sin \theta \right) = P_{E} \\
P_{0} = \sqrt{P_{\alpha}^2 + P_{\beta}^2} = \pm \frac{F_0 D}{2l_1} \left( \frac{1}{i} \right)
\]

2. Simulation of bogie loads due to the drive system

In order to carry out the analysis of the loads introduced by the drive system on the LE 060 EA bogie frame, it was geometrically modelled on a 1:1 scale in its 3D structure, using Autodesk Inventor. [5, 6] They have also been modelled with the drive system and electric traction motor (figure 5), as they can be seen on the bogie.

Figure 3. Concentration of forces at point O [4].

Figure 4. Transmitting efforts to the bogie frame [4].

Figure 5. 3D model of LE 060 EA locomotive bogie with axle drive system.
In order to perform an analysis of the forces introduced by the axle drive and the load on the bogie frame, four different gear ratios were considered \( (i_t = 3.65, 2.74, 2.66 \text{ and } 2.106) \). These values are those used on this type of locomotive and correspond to the maximum design driving speeds as follows: \( v_{\text{max}} = 120 \text{km/h; 140km/h, 160km/h and 200km/h}. \)

To ease the simulation and analyse of the influence of the transmission ratio of the gear unit, it was considered that the traction motors and the gearbox housings were not modified. As such, they have the same values for their masses in all simulations.

Other parameters were used (as shown in figure 1-4) for determining the forces introduced by the drive system on the bogie frame is shown in Table 1.

### Table 1. Parameters considered.

| Parameter                          | Unit  | Value | Parameter                          | Unit  | Value |
|------------------------------------|-------|-------|------------------------------------|-------|-------|
| Pinion radius \(- r_1\)           | [mm]  | 100   | Elevation \(- h\)                  | [mm]  | 300   |
| Pinion pitch radius \(- r_2\)     | [mm]  | 250   | Locomotive starting force \(- F_0\) | [kN]  | 390   |
| Traction wheel diameter \(- D\)    | [mm]  | 1250  | Locomotive axle number \(- n_o\)   |       | 6     |
| Angle \(- \gamma\)                | [deg] | 20    | Gearbox efficiency \(- \eta_{am}\) |       | 0.9   |
| Angle \(- \theta\)                | [deg] | 30    | Traction motor mass \(- m_{net}\)  | kg    | 3100  |
| Length \(- l\)                    | [mm]  | 700   | Gearbox housing mass \(- m_{cr}\)  | kg    | 800   |

The maximum force developed by the traction electric motors is obtained when starting the locomotive. As such, the maximum load generated by the drive system on the bogie frame will also be obtained. It was considered a traction characteristic of the locomotive where the maximum force is as shown in Table 1.

At the force values determined by the weight of the elements requesting the bogie (a motor at a point of attachment \( F_{g, \text{ met}} = -10.134 \text{kN}, \) respectively for a gear housing at the point E in the vertical and horizontal direction \( F_{g, E, \text{ cr, v}} = -3.923 \text{kN}; \) \( F_{g, E, \text{ cr, h}} = -2.265 \text{kN} \) were added the forces and moments generated by the drive system. The values obtained for the forces and moments introduced by the drive system 1-4 are centralized in Table 2. When the axe is located ahead of the electric traction motor the force values at the suspension point of the horizontal gear housing are positive, and in the situation when the engine is located in front of the axle, they are negative.

### Table 2. Calculation parameters.

| Force type | Unit | \( i_t = 3.65 \) | \( i_t = 2.74 \) | \( i_t = 2.66 \) | \( i_t = 2.107 \) |
|------------|------|-----------------|-----------------|-----------------|-----------------|
| \( P_E \)  | [kN] | 34,534          | 49,289          | 51,18           | 69,202          |
| \( P_{E,v} \) | [kN] | -29,907         | -42,685         | -44,323         | -59,931         |
| \( P_{E,h} \) | [kN] | 17,267          | 24,644          | 25,59           | 34,601          |
| \( Cr \)   | [kNm]| 4,947           | 6,59            | 6,788           | 8,565           |

In order to determine the loads in the bogie frame, this was fixed to the axe suspension clamping elements and to the connecting joint between them (figure 6).
Figure 6. 3D model of LE 060 EA locomotive bogie with axle drive system.

In figure 7 are showed the arrangement of the forces on the bogie frame.

Figure 7. Arrangement of forces on the bogie frame.

determined by the equipment mass
determined by the drive systems

After finite element analysis, it has resulted a mesh with 32,743 elements and 66,843 nodes.
The distribution of the deformations resulting from the simulations for the action of the weight forces is shown in figure 8, and for the determined forces and the drive system are presented in figure 9.

Figure 8. Deformations due to the weight forces.
Figure 9. Deformations due to the drive system and the weight forces.

3. Conclusions

The input forces applied by the use of a suspended traction motor system and a semi-suspended gearbox, strain the bogie frame on the vertical and horizontal direction, this all together with a rotation torque.

As can be seen from table 2, the values of forces and couples increase as the transmission ratio decreases.

Deformations that occur on the bogie frame increases with the increase of forces and couples. The maximum deformation value resulting from the simulation is obtained with the transmission ratio of \( \text{it}=2.107 \) and it is 0,4284 mm.

Acknowledgments

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4. References

[1] Ansari Z 2016 Design and Analysis of Railway Casnub Bogie Using Fem, *International Journal on Mechanical Engineering and Robotics* 4 68-72

[2] Abid M, Waqas 2013 Analysis and redesign of bolster beam of the bogie frame of a locomotive, *A Journal of Engg.Research* 1(1) 271-287

[3] Zakaria I 2014 Analyzing a bogie frame behavior by using the experimental method and ansys simulations *U.P.B. Sci. Bull., Series D* Vol. 76 149-164
[4] Popa G, Tăruș B 2005 *Carrier structures for railway vehicles (in Romanian)*, Ed. MatrixRom, Bucharest

[5] Arsene S, Sebesan I, Popa G, Stefan V 2015 The aerodynamic resistances determined by the rolling equipment for the electric locomotive LE 060 EA 5100 kW, *U.P.B. Sci. Bull., Series D* 77 99-106

[6] Sebesan I, Spiroiu M A, Arsene S, Popa G, Dinu G 2015 Deformation Analysis of Clouth-type Springs of Railway Vehicles Suspension *Materiale Plastice* vol 52(4) 560-563