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ANALYSIS OF THE BEHAVIOR OF THE CONNECTION SYSTEM BETWEEN LOCOMOTIVE BODY AND THE BOGIE AT CFR 060-EA 5100KW LOCOMOTIVE

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Abstract: When driving the CFR 060-EA locomotive on the track, there was a pronounced wear on the wheels afferent to axle 1 and 6 respectively, which is given by the fact that, at the exit of the curve, the bogies do not return perfectly under the locomotive's box. Connecting systems should provide both the displacement and return locomotive body in the middle position after the forces that caused that movement stopped. The literature considers that the moment of return is not appropriate for this locomotive. In the paper, the connection system between the box and the bogie is studied and it is checked whether the return time is sufficient to bring the bogie under the box at the exit of the curve.

Keywords: fictional pivot, crank mechanism, secondary suspension, suspenders

1. INTRODUCTION

The connecting systems between bogies and locomotive body must accomplishment the following basic functions:

- To ensure rotation in horizontal plane of the bogies beside locomotive body on curved traverse. Each bogie must have own spin vertical axis, which can be materialized(through king bolt or pivot) or can be fictional(unreal, imaginary);
- To allow each bogie rotation around a transverse horizontal axis so that it can track changes in slope of the railway(gallop);
- Enabling each bogie rotation around a horizontal longitudinal axis so that it can track rail irregularities(roll axis);
- To ensure transmission from the locomotive body to the bogies of the vertical forces in elastic or rigid mode, mutual transmission of transverse forces, transmitting traction and braking forces and in general transmission of horizontal forces from locomotive body and the bogies;
- To ensure uniform distribution of loads on wheels(uniform static load) and as small
- deviations from this distribution in traction and braking system:
- To ensure overall stability (locomotive body-bogies);
- To ensure proper runs, especially on enrollment curve, locomotive body is given the opportunity to move laterally in relation to the bogies.

This movement significantly reduces mass movement involving first time for toking shock over the rail track, due to changes in direction of travel.

Connecting systems should provide both the displacement and return locomotive body in the middle position after the forces that caused that movement stopped.

Locomotive body restoring is made by lateral forces developed by booster devices on the transverse deviation of the box from the bogies.

In Fig.1[1], the connecting system between locomotive body and the bogie belongs to CFR 060-EA locomotive has three components, namely:

- Articulated quadrilateral;
- Secondary suspension;
- Vertical suspenders.

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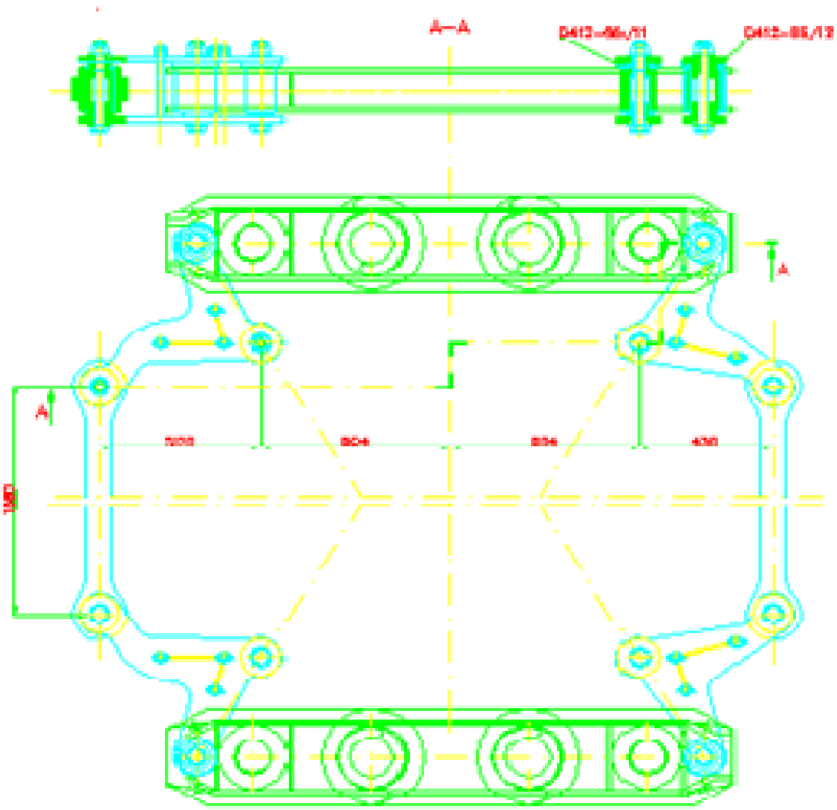

Fig.1.Connecting system between locomotive body and the bogie from CFR 060-EA locomotive

2. ANALYSIS OF THE CONNECTING SYSTEM BETWEEN LOCOMOTIVE BODY AND THE BOGIE AT CFR 060-EA LOCOMOTIVE

Constructive connection studied: bogie-locomotive body is represented through a mechanism scheme in Fig.2.[3], which justify name: “fictional pivot” by its coincidence with a snapshot of the rotation center from mechanism mentioned above.

On the flow through curved portions of the rail tracks, the locomotive’s bogie rotating versus locomotive body around the pivot, pivot which is fictional in that case and is provided by articulated quadrilateral consisting of:

2 longitudinal beams EL and BC with length 1630 mm, 2 cross bars FG and JK with length 1680 mm and 4 cranked lever articulated in A,B,C,D with both the beams and bars of the quadrilateral and the bogie frame through rubber silent-blocks.

Scheme’s constructive materialization from Fig.2. contains “elastic couplings”(silent-block type)into joints, highlighting the location of flexi-coil springs and vertical suspenders.

Points A, B, C and D related to bogie frame forms a rectangle with sides of 1980 mm and 1208 mm, with the diagonals AC and BD intersect always at the point A, in fact the "fictional pivot" for any rotated position of bogie box to the movement on the curve. These points are always on a circle of radius R with value:

$$R = \sqrt{\left(\frac{1980}{2}\right)^2 + \left(\frac{1208}{2}\right)^2}, R = 1159{,}705 \quad \text{mm}$$

and point O-center

Bogie rotation from locomotive body in relation to fictional pivot is done through distortion of articulated quadrilateral from rectangle into a parallelogram forms(see Fig.3.[3]).

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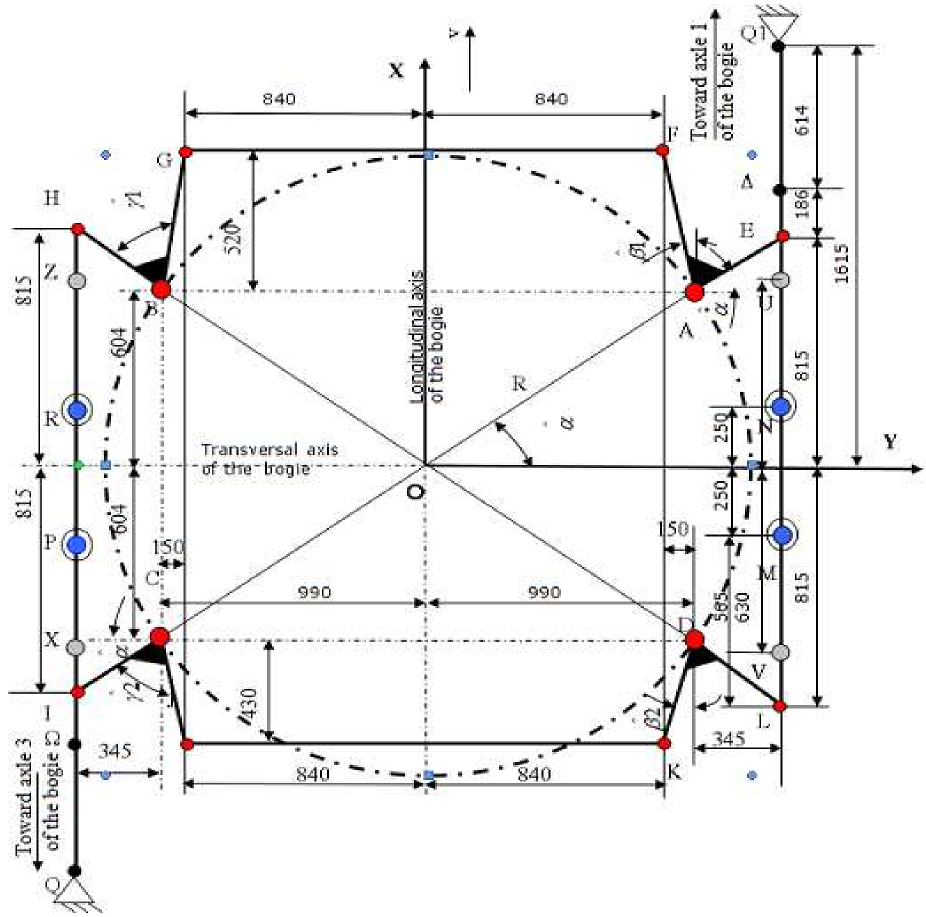

Fig.2.Undistorted articulated quadrilateral

On the exit of the curve, this articulated quadrilateral, due to silent blocks, give a restoring moment of the bogie under the locomotive body equivalent with 80% from the total amount of restoring moment (return). Distortion of the crank mechanism on locomotive circulation through curve modify initial position of own bars and cranked lever and also angles between these.

In this paper it was realized particular geometric computation of the linear and angular dimensions corresponding to scheme given in Fig.2, at locomotive circulation in alignment and landing respectively in curved portions of the railway, using relationships from analytical geometry.

Calculations takes into account the bogie swing angle to maximum 3,5 degree discretized in 0,1 degree. **2.1.**

2.1. Determining the coordinates of the characteristic points of articulated quadrilateral

For studying displacements and rotations of quadrilateral bars and thus changing angles of the bars when it is deformed into a parallelogram was considered a system of orthogonal rectangular coordinate axes XOY with origin O in fictional pivot, OX axis for direction of travel and OY toward the center of the curve that locomotive circulate (Fig.4[3].).

The characteristic points of articulated quadrilateral means the following points:

a) A, B, C, D – binding points of the cranked lever respectively of the quadrilateral and the bogie frame;

b)E, F, G, H, I, J, K and L-articulation points of each bar belongs to the quadrilateral;

c) Q and Q_1 – points where the longitudinal beams of the quadrilateral tied through the traction linkages by the locomotive body(box).

Knowing the geometrical dimensions [mm] of the quadrilateral components represented in

Fig.2, rectangular coordinates of the quadrilateral characteristic points are the following:

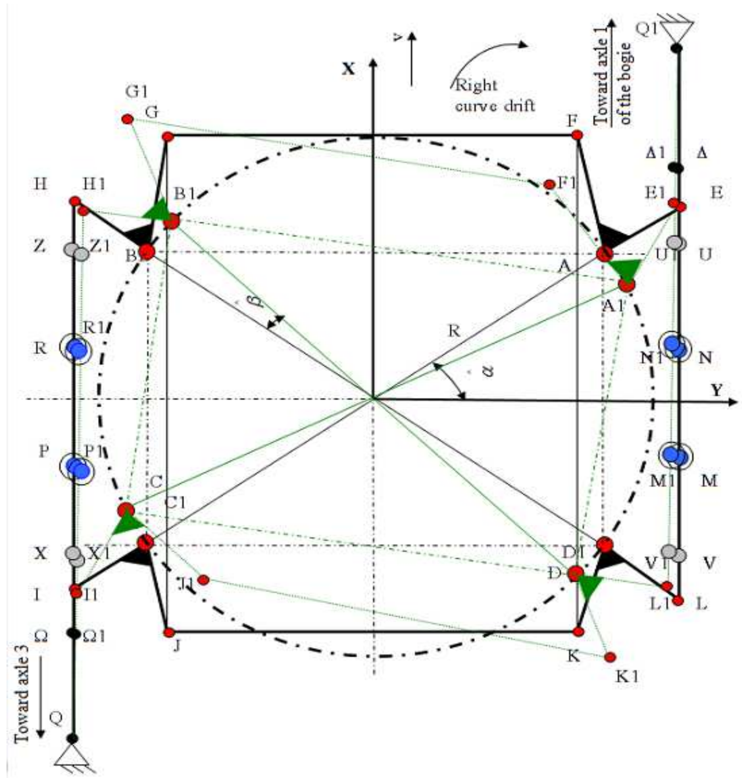

Fig.3. Articulated quadrilateral for curve of radius R

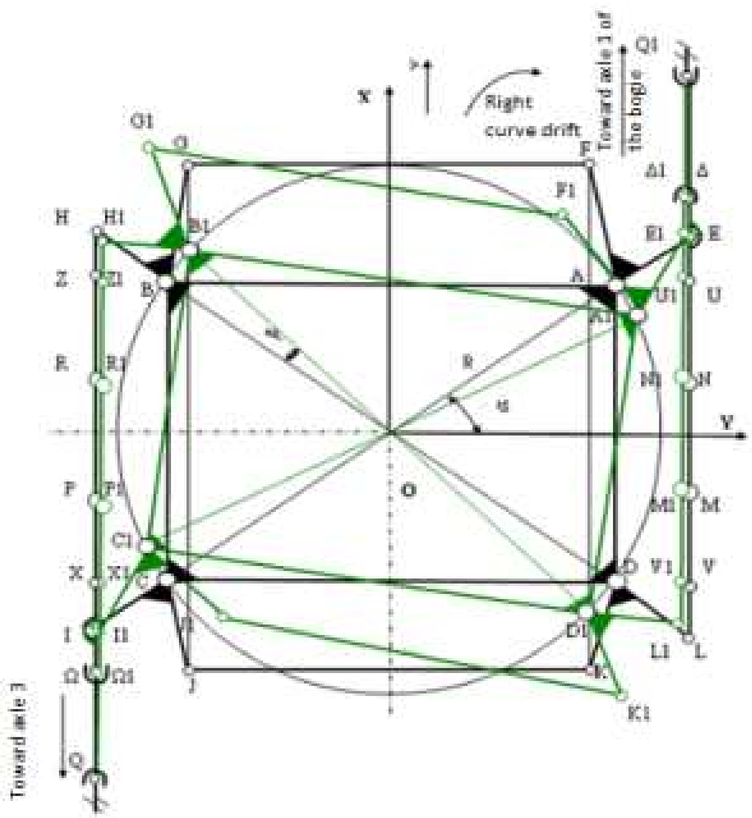

Fig.4. Articulated quadrilateral:normal state(black);deformed (green)

a)

$$A\begin{cases}xA=604\\yA=990\end{cases};\quad B\begin{cases}xB=604\\yB=-990\end{cases};\quad C\begin{cases}xC=-604\\yC=-990\end{cases};\quad D\begin{cases}xD=-604\\yD=990\end{cases}\tag{1}$$

b)

$$E\begin{cases}xE=815\\yE=1335\end{cases};\quad F\begin{cases}xF=1124\\yF=840\end{cases};\quad G\begin{cases}xG=1124\\yG=-840\end{cases};$$

$$H\begin{cases}xH=815\\yH=-1335\end{cases}\quad I\begin{cases}xI=-815\\yI=-1335\end{cases};\quad J\begin{cases}xJ=-1034\\yJ=-840\end{cases};$$

$$K\begin{cases}xK=-1034\\yK=840\end{cases};\quad L\begin{cases}xL=-815\\yL=1335\end{cases}\tag{2}$$

c)

$$Q\begin{cases}xQ=1616\\yQ=1335\end{cases};\quad Q_1\begin{cases}xQ_1=-1615\\yQ_1=-1335\end{cases}.\tag{3}$$

2.2. Determination of cranked lever arms length

Fig.4. shows that cranked lever A and B are identical in terms of constructive and cranked lever from the points C and D - also identical.

Short arms of both types of levers are identical(AE=BH=CI=DL).

Knowing the coordinates of the extremity lever arm can determine their lenghts using relationships know from analytical geometry:

$$\overline{AE}=\sqrt{(xA-xE)^2+(yA-yE)^2},$$

$$\overline{AE}=404{,}408 \text{ mm};\tag{4}$$

$$\overline{AE}=\overline{BH}=\overline{CI}=\overline{DL}$$

$$\overline{AF}=\sqrt{(xA-xF)^2+(yA-yF)^2},$$

$$\overline{AF}=541{,}202 \text{ mm};\tag{5}$$

$$\overline{AF}=\overline{BG}$$

$$\overline{EF}=\sqrt{(xE-xF)^2+(yE-yF)^2},$$

$$\overline{EF}=583{,}529 \text{ mm};\tag{6}$$

$$\overline{EF}=\overline{GH};$$

$$\overline{DK}=\sqrt{(xD-xK)^2+(yD-yK)^2},$$

$$\overline{DK}=455{,}412 \text{ mm};\tag{7}$$

$$\overline{CJ}=\overline{DK}$$

$$\overline{KL}=\sqrt{(xK-xL)^2+(yK-yL)^2},$$

$$\overline{KL}=541{,}282 \text{ mm};\tag{8}$$

$$\overline{KL}=\overline{IJ}.$$

2.3. Determining the coordinates of the points A1, B1, C1 and D1

The coordinates of these point will be determine with following relations:

a)Point A1: $$A_1\begin{cases}xA_1=R\sin(\alpha-\beta)\\yA_1=R\cos(\alpha-\beta)\end{cases}\tag{9}$$

b) Point B1: $$B_1\begin{cases}xB_1=R\sin(\alpha+\beta)\\yB_1=-R\cos(\alpha+\beta)\end{cases}\tag{10}$$

c) Point C1: $$C_1\begin{cases}xC_1=-R\sin(\alpha-\beta)\\yC_1=-R\cos(\alpha-\beta)\end{cases}\tag{11}$$

d)PointD1: $$D_1\begin{cases}xD_1=-R\sin(\alpha+\beta)\\yD_1=R\cos(\alpha+\beta)\end{cases}\tag{12}$$

Knowing the value of the angle α= 31.3875° (0.5478 rad) are given values for angle β, from $0{,}1^0$ to $0{,}1^0$, between 0 and $3{,}5^0$ for which it will be determine the coordinates of the quadrilateral's characteristic points.

2.4. Determining the coordinates of the points E1, F1, G1, H1, I1, J1, K1 and L1

The coordinates [mm] of these points will be determine with following relations:

a) Point E1: $\begin{cases}\overline{AE}=\overline{A_1E_1}\\\overline{QE}=\overline{QE_1}\end{cases}$ or

$$\begin{cases}\sqrt{(xA1_i-xE1_i)^2+(yA1_i-yE1_i)^2}=404{,}408\\\sqrt{(xQ-xE1_i)^2+(yQ-yE1_i)^2}=800\end{cases}\tag{13}$$

b)PointF1: $\begin{cases}\overline{AF}=\overline{A_1F_1}\\\overline{EF}=\overline{E_1F_1}\end{cases}$ or

$$\begin{cases}\sqrt{(xA1_i-xF1_i)^2+(yA1_i-yF1_i)^2}=541{,}202\\\sqrt{(xE1_i-xF1_i)^2+(yE1_i-yF1_i)^2}=583{,}529\end{cases}\tag{14}$$

c) PointG_1: $\begin{cases} \overline{GF} = \overline{G_1F_1} \\ \overline{BG} = \overline{B_1G_1} \end{cases}$ or

$$\begin{cases} \sqrt{(xG1_i - xF1_i)^2 + (yG1_i - yF1_i)^2} = 1680 \\ \sqrt{(xB1_i - xG1_i)^2 + (yB1_i - yG1_i)^2} = 541{,}202 \end{cases} \quad (15)$$

d) PointH_1: $\begin{cases} \overline{GH} = \overline{G_1H_1} \\ \overline{BH} = \overline{B_1H_1} \end{cases}$ or

$$\begin{cases} \sqrt{(xG1_i - xH1_i)^2 + (yG1_i - yH1_i)^2} = 583{,}529 \\ \sqrt{(xB1_i - xH1_i)^2 + (yB1_i - yH1_i)^2} = 404{,}408 \end{cases} \quad (16)$$

e) PointI_1: $\begin{cases} \overline{HI} = \overline{H_1I_1} \\ \overline{CI} = \overline{C_1I_1} \end{cases}$ or

$$\begin{cases} \sqrt{(xH1_i - xI1_i)^2 + (yH1_i - yI1_i)^2} = 1630 \\ \sqrt{(xC1_i - xI1_i)^2 + (yC1_i - yI1_i)^2} = 404{,}408 \end{cases} \quad (17)$$

f) PointJ_1: $\begin{cases} \overline{KJ} = \overline{K_1J_1} \\ \overline{CJ} = \overline{C_1J_1} \end{cases}$ or

$$\begin{cases} \sqrt{(xK1_i - xJ1_i)^2 + (yK1_i - yJ1_i)^2} = 1680 \\ \sqrt{(xC1_i - xJ1_i)^2 + (yC1_i - yJ1_i)^2} = 455{,}412 \end{cases} \quad (18)$$

g) Point K_1: $\begin{cases} \overline{KL} = \overline{K_1L_1} \\ \overline{DK} = \overline{D_1K_1} \end{cases}$ or

$$\begin{cases} \sqrt{(xK1_i - xL1_i)^2 + (yK1_i - yL1_i)^2} = 541{,}282 \\ \sqrt{(xD1_i - xK1_i)^2 + (yD1_i - yK1_i)^2} = 455{,}412 \end{cases} \quad (19)$$

h) Point L_1: $\begin{cases} \overline{EL} = \overline{E_1L_1} \\ \overline{DL} = \overline{D_1L_1} \end{cases}$ or

$$\begin{cases} \sqrt{(xE1_i - xL1_i)^2 + (yE1_i - yL1_i)^2} = 1630 \\ \sqrt{(xD1_i - xL1_i)^2 + (yD1_i - yL1_i)^2} = 404{,}408 \end{cases} \quad (20)$$

2.5.Determination of the cranked lever's rotation angles in relation to their axis

To determine the cranked lever's rotation angles in relation to its axis is sufficient and necessary to know the angle of rotation of one of its arm.

Thus, for the A cranked lever that by rotating with the angle β of the bogie arrived in A_1, its rotation angle is the angle between the arms AE and A_1E_1 respectively AF and A_1F_1.

Angle [◦] between two straights that known angular coefficients are determined by the relationship from the analytical geometry:

$$tg\delta = \frac{m_1 - m_2}{1 + m_1 \cdot m_2} \quad (21)$$

where: m_1 and m_2, angular coefficients of the those two straights mentioned above, are calculated with the following relationship:

So, for the A cranked lever will have:

$$tg\alpha A1_i = \frac{\dfrac{xE - xA}{yE - yA} - \dfrac{xE1_i - xA1_i}{yE1_i - yA1_i}}{1 + \dfrac{xE - xA}{yE - yA} \cdot \dfrac{xE1_i - xA1_i}{yE1_i - yA1_i}} = u$$

$$\alpha A1_i = arctgu \quad (23)$$

By similarity:

$$tg\alpha B1_i = \frac{\dfrac{xG - xB}{yG - yB} - \dfrac{xG1_i - xB1_i}{yG1_i - yB1_i}}{1 + \dfrac{yG - yB}{xG - xB} \cdot \dfrac{yG1_i - yB1_i}{xG1_i - xB1_i}} = v$$

$$\alpha B1_i = arctgv \quad (24)$$

$$tg\alpha C1_i = \frac{\dfrac{xI - xC}{yI - yC} - \dfrac{xI1_i - xC1_i}{yI1_i - yC1_i}}{1 + \dfrac{yI - yC}{xI - xC} \cdot \dfrac{yI1_i - yC1_i}{xI1_i - xC1_i}} = w$$

$$\alpha C1_i = arctgw \quad (25)$$

$$tg\alpha D1_i = \frac{\dfrac{xK - xD}{yK - yD} - \dfrac{xK1_i - xD1_i}{yK1_i - yD1_i}}{1 + \dfrac{yK - yD}{xK - xD} \cdot \dfrac{yK1_i - yD1_i}{xK1_i - xD1_i}} = z$$

$$\alpha D1_i = arctgz \quad (26)$$

2.6. Determination of rotation angle of the bars belonging articulated quadrilateral

EL, HI, FG, JK , the bars belonging articulated quadrilateral, change their positions on the curve movement in E_1 L_1 , H_1I_1, F_1G_1 and J_1K_1.

Rotation angles [◦] of these bars to their original position is determined by the following relations:

$$tg\alpha E_i = \frac{\dfrac{xE - xL}{yE - yL} - \dfrac{xE1_i - xL1_i}{yE1_i - yL1_i}}{1 + \dfrac{yE - yL}{xE - xL} \cdot \dfrac{yE1_i - yL1_i}{xE1_i - xL1_i}} = p$$

$$\alpha E_i = arctgp \tag{27}$$

$$tg\alpha H_i = \frac{\dfrac{xH - xI}{yH - yI} - \dfrac{xH1_i - xI1_i}{yH1_i - yI1_i}}{1 + \dfrac{xH - xI}{yH - yI} \cdot \dfrac{xH1_i - xI1_i}{yH1_i - yI1_i}} = r$$

$$\alpha H_i = arctgr \tag{28}$$

$$tg\alpha G_i = \frac{\dfrac{xG - xF}{yG - yF} - \dfrac{xG1_i - xF1_i}{yG1_i - yF1_i}}{1 + \dfrac{xG - xF}{yG - yF} \cdot \dfrac{xG1_i - xF1_i}{yG1_i - yF1_i}} = s$$

$$\alpha G_i = arctgs \tag{29}$$

$$tg\alpha K_i = \frac{\dfrac{xK - xJ}{yK - yJ} - \dfrac{xK1_i - xJ1_i}{yK1_i - yJ1_i}}{1 + \dfrac{xK - xJ}{yK - yJ} \cdot \dfrac{xK1_i - xJ1_i}{yK1_i - yJ1_i}} = t$$

$$\alpha K_i = arctgt \tag{30}$$

2.7. Determining angles between crank arms and the bars belonging articulated quadrilateral

Angles [°] from articulation points of the bars belonging articulated quadrilateral with the crank arms in points E_1, F_1, G_1, H_1, I_1, J_1, K_1 and L_1 were determinate with the following relationships:

$$tg\alpha E1_i = \frac{\dfrac{xA1_i - xE1_i}{yA1_i - yE1_i} - \dfrac{xL1_i - xE1_i}{yL1_i - yE1_i}}{1 + \dfrac{xA1_i - xE1_i}{yA1_i - yE1_i} \cdot \dfrac{xL1_i - xE1_i}{yL1_i - yE1_i}} = e1$$

$$\alpha E1_i = arctg(e1) \tag{31}$$

$$tg\alpha F1_i = \frac{\dfrac{xF1_i - xG1_i}{yF1_i - yG1_i} - \dfrac{xF1_i - xA1_i}{yF1_i - yA1_i}}{1 + \dfrac{xF1_i - xG1_i}{yF1_i - yG1_i} \cdot \dfrac{xF1_i - xA1_i}{yF1_i - yA1_i}} = f1$$

$$\alpha F1_i = arctg(f1) \tag{32}$$

$$tg\alpha G1_i = \frac{\dfrac{xB1_i - xG1_i}{yB1_i - yG1_i} - \dfrac{xF1_i - xG1_i}{yF1_i - yG1_i}}{1 + \dfrac{xB1_i - xG1_i}{yB1_i - yG1_i} \cdot \dfrac{xF1_i - xG1_i}{yF1_i - yG1_i}} = g1$$

$$\alpha G1_i = arctg(g1) \tag{33}$$

$$tg\alpha H1_i = \frac{\dfrac{xH1_i - xI1_i}{yH1_i - yI1_i} - \dfrac{xB1_i - xH1_i}{yB1_i - yH1_i}}{1 + \dfrac{xH1_i - xI1_i}{yH1_i - yI1_i} \cdot \dfrac{xB1_i - xH1_i}{yB1_i - yH1_i}} = h1$$

$$\alpha H1_i = arctg(h1) \tag{34}$$

$$tg\alpha I1_i = \frac{\dfrac{xC1_i - xI1_i}{yC1_i - yI1_i} - \dfrac{xH1_i - xI1_i}{yH1_i - yI1_i}}{1 + \dfrac{xC1_i - xI1_i}{yC1_i - yI1_i} \cdot \dfrac{xH1_i - xI1_i}{yH1_i - yI1_i}} = i1$$

$$\alpha I1_i = arctg(i1) \tag{35}$$

$$tg\alpha J1_i = \frac{\dfrac{xC1_i - xJ1_i}{yC1_i - yJ1_i} - \dfrac{xJ1_i - xK1_i}{yJ1_i - yK1_i}}{1 + \dfrac{xC1_i - xJ1_i}{yC1_i - yJ1_i} \cdot \dfrac{xJ1_i - xK1_i}{yJ1_i - yK1_i}} = j1$$

$$\alpha J1_i = arctg(j1) \tag{36}$$

$$tg\alpha K1_i = \frac{\dfrac{xD1_i - xK1_i}{yD1_i - yK1_i} - \dfrac{xK1_i - xJ1_i}{yK1_i - yJ1_i}}{1 + \dfrac{xD1_i - xK1_i}{yD1_i - yK1_i} \cdot \dfrac{xK1_i - xJ1_i}{yK1_i - yJ1_i}} = k1$$

$$\alpha K1_i = arctg(k1) \tag{37}$$

$$tg\alpha L1_i = \frac{\dfrac{xD1_i - xL1_i}{yD1_i - yL1_i} - \dfrac{xL1_i - xE1_i}{yL1_i - yE1_i}}{1 + \dfrac{xD1_i - xL1_i}{yD1_i - yL1_i} \cdot \dfrac{xL1_i - xE1_i}{yL1_i - yE1_i}} = l1$$

$$\alpha L1_i = arctg(l1) \tag{38}$$

2.8. Determination of the moving distances for the flexi-coil springs bottom

Flexi-coil type springs resting on the bottom in points M, N, P and R on longitudinal beams EL and HI belonging articulated quadrilateral of the bogie.

$$M\begin{cases} xM = 250 \\ yM = 1335 \end{cases} N\begin{cases} xN = -250 \\ yN = 1335 \end{cases}$$
$$P\begin{cases} xP = -250 \\ yP = -1335 \end{cases} R\begin{cases} xR = 250 \\ yR = -1335 \end{cases} \tag{39}$$

β[∘]represent rotation angle of the bogie towards locomotive body. Points M, N, P and R will occupy other positions M_1, N_1, P_1, and R_1 due to deformation of the articulated quadrilateral.

Coordinates of M point are determined by solving the system:

$$\begin{cases}\overline{LM}=\overline{L1M1}\\ \overline{EM}=\overline{E1M1}\end{cases}$$

$$\begin{cases}\sqrt{\left(xL1_i-xM1_i\right)^2+\left(yL1_i-yM1_i\right)^2}=565\\ \sqrt{\left(xE1_i-xM1_i\right)^2+\left(yE1_i-yM1_i\right)^2}=1065\end{cases} \quad (40)$$

and the displacement distance ΔM of the point M by relation:

$$\Delta M=\sqrt{\left(xM1_i-xM\right)^2+\left(yM1_i-yM\right)^2} \quad (41)$$

By similarity:

$$\begin{cases}\overline{LN}=\overline{L1N1}\\ \overline{EN}=\overline{E1N1}\end{cases}$$

$$\begin{cases}\sqrt{\left(xL1_i-xN1_i\right)^2+\left(yL1_i-yN1_i\right)^2}=1065\\ \sqrt{\left(xE1_i-xN1_i\right)^2+\left(yE1_i-yN1_i\right)^2}=565\end{cases} \quad (42)$$

$$\Delta N=\sqrt{\left(xN1_i-xN\right)^2+\left(yN1_i-yN\right)^2} \quad (43)$$

$$\begin{cases}\overline{HP}=\overline{H1P1}\\ \overline{IP}=\overline{I1P1}\end{cases}$$

$$\begin{cases}\sqrt{\left(xH1_i-xP1_i\right)^2+\left(yH1_i-yP1_i\right)^2}=1065\\ \sqrt{\left(xI1_i-xP1_i\right)^2+\left(yI1_i-yP1_i\right)^2}=565\end{cases} \quad (44)$$

$$\Delta p=\sqrt{\left(xP1_i-xP\right)^2+\left(yP1_i-yP\right)^2} \quad (45)$$

$$\begin{cases}\overline{HR}=\overline{H1R1}\\ \overline{IR}=\overline{I1R1}\end{cases}$$

$$\begin{cases}\sqrt{\left(xH1_i-xR1_i\right)^2+\left(yH1_i-yR1_i\right)^2}=565\\ \sqrt{\left(xI1_i-xR1_i\right)^2+\left(yI1_i-yR1_i\right)^2}=1065\end{cases} \quad (46)$$

$$\Delta_R=\sqrt{\left(xR1_i-xR\right)^2+\left(yR1_i-yR\right)^2} \quad (47)$$

2.9. Determination of the tilt angles of vertical suspenders

Locomotive body is based through secondary suspension on the longitudinal beams belonging articulated quadrilateral.

Locomotive body's weight corresponding to a bogie ($G_C/2$) is transmitted to the bogie frame by four vertical suspenders, two for each longitudinal beam, such that through each vertical suspenders transmit load $G_C/8$ to the bogie frame[4].

On the curve movement, due to the rotation of the bogie toward locomotive body with angle β, all vertical suspenders tilts from vertical position with angle θ due to relative displacements of both ends of the suspenders; angle θ has different values for those four vertical suspenders (see Fig.5[3]).

Bottom ends of the vertical suspenders mentioned above will move from initial points U, V(EL beam) and Z, X(HI beam) into U_1, V_1, Z_1 and X_1 due to rotation angle β of the bogie toward locomotive body.

Coordinates of U_1, V_1, Z_1 and X_1 points will be determine as following:

- U_1 coordinates from the system of equations:

$$\begin{cases}\overline{LU}=\overline{L1U1}\\ \overline{EU}=\overline{E1U1}\end{cases} \quad (48)$$

$$\begin{cases}\sqrt{\left(xL1_i-xU1_i\right)^2+\left(yL1_i-yU1_i\right)^2}=1445\\ \sqrt{\left(xE1_i-xU1_i\right)^2+\left(yE1_i-yU1_i\right)^2}=185\end{cases}$$

- A_2 coordinates from the system of equations:

$$\begin{cases}\overline{OA2}=\overline{OA3}\\ \overline{A1A2}=\overline{AA3}\end{cases} \quad (49)$$

$$\overline{OA3}=\sqrt{xA3^2+yA3^2}=\sqrt{990^2+\left(604+26\right)^2}$$

$$\begin{cases}\sqrt{xA2^2+yA2^2}=\sqrt{xA3^2+yA3^2}=\sqrt{990^2+630^2}\\ \sqrt{\left(xA1-xA2\right)^2+\left(yA1-yA2\right)^2}=26\end{cases}$$

yA3=990 mm

xA3=604+26=630 mm, both values from used tehnical documentation.

- S_1 coordinates from the system of equations:

$$\begin{cases}\overline{OS1}=\overline{OS}\\ \overline{A2S1}=\overline{A3S}=345\end{cases} \quad (50)$$

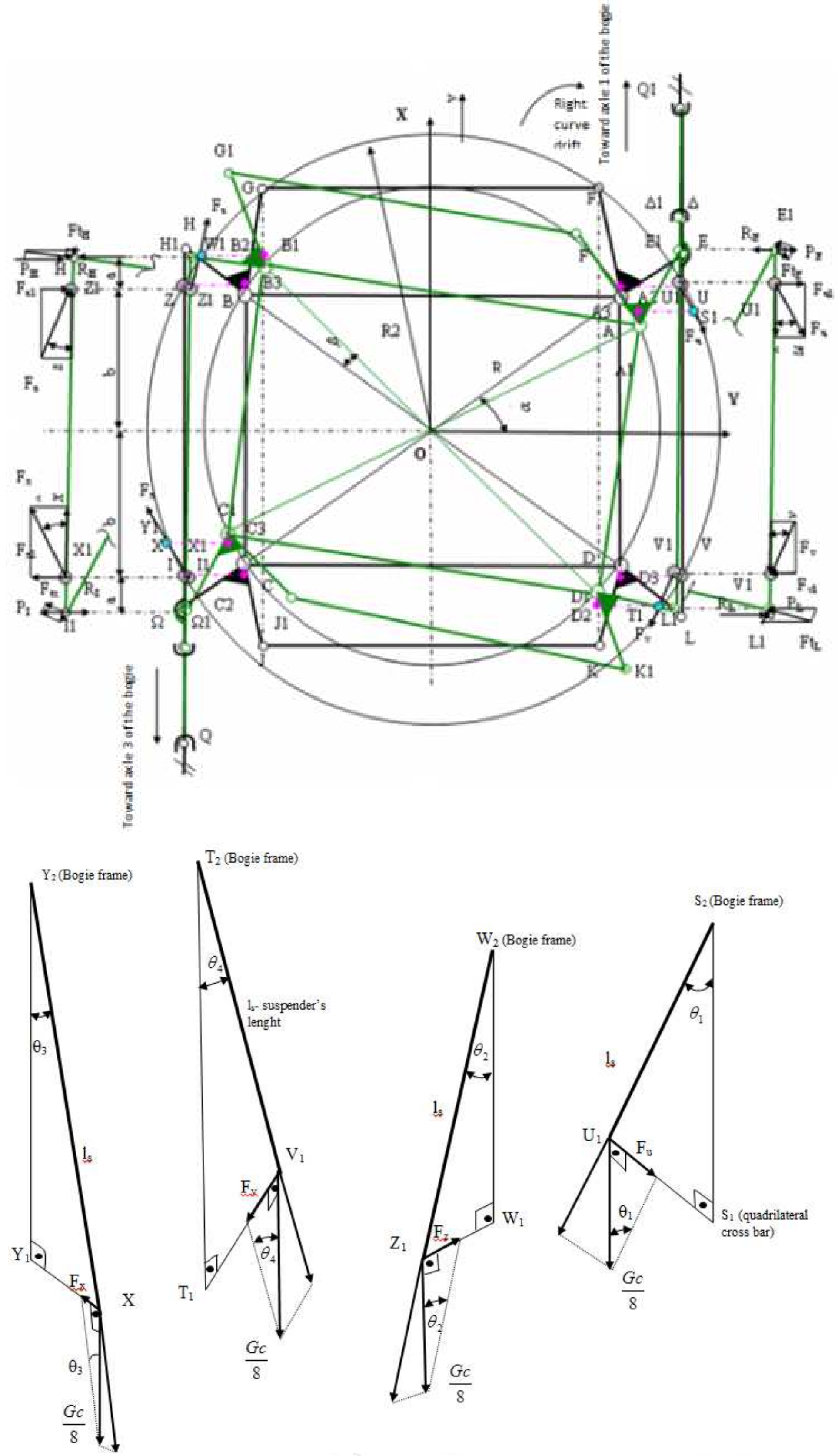

Fig.5. Articulated quadrilateral and the specific forces acting on the vertical suspenders

$$\begin{cases} \sqrt{xS1^2 + yS1^2} = \sqrt{xS^2 + yS^2} = \sqrt{(990+345)^2 + (604+26)^2} \\ \sqrt{(xA2 - xS1)^2 + (yA2 - yS1)^2} = 345 \end{cases}$$

$$\begin{cases} \sqrt{xS1^2 + yS1^2} = \sqrt{(990+345)^2 + (604+26)^2} = R2 \\ \sqrt{(xA2 - xS1)^2 + (yA2 - yS1)^2} = 345 \end{cases}$$

- Distance $U_1S_1 = d_1$

So:

$$\sin \theta 1_i = \frac{U1S1_i}{l_s}$$

$$\sin \theta 2_i = \frac{Z1W1_i}{l_s}$$

$$\sin \theta 3_i = \frac{X1Y1_i}{l_s}$$

$$\sin \theta 4_i = \frac{V1T1_i}{l_s} \qquad (51)$$

2.10. Calculation of the total restoring moment of the bogie under the locomotive body

Based on mechanical features of silent-blocks and angular displacements of joints, on spatial position of suspenders and system of forces which action on these respectively based on mechanical features of flexi-coil springs and their deformations were calculated restoring moments due to silent-blocks (see Fig.6[3]), suspenders (see Fig.7[3]) respectively flexi-coil springs (see Fig.8[3]) amounting in total restoring moment which comply with the recommended value from EN (see Fig. 9[3]).

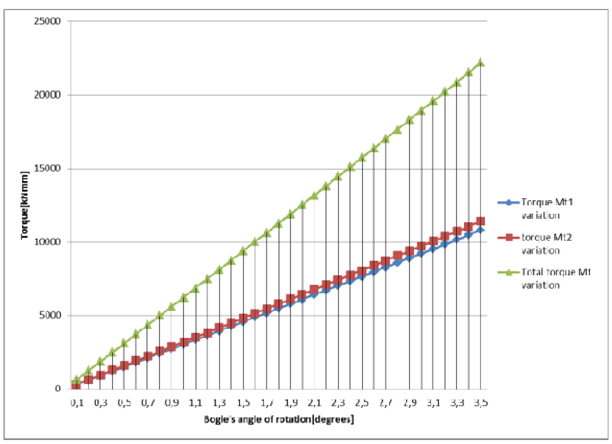

Fig.6. Restoring moment due to silent-blocks

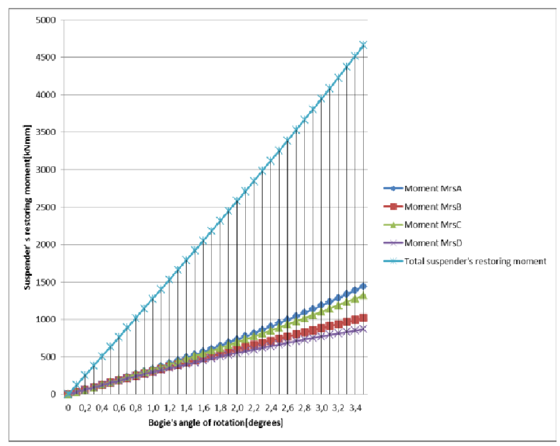

Fig.7. Restoring moment due to suspenders

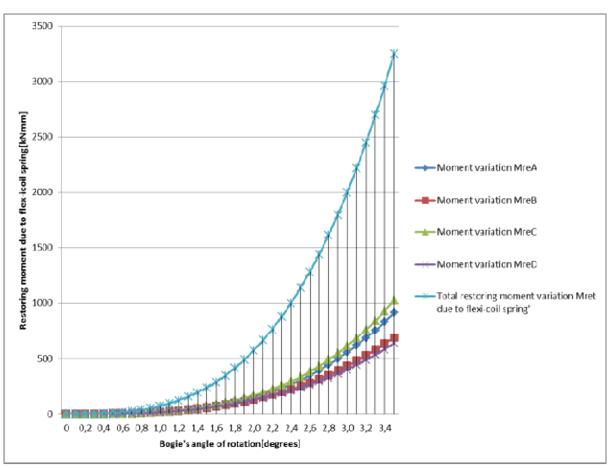

Fig.8. Restoring moment due to flexi-coil spring

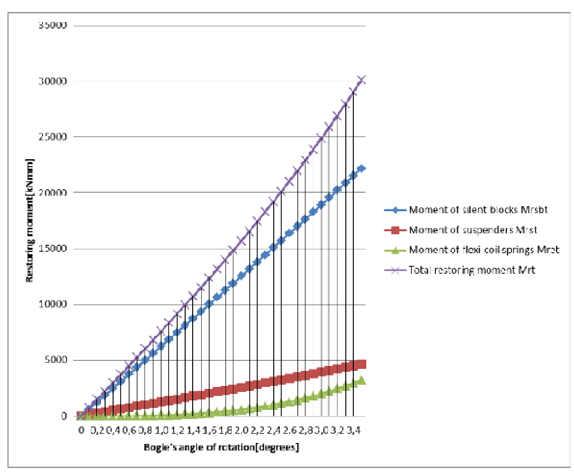

Fig.9. Total restoring moment of the bogie under the locomotive body

Further, were calculated percentage share of each component of the total restoring moment from total restoring moment and in Fig.10[3] was presented variation of the weights depending on the β [◦] angle of bogie rotation in relation with locomotive body, in case of locomotive traffic through the curve.

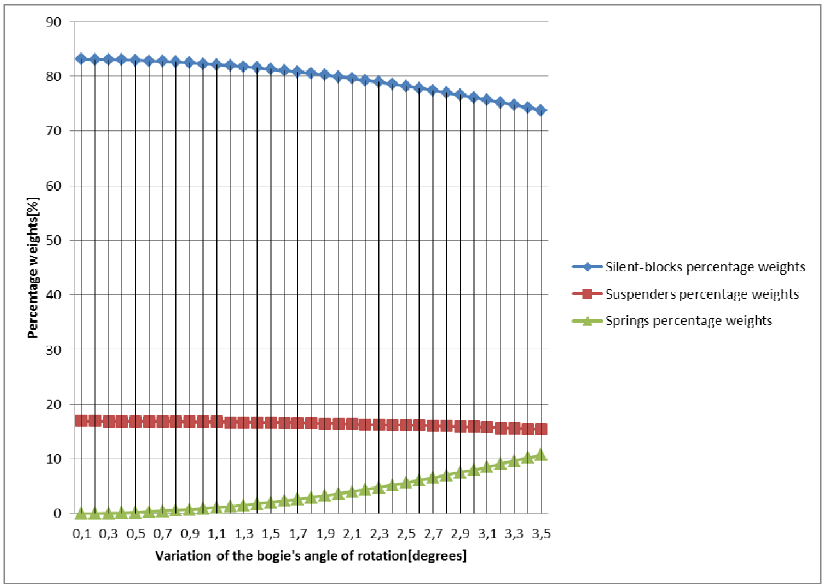

Fig.10. Percentage of its components from total restoring moment

Making the average of the weight of each component of total restoring moment, we obtain the following result:

- 80% share of total restoring moment due to silent-blocks;
- 16% share of total restoring moment due to suspenders;
- 4% share of total restoring moment due to coil springs.

Examining the results shown that component size of the moment due to silent-blocks decreases as the angle β [◦] increases, component size of the restoring moment due to tilt of suspenders is almost constant and the component size of the restoring moment due to coil springs increases as angle β [◦] increases.

Calculation of each component of the total restoring moment was done separately for each component as one for bogie but the effect of restoration of the bogie is produced simultaneously by the action of the three components, can occur mutual influences between them, actually more difficult to research.

3. CHECKING THE TOTAL RESTORING MOMENT FOR CFR 060-EA LOCOMOTIVE

UNIEN 14363[2] prescribes the ratio of total restoring moment Mr_t and $2Q_0 \cdot a$ in case of locomotives to comply relationship:

$$x = \frac{Mr_t}{2Q_0 \cdot a} \le 0,1 \qquad (52)$$

where: $2Q_0$ [kN] represent static load on the axle a [mm] represent locomotive axle base.

Covaciu[1] recommended that this report, for curve of radius $R \in \{90...100\}$ m, to be between 0,03...0,05.

These radiuses meet at the entrance of depot and corresponding to maximum angle β [◦] of bogie rotation under locomotive body. Generally, $\beta=3,5^0$.

From Fig.9.results that Mr_t=30097, 25 kNmm for $\beta=3,5^0$.

For CFR 060-EA locomotive: $2Q_0$=196,2 kN (20 tf) and a=4,350m=4350 mm.

So, in that case: $x = \frac{30097{,}25}{196{,}2 \cdot 4350} = 0{,}0353$ (53)

4. CONCLUSIONS

From those mentioned above result that the value of total restoring moment is both within the standard prescriptions[2] and Covaciu's results[1], id est:
$x = 0{,}0353 \le 0{,}1$ and respectively
$x = 0{,}0353 \in \{0{,}03...0{,}05\}$. (54)
The value of the total restoring moment previously determined is subject to prior modifying in operation due to the fact that both silent-blocks from 12(twelve) joints of the crank system and spherical elastic elements at the ends of suspenders made from galvanized rubber by changing operating parameters with degradation and aging of the rubber.
Besides the alleged cause its possible that elastic cross-coupling between the bogies to not fulfill their role, that of relief locomotive traffic through the curve portions of the rail tracks.

5. REFERENCES

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Analiza comportamentului sistemului de legătură dintre carcasa (cutia) locomotivei și boghiuri pentru locomotiva CFR 060-EA 5100 KW

Rezumat La deplasarea locomotivei CFR 060-EA pe cale s-a constat o uzură pronunțată a roților aferente osiilor 1, respectiv 6, datorită faptului că la ieșirea din curbă boghiurile nu revin perfect înapoi sub cutia locomotivei. Sistemele de legătură dintre boghiuri și cutia locomotivei ar trebui să asigure atât deplasarea cât și revenirea boghiurilor în poziția de mijloc după oprirea forțelor care au determinat această mișcare. În aceasta lucrare se studiază sistemul de legătură dintre cutie și boghiu și se verifică dacă momentul de rapel este suficient pentru a aduce boghiul sub cutie la ieșirea din curbă.

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