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PARTICULAR CASES FOR THE CONSTRUCTIVE OPTIMIZATION OF THE LIFTING ARM FROM THE FRONTAL LOADER WORKING EQUIPMENT

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Abstract: *This article presents and discusses particular cases for the constructive optimization for the lifting arm of the frontal loader equipment. As a general shape, this is considered as a double bent upside down Z, with forces and moments placed on it. All the mathematical expressions for the final value of the vertical and horizontal displacements of the bucket joints, get particularities as in the shown cases.*
Key words: *frontal loader, double bent upside down Z, joints, motor forces, weight forces, elastically forces.*

1.INTRODUCTION

The frontal loaders (Fig.1) are machines used for loading-unloading the powder or granular materials and shallow depth digging (200 mm max.) with the base equipment. The working equipment has different structures and the existing forces are stressing them, causing distortions valid for the design process. So far there are no algorithms for calculating the resistance in order to assess the distortion of the lifting arm, when the bucket meets an obstacle. There are only specifications for an allowed value of it. This paper advances a calculating process for equipment distortion as an idea which may be included in the designing process (for a good final result).

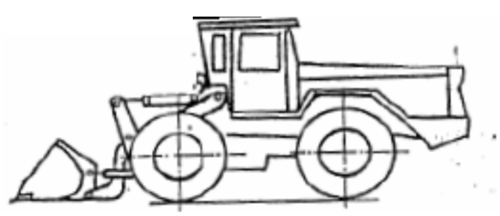

Fig.1. Frontal loader

2.THE EXISTING MODELS FOR ASSESSING THE FORCES FROM THE WORKING EQUIPMENT, CONSIDE-RING SOME WORKING HYPOTHESES

According to [3] & [4], the shape of the lifting arm is different for any frontal loader, as shown in Fig.2.
The process of dynamical optimization of the working equipment, means the reducing of the forces which act in the working process, which does not affect -the productivity and the overall functioning of the machine.
The forces which act in the working mecha-nism of the frontal loader are as follows [4]:
1.forces and momentums of the technological or useful forces; 2. weight forces; 3. elastical forces; 4. passive resistance forces; 5.inertial forces; 6. reactions from cinematically joints; 7. motor forces.

Only two of these categories can be de-creased: the motor and weight forces, except the elastical forces used for constructive optimizing according to [2] & [4].

2.1. External resistant forces according to the considered hypotheses for design

For an accurate estimate of the external forces acting on the equipment in calculating the resistance of the arm four hypotheses are used, according to [1] & [4], one of which is considered the least favorable, as in Fig.3.

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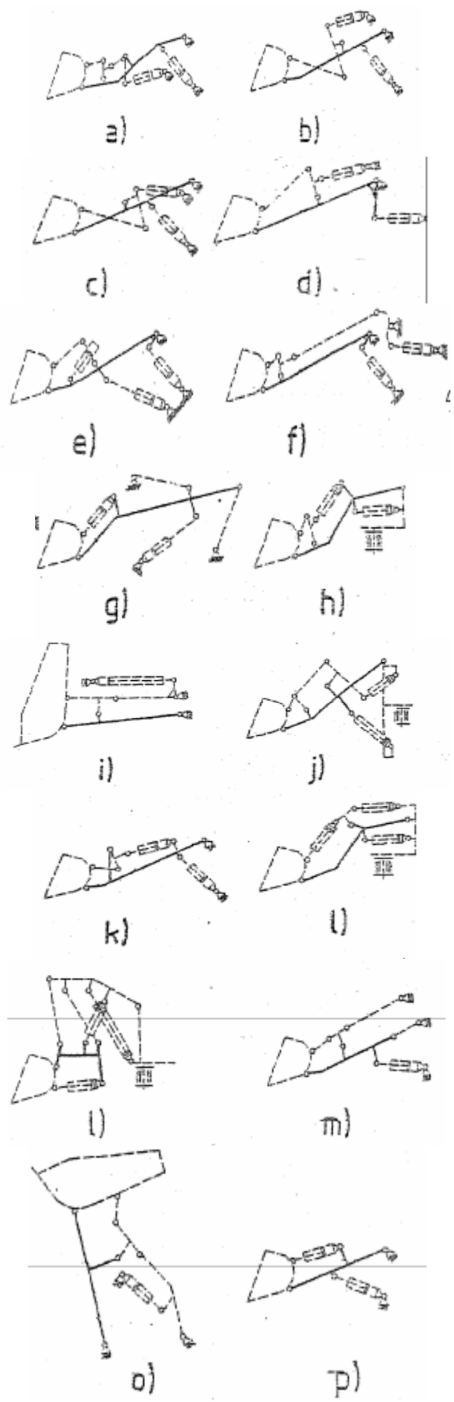

Fig.2: The shapes of the lifting arm (continuous line) of the frontal loader

The loader moves horizontally with all its traction force. The bucket's cylinders are acting with the force needed to break the material (at the upward rotation bucket). The arm's cylinders are blocked and the resistant forces are acting in the axis of the lateral extreme tooth.

The calculating algorithm is made considering the third hypothesis and the following situation: The forces acting on the cup act in the axis of the lateral extreme tooth, considering

R_Z=T

T-the maximal traction force in good adherence conditions, considering the slipping coefficient

δ_P=0.07

R_y=0.75*N_S, N_S-the snatching force, determined by the stability conditions (the raising of the back wheels from the ground)

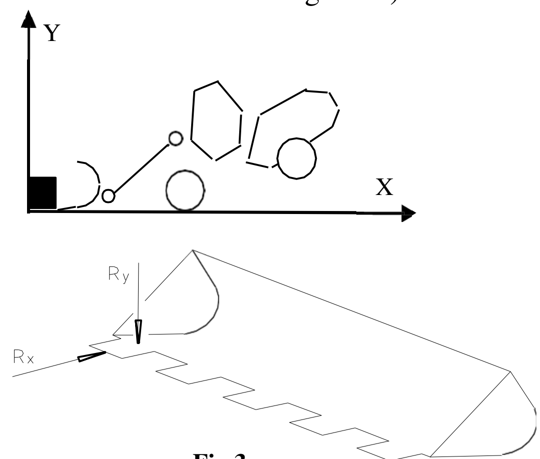

Fig.3

2.2.The existing model for the optimization steps of the lifting arm

According to [4], the steps for the constructive optimization of the lifting arm are the following: 1- choosing of the shape for the lifting arm of the frontal loader (the general shape is an upside down Z); 2- locating the active forces and momentums on the arm; 3- calculating the reacting forces and drawing of the forces diagram; 4-calculation of the distortions and comparison to the allowed values; 5- choise of the final form of every section for every sequence of the lifting arm. The expressions of the resulted forces will be considering [4].

$$\begin{cases} R = \frac{F_V \cdot L_V + F_H \cdot L_H + M(G)}{L_{RH} \cdot cos\delta + L_{RV} \cdot sin\delta} \\ H = R \cdot cos\delta - F_H \\ V = F_V + G - R \cdot sin\delta \end{cases} \quad (1)$$

where

$$M(G) = G_1 \cdot (L_V - l_{11} \cdot cos\alpha) + G_2 \cdot [L_V - (l_{11} + l_{12}) \cdot cos\alpha - l_{21} \cdot cos\beta] + G_3 \cdot l_{32} \cdot cos\gamma \quad (2)$$

$G = G_1 + G_2 + G_3$

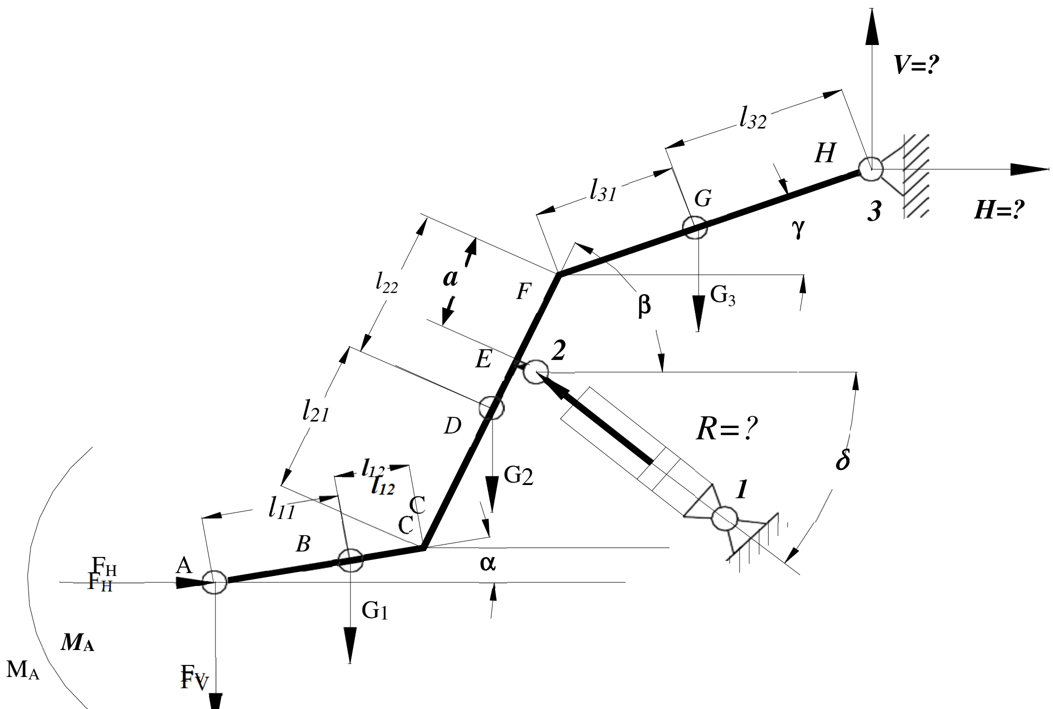

Fig.4: The general model for the constructive optimization of the lifting arm

And

$L_V = (l_{11} + l_{12}) \cdot \cos\alpha + (l_{21} + l_{22}) \cdot \cos\beta + (l_{31} + l_{32}) \cdot \cos\gamma$

$L_H = (l_{11} + l_{12}) \cdot \sin\alpha + (l_{21} + l_{22}) \cdot \sin\beta + (l_{31} + l_{32}) \cdot \sin\gamma \qquad (3)$

$L_{RH} = a \cdot \sin\beta + (l_{31} + l_{32}) \cdot \sin\gamma$

$L_{RV} = a \cdot \cos\beta + (l_{31} + l_{32}) \cdot \cos\gamma$

According to [4], if only concentrated loads are considered, the momentum's diagram (M) has only a linear form and for drawing it, values below should be enough:

$M_A=0$

$M_B=-F_H \cdot l_{11} \cdot \sin\alpha - F_V \cdot l_{11} \cdot \cos\alpha$

$M_C=M_B-(F_H \cdot \sin\alpha+F_V \cdot \cos\alpha) \cdot l_{12}-G_1 \cdot l_{12} \cdot \cos\alpha$

$M_D=M_C-(F_H \cdot \sin\beta+F_V \cdot \cos\beta) \cdot l_{21}-G_1 \cdot l_{21} \cdot \cos\beta$

$M_E=M_D-(F_H \cdot \sin\beta+F_V \cdot \cos\beta) \cdot (l_{22}-a)$ –(4)
$(G_1+G_2) \cdot (l_{22}-a) \cos\beta$

$M_F=M_E-(F_H \cdot \sin\beta+F_V \cdot \cos\beta) \cdot a+R \cdot \sin(\beta+\delta) \cdot a-(G_1+G_2) \cdot a \cos\beta$

$M_G=M_F-(F_H \cdot \sin\gamma+F_V \cdot \cos\gamma) \cdot l_{31}+R \cdot \sin(\gamma+\delta) \cdot l_{31}-(G_1+G_2) \cdot l_{31} \cos\gamma$

$M_H=M_G$

Having drawn the momentums diagram, one has to dimension more sections with the Navier's formula: $\sigma = M/Wz$, where W_Z is the polar resistance module.

After this, the positions of the gravity forces G_1, G_2 and G_3 are reestablished

The deformation expressions by Castigliano's theorem are written, starting with the condition of considered rigidity of the equipment, according to [1] and [4]: C_1=Ke•Gn, where Ke=0,1cm^{-1} and Gn is the weight of base machine (daN).

According to this, the maximal allowed deformation of the equipment will be established.

The steps to follow for the calculation of distortion (displacement and rotation) are as follows:

1-writing the mathematical expressions for bending moments on every sequence of the arm;

2-writing the partial derivates after fictitious forces and moments (F_A and Ma are the re-duced moment of the components of unloaded bucket, including the bucket);

3- writing the final expressions of the distortions (displacement and rotation);

4- replacing the forces and moments after the derivation with their real values.
Steps 1-3 get the following expressions

$$A - B \begin{cases} x_1 \in (0,\ l_{11}) \\ M(x_1) = -x_1 F_1 - M_1 \\ \frac{\partial M(x_1)}{\partial F_H} = -x_1 \cdot sin \propto \\ \frac{\partial M(x_1)}{\partial F_V} = -x_1 \cdot cos \propto \\ \frac{\partial M(x_1)}{\partial M_1} = -1 \end{cases} \qquad (5)$$

where

$$\begin{cases} F_2 = F_H sin\alpha + F_V cos\alpha \\ M_1 = M_A \end{cases}$$

$$B - C \begin{cases} x_2 \in (0,\ l_{12}) \\ M(x_2) = -x_2 F_2 - M_2 \\ \frac{\partial M(x_2)}{\partial F_H} = -(x_2 + l_{11}) \cdot sin \propto \\ \frac{\partial M(x_2)}{\partial F_V} = -(x_2 + l_{11}) \cdot cos \propto \\ \frac{\partial M(x_2)}{\partial M_A} = -1 \end{cases} \qquad (6)$$

where

$$\begin{cases} F_2 = F_H sin\alpha + F_V cos\alpha + G_1 cos \propto \\ M_2 = M_A + F_H l_{11} sin\alpha + F_V l_{12} cos\alpha \end{cases}$$

....

$$G - H \begin{cases} x_7 \in (0,\ l_{32}) \\ M(x_7) = -x_7 F_7 - M_7 \\ \frac{\partial M(x_7)}{\partial F_H} = -(x_7 sin\gamma + L_{H7}) \\ \frac{\partial M(x_7)}{\partial F_V} = -(x_7 sin\gamma + L_{V7}) \\ \frac{\partial M(x_2)}{\partial M_A} = -1 \end{cases} \qquad (7)$$

where

$$\begin{cases} F_7 = F_H sin\gamma + F_V cos\gamma + R sin(\gamma + \delta) \\ \quad +(G_1 + G_2 + G_3) cos\gamma \\ M_7 = F_H L_{H7} + F_V L_{V7} + G_1 (l_{12} cos \propto + l_2 \\ cos\beta \ + l_{31} cos\gamma) + G_2 (a cos\beta + l_{31} cos\gamma) + \\ R[a sin(\beta + \delta) + l_{31} sin(\gamma + \delta)] + M_A \\ L_{H7} = l_1 sin \propto + l_2 sin\beta + l_{31} sin\gamma \\ L_{V7} = l_1 cos \propto + l_2 cos\beta + l_{31} cos\gamma \end{cases}$$

The expressions of the displacement and the rotation for the free end will be as

$$f_H = \sum_{i=1}^{7} \int_{Li} \frac{M(x_i)}{EI(x_i)} \cdot \frac{\partial M(x_i)}{\partial F_H} dx_i$$

$$f_V = \sum_{i=1}^{7} \int_{Li} \frac{M(x_i)}{EI(x_i)} \cdot \frac{\partial M(x_i)}{\partial F_V} dx_i \qquad (8)$$

$$\varphi = \sum_{i=1}^{7} \int_{Li} \frac{M(x_i)}{EI(x_i)} \cdot \frac{\partial M(x_i)}{\partial M_A} dx_i$$

$I(x_i)$ - the inertia momentum of the cross section; it is considered with the same expre-ssion along the arm.

2.3. The straight form, a particular case of the lifting arm

According to Fig.2, lifting arms exist in many shapes. In our case, the straight one will be considered as the one in Fig.2, c, d, f, i,o, p. All the considered expressions will be simpli-fied, because the angle of every section of the arm will be the same. Fig. 4 will become Fig.5 also for the positioning of forces and moments. The notation of the general model was main-tained, in order toclarify how the equations are changed, considering that all angles to be noted with θ, except angle δ; the final relations for forces and moments becomes:

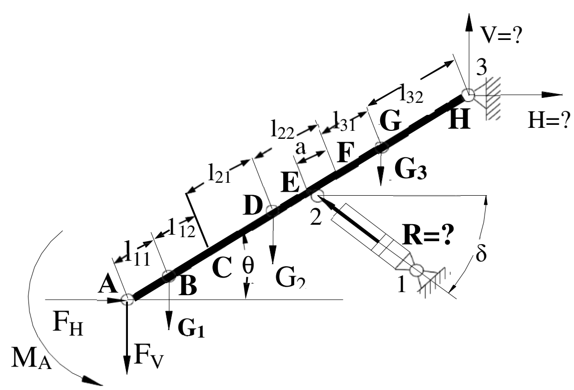

Fig.5: The model for constructive optimization of the straight shape lifting arm

$M_A = 0$

$M_B = -F_H \cdot l_{11} \cdot \sin\theta - F_V \cdot l_{11} \cdot \cos\theta$

$M_C = -(F_H \cdot \sin\theta + F_V \cdot \cos\theta) \cdot (l_{11} + l_{12}) - G_1 \cdot l_{12} \cdot \cos\theta$

$M_D = -(F_H \cdot \sin\theta + F_V \cdot \cos\theta) \cdot (l_{11} + l_{12} + l_{21}) - G_1 \cdot (l_{12} + l_{21}) \cdot \cos\theta$

$M_E = -(F_H \cdot \sin\theta + F_V \cdot \cos\theta) \cdot (l_{11} + l_{12} + l_{21}) - 2G_1 \cdot (l_{12} + l_{22}) \cdot \cos\theta - [(F_H \cdot \sin\theta + F_V \cdot \cos\theta) - (G_1 + G_2) \cdot \cos\theta] \cdot (l_{22} - a)$

$M_F = -(F_H \cdot \sin\theta + F_V \cdot \cos\theta) \cdot (l_{11} + l_{12} + l_{21} + l_{22} - a) - 2G_1 \cdot (l_{12} + l_{22}) \cdot \cos\theta + G_2 \cdot$

$l_{22} \cdot \cos\theta + R \cdot \sin(\theta + \delta) \cdot a$
(9)
$M_G = -(F_H \cdot \sin\theta + F_V \cdot \cos\theta) \cdot (l_{11} + l_{12} + l_{21} + l_{22} - a + l_{31} + a) + R \cdot \sin(\theta + \delta) \cdot (a + l_{31}) - G_1 \cdot [2(l_{12} + l_{22}) - l_{31}] \cdot \cos\theta + G_2 \cdot (l_{22} + l_{31}) \cdot \cos\theta$

If one considers only a single general weight force G acting in the general mass center of the arm, it is possible to get different values of forces and momentums than the cases with weight forces in every sector.

This was done starting from the general model, considering all angles (α, β and γ) equal and noted with θ. The rest of expressions for calculating the displacement and rotation are similar to 4-8 with angles α, β and γ noted with θ.

To conclude how to consider correctly: one general weight force G or more forces G1, G2, ..., for the same angle in several sectors, laboratory experi-ments will be needed.

2.4. Another particular case of the lifting arm: the upside down Z shape with middle vertical sector,

Starting with Fig 1 and Fig.2, mechanisms where the lifting arm could have the middle part vertical could be considered, as in Fig.2, g, h, l. All the considered expressions will be simplified, be-cause the angle of every section of the arm will be the same, and Fig. 4 will become as in Fig.6 as the positioning of forces and moments.

In this case, the angle β is 90°, which will modify all expressions containing angle β and the expression (2) becomes:

$$M(G) = G_1 \cdot (L_V - l_{11} \cdot \cos\alpha) + G_2 \cdot [L_V - (l_{11} + l_{12}) \cdot \cos\alpha] + G_3 \cdot l_{32} \cdot \cos\gamma \qquad (10)$$

And the expressions from (3) with angle β=90° becomes:

$$M_A = 0$$
$$M_B = -F_H \cdot l_{11} \cdot \sin\alpha - F_V \cdot l_{11} \cdot \cos\alpha$$
$$M_C = M_B - (F_H \cdot \sin\alpha + F_V \cdot \cos\alpha) \cdot l_{12} - G_1 \cdot l_{12} \cdot \cos\alpha$$
$$M_D = M_C$$
$$M_E = M_D \qquad (11)$$
$$M_F = M_E + R \cdot \sin(90° + \delta) \cdot a$$
$$M_G = M_F - (F_H \cdot \sin\gamma + F_V \cdot \cos\gamma) \cdot l_{31} + R \cdot \sin(\gamma + \delta) \cdot l_{31} - (G_1 + G_2) \cdot l_{31} \cdot \cos\gamma$$

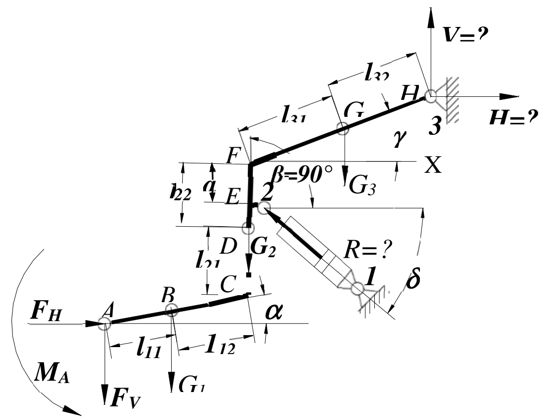

Fig.6:The model for constructive optimization of the upside down Z shape lifting arm with vertical sector

The expressions for displacement and rotation are simplified in this case and the integrals 8 will be easier to calculate.

3. CONCLUIONS

Both the general and particular cases of shapes for the lifting arm could be used for calculating the displacement and rotation of the bucket joint point in order to see whether they are within the allowed range for a good long time functioning of the frontal loader. Also, these can be used as a base for reducing the weight of the entire working mechanism, which involves a lower fuel consumption for acting it.

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Cazuri particulare pentru optimizarea constructivă a braţului de ridicare de la echipamentul de lucru al încărcătorului frontal

Rezumat: Articolul este despre cazuri particulare de optimizare constructivă a braţului de ridicare de la încărcătorul frontal. Pornind de la cazul general, de forma braţului de forma dublu Z întors răsturnat, cu forte şi momente dispuse pe el, Toate expresiile matematce cu două particularizări, formă cu o porţiune vertical şi a doua, braţ de formă dreaptă din cap în cap

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