COBEM 99
XV Congresso Brasileiro de Engenharia Mecânica
15th Brazilian Congress of Mechanical Engineering
22 - 26 de Novembro de 1999 / November 22 - 26, 1999 Águas de Lindóia, São Paulo,

THE OPTIMIZATION MODELS IN THE SYNTHESIS OF THE FRONTAL LOADER MECHANISMS

Cezar Oprişan
Adrian Popovici,
Technical University "Gh. Asachi" Iasi
Blvd. "D.Mangeron" 61-63, 6600 Iaşi România

Abstract. *The paper presents a method for solving the problem of the frontal loader mechanisms synthesis .The specific element for these types of mechanisms is, generally the hydraulic cylinder which swings the bucket. This element has the length adjustable in steps. This fact imposes the establishing of the mathematics models for the kinematic synthesis which will include the functional parameters required by the design both for the raising phase and for the decent phase of the bucket. The author developed mathematical models which have as basis the synthesis for the prescribed positions of the bucket and for the bucket's raising arm. To simplify the mathematical model it is applied the movements inversion procedure, using as reference element the arm. In the same time it is proposed a method for the modular solving of the synthesis, where a module represents a loop with four elements . The mathematical model is solved with an algorithm which is developed on the optimization theory basis using the simplex method. Also, the paper presents modalities for applying these models to different kinematic schemes which have one and two loops with four elements.*

Keywords: *mechanism, frontal loader, synthesis, optimization.*

1.INTRODUCTION

The design of the working equipment for the frontal loaders becomes a complex process especially for cases in which it is aimed a diversification of the using domains. The growing of the bucket volume involves the maintaining of the rising arm length at a necessary minimum. Because of this it is realised an improvement of the outfit movement stability, but a series of constraints appear which are imposed to the mechanism synthesis. In this way, the optimization theory satisfies the mathematics model pretensions regarding the synthesis problem. A difficult aspect is the mathematics form description of the constraints. Surely, the synthesis problem can be modeled using other methods, for example the method of the functions approximation (Oprişan, Popescu & Popovici 1995), but the optimization theory allows the achievment of a mathematics model whose solution leads at the manufacture of a performant outfit both using the kinematic of the working equipment and using the stability during the movement.

In this paper it is presented a way to elaborate the mathematics model and also a series of possible constraints mathematical expressed and verified using numeric examples.

2 .THE WORDING OF THE SYNTHESIS PROBLEM

The frontal loaders mechanisms are activated through hydraulic cylinders. The bucket's movement law can be obtained from a mechanic correction of the bucket angle when the position parameter of the bucket and from a hydraulic correction when the position parameters of the bucket depends on two independent parameters: the position parameter of the arm and the length of the hydraulic cylinder attached to the bucket.

Although the hydraulic correction assures concise positions for the bucket, this one is less used in the outfits construction due to the fact that it enlarges the cost price, and the outfit has a·lower reliability in comparison with the ones which use the mechanic correction. For mechanisms, which use the mechanic correction of the bucket angle, the synthesis is a base element in the outfit design, which constitutes the bases of this paper.

The synthesis problem wording is made on the basis of the outfit work phases: the bucket loading; the bucket rises; the bucket unloading; the bucket descent (Fig. 1).

Theoretically, the full bucket must move parallel in the movement plane, for the avoidance of the material losses, also the tipping must be performed in any position and at any height. Because of the approximate solution obtained through the solution of the synthesis problem, this change of places is not exactly realized.

The functional parameters necessary in the synthesis of the mechanism, which fits out these outfits, are (Fig.1):

i) the bucket capacity;

ii) the maximum unloading height under an angle α >45°, h;

iii) the unloading distance at the maximum height, l;

iv) the unloading distance at an angle α=45°, l_1;

v) the unloading height at the maximum unloading distance, h_1;

vi) the digging depth, h_2;

vii) the digging angle, α_5;

viii) the down closing angle of the bucket, α_3;

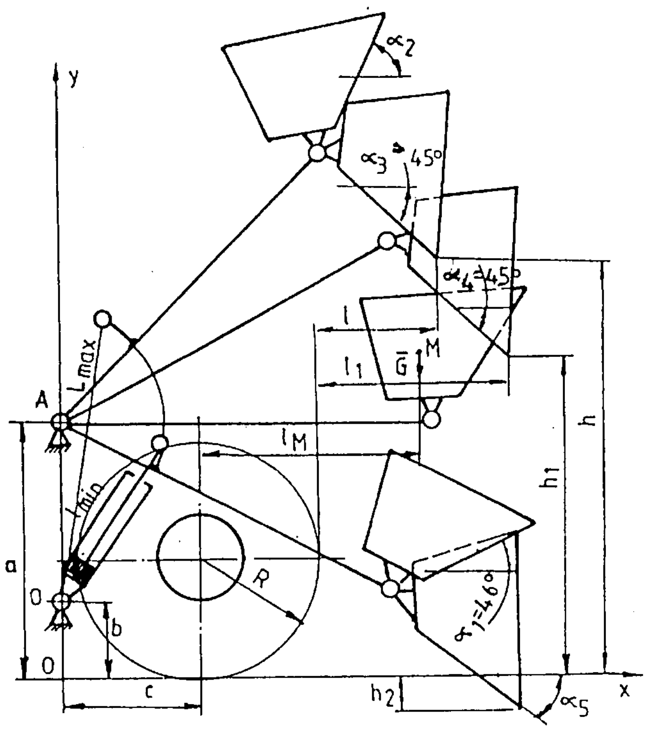

Figure 1. The functional parameters of the frontal loader

ix) the up closing angle of the bucket,α_2;
x) the static radius of the tyre, R.

Also it is required that the positions of the mass center M, determined for the full bucket, in the horizontal position of the arm to be as close as possible to the overthrow edge, distance noted in figure 1 with l_M.

The parameters a and b position the joints of the arm and rising cylinder, with chassis, and c positions the wheel center in relation with the A joint of the arm. The dimensions l_{max} and l_{min} represents the maximum and minimum dimension of the hydraulic cylinder for rising of the arm.

In the case of the bucket positions for the unloading phase, the exploitation impose big pretensions. So, for the emptying of the sticky materials the bucket wall must be in vertical position (α=90), and for other materials $\alpha \geq 45°$ (Lohse,1968).

3. SOLUTION METHODS OF THE SYNTHESIS PROBLEM

The synthesis is applied if the bucket's geometry and a initial scheme are considered known. In this case it is imposed the optimization of the kinematic scheme, which describes with precision the bucket's prescribed positions. Surely, a global mathematical model can be described but its solution using the optimization method does not always assure the wanted solution, because the number of the optimization problem variables is big especially at mechanism with many loops. Because of that, the author propose the solution of the loops problem, which determines the realization of a mathematical model which is applied to all kinematic schemes which use one or many loops tied in a series. Also, the synthesis problem can be brought to a problem which imposes an easier solution, using the method of movements inversion. The obtaining of approximate kinematic scheme does not constitutes a difficult problem for a designer in this domain. The complex aspect of the optimal synthesis problem is given by the mathematical modeling of the imposed constraints for each loop.

3.1.The determination of the synthesis parameters for a mechanism which contains a four elements loop

The mechanism is presented in figure 2 and contains an element with an adjustable in steps length (element 3) in the ADCBA loop.

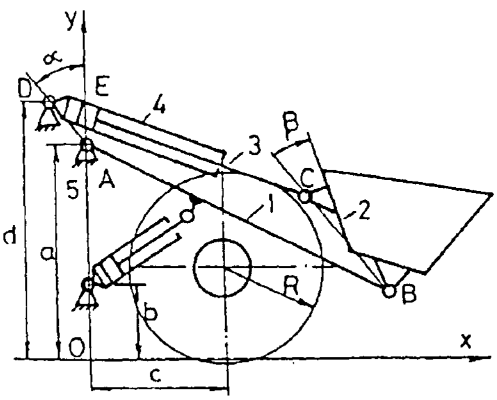

Figure 2. The working equipment with a four bar mechanism

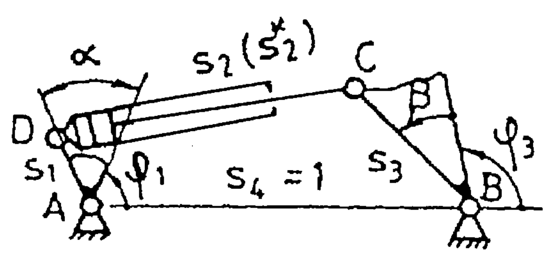

Figure 3.The synthesis parameters

In figure 3 is presented the mechanism obtained through the inversion of the movements, in which the reference element is the loading arm AB. The synthesis method is applied to this mechanism. For this mechanism are known the prescribed positions (φ_1, φ_3) for the elements 1 and 3. The synthesis problem variables are dimensionless parameters s_1, s_2, s_3, noted in figure 3 with AD=s_1, DC=s_2, BD=s_3 (AB=s_4=1), and the angles α and β. The design imposes the next constraints: the convexity of the loop with four elements ADCBA and the respecting of the minimal transmission admissible angle. The convexity constraints are imposed to avoid the alignment of the points D, A, B, because the hydraulic cylinder 4 would hit in the joint A for the solution in which ADCB are in the same plane. At the same time the prolongation of the element AB and BC must by avoided which will conduct to an little transmission angle (under 7°). The condition for the respecting the minimum transmission admissible angle conducts to the obtaining of a solution for which the minimum transmission angle has a bigger value than the minimum admissible value.

3.2 .The defining of the synthesis parameters for a mechanism with two loops with four elements

The mechanism is presented in figure 4. Changing the reference element, the Watt I mechanism in figure 4 changes to the Watt II mechanism in figure 5.

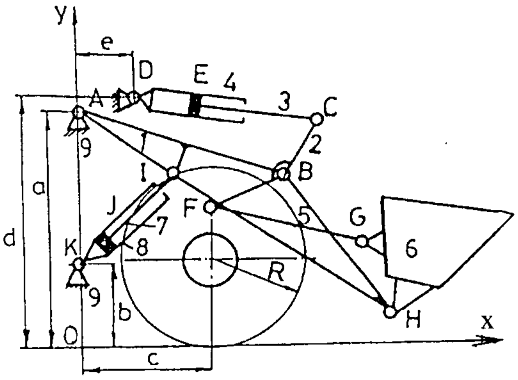

Figure 4. Watt I six elements mechanism

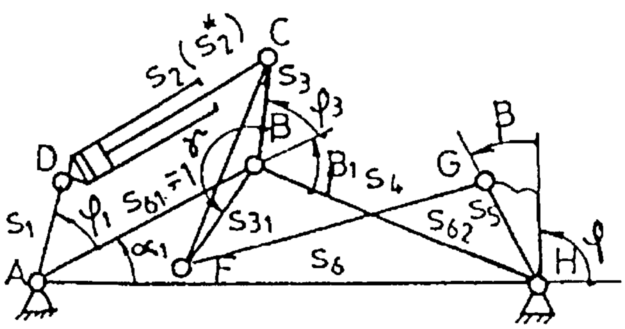

Figure 5. Watt II six elements mechanism

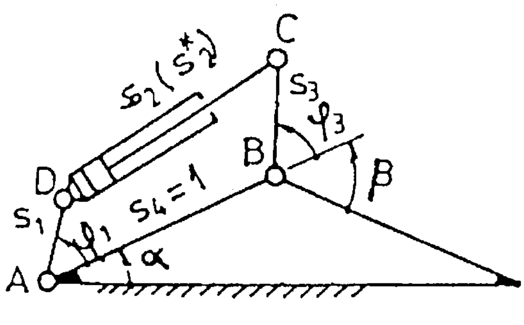

Figure 6. Loop with adjustable in steps in steps length element

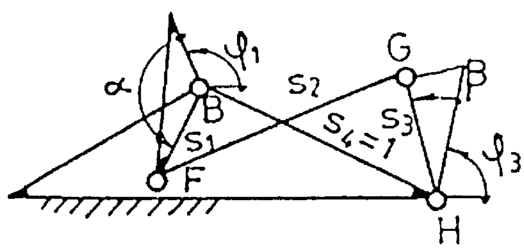

Figure 7. Loop with constant length elements

The mechanism in figure 5 is decomposed in two loops with four elements (Fig.6 and 7). The imposed constraints are:

- for the loop ABCDA (Fig. 6) in which the input element is AD, the output element is BC, and the reference element is AB, must by respected the mobility condition when AD superimpose AB and the minimal transmission admissible angle respecting condition ;

- for the loop BFGHF input element is BF, the output element is GH, the reference element is BH, and the constraints are given by the condition that the four linkage mechanism to be crossed and the minimum transmission admissible angle respecting condition.

The objective function for both cases it is given by the maximum value of the bucket's imposed angles error module.

4. THE MATHEMATICAL MODEL

The mathematical model of the synthesis problem is developed for the general case of the prescribed position generated by the four bar mechanism which has constant lengths elements (Fig. 8) and coupler length adjustable in steps (Fig. 9).

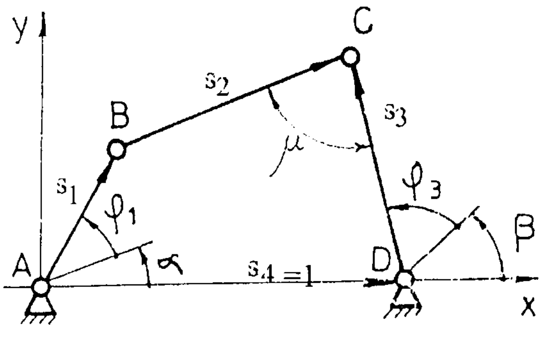

Figure 8. Four-bar mechanism with elements lengths constants

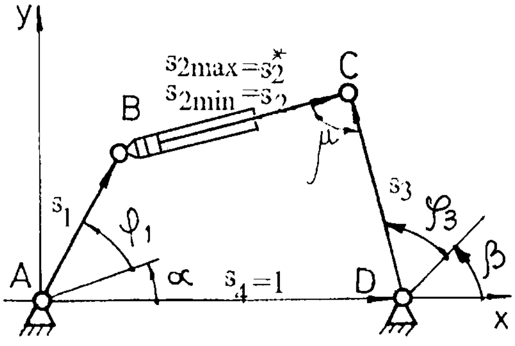

Figure 9. Four-bar mechanism with adjustable in steps coupler

4.1. Four-bar mechanism with the constant elements lengths

The objective function

The objective function is given by the maximum value of the error module of output positions element 3 (Fig. 8):

$$F(\mathbf{u},\varphi_{1i})=\max_{i=1\ldots n} |\varphi_{3i}(\mathbf{u},\varphi_{1i})-\varphi_{3i}|, \qquad (1)$$

where

$\mathbf{u}=\mathbf{u}(s_1,s_2,s_3,\alpha,\beta)$ is the design parameter vector ;

$\varphi_{3i}(\mathbf{u},\varphi_{1i})$- the calculated values of the φ_3 angle;

φ_{3i}-the values imposed to the φ_3 angle.

Possible constraints

The mobility constraints are determined from the condition that the mechanism should work as a crank-rocker or a double crank mechanism:

$$g_1=s_1+s_2-s_3-1,\ g_1(s_1,s_2,s_3)\geq 0\ ; \qquad (2)$$

$$g_2=(s_1-1)^2-(s_2-s_3)^2,\ g_2(s_1,s_2,s_3)\geq 0\ ; \qquad (3)$$

The convexity constraints are defined by the relations:

$g_3(s_3,\varphi_{1i},\varphi_{3i})=s_2 \sin(\varphi_{1i}+\alpha-\varphi_{3i}(\mathbf{u},\varphi_{1i})) + \sin(\varphi_{1i}+\alpha);$ (4)

$g_4(s_3,\varphi_{1i},\varphi_{3i})=s_1 \sin(\varphi_{1i}+\alpha-\varphi_{3i}(\mathbf{u},\varphi_{1i})) + \sin\varphi_{3i}(\mathbf{u},\varphi_{1i});$ (5)

$g_5(\mathbf{u},\varphi_{1i})=\sin\varphi_{3i}(\mathbf{u},\varphi_{1i});$ (6)

$g_6(\varphi_{1i},\alpha)=\sin(\varphi_{1i}+\alpha);$ (7)

$g_j \geq 0, j=3...6.$

The minimum transmission admissible angle respecting constraint is:

$$g+(\mathbf{u})=\cos\mu_a - \max_{i=1...n} |\cos\mu(\mathbf{u},\varphi_{1i})|, \quad (8)$$

where:

$\cos\mu(\mathbf{u},\varphi_{1i})=(s_2^2+s_3^2-1-s_1^2+2s_1\cos(\mathbf{u},\varphi_{1i}))/(2s_2s_3)$,

μ_a- the minimum transmission admissible angle .

The wording of the optimization problem

The synthesis problem is defined as an optimization problem:

$$F(\mathbf{u}^*)=\min_{\mathbf{u}} \max_{i=1...n} |\varphi_{3i}(\mathbf{u},\varphi_{1i})-\varphi_{3i}|, \quad (9)$$

where:

$\mathbf{u}^*$ -the optimal vector for which the objective function has the minimum value and it is situated in the domain established by the constraints.

4.2.The four-bar mechanism with an adjustable by steps length element

The objective function is given by the maximum value of the error on the output element positions written for both working phases: for the first phase the mechanism works with the minimum length of the coupler (Fig.9) specified in the function using the dimensionless parameter s_2 , and in the second phase works with the minimum length of the coupler specified using the dimensionless parameter s_2*:

$$F(\mathbf{u}^*)=\max_{\substack{i=1...l,\\ j=l+1...n}}\{F_1(\mathbf{u},\varphi_{1i}),F_2(\mathbf{u}_2,\varphi_{1j})\}, \quad (10)$$

where:

$$F_1(\mathbf{u}_1,\varphi_{1i})=\max_{i=1...l}|\varphi_{3i}(\mathbf{u}_1,\varphi_{1i})-\varphi_{3i}|, \quad (11)$$

$$F_2(\mathbf{u}_2,\varphi_{1j})=\max_{j=l+1...n}|\varphi_{3j}(\mathbf{u}_2,\varphi_{1j})-\varphi_{3j}|, \quad (12)$$

$\mathbf{u}=\mathbf{u}(s_1, s_2, s_2^*, s_3, \alpha, \beta)$-the vector of the synthesis parameters.

The vectors $\mathbf{u}_1$ and $\mathbf{u}_2$ are described by the synthesis parameters of the mechanism for the first working phase (s_1, s_2, s_3, α, β) and for the second working phase (s_1, s_2*, s_3, α, β).

The constraints are imposed for one or for both working phases. This ones are chosen from the relation specified in (Oprişan,1996) with the changes made in relation with the specific working phase.

The wording of the optimization problem is given in the relation:

$$F(\mathbf{u}^*) = \min_{u} \max_{\substack{i=1...l \\ j=l+1...n}} \{F_l(\mathbf{u}, \varphi_{1i}), F_2(\mathbf{u}_2, \varphi_{1j})\}, \quad (13)$$

$\mathbf{u}^*$ - the optimal vector for which the objective function has the minimum value.

5.THE NUMERICAL RESULTS

The numeric calculation is presented for the frontal loader mechanism in figure 2,with the bucket's capacity of 2,6 m^3 . Because it is necessary a relatively big space allocated to the numeric data it will be presented the solution of the loop ABCDA (Fig.2).

The mathematical model is formed from the objective function presented in relation (10) and the constraints which define the function (3) and (8).

The prescribed position are specified in tables 1 and 2.

Table 1. The prescribed position for the rising phase

φ_{1i}	45°	18°	0°	350	344	330
φ_{3i}	68°	50°	40°	37.5°	38°	39°

Table 2.The prescribed position for the descent phase

φ_{1i}	45°	18°	0°	350°	344°	330°
φ_{3i}	132°	120°	115°	113°	112°	111°

The calculation is made for a minimum transmission admissible angle $\mu_a=10°$.

The synthesis problem is defined in the relation (13) and the optimization algorithm is developed on the simplex method basis (Merticaru,1995).

The problem solution is presented in table 3.

Table 3. The synthesis problem solution

$s_l=0.1165$, $s_2=0.189$, $s_2^*=1.094$, $s_3=0.252$, $\alpha=26°15'20''$, $\beta=68°7'26''$						
Rising phase						
φ_{3i}	68°	50°	40°	37.5°	38°	39°
$\varphi_{3i}(\mathbf{u}, \varphi_{1i})$	67.56°	49.72°	40.32°	36.86°	37.45°	38.78°
ε	-26'24"	-16'48"	19'12"	-35'24"	-33'	13'12"
Descent phase						
φ_{3i}	132°	120°	115°	113°	112°	111°
$\varphi_{3i}(\mathbf{u}, \varphi_{1i})$	132.34°	119.58°	114.73°	113.64°	112.85°	110.25°
ε	20'24"	-25'12"	-16'12"	38'24"	51'	45'

In table 3 the parameter ε represents the structural error defined in the relation:

$$\varepsilon=\varphi_{3i}-\varphi_{3i}(\mathbf{u}, \varphi_{1i}).$$

For $l_{AB}=2190.52$ [mm] , the dimension of the vectorial loop ABCDA are: $l_{AD}=255.19$ [mm], $l_{CD}=1789.42$ [mm], $l_{CD}^*=2396.43$ [mm] and $l_{BC}=552$ [mm].

The calculation position for the first loop become prescribed position for the next loop

BFGHB .

The discussions in relation with the structural error values are important for the second loop, because the design establishes limits for the bucket position (Oprişan,1996).

6. CONCLUSIONS

The solving of the loop synthesis problem assures a bigger generality degree in relation with the global model which must be developed for each kinematic scheme type. In the same time the obtained solution using this method has a relative bigger precision in relation with the global method.

The application of the movements inversion principle (the changing of the reference element) leads to the choosing of a synthesis type which offers simplicity in solving.

References:

Lohse, P., Zur Konstruktion von Gelenkgetrieben an Ladefahrzengen, Konstruktion, Heft 9, 1968, pp.350-353.

Luck, K., Modler, K., Computer-Aided Design in Mechanisms, Mechanism and Machine Theory, Vol. 20, No. 4, 1985, pp. 297-302.

Merticaru, V., Oprişan, C., Ciauşu, V., Contributions on the optimal synthesis of mechanisms by associated positions, Ninth World Congress on the Theory of Machines and Mechanisms, Vol.1, Milano, Italia, 1995, pp. 197-201.

Oprişan, C., Popescu, G., Popovici, A., La sintesis de los mecanismos con elementos hidraulicos, Congresso Ibero Americano de Engenharia Mecânica COBEM-CIDIM/95, Belo Horizonte, Brazilia, 1995, pp. 1-4.

Oprişan, C., Researches About Optimization of the Bar Mechanisms Synthesis, Ph. D Thesis, (in Romanian), Technical University "Gh. Asachi", Iaşi, România, 1996.