KINEMATIC ANALYSIS OF A MECHANISM, WITH ARTICULATED PRECOMPACTION BARS, OF MUNICIPAL SOLID WASTE COLLECTING MACHINES
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ANALIZA CINEMATICĂ A UNUI MECANISM, CU BARE ARTICULATE DE PRECOMPACTARE, AL MAȘINILOR DE COLECTAT DEȘEURI MENAJERE

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ABSTRACT
In this paper, the structural and kinematic analysis of the mechanism of a municipal waste pressing system is made. The mechanism works in four phases. Two of the phases represent the operation itself, and two phases are for bringing the mechanism into pressing position. For the modules of which the actuation mechanism is constituted, kinematic calculation procedures have been drawn up, procedures that have been accessed by a main computing program. The results obtained were transposed graphically in the form of diagrams to give a clearer picture of the kinematic parameters of the mechanism elements.

REZUMAT
În lucrarea de față se face analiza structurală și cinematică a mecanismului unui sistem de presare a materialului menajer. Mecanismul lucrează în patru faze. Două dintre faze sunt de lucru propriu-zis, iar două faze sunt de aducere a mecanismului în poziție de presare. Pentru modulele din care este constituit mecanismul de acționare s-au întocmit proceduri de calcul cinematic, proceduri ce au fost apelate într-un program principal de calcul. Rezultatele obținute au fost transpuse grafic sub formă de diagrame, pentru a da o imagine mai clară asupra parametrilor cinematici ai elementelor mecanismului.

INTRODUCTION
The transport of residues is the second operation of the organized evacuation process, linked to the collection operation, as an inseparable part of it, after pre-collection at the level of economic agents and housing assemblies. There are very varied types of machines which, in addition to transport, allow easier loading of residues in the collector's bins *(Voicu Gh., 2007).* The basic condition of the transport economy is the compaction degree of municipal solid waste in the garbage trucks, correlated with the loading to its useful capacity *(Voicu Gh., 2007).*

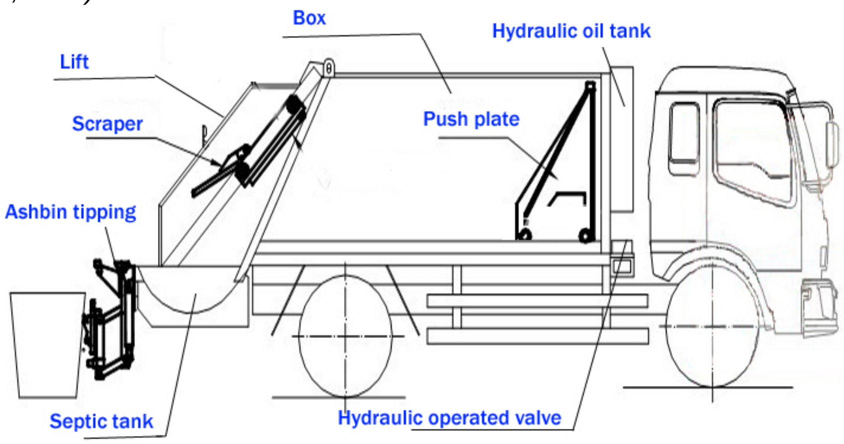

Fig. 1 - Garbage truck for collecting and transporting municipal solid waste with hydraulic compaction
(Voicu Gh., 2007)

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The fast displacement of the material from the loading area to the front side of the collector container and its uniform filling is a requirement that has been solved differently for different types of municipal waste trucks. Most municipal waste collection and transport machines are today with transshipment compaction. In these, the collection container has parallelipipedic shape, inside which a compaction and unloading plate moves from one end to the other. At the back of the machine is located the system of pickup and lifting of waste in the collection container, which effectively closes the collection container. The supply of the container is made through the scraping system mechanism, which has different constructions. Compaction is progressively achieved between the compaction plate in the container and the inclined plate of the scraping and lifting system as the waste is raised in the container *(Voicu Gh., 2007; Voicu Gh., Lazea M., Zabava B.S. et al., 2019; Voicu Gh., Lazea M., Tudor P.et al., 2019)*

Most of the pick-up and precompacting mechanisms are plane mechanisms with articulated bars, the elements of which are operated by one or two pairs of hydraulic cylinders *(Voicu Gh., 2007; Voicu Gh., Lazea M., Zabava B.S. et al., 2019; Voicu Gh., Lazea M., Tudor P.et al., 2019).*

MATERIALS AND METHODS

In figure 2 is presented, the kinematic scheme of a mechanism for the scraping and precompaction of the residual material from the collecting and transporting truck for municipal solid waste.

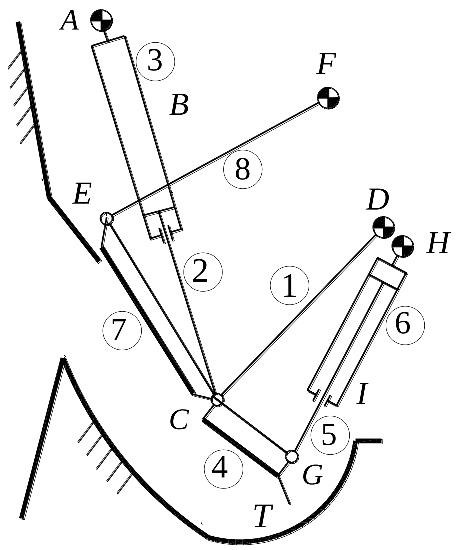


Fig. 2 – Kinematic scheme of the scraping and precompaction mechanism
(Voicu Gh., Lazea M., Zabava B.S. et al, 2019; Voicu Gh., Lazea M., Tudor P.et al, 2019)

A,F,D,H – fixed cylindrical joints ; C,E,G – mobile cylindrical joints; B,I – hydraulic cylinders; 1,4,7,8 – fixed length bars; 2-3 and 5-6 – hydraulic cylinders

The displacement trajectory of the tracer *T* point is shown in figure 3. It should be noted that the tracer *T* point is the tip of the collection and lifting plate of the machine, pos. *4*, while the bare, pos.*7*, represents the precompaction plate of the pickup and precompaction mechanism.

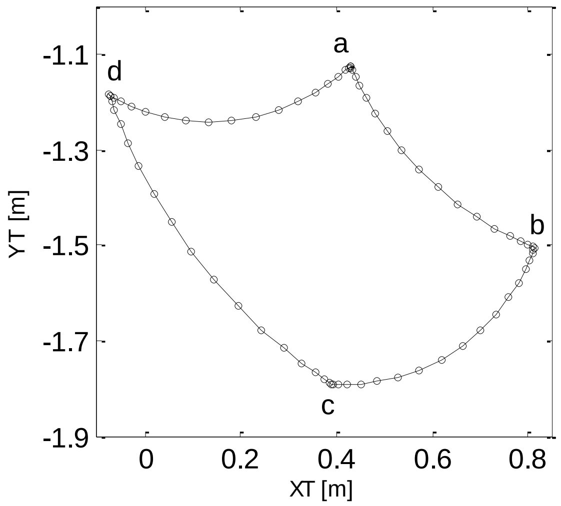


Fig. 3 – Tracer *T* point displacement diagram

Phase 1, trajectory *ab*:
s23(1) ∈ [s230,s230+course23];
s56(1) = s560;

Phase 2, trajectory *bc*:
s23(1) =s230+course23;
s56(1) ∈ [s560,s560+course56];

Phase 3, trajectory *cd*:
s23(1) ∈ [s230+course23,s230];
s56(1) = s560+course56;

Phase 4, trajectory *da*:
s23(1) = s230;
s56(1) ∈ [s560+course56, s560];

To determine the kinematic parameters of the mechanism elements, theoretical research regarding the structural analysis must first be carried out *(Artobolevski I.I., 1977; Demidovitch B., Maron I., 1987; Duca C., Buium Fl., Părăoanu G., 2003; Moise V., Maican E., Moise Şt. I., 2003).*

To determine the kinematic parameters of the mechanism elements, the procedures used were **A2APVA** and **D1PVA**, drawn up by the authors *(Moise V., Simionescu I., Ene M., et al, 2008; Moise V., Simionescu I., Ene M., Rotaru Al., 2015; Moise V., Simionescu I., Ene M., 2018; Simionescu I., Moise V., 1999).*

1. Structural analysis of the mechanism

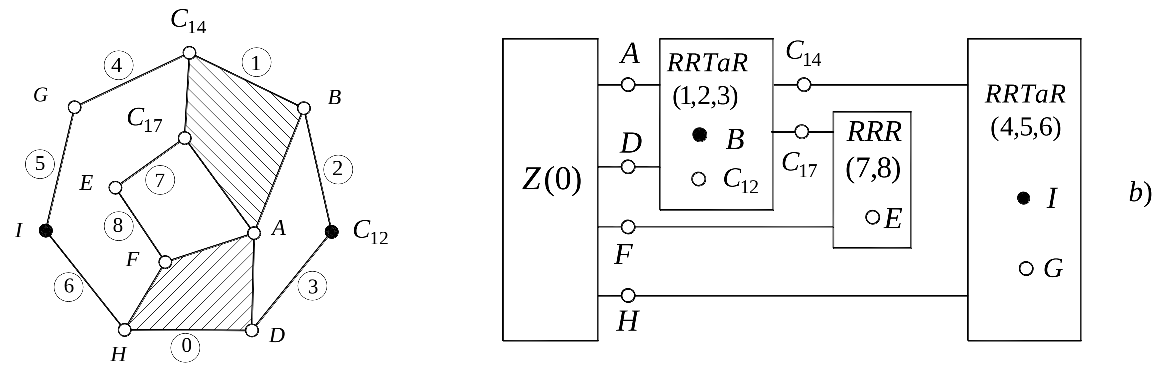
If the relative movements between the elements are taken into account, it is noted that the mechanism has following kinematic joints: $A(3R0)$, $B(2T3)$, $C12(1R2)$, $C14(1R4)$, $C17(1R7)$, $E(7R8)$, $F(8R0)$, $G(4R5)$, $E(3R8)$, $F(4R7)$, $I(7T8)$ (.

The number of upper couplings is zero.

The mobile elements of the mechanism are: $1(A,B,C_{14},C_{17})$, $2(B,C_{12})$, $3(C_{12},D)$, $4(C_{14},G)$, $5(G,I)$, $6(H,I)$, $7(C_{17},E)$, $8(E,F)$;

Considering the number of mobile elements and the number of kinematic joints, the mobility of the mechanism is: *M=2*.

The structural scheme of the mechanism is shown in the figure 4 *a.* The multipolar scheme and structural relationship of the mechanism are presented in the figure 4 b and figure 4 c.

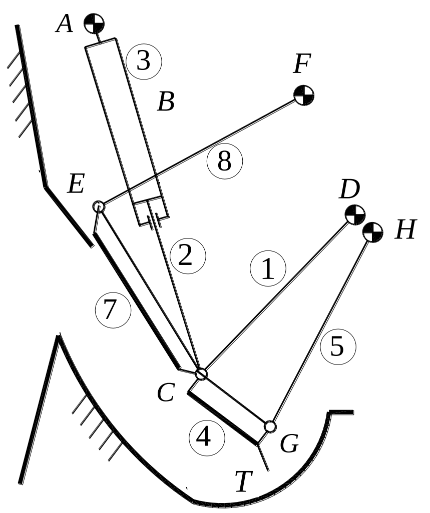


a) $Z(0)+RTaR\ (1,2,3)+RRR\ (7,8)+RRTaR\ (4,5,6)$ c)

Fig. 4 – Structural and multipolar schemes of the mechanism as the structural relationship

From the structural scheme, it is noted that the mechanism consists of the base *Z(0)*, the motor groups *RRTaR*(1,2,3), *RRTaR*(4,5,6) and dyad of appearance 1, *RRR*(7,8).

During the technological process, the mechanism in figure 2 has a variable structure, due to the fact that hydraulic cylinders *2-3* and *5-6* do not work simultaneously.

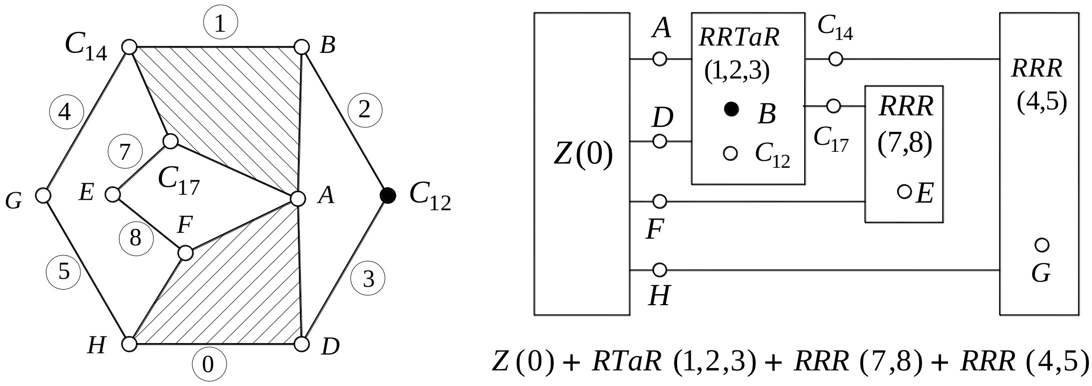


Therefore, if the hydraulic cylinder *5-6* (fig.2) is blocked, which means that the motor coupling *I* is canceled, elements *5* and *6* form a rigid, denoted by *5*. In this case, the kinematic scheme of the mechanism is shown in figure 5.

Structural and multipolar schemes, as well as the structural relationship, are shown in figure 6.

From figures 5 and 6, it is noted that the mechanism consists of *Z* base (0), *RRTaR(1,2,3),* motor groups and dyads *RRR(7,8)* and *RRR(4,5)*

Fig. 5 - The kinematic scheme of the mechanism for the *ab* and *cd* trajectory of the diagram in figure 3



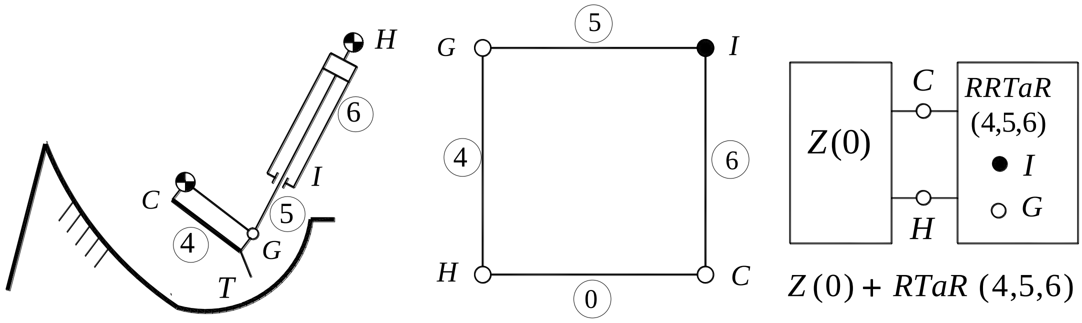
a) b)

Fig. 6 - Structural scheme

a) Multipolar scheme; b) Structural relationship of the mechanism, for the AB and CD branches of the diagram in figure 3

Observation. On the *ab* and *cd* branches of the diagram in figure 3, the mechanism can be studied from kinematic and kinetostatic standpoint even if it considered the constant length of the hydraulic cylinder consisting of elements *5* and *6* so, the relative velocity between these elements equals zero.

When the tracer *T* is moving on the branches of *bc* and *da* of the diagram in figure 3, it cancels the motor coupling B, and elements 2 and 3 form a rigid, denoted by *2*. As a result of the triangle formed by points *A*, *C* and *D*, elements *1,2,7* and *8* form a rigid, fixed at the base. The kinematic, structural and multipolar schemes as well as the structural relationship are presented in figure 7.



a) b) c)

Fig. 7 - The kinematic scheme

a) structural scheme; b) multipolar scheme and structural relationship of the mechanism, for BC and DA branches of the diagram in figure 3

From figure 7, it is noted that the mechanism is composed of the base *Z*(0) and the motor group *RRTaR(4,5,6)*

2. Kinematic analysis of the mechanism

The kinematic analysis of the mechanism consists in determining the parameters of positions, speeds and accelerations, corresponding to all its elements.

Figure 8 presents the kinematic scheme of the mechanism, with the position parameters.

For the kinematic analysis of the mechanism there are several stages, namely:

a) elaboration of the calculation program for the determination of the kinematic parameters of the mechanism elements, considering the four phases of a kinematic and dynamic cycle.

b) tabular presentation of the angles values made by vectors $\overline{AC}, \overline{DC}, \overline{CG}, \overline{HG}, \overline{CE}$ and $\overline{FE}$ corresponding to the elements of the mechanism, with the positive meaning of the axis *AX*

c) drawing the diagrams of variation of angles, velocities and angular accelerations of the mechanism elements, depending on the position of the mechanism.

d) drawing of velocities and accelerations hodographs corresponding to the tracer T point.

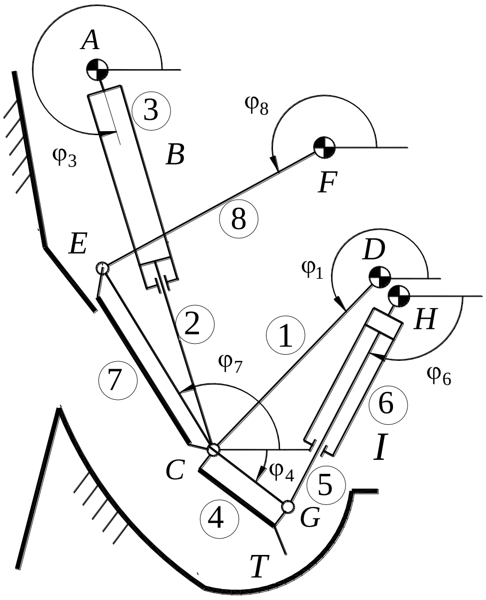


Fig. 8 - The kinematic scheme of the mechanism, with the parameters of positions

Figure 9 shows the kinematic diagrams of the structural groups, based on which the formal parameters of the calculation procedures are selected.

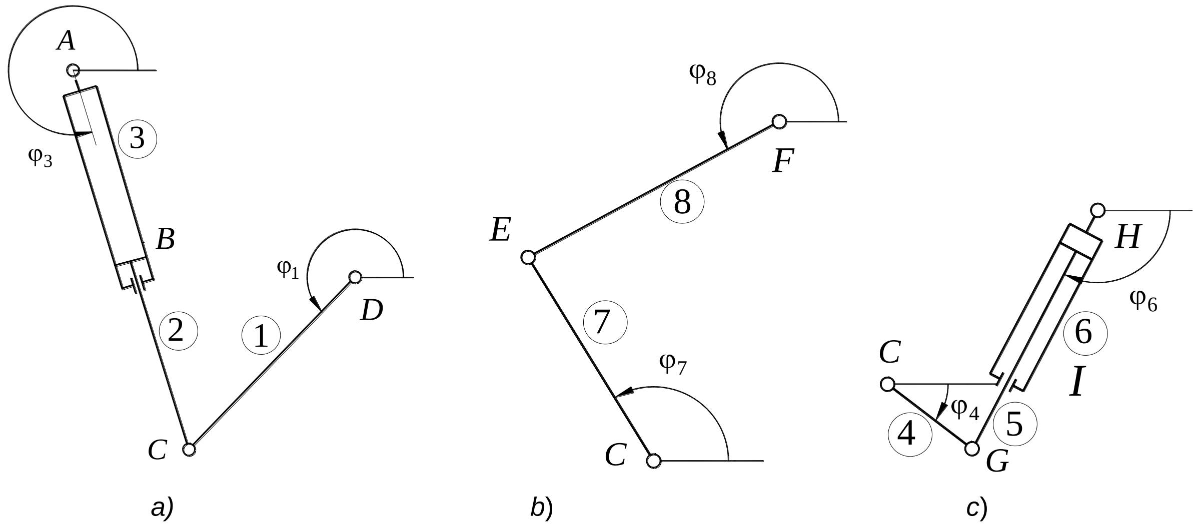


Fig. 9 – a) The kinematic diagrams of structural groups in the composition of the mechanism motor group *RRTaR*(1,2,3); b) dyad *RRR*(7,8); c) motor group *RRTaR*(4,5,6)

RESULTS

The theoretical investigations presented in the previous chapter were used, taking into account the constructive elements of the mechanism that equipped the machine, to obtain concrete results regarding the kinematics of the mechanism.

For the analysis of the mechanism, they are known:

a) The kinematic scheme of the mechanism (Fig.3);

b) The position of the coupling adjacent to the base and dimension of the elements as follows: *XA* = 0 m, *YA* = 0 m, *XD* = 1.000 m, *YD* = –0.733 m, *XF* = 0.800 m, *YF* = –0.270 m, *XH* = 1.100 m, *YH* = –0.800 m, *CE* = 0.770 m, *CD* = 0.870 m, *EF* = 0.900 m; *CG* = 0.330 m;

c) Phase working times: t_1 = 5 sec, t_2 = 5 sec, t_3 = 5 sec, t_4 = 5 sec,

d) Initial positions of the mechanism: S230 = 0.833 m, S_{560} = 0.667 m;

e) Hydraulic cylinder piston work strokes: $Stroke_{23}$ = 0.600 m, $Stroke_{56}$ = 0.400 m;

f) Transmission function used for hydraulic cylinder actuation: sinusoidal function (reduced acceleration is of sinusoidal type)

Figure 10 shows the variation diagram of the angles φ_1, φ_1, φ_3, φ_4, φ_6, φ_7 and φ_8.

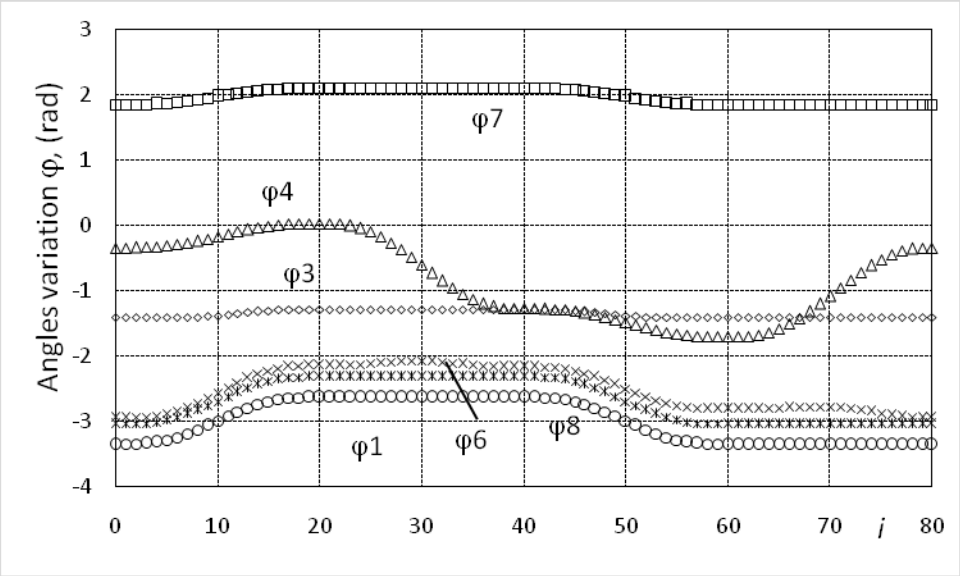


Fig. 10 – The diagram of variation of angles φ_1, φ_2, φ_3, φ_4, φ_6, φ_7 and φ_8

Figure 11 shows the diagrams of the angular velocities of the mechanism elements and in figure 12, the diagrams of the corresponding angle accelerations.

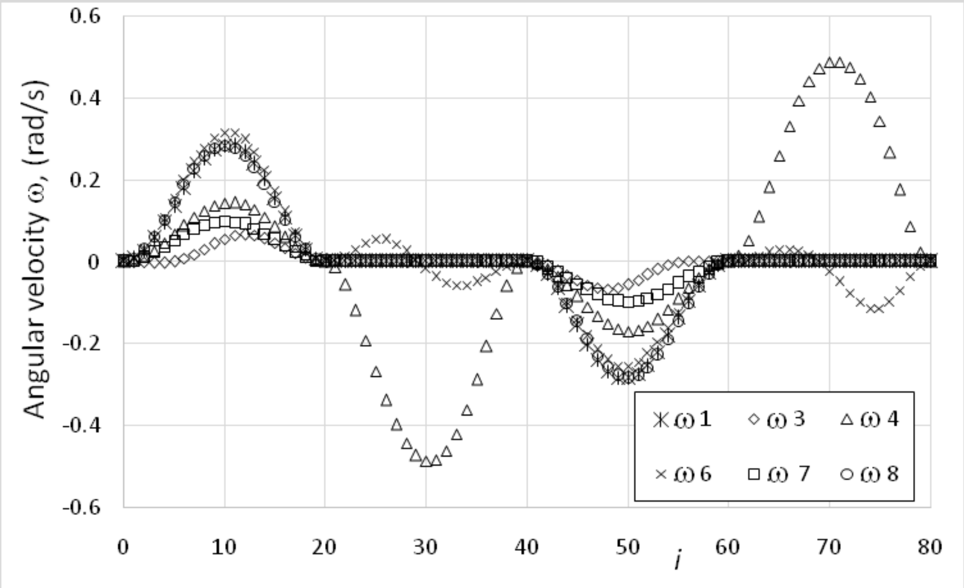


Fig. 11 - The diagram of the angular velocities of the mechanism elements

From the analysis of the angular velocities hodographs (fig.11) of the working element 4 (fig.8) it is observed that this follows a cyclical variation with maximum values (about 0.5 rad / s) for positions 30 and 70 respectively of the driving element (ie the hydraulic drive cylinder), on the pushing stroke, respectively on the retraction stroke.

The same cyclical variation is also observed for the angular acceleration of the working element 4 (see fig. 12), maximum values for this being noted for four positions of the mechanism (respectively of the hydraulic actuating cylinder).

The maximum values of the angular acceleration, for the working element of the mechanism, are around 0.35 rad / s2, for positions 23-24, respectively 63-64, slightly higher for positions 37-38 and 77-78 respectively.

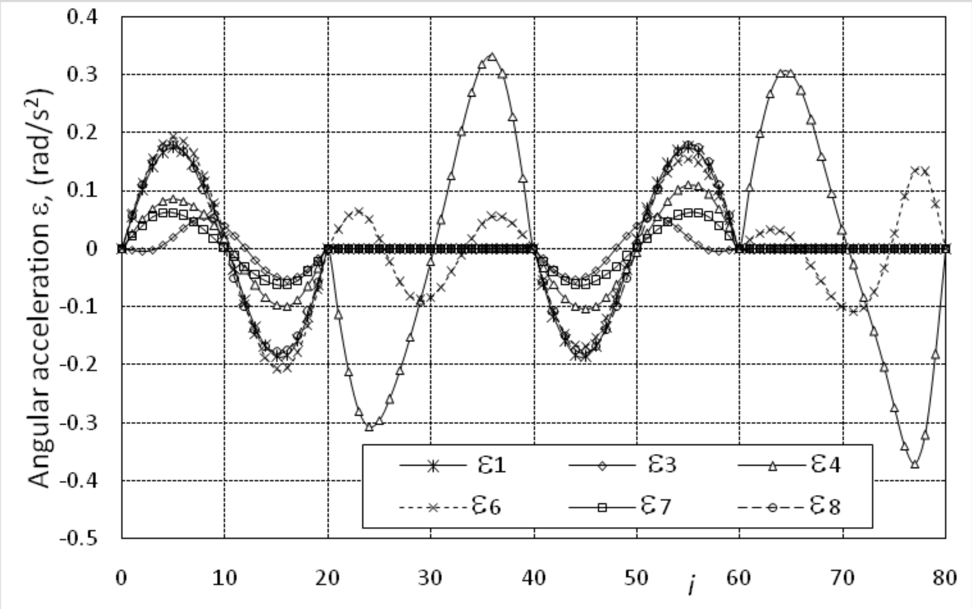


Fig. 12 - The diagram of the angular accelerations of the mechanism elements

Table 1 shows the numerical values of the kinematic parameters of positions for the mechanism elements

Table 1

Pos.	φ_1	φ_3	φ_4	φ_6	φ_7	φ_8
0	-3.0390	-1.4085	-0.3369	-2.9437	1.8536	-3.3513
1	-3.0385	-1.4086	-0.3366	-2.9431	1.8538	-3.3507
2	-3.0346	-1.4088	-0.3347	-2.9388	1.8553	-3.3465
3	-3.0244	-1.4093	-0.3297	-2.9277	1.8593	-3.3355
4	-3.0055	-1.4100	-0.3204	-2.9071	1.8667	-3.3152
5	-2.9764	-1.4103	-0.3061	-2.8753	1.8778	-3.2842
...						
24	-2.3151	-1.2802	-0.0358	-2.1222	2.1090	-2.6285
25	-2.3151	-1.2802	-0.0935	-2.1095	2.1090	-2.6285
26	-2.3151	-1.2802	-0.1695	-2.0958	2.1090	-2.6285
27	-2.3151	-1.2802	-0.2618	-2.0836	2.1090	-2.6285
28	-2.3151	-1.2802	-0.3671	-2.0749	2.1090	-2.6285
29	-2.3151	-1.2802	-0.4819	-2.0713	2.1090	-2.6285
30	-2.3151	-1.2802	-0.6023	-2.0732	2.1090	-2.6285
31	-2.3151	-1.2802	-0.7241	-2.0803	2.1090	-2.6285
...						
70	-3.0390	-1.4085	-1.0760	-2.7729	1.8536	-3.3513
71	-3.0390	-1.4085	-0.9535	-2.7820	1.8536	-3.3513
72	-3.0390	-1.4085	-0.8326	-2.7978	1.8536	-3.3513
73	-3.0390	-1.4085	-0.7171	-2.8198	1.8536	-3.3513
74	-3.0390	-1.4085	-0.6106	-2.8465	1.8536	-3.3513
75	-3.0390	-1.4085	-0.5169	-2.8752	1.8536	-3.3513
76	-3.0390	-1.4085	-0.4402	-2.9023	1.8536	-3.3513
77	-3.0390	-1.4085	-0.3847	-2.9239	1.8536	-3.3513
78	-3.0390	-1.4085	-0.3520	-2.9373	1.8536	-3.3513
79	-3.0390	-1.4085	-0.3388	-2.9429	1.8536	-3.3513
80	-3.0390	-1.4085	-0.3369	-2.9437	1.8536	-3.3513

CONCLUSIONS

From the analysis of numerical data, as well as the distribution diagrams of angles, speeds and accelerations, conclusions can be drawn on the driveline operation of the mechanism. Based on this data, it can be interfered with improving the performance of the mechanism. To improve the performance of the mechanism, different transmission functions may be used to actuate hydraulic cylinders *2-3* and *5-6*.

After the cinematic analysis of the mechanism, we passed to its kinetostatic analysis (determination of the forces and moments acting on the elements of the mechanism).

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