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DETERMINATION OF THE REACTIONS IN LINKAGES WITH AUTOLISP FUNCTIONS

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***Abstract*—**The present paper completes a previous paper in which were determined the positions, velocities and accelerations of a jointed quadrilateral mechanism with the aid of some certain AutoLisp functions. The completion consists in the realization of two AutoLisp functions which determine the reactions in the RRR dyad, at the active element and the animation of the vector polygonals or the animation of a wished reaction. The AutoLisp functions are easy to write, the relation that stay at the base of the thinking are vector relations used in the graph-analytical analysis. In the end are shown, as diagrams, the obtained numerical results.

***Keywords*—**animation, AutoCAD, AutoLisp, reactions, mechanism

I. INTRODUCTION

IN the design activity a remarkable aid is due to AutoLisp. This is a programming language that permits to the user the realization of mathematic calculation and the work with objects in AutoCAD.

In this paper we have the goal to solve the problem of kineto-static analysis with AutoLisp functions.

First of all we have to perform the kinematic analysis. In references [7], [8] we presented modalities of solving the problems of kinematic analysis with the aid of certain AutoLisp functions.

These are easy to be written, the used relations are the vector ones used in the graph-analytical analysis.

One obtains numerical results with the same precision of the assisted analytical methods.

To complete the reference [8] with the determination of the reactions in the kinematic joints of an articulated quadrilateral mechanism, we will write two AutoLisp functions.

The first one will determine the reactions in RRR dyad, while the second one determines the reactions at the active element.

The relations that stay at the base of thinking for the two functions are vector relations.

Finally, we will present the way of animation of the vector polygonals of forces.

II. DETERMINATION OF THE REACTIONS BY CLASSICAL GRAPH-ANALYTICAL METHOD

Dyads enter the category of the passive modular groups. These are statically determined and for this reason the kineto-static analysis of a mechanism starts from the last modular element, which is in reverse sense comparing to the kinematic analysis.

To realize an AutoLisp function used for any configuration of mechanism with rotational linkages, the elements of the dyad will have plan-parallel motion. Such a RRR dyad may be obtained from the bi-mobile mechanism O_1ABCO_2 in fig.1. Knowing the motions of elements 1 and 4, the mechanism O_1ABCO_2 is a desmodrome one.

In Fig. 1 is presented the isolation of the RRR dyad. One considers the elements of the dyad acted by known forces (given and inertial).

The element 2 is considered to be composed from the bars AB and BM solidary linked one to another and making the angle α.

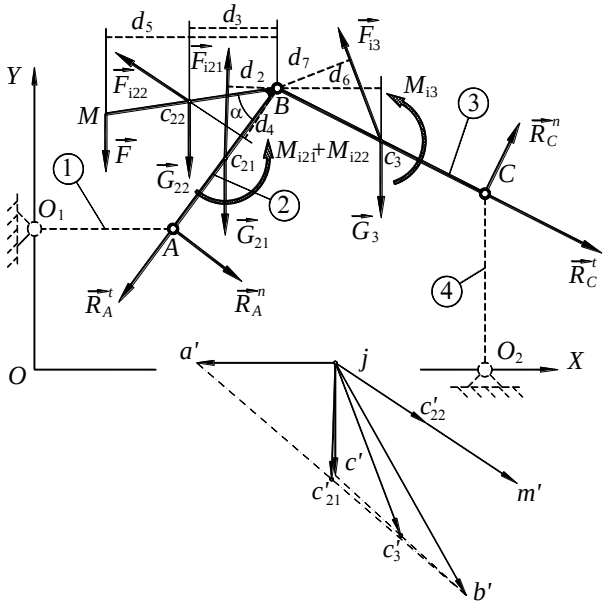

Fig. 1. The RRR dyad isolated from the bi-mobile mechanism O_1ABCO_2.

Denoting by c_{21} and c_{22}, respectively, the centers of gravity of the two bars, it is easier to determine the inertial forces of the element 2; these forces will be denoted by F_{i21} and F_{i22}, respectively.

The inertial torques are denoted by M_{i21} and M_{i22}, respectively.

On the element 2 acts also the force F, with the expression ([5]):

$$F = \begin{cases} 0 & \text{for } \varphi \in [0,80°) \\ 50\text{ N} & \text{for } \varphi \in [80°,280°] \\ 0 & \text{for } \varphi \in [280°,360°] \end{cases}. \quad (1)$$

The bars AB and BM are also acted by the weight forces G_{21}, and G_{22} (the masses of the elements $m_{21} = 0.125\,\text{kg}$, and $m_{22} = 0.125\,\text{kg}$ are known).

The element 3 has the center of gravity denoted by c_3, the mass m_3 ($m_3 = 0.125\,\text{kg}$) and the weight G_3. The inertial force was denoted by F_{i3}, while the inertial torque was denoted by M_{i3}.

We considered that the bars are homogeneous; hence the centers of gravity are situated at the middle of the bars.

The torsor of the inertial forces is given by the relations:

$$\bar{F}_i = -m_i \bar{a}_{c_i},\ \bar{M}_i = -J_{c_i}\bar{\varepsilon}_i, \quad (2)$$

where i takes the values 21, 22 and 3.

In figure the inertial forces ($\bar{F}_i$) were drawn in opposite sense to the accelerations of the elements, while $\bar{M}_i$ were represented in opposite direction to the angular accelerations.

That is why in the bottom part of Fig. 1 we represented the acceleration polygonals at which we added the accelerations of the gravity centers of the elements.

To determine the reactions in the kinematic joints A, B and C, one isolates the elements, and decomposes the reactions in A and C into the normal components $\bar{R}_A^n$, $\bar{R}_C^n$, and into the components along the bars $\bar{R}_A^t$, $\bar{R}_C^t$. From the equations of moments relative to the point B, one determines the components $\bar{R}_A^n$ and $\bar{R}_C^n$. Thus, for the dyad in Fig. 1 it results

$$R_A^n = \left(-G_{21}d_1 + F_{i21}d_2 - G_{22}d_3 + F_{i22}d_4 - Fd_5 - M_{i21} - M_{i22}\right)/AB, \quad (3)$$

$$R_C^n = \frac{G_3 d_6 - F_{i3}d_7 - M_{i3}}{BC} \quad (4)$$

where the distances d_1, …, d_7 correspond to the forces marked in Fig. 1.

Further on, writing the equilibrium of the forces for the all dyad,

$$\underline{\underline{\bar{R}_A^n}} + \underline{\underline{\bar{G}_{21}}} + \underline{\underline{\bar{F}_{i21}}} + \underline{\underline{\bar{G}_{22}}} + \underline{\underline{\bar{F}_{i22}}} + \underline{\underline{\bar{F}}} + \underline{\underline{\bar{G}_3}} + \underline{\underline{\bar{F}_{i3}}} + \underline{\underline{\bar{R}_C^n}} + \underset{\|BC}{\bar{R}_C^t} + \underset{\|AB}{\bar{R}_A^t} = 0, \quad (5)$$

result the components R_C^t and R_A^t; hence the reactions at A and C were completely determined,

$$\bar{R}_A = \bar{R}_A^n + \bar{R}_A^t,\ \bar{R}_C = \bar{R}_C^n + \bar{R}_C^t. \quad (6)$$

From the equilibrium of forces which act upon the element 2,

$$\underline{\underline{\bar{R}_A}} + \underline{\underline{\bar{G}_{21}}} + \underline{\underline{\bar{F}_{i21}}} + \underline{\underline{\bar{G}_{22}}} + \underline{\underline{\bar{F}_{i22}}} + \underline{\underline{\bar{F}}} + \bar{R}_B = 0, \quad (7)$$

one determines the reaction $\bar{R}_B$.

The active element 1 has the mass m_1 ($m_1 = 0.05\,\text{kg}$) and it is acted by: the weight G_1, the torsor of the inertial forces calculated relative to the rotational axis, and the reaction $\bar{R}_A$ (equal and of opposite direction to that calculated at the RRR dyad).

Because the active element has constant angular speed, the torsor of the inertial forces reduces at the inertial force $\bar{F}_{i1} = -m\bar{a}_{c1}$, where c_1 marks the center of gravity for the element 1.

Since OA is a homogeneous bar, c_1 is at the middle of the element.

To determine the reactions of the active element, one isolates the element 1 (Fig. 2).

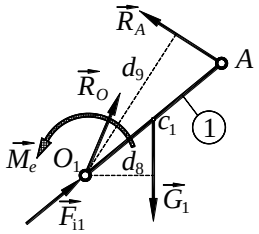

Fig. 2. Isolation of the active element.

From the addition of forces

$$\underline{\underline{\bar{R}_A}} + \underline{\underline{\bar{F}_{i1}}} + \underline{\underline{\bar{G}_1}} + \bar{R}_B = 0, \quad (8)$$

results the reaction $\bar{R}_B$, while from the sum of moments relative to O_1 one obtains the moment of equilibration M_{e1},

$$M_{e1} = G_1 d_8 - R_A d_9. \quad (9)$$

III. AUTOLISP FUNCTION TO DETERMINE THE REACTIONS OF THE RRR DYAD

Based on the relations (1) – (7) we wrote the AutoLisp function named "**Reacţiuni_RRR**", the content of which is as follows:

```
(Defun Reactiuni_RRR ()
 (Setq m21 0.125
       m22 0.125
       m3 0.125
    G21(* m21 9.8)
    G22(* m22 9.8)
     G3(* m3 9.8)
    J21(/ (* m21 lAB lAB) 12)
    J22(/ (* m22 lBM lBM) 12)
     J3(/ (* lBC lBC) 12) fmic(List 50 50))
 (Setq pctC21(Polar aprim (Angle aprim
bprim) (/ (Distance aprim bprim) 2))
       pctC22(Polar bprim (Angle bprim
pctmprim) (/ (Distance bprim pctmprim) 2))
        pctC3(Polar bprim (Angle bprim
cprim) (/ (Distance bprim cprim) 2))
        acc21(Distance jmic pctC21)
        acc22(Distance jmic pctC22)
         acc3(Distance jmic pctC3))
 (Setq fFi21(* m21 acc21)
       fFi22(* m22 acc22)
        fFi3(* m3 acc3)
       Mi21(* J21 eps2 semnEps2)
       Mi22(* J22 eps2 semnEps2)
       Mi3(* J3 eps3 semnEps3)
       Fmare 0.0)
  (If (> fi1 70) (Setq Fmare 50))
  (If (> fi1 280) (Setq Fmare 0))
  (Setq aG21(- (/ pi 2) fi2)
       aFi21(- (Angle pctC21 jmic) fi2)
      aG22(- alfaRad fi2 (/ pi 2))
     aFi22(- (Angle pctC22 jmic) (+ fi2 pi
(* -1 alfaRad)))
  aG3(- fi3 (* Pi 1.5))
  aF3(- fi3 (Angle pctC3 jmic))
  d1(* (/ lAB 2) (Sin aG21))
  d2(* (/ lAB 2) (Sin aFi21))
  d3(* (/ lBM 2) (Sin aG22))
  d4(* (/ lBM 2) (Sin aFi22))
  d5(* lBM (Sin aG22))
  d6(* (/ lBC 2) (Sin aG3))
  d7(* (/ lBC 2) (Sin aF3)))
  (Setq RAn(/ (+ (* G21 d1 -1) (* fFi21 d2)
(* G22 d3 -1) (* fFi22 d4) (* Fmare d5 -1)
(* (+ Mi21 Mi22) -1)) lAB)
  RCn(/ (+ (* G3 d6) (* fFi3 d7 -1) (* Mi3
-1)) lBC))
  (Setq aRAn(+ fi2 (* pi 1.5))
  aRCn(- fi3 (* pi 1.5))
  pRAn(Polar fmic aRAn RAn)
  pG21(Polar pRAn (* pi 1.5) G21)
  pFi21(Polar pG21 (Angle pctC21 jmic)
fFi21)
  pG22(Polar pFi21 (* pi 1.5) G22)
  pFi22(Polar pG22 (Angle pctC22 jmic)
fFi22)
 pFmare(Polar pFi22 (* pi 1.5) Fmare)
    pG3(Polar pFmare (* pi 1.5) G3)
   pFi3(Polar pG3 (Angle pctC3 jmic) fFi3)
   pRCn(Polar pFi3 aRCn RCN)
  pfRCt(Polar pRCn fi3 10)
  pfRAt(Polar fmic fi2 10)
    int(Inters pRCn pfRCt fmic pfRAt Nil)
    RAt(Distance fmic int)
    RCt(Distance pRCn int)
     RA(Distance int pRAn)
     RC(Distance pFi3 int)
     RB(Distance pFmare int))
(Command "Line" fmic pRAn pG21 pFi21 pG22
pFmare pG3 pFi3 pRCn int "C")
  (setq l(/ RA 40) g(/ l 0.353))
  (Sageti pRAn fmic)
  (Sageti pG21 pRAn)
  (Sageti pFi21 pG21)
  (Sageti pG22 pFi21)
  (Sageti pFmare pG22)
  (Sageti pG3 pFmare)
  (Sageti pFi3 pG3)
  (Sageti pRCn pFi3)
  (Sageti int pRCn)
(Sageti fmic int)
  )
```

The AutoLisp function starts by assigning values (**Setq**) to the masses of elements, continues with the calculation of gravity forces and inertial moments. It also assigns to the forces pole the coordinates $f(50,50)$.

To determine the accelerations of the gravity centers a_{c21}, a_{c22} and a_{c3}, one firstly determine the coordinates of the middles of segments $a'b'$, $b'c'$ and jm', respectively, from the accelerations polygonal presented in [5] with the AutoLisp function **Polar**.

The polygonal uses the accelerations determined with the AutoLisp function "**Acceleratii**" and presented in [5], and the names of the points in the accelerations plan. In the AutoLisp function the points were denoted by **pctC21, pctC22 pctC3**, the accelerations being the distances between these points (**Distance**) and the pole j of the accelerations.

The notations for these accelerations are **acc21, acc22** and **acc3**, respectively.

The inertial forces given by (2) were denoted by **fFi21, fFi21, fFi3**, and the inertial torques by **Mi21, Mi22, Mi3**. Due to the fact that on the elements the inertial forces draw in the opposite sense to accelerations, and the inertial moments in the opposite sense of the angular accelerations, we have to solve the problem of the sense of angular acceleration. The theory states that the geometric figure in the accelerations plan is similar to that in the position plan and rotated by the angle

$$\gamma = \pi - \arctan\frac{\varepsilon}{\omega^2} \tag{10}$$

in the sense of the angular acceleration. To do this, one writes an AutoLisp function which compares the two angles from the accelerations and positions plans, respectively, the angle being measured from the end of the element in trigonometric sense. If the difference is equal to γ, then **semn** takes the value 1, otherwise it takes the value –1.

To define the force F given by (1), one used two interrogations **IF**.

The determination of the distances d_j from a point B_j to the support straight line of the force F_j (Fig. 3) is performed with the aid of the relation

$$d_j = C_j B_j \sin(\varphi_F - \varphi_j). \quad (11)$$

We denoted by φ_F the angle made by the force F_j with the horizontal, and by φ_j the angle made by the orientated segment $C_j B_j$ with the horizontal.

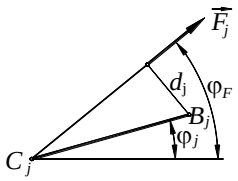

Fig. 3. The distance from a point to a straight line.

In the AutoLisp function, the distances were denoted by **d1, …, d7,** they being determinate according to the representation in Fig. 3. Further on, were determined the components R_A^n and R_C^n with the algebraic relations (3) and (4).

To obtain the vector contour given by (5) one started **Polar** from the pole of forces f with the angle $\varphi_2 + 3\pi/2$ and the distance R_A^n.

One obtained the point **pRAn**. Further on, again with the function **Polar**, one obtains, one after another, the points **pG21, pfi21, PG22, pFi22, pF, pG3, pFi3, pRCn**, keeping into account the forces and their magnitudes, according to the vector polygonal [5].

To obtain the intersection between the parallel to BC and passing through **pRCn**, and the parallel to AB and passing through the pole f, one constructs two points **pfRCt** and **pFRAt** situated on the two straight lines at an arbitrary distance (10).

With the function **Inters** one analyzes the four point **pRCn, pfRCT, fmic** and **pfRAt** and if there exists point of intersection (**Nil**), then it is denoted by **int**.

We thus obtain the components: R_A^t as distance (**Distance**) between the points **fmic** and **int**, and R_C^t as distance (**Distance**) between the points **pRcn** and **int**. R_A, according to (6), is the distance between the points **int** and **pRAn**, while R_C is the distance between the points **pFi3** and **int**.

The reaction $\bar{R}_B$, according to the vector relation (7), is obtained from the same contour as distance (**Distance**) between the points **pF** and **int**.

We thus obtained the magnitudes of the reactions in the joints of RRR dyad, with no representation of the vector contour.

One may also draw the vector contour of the polygonal using the AutoCAD command LINE.

This vector contour completes with arrows with the AutoLisp function "**Sageti**" described in [8] (Fig. 4).

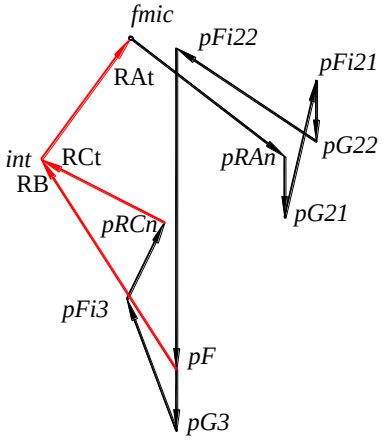

Fig. 4. The RRR dyad – the forces polygonal.

IV. AUTOLISP FUNCTION TO DETERMINE THE REACTIONS AT THE ACTIVE ELEMENT

To obtain the components at the active element we write a new AutoLisp function named "**React_Motor**". It calls the function "**Reactiuni**" or from the main function "**R_3R**" presented in [8]. Its construction follows the algorithm given by (8) and (9).

```
(Defun React_Motor ()
 (Setq m1 0.05
       G1(* m1 9.8))
 (Setq pctC1(Polar jmic (Angle jmic aprim)
(/ (Distance jmic aprim) 2))
     acC1(Distance jmic pctC1)
     fFi1(* m1 acC1))
 (Setq pF1(Polar int (Angle jmic pctC1)
Fi1Rad)
    pG1(POlar pF1 (* pi 1.5) G1)
     RO(Distance pG1 pRAn))
 (Setq aRA(- (Angle pRAn int) (+ fi1RAD (/
pi 2)))
     d8(* (/ lOA 2) (Sin Fi1RAD))
     d9(* lOA (Sin aRA))
    Me1(- (* G1 d8) (* RA d9))
  )
)
```

After the determination of the inertial force, one obtains R_O using the previous vector contour. One uses a new pole of forces, the point **pRAN**. The force R_A is at the point **int**. We continue from this point with the force F_{i1} (it results the point **pFi1**) and with the force G_1 (it results the point **pG1**). One thus obtained the reaction R_O as distance (**Distance**) between the points **pG1** and **pRAn** (fig. 5).

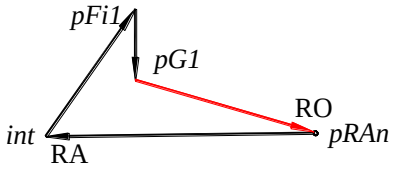

Fig. 5. Active element – the forces polygonal.

The moment of equilibration is determined with the aid of (9), after we previously determined the distances d_8 and d_9 with (11). In this mode, we completely determined the reactions at the active element.

V. Animation of the Vector Polygonals of Forces

The functions presented above are called from the function **"R_3R"** presented in [5]. The function **"R_3R"** was though to also realize files of values in which will be written the reactions in the mechanism joints. The function **"R_3R"** was performing the animation of the mechanism, velocities and accelerations polygonals. With the aid of the described functions one also obtains the animation of the polygonals of reactions or, separately, the reactions of interest.

The visualization of the animation is made in proper windows, the angle at the active element varying from 0 to 2π. To do this, one uses the AutoCAD command ZOOM. One establishes a point of visualization (the option Center of the command) and a magnification factor. For instance, if one wishes to visualize only the animation of the reaction R_C, then one chooses as central point the point **pFi3** and draws only the segment between the points **pFi3** and **int** with the command LINE. One may also draw with the function **"Sageti"** the arrow with the peak at the point **int**. In this window of visualization, when the angle φ of the active element varies, we will observe the rotation about the chosen point of the reaction. If one wishes, then one may superimposes the 360 components of the reactions, obtaining thus a diagram with partially or totally blacked zones.

VI. Conclusions

The way of approaching of the kineto-static analysis in the paper hast at its basis the graphic methods which were forgotten a period of time because their low precision in obtaining the results.

With the apparition of the CAD soft, the notion of imprecision for the graphical methods disappeared. The results obtained with these softs have the same precision to that of the assisted analytical methods.

The vector mode in which works AutoCAD creates a strong closing to the vector methods used in mechanics and in the kinematic and kineto-static analysis of the mechanisms.

The present paper wishes, first of all, to prove this statement and to re-bring in nowadays the old graphic methods which are also intuitive.

When one produces an imagine of the mechanism or its animation, the obtained results give a distinct note to the work comparing to the tables of the values obtained with the aid of the analytical methods.

With the aid of the AutoLisp functions, one obtains numerical results from vector equations, without any representation of the vector polygonal. But it is very useful and easy to give a representation of it.

To realize the animation, in fact one establishes the parameters of interest and how must be realized the representation. In the AutoLisp functions presented in the paper are determined all the parameters; the only thing we have to establish is what we wish visualize.

The application was realized for a jointed Chebyshev type quadrilateral mechanism for 360 positions of the active element. In reference [8] were presented the all six AutoLisp functions that realize the kinematic analysis of the mechanism. From the main function presented there, one calls the two functions presented in this paper, the first determines the reactions in the RRR dyad, and the second one the reactions at the active element.

In the function **"R_3R"** presented in [8] after the calling of the function "**Reactiuni_RRR**", the results may be also obtained in files of data. Based o0n these files one plots the graphics in Figs. 6–8, containing the variation of the reactions R_A, R_B and R_C as functions of the angle φ_1 of the active element 1.

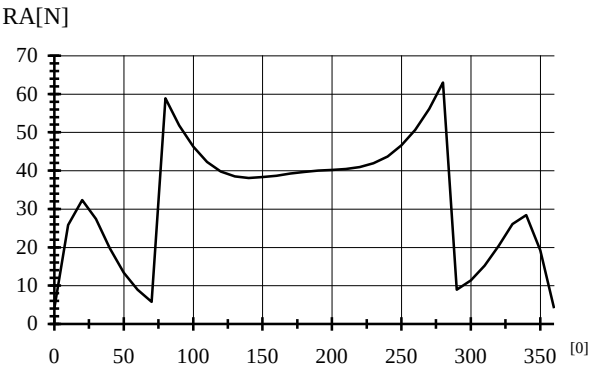

Fig. 6. The reaction in A.

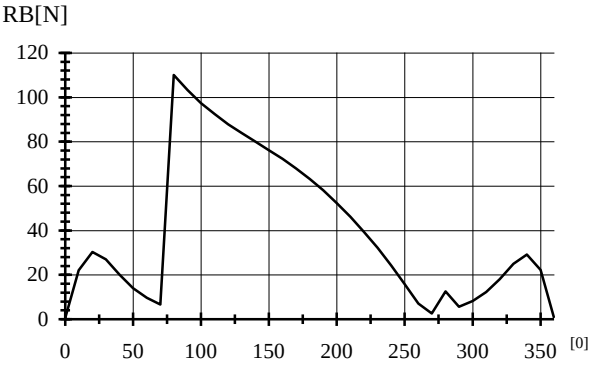

Fig. 7. The reaction in B.

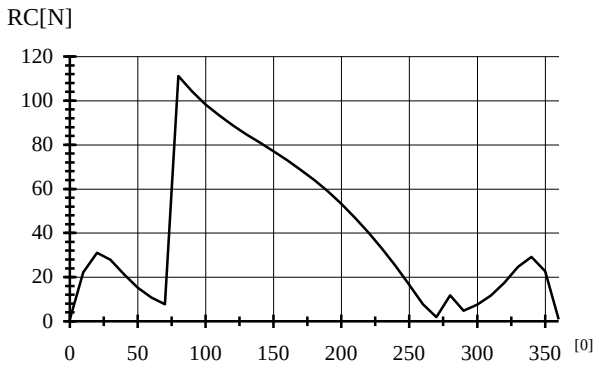

Fig. 8. The reaction in C.

In similar way for the active element, after the calling of the function "**React_Motor**" one obtains the graphic in Fig. 9 for the reaction R_O and the graphic in Fig. 10 for M_{e1}.

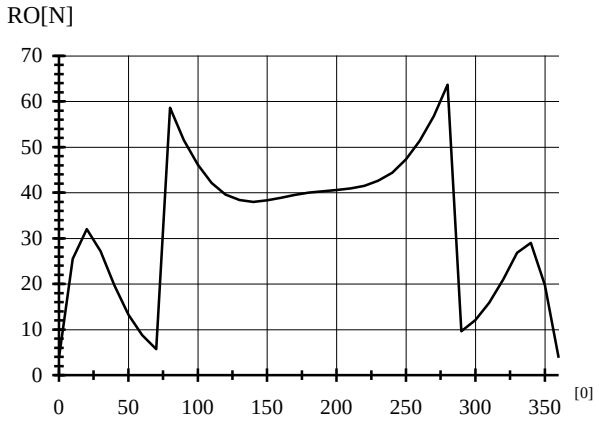

Fig. 9. The reaction in the joint O.

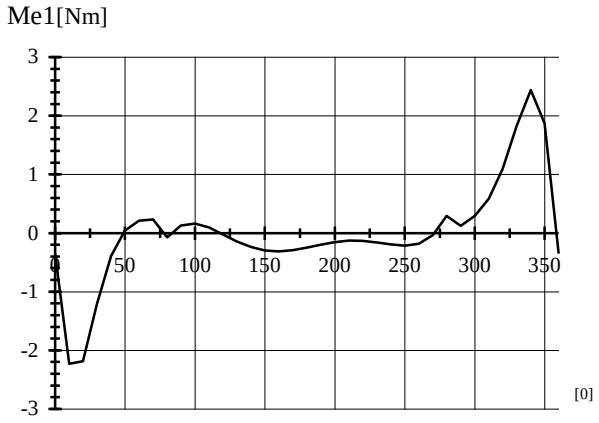

Fig. 10. The moment of equilibration.

In the 360 layers one obtained the position of the mechanism, the velocities, accelerations and forces polygonals. The polygonals are accompanied by letters at the vectors' arrows; in the case of the animation the letters move simultaneously with the vector. It is thus obtained a better clarity of the representation.

One can combine the results obtained in the kinematic analysis with those from the kineto-static analysis.

For instance, one can realize the animation only for shaft 2 in Fig. 1, accompanied by the representation of the reactions R_A and R_B in the joints in A and B. For this one must write the following lines of program:

```
(Command "Line" Amare Bmare "")
(Setq pFAmare(Polar Amare (Angle int pRAn)
(* RA kf)))
(Command "Line" Amare pFAmare "")
(Setq pFBmare(Polar Bmare (Angle pF int) (*
RB kf)))
(Command "Line" Bmare pFBmare "")
```

The following things were realized:

- the drawing of the segment AB with the command Line,
- the determination of the point pFAmare starting from the point A, **Polar** with the angle of the force R_A and a length $R_A k_f$, where by k_f was denoted the scale of representation of the force in the forces polygonal,
- the drawing of the force R_A at the point A with the command,
- the determination and the drawing of the force R_B at the point B in a similar mode.

Further on, one chooses a window of visualization that is kept constant when the element 1 takes the 360 positions.

One can proceed in an analogous way for any other element or vector which accompany the representation in a certain animation.

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