UDC 621.01(06)

V.A. Kyrylovych, R.S. Morgunov

KINEMATICS PROBLEMS OF INDUSTRIAL ROBOTS' GRIPPERS INTERACTION WITH OBJECTS OF MANIPULATION

Abstract. The heuristic algorithm of kinematics problems sequence solving, that suitable for automated searching of proposed before geometrically-forces and trajectory-dynamics parameters of industrial robots' grippers interactions with objects of manipulations which are components of automatic synthesis of robotic mechanical assembly technologies in flexible manufacturing cells is proposed.

Introduction. The solving of industrial robots' (IR) grippers (Gr) interactions with objects of manipulations (OM) is one of the stages of flexible manufacturing cells' (FMC) designing, and involves the interactions parameters components (vector-projection, geometrically-force, trajectory-dynamic) determination [3, 6]. All interactions components are interconnected, the search of one component is impossible without definition of another. The geometrically-forces and trajectory-dynamics parameters searching involves the limited set of kinematics problems (KP) solving, which include the search of IR' manipulation systems (MS) configuration states (CS) with Gr for each Gr's trajectories moving with and without OM which are generated earlier. In this the CS's changing for Gr's moving between neighboring points is performed by generalizes coordinates (GC) changing and should provide a possibility to realize the trajectory in control level [4, 5, 7, 8].

The information sources analysis has shown that today there are known a lot of methods of KP solving, which provides solving on geometrical level (definition of trajectories check points geometrical parameters based on terms of geometric IR's compatibility and technological equipment and ensure non-collision condition between IR's MS's construct elements and FMC's work positions (WP)) and kinematic level (could quickly find the MS's links final position, trajectories and velocity strictly for specific IR's MS's models which constructions are previously analysed and corresponding analytical expressions are established) [4, 5, 8]. Each of KP's methods has own advantages and disadvantages, but does not provide universal Gr's interaction with OM problem solving.

The contents of these Gr's interaction with OM problems has points to necessity for methodical sequence (algorithm) of KP's solving, which will take into account not only the Gr's pole coordinates, but also the Gr's final orientation with and without OM. In most cases in known methods of KP's solving the accent provided only for Gr's pole, and thus the result of KP's solving could be the final set of MS's links GC, which in further analyzed and then the best option will be selected. Its perfomed by exhaustive search of IR's MS's CS's set, which could last too long and in general case the none of received options will not be suitable for using in Gr's interaction with OM problems. Therefore we could say that the methodical sequence and algorithm for KP's solving, that are suitable for Gr's interaction with OM problems solving, in general case are missing.

The aim of the work is developing KP's solving algorithm which take into account Gr's pole coordinates and orientation, OM's orientation fixed in Gr for each different IR's MS's constructions with theirs kinematic redundancy, suitable for Gr's interactions with OM problems solving in automated synthesis of robotic mechanical assembly technologies.

Main part. The proposed algorithm of KP's solving consists of three main steps. First two steps based on one of the methods of discrete optimization – the method of branches and boundaries [1]. The content of the proposed algorithm is reduced to KP's solving through iterative determination of the distance between the end (which were set) and the current points of Gr's pole and also Gr's fixing points to the last MS's link (with further index CFP) and choosing of the MS's CS, which provides minimal distance between selected points.

The set Gr's points pole (P_{Gr}) and in accordance with Gr's fixing points to the last MS's link (P_{CFP}) which are obtained at the stage of determining the vector-projection component of Gr's interaction with OM [6] and defining a set of possible Gr's orientations that will ensure non-colission between elements of IR (MS, Gr) and WP (OM, device (Dv) and work equipment (WE)). Solving geometrically-force and trajectory-dynamic problems of Gr's interaction with OM involves generating corresponding trajectory of Gr's movement between WP and determining corresponding MS's CS for each point of the trajectory strictly given initial and final MS's CS, defined by KP solving by two (j-th starting and (j + 1)-th final) check points of trajectory with a set of linear and angular services parameters (LSP and ASP) [3].

A simplified diagram of the algorithm presented in the form SADT-diagram in fig. 1.

For correct working of algorithm the dimensions of each i_q-th GC q_{i_q} built to so-called local time, the value of which is in the range [0...1] where 0 and 1 – respectively the minimum and maximum values of each q_{i_q}-th MS's GC according to formalized description of MS [2]. So MS's configuration searching is automatically takes into account the structure of IR's MS's construction and type of GC (linear, angular).

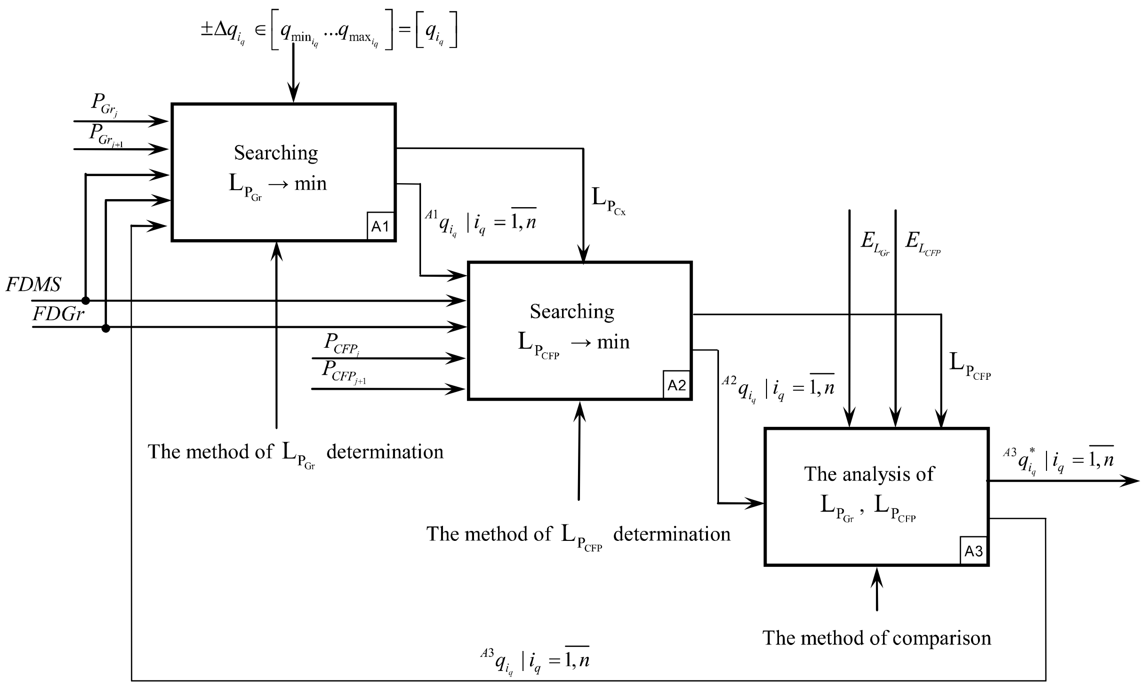


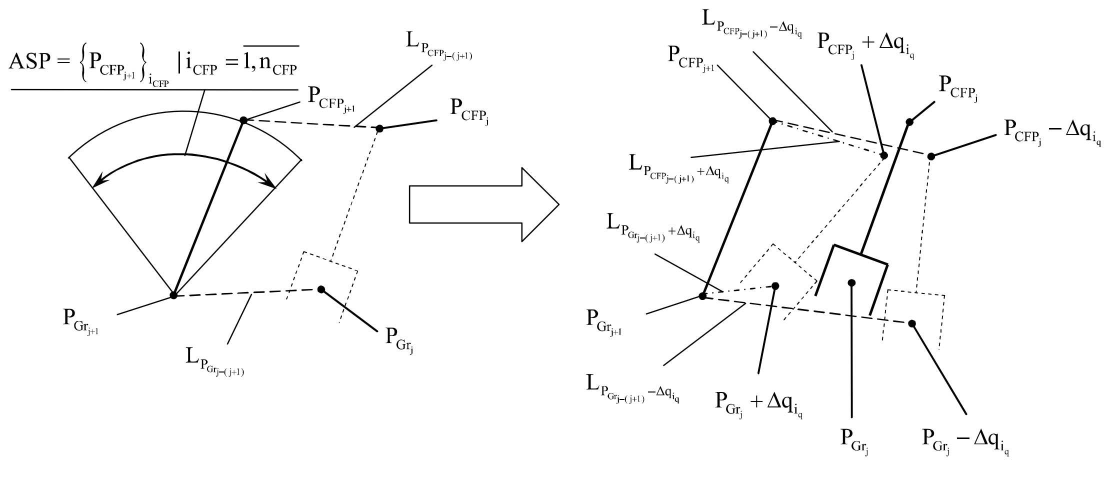
Fig. 1. SADT-diagram of proposed algorithm's work

Briefly the work of proposed algorithm consists of next few steps. The first step is searching the minimum $L_{P_{Gr_{j-(j+1)}}}$ distance between the current j-th and given (j + 1)-th P_{Gr} points. On the second step algorithm searches for the minimum $L_{P_{CFPj-(j+1)}}$ distance between j-th and (j + 1)-th P_{CFP} points. The content of the third step is comparing the obtained values $L_{P_{Grj-(j+1)}}$ and $L_{P_{CFPj-(j+1)}}$ with specified acceptable accuracy Gr's values ($E_{P_{Gr}} \equiv E_{P_{CFP}}$) according to passport data of IR.

The first step (block A1, fig. 1) provides step-changing of each i_q-th MS's GC in the direction from the base (first) MS's link to Gr with the saving of current MS's configuration. Then, for each i_q-th GC should change their local time by the initial step ($\pm\square q_{i_q}$), equal to 0.1. The resulting local time converting into GC's value, then the direct problem of kinematics (DPK) is solving based on converted new MS's GC's values and then analyzes the distances between the current Gr's poles coordinate $P_{Gr_{j/\pm q_i}}$ and setted points coordinate $P_{Gr_{j+1}}$ (fig. 2) then the option with the lowest difference of received distances values is selecting. So, during comparing process of corresponding parameters of Gr's moving by $+\Delta q_{i_q}$ and $-\Delta q_{i_q}$ values only the branch with best, ie minimal results, should considered. If the minimum values of two options of GC's changing (with $\tau_{\left(+\Delta q_{i_q}\right)}$ and $\tau_{\left(-\Delta q_{i_q}\right)}$) are equals so the steps value should decrease by the n!, ie $\Delta q_{i_q} = \Delta q_{i_q} \cdot n!^{-1}$, where n_i – iteration index, and the search operation of the minimum distance between points $P_{Gr_{j/\pm q_i}}$ and $P_{Gr_{j+1}}$ repeated until the smallest distance will founded or the step reduction will not lead to the reduction of distance between the analyzed j-th and (j + 1)-th points.

The second step (block A2, fig. 1) provides the search of minimal distance between P_{CFP_j} and $P_{CFP_{j+1}}$ points in direction from Gr to MS's base (1-th) link, namely the inverse kinematic problem is solving step by step for each i_q-th GC. The local time serching is same as in step 1.

 ISSN 1562-9945



a) b)

Fig.2. Illustration of new P_{Gr} points coordinates generation by GC's $+\Delta q_{i_q}$ and $-\Delta q_{i_q}$ values changing (b) within ASP (a)

The third step (block A3, fig. 1) provides the analysis of received values of distances between P_{CFP_j} and $P_{CFP_{j+1}}$, P_{Gr_j} and $P_{Gr_{j+1}}$ points, which should not exceed the values of IR's passport data's accuracy positioning – $E_{CFP} \equiv E_{Gr}$. If the deviation of distances between P_{CFP_j} and $P_{CFP_{j+1}}$, P_{Gr_j} and $P_{Gr_{j+1}}$ points not comply with the condition

$$\left(L\left(P_{CFP_j} - P_{CFP_{j+1}}\right) < E_{CFP}\right) \wedge \left(L\left(P_{Gr_j} - P_{Gr_{j+1}}\right) < E_{Gr}\right), \qquad (1)$$

then the step 1 should perfomed, but with current (calculated by step 1, 2) MS's CS. The search continues until the condition (1) will executed or a moment where on each iteration the values $L\left(P_{CFP_j} - P_{CFP_{j+1}}\right)$ and $L\left(P_{Gr_j} - P_{Gr_{j+1}}\right)$ will not decrease.

The results of proposed algorithm's work of KP's solving, that was realized in Delphi programming language, for IR's MS KUKA KR-30, kinematic structure of which is presented at fig. 3 (10 count of links, 6 GC: $q_{i_q} \mid i_q = \overline{1,6}$), is illustrated at fig. 4 and fig. 5.

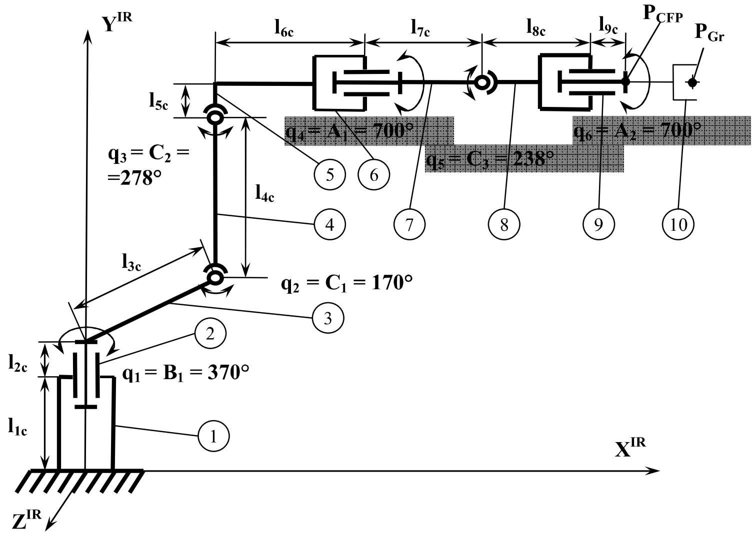
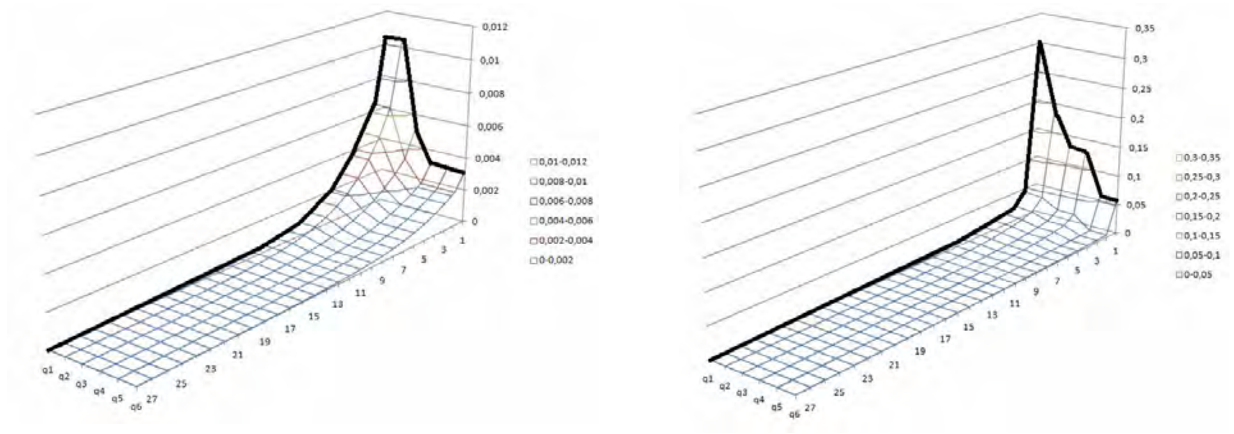
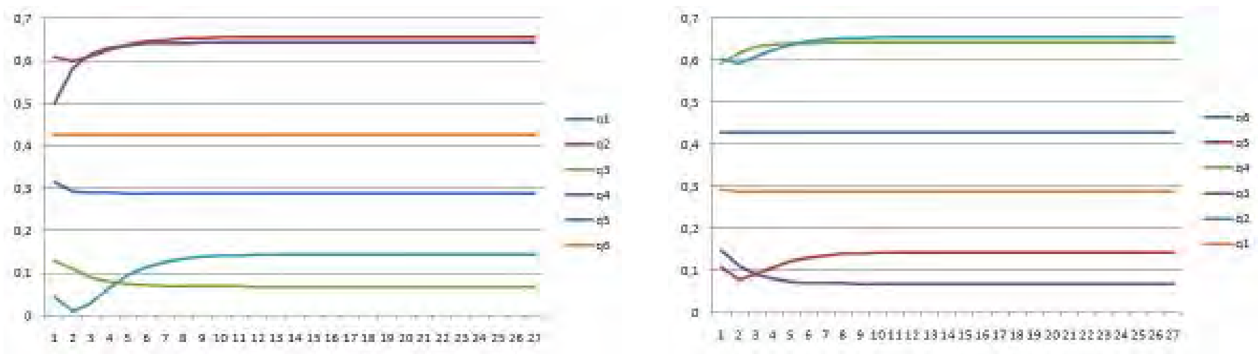


Fig. 3. Illustration of IR's MS KUKA KR-30 kinematic structure



a) b)

Fig. 4. Illustration of $L_{P_{Gr_{j-(j+1)}}}$ (a) and $L_{P_{CFP_{j-(j+1)}}}$ (b) distances decreasing during the cycle of KP solving with total iteration count ni = 28



a) b)

Fig. 5. Illustration of each MS's GC local times changing during the cycle with 28 iterations of KP solving by fig. 3

 ISSN 1562-9945

Fig. 4 indicates that through actual 28 iterations the received $L_{P_{Gr_{j-(j+1)}}}$ value is smallest and equal 0,147 mm, and in further with incrementing the iterations count actually unchanged (fig. 4, a and fig. 5, a).

Fig. 4, b illustrates the $L_{P_{CFP_{j-(j+1)}}}$ difference changing of each -th GC ($i_q = \overline{1,6}$) with corresponding local times changing by fig. 5, b and shows that by iterations count i_L = 28 the distance $L_{P_{CFP_{j-(j+1)}}}$ =0,145 mm. Note that $E_{CFP} \equiv E_{Gr} = \pm 0{,}15$ mm [9].

Calculated in proposed way IR's MS's GC are compared with ASP's and LSP's values and used in effective Gr's interaction with OM problems solving.

Conclusions. The analysis of the results for different points $P_{CFP_{j+1}}$ and $P_{Gr_{j+1}}$ coordinates has shown that the decreasing of the distance between analyzed points has changing in first 12 iterations of step 3, as it shown at fig. 4, after that the changing of Δq_{i_q} characterized by thousandths values of $\pm\Delta q_{i_q}$, that are too small and further calculation has not lead to significant changes by condition (1) and therefore ignored.

Thus for increasing the speed of mentioned calculations the number of iterations with GC's values receiving that will satisfy to condition (1) could be reduced (bold line at fig. 4, a and fig. 4, b), which will reduce CPU load at high iterations count (the order of tens of thousands), that defined first of all by each q_{i_q} GC's parameters and their count

The proposed KP's solving algorithm allows fully generate the trajectories of Gr's moving between WP (required for solving geometrically-force and trajectory-dynamic Gr's interactions with OM problems) and has used in automated synthesis of robotic mechanical assembly technologies wich developed in Zhytomyr State Technological University.

REFERENCES

1. Андерсон Д. А. Дискретная математика и комбинаторика / Д. А. Андерсон – Пер. с англ. – М.: Издательский дом "Вильямс", 2004. – 960 с.
2. Кирилович В.А. Узагальнена функціональна модель промислових роботів / В.А. Кирилович, Р.С. Моргунов // Вісник національного університету "Львівська політехніка" "Оптимізація виробничих процесів і технічний контроль у машинобудуванні та приладобудуванні". – Львів. – 2012. – Вип. №746. – С. 66–70.
3. Кирилович В.А. Методично-програмне забезпечення визначення технологічних параметрів сервісу для тіл обертання / В.А. Кирилович, П.П. Мельничук, Р.С. Моргунов // Науковий вісник Херсонської державної морської академії: Науковий журнал. – Херсон: Видавництво ХДМА. – 2013. – №1 (8). – С.225–232.
4. Корендясев А.И. Теоретические основы робототехники: В 2 кн. : Монография. Кн. 1 / Под ред. С.М. Каплунова. – М. : Наука, 2006. – 383 с.
5. Корендясев А.И. Теоретические основы робототехники: В 2 кн. : Монография. Кн. 2. – М. : Наука, 2006. – 376 с.
6. Мельничук П. П. Задачі технологічної взаємодії схватів промислових роботів з об'єктами маніпулювання в механоскладальних гнучких виробничих комірках / П. П. Мельничук, В. А. Кирилович, Р. С. Моргунов // Збірник наукових праць Житомирського державного технологічного університету "Процеси механічної обробки в машинобудуванні". – Житомир. – 2011. – Вип. №10. – С.24–41.
7. McCarthy J. M. An Introduction to Theoretical Kinematics / J. M. McCarthy. - Cambridge, MA : MIT Press, 1990. – 145 p.
8. Siciliano Bruno. Springer Handbook of Robotics / Bruno Siciliano, Oussama Khatib. – Berlin : Springer, 2008. – 1631p.
9. Kuka Robotics: technical data KR 30-3. [Electronic resource] – the mode of access to the directory: http://roboticturnkeysolutions.com/robots/kuka/datasheet/kr_30.pdf