Information Models of Flexible Manufacturing Cell Components and Related Drawing up Features

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Abstract

The paper analyses the feasibility of using the quaternion as a single semantic unit for compiling the information models supported by the analysis results of existing creation methods of information models of flexible manufacturing cell individual components, in relation to the general concepts of the theory of quaternions. By structural components the authors refer to industrial robots (handling systems and grippers), main and auxiliary technological equipment units, used on devices and objects of manipulation (OM) such as workpieces, semi-finished products, assembly components, etc. The authors present the use of the proposed approach for compiling the information models of the separate geometric primitives and the ordered set for the kinematic structure of the manipulation system of a real industrial robot. Further indicated is the versatility of the proposed approach, describing basic geometric primitives and their possible combinations of 3D parameters of the individual structural components of a flexible manufacturing cell, while displaying the mobility of the components or the immobility of units or elements, specifying the type and the value of relative displacements.

Keywords

information model, geometric primitive, industrial robot, quaternion, working position, component

1. Introduction

1.1. Relevance

Modern automated production, especially small-series batch production is actually impossible without using universal remedies of flexible automation like industrial robots (IR) are [1 ... 4]. The flexible manufacturing cell (FMC) is an elementary component of modern flexible manufacturing systems. It is rather simple, but as to date not completely investigated from the point of view of its effective operation. Thus, one IR technologically serves certain units of processing equipment (the basic and the auxiliary processing equipment). It carries out many auxiliary technological operations. For example, the IR ensures the unloading of objects of manipulation (OM) (preparations, assembly elements and so on) to the working posts, their transportation between various working posts, the loading of working posts with OM according to a known route of technological impact.

The production of FMC entails a synthesis of the robotized technologies. It is necessary to have information on devices, on robots and their geometrical and kinematic parameters. It is also important to have information on the OM because their design features define what types of processes and grippers will be used for interaction with the objects. Components of the FMC are the specified structural elements, manipulation objects and the features of working zones influencing the automated synthesis of trajectories. The information models (IM) of components are necessary for the solution of a wide range of tasks, allowing decisions that determine the efficiency of the robotized production.

It is obvious that IM (the structure and contents of information on components) have to be informative and sufficient and have to be presented in a form accepted for the further automated solution of a final set of problems in this domain.

1.2. Critical Analysis of Literature in the Field

There are IM of machine-building details which are focused on the use of computer-aided engineering systems, meaning that they use automated design of route and operational metalworking technologies. Basis of the design are the tables of correspondence previously devised by the designer. One of the parameters of these tables is the IM of a detail. Thus the system of coding of design-technology information is the basis for the model [5]. Initially information is not focused on use in the specified domain. It is essentially superfluous on the one hand and insufficiently informative on the other hand. This means that it cannot be used in the context of the solution for technological tasks in the robotics of machine-assembling productions.

A more acceptable option for the possible use of robotized machine-assembling technology synthesis is the data presentation method of the OM in the form of the full IM [5, 6] consisting of the ordered set of partial models of a certain structure and their respective contents. Such information models can be used only for the solution of tasks of the vector and projective contents. They do not allow to solve the entire complex of problems, for example, to solve kinematics problems.

The method of R-functions is a known approach of receiving or drawing up information on the OM and other components of FMC [6]. The device of R-functions allows to work out the equations of assembly drawings and spatial objects, and also to build the equations of families of the surfaces including the set geometrical objects. Thus there is the algebraic function $F(x,y,z)$, the derivative is in all points of a contour positive, outside a contour negative, and on the border equal to zero. Such description gives information only on the geometrical characteristics of a contour of the studied objects (as mentioned before). The use of this device is partially possible, but inexpedient for the solved tasks as it entails a rather work-intensive effort of the designer for the formation of the specified function F. The mathematical processing of such information and its automated realization is rather difficult. Thus it is not deemed possible to display the mobility of the manufacturing of the described FMC components in the devised models.

There is one more method focused on the solution of technological problems of robotics. The method involves the description of the internal and external contours of the studied objects (such as the OM), allowing to have full geometrical information on the object [7]. While it can be used for the solution of certain problems of the technological interaction of the gripper with the OM [4, 8], it is unacceptable for other problems because of a narrow orientation of such IM.

Another method of OM description is based on a marking of the OM drawing and consists in allocating numbers to the OM constructive elements, a marking of the drawing, coding of the components, and then of the elementary elements of a form [5, 6]. The marking of the basic contour elements of a detail without the central holes is carried out from an extreme left or top end face. Then all external surfaces are marked in sequence and the process is finalized at the extreme right (lower) end face. The marking of the contour elements having openings begins with an extreme left (top) end face and ends with the central hole. The marking of the details which are not rotation bodies is carried out in any order.

Coding of the constructive elements requires specialized software. This method is not universal as it is not created on the general basis of the relation “a code – an OM constructive element”. It does not allow the solving of a number of geometrical and kinematic problems in robotized productions.

Another approach to drawing up and achieve the formalized description of IM utilizes the theory of quaternions [9, 10]. Quaternions, due to their mathematical features allow describing an immovability and / or mobility of separate parts of the studied objects, but do not display them in 3D-parameters.

The proposed technique of IM drawing expands the advantages of using quaternions by offering solutions of the geometrical and kinematic tasks, and of the dynamic contents due to introduction of the relevant data, 3D-parameters, the mass of links, speeds of their relative movements. It considerably simplifies and in some cases makes possible carrying out the intermediate and final calculations defining these or those results, for example the solution of problems of interaction between the IR gripper and OM [8, 11, 12], between OM and devices of the FMC’s working posts [4, 8].

There are cases where the need for the availability of IM of robots is not so pronounced. For example, information models are not relevant with cognitive control robots in a dynamically changing environment [14]. The subsequent detailing, however, of the composition of tasks requires the availability of relevant information models especially for mobile robots moving in this environment. Information models of robots are needed to simulate situations to prevent collisions with external static and / or dynamic obstacles. One approach for devising such information models is described below.

There are many specialized MBS packages using comparisons of different geometrical objects in real time, together with the determination of the parameters of these comparisons [15]. Such packages are used for architectural, geodetic and others areas. For problems pertaining to industrial robotics they cannot be used because their contents does not reflect features of the domain. Further, the packages are actually not acceptable for the solution of tasks (first of all the kinematic contents) necessary for the synthesis of robotized technologies.

The widely known operating system for robots ROS (Robot Operation System) [16] is a flexible framework for writing software for the functioning of robots for various purposes, including for industrial robots. ROS is a set of tools, libraries and conventions aimed at simplifying the task of creating complex and simplified behavior of the analyzed robot in a variety of robotic platforms. Despite the obvious advantages of scientific and practical use of the package of ROS, its application in solving problems of automated synthesis of robotized mechanical assembling technologies is impossible. Its utilization is not possible at the stage of technological preparation of machine-assembling robotic production, because the package does not allow the simulation of the process of synthesis of the gripper trajectories when they are moved to production cells. ROS cannot be used without information models of the components of flexible manufacturing cells, the basis of preparation and the IM not being clear from the available information about the capabilities of ROS.

The common fault of the discussed approaches to drawing up the IM components of FMC is the lack of universality and a fragmentariness in application that causes the necessity of IM development, such as to eliminate these shortcomings at least partially.

1.3. Purpose of the Paper

The purpose of the paper is the consideration of the generalized approach to drawing up IM of FMC components by means of the theory of quaternions and geometric primitives bearing information on the geometrical, kinematic and design features of each of the components, which will be used as the information part in the system of automated synthesis of the robotized machine-assembling technologies in mechanical engineering and tool making.

1.4. Novelty of the Paper

For the first time in uniform mathematical representation by the concepts of the theory of quaternions, the developed information models of all structural components of FPC give the possibility of their joint analysis as a complex and allow researchers to make technological system related decisions. For industrial robots the offered information models of their handling systems as complete systems regarding structure, kinematic opportunities and geometrical parameters of their links due to information completeness and sufficiency of such description and in combination with the similar description of other FPC structural elements give the possibility systemically and effectively to solve geometrical, kinematic and other optimizing problems of the automated synthesis of the robotized machine-assembling technologies [17].

2. Contents

2.1. Description of the Geometrical Primitives

Drawing up IM of FMC components entails a sequence of steps. The first step is the analysis of a component design, followed by the drawing up of a so-called equivalent circuit (this is the drawing up of a wire model of a component). The second step is the replacement of mobile and / or motionless elements of an equivalent circuit of a component by their 3D - equivalents by means of geometrical primitives. The third step - drawing up the information model of components by taking into account their possible mobility or immovability.

The form of each structural element of a cell can be described by means of a set of elementary geometric primitives (SE – sphere, CR – cylinder, CE – cone, PD – parallelepiped, TZ – trapeze) and their combinations [18].

The reference point in the description of each of geometric primitive is formally described by the so-called target point with the coordinates corresponding to it of the geometric primitives, in the following (possible) ordered description:

$$X_{Gp}, Y_{Gp}, Z_{Gp} | G_p \epsilon (Pd, Cr, Se, Ce, Tz). \tag{1}$$

Figures 1 ... 6 give examples of descriptions of each of the mentioned geometric primitives, the corresponding comments to the designations being given below.

“Sphere” description:
SE: X_{Se}, Y_{Se}, Z_{Se}, R_{Se}
a)

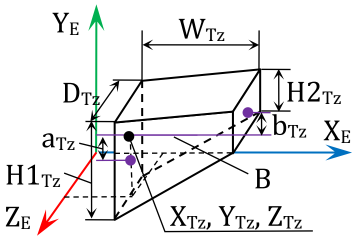
“Cylinder” description:
CR: X_{Cr}, Y_{Cr}, Z_{Cr}, R_{Cr}, L_{Cr}
b)

Fig. 1. Basic placement of the center (target point) of “sphere” (a) and “cylinder” (b) in the system of coordinates of the FMC element

“Cone” description:
CE: X_{Ce}, Y_{Ce}, Z_{Ce}, R_{Ce}, r_{Ce}, L_{Ce}
a)

“Parallelepiped” description:
PD: X_{Pd}, Y_{Pd}, Z_{Pd}, W_{Pd}, H_{Pd}, D_{Pd}
b)

Fig. 2. Basic placement of the center (target point) of “cone” (a) and “parallelepiped” (b) in the system of coordinates of the FMC element



“Trapeze” description:
TZ: X_{Tz}, Y_{Tz}, Z_{Tz}, D_{Tz},
W_{Tz}, $H1_{Tz}$, $H2_{Tz}$, a_{Tz}, b_{Tz}

Fig. 3. Basic placement of the center (target point) of “trapeze” in the system of coordinates of the FMC element

The notations in Figure 1a are:

SE - primitive identifier **SE** (sphere);
X_{Se} - sphere arrangement along axis X in the system of coordinates of an element E, in mm;
Y_{Se} - sphere arrangement along axis Y in the system of coordinates of an element E, in mm;
Z_{Se} - sphere arrangement along axis Z in the system of coordinates of an element E, mm;
R_{Se} - sphere radius, in mm.

The notations in Figure 1b are:

CR - primitive identifier **CR** (cylinder);
X_{Cr} - cylinder arrangement along axis X in the system of coordinates of an element E, in mm;
Y_{Cr} - cylinder arrangement along axis Y in the system of coordinates of an element E, in mm;
Z_{Cr} - cylinder arrangement along axis Z in the system of coordinates of an element E, in mm;
R_{Cr} - cylinder radius, in mm;
L_{Cr} - cylinder length, in mm.

The notations in Figure 2a are:

CE - primitive identifier **CE** (cone);
X_{Ce} - cone arrangement along axis X in the system of coordinates of an element E, in mm;
Y_{Ce} - cone arrangement along axis Y in the system of coordinates of an element E, in mm;
Z_{Ce} - cone arrangement along axis Z in the system of coordinates of an element E, in mm;
R_{Ce} - left cone radius, in mm;
r_{Ce} - right cone radius, in mm;
L_{Ce} - cone length, in mm.

The notations in Figure 2b are:

PD - primitive identifier **PD** (parallelepiped);
X_{Pd} - parallelepiped arrangement along axis X in the system of coordinates of an element E, in mm;
Y_{Pd} - parallelepiped arrangement along axis Y in the system of coordinates of an element E, in mm;
Z_{Pd} - parallelepiped arrangement along axis Z in the system of coordinates of an element E, in mm;
W_{Pd} - parallelepiped length, in mm;
H_{Pd} - parallelepiped height, in mm;
D_{Pd} - parallelepiped depth, in mm.

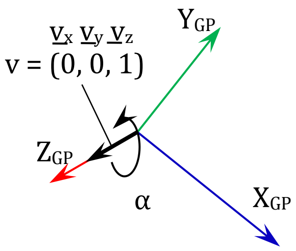
The notations in Figure 3 are:

TZ - primitive identifier **TZ** (Trapeze);
X_{Tz} - trapeze arrangement along axis X in the system of coordinates of an element E, in mm;
Y_{Tz} - trapeze arrangement along axis Y in the system of coordinates of an element E, in mm;
Z_{Tz} - trapeze arrangement along axis Z in the system of coordinates of an element E, in mm;
D_{Tz} - trapeze depth, in mm;
W_{Tz} - trapeze length, in mm;
$H1_{Tz}$, $H2_{Tz}$ - trapeze left height, and trapeze right height, respectively, in mm;
a_{Tz} - distance between basic axis B and the center of a side with height of H1, in mm;
b_{Tz} - distance between basic axis B and the center of a side with height of H2, in mm.

At the orientation change of the geometric primitives it is necessary to specify the orientation quaternion described by four auxiliary parameters of quaternions:

$$Q = [S_Q, X_Q, Y_Q, Z_Q]. \tag{2}$$

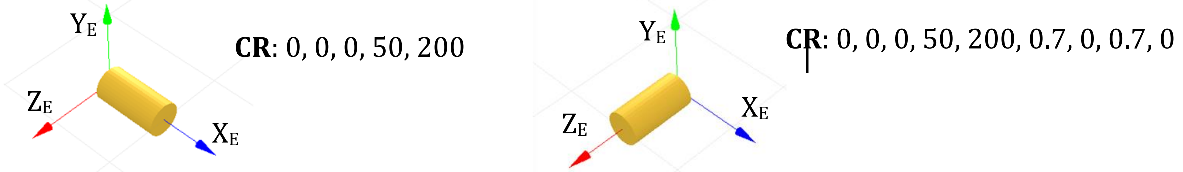
The parameters specified in (2) influence only the orientation of one geometric primitive of the considered element *E*, which in this case is the geometric primitive presented in Figure 4.



$$\mathbf{Q_E} = (\mathbf{s}, \mathbf{v}) = (\mathbf{s}, \mathbf{v_x}, \mathbf{v_y}, \mathbf{v_z}) = \\ = \left(\cos\frac{\boldsymbol{\alpha}}{2}, v_x \cdot \sin\frac{\boldsymbol{\alpha}}{2}, v_y \cdot \sin\frac{\boldsymbol{\alpha}}{2}, v_z \cdot \sin\frac{\boldsymbol{\alpha}}{2}\right)$$

Fig. 4. Example of the rotation of element *E* by axis Z by α°

Figure 5 presents the example of the information model of a “cylinder” (CR) geometric primitive before and after orientation (rotation by axis Y by 90°).



a) b)

Fig. 5. An example of the description and the corresponding 3D model of a "cylinder"geometric primitive a) without orientation quaternion (initial situation); b) with an orientation quaternion (final situation)

2.2. Example of Drawing up the Information Models of the Real IR Handling System

The example of the IR IM handling system (the model KUKA KR-30) giving the general idea of the content of the described approach to drawing up information models of FMC components is given below.

As a result of splitting (decomposition) of the handling system of the IR model KUKA KR-30, the kinematic structure of which is shown in Figure 6, separate geometrical primitives are obtained, ordered in the direction from stand to gripper, in the case of compilation of the IM of the IR handling system.

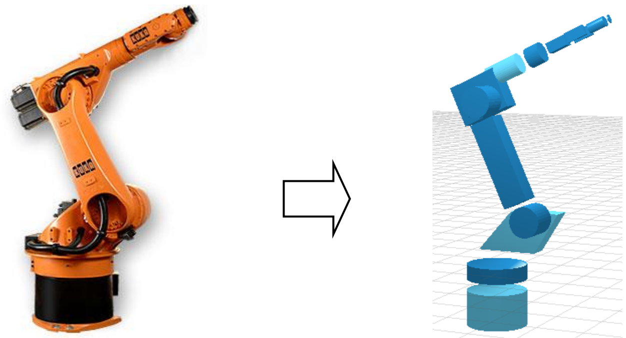


Fig. 6. An illustration of the definition of quantity and types of geometric primitives for 3D - an equivalent of the IR handling system model KUKA KR-30

The IR handling system consists of nine links, indicated by circled numbers in Figure 7, namely six mobile links – 2, 4, 5, 7, 8 and 9, and tree motionless links – 1, 3 and 6. Each link is identified by the corresponding geometric primitive, each of which is described by the corresponding information model.

Figure 8 and expression (3) illustrate a form and information model of link 1, and Figure 9 and expression (4) – a form and information model of the entire handling system of the industrial robot.

$$(\text{KUKA KR}-30) = \{\mathbf{L1}: (\mathbf{D}: 0{,}1{,}0; \mathbf{S}: 350; \mathbf{M}: 250;\ \mathbf{GP}: [\mathbf{CR}: 0, 0, 0, 300, 350;])\}, \tag{3}$$

where

(KUKA KR-30) is the IR model of the analysed handling system;

L1 is element 1 in the handling system of IR

D:0,1,0 – L1 link arrangement vector in the handling system of the IR system of coordinates

arrangement L1 along an axis Z^{IR}

arrangement L1 along an axis Y^{IR}

arrangement L1 along an axis X^{IR}

M:250 – mass of a link of L1, in kg

GP: – the identifier of the group of geometric primitives by means of which the IR handling system link form is described

CR: 0, 0, 0, 300, 350 – "cylinder" geometric primitive

L – length of the cylinder, mm

R – radius of the cylinder, mm

arrangement of a geometrical primitive along axis Z in SC of a link L1, mm

arrangement of a geometrical primitive along axis Y in SC of a link L1, mm

arrangement of a geometrical primitive along axis X in SC of a link L1, mm

identifier of a primitive of CR – "cylinder"

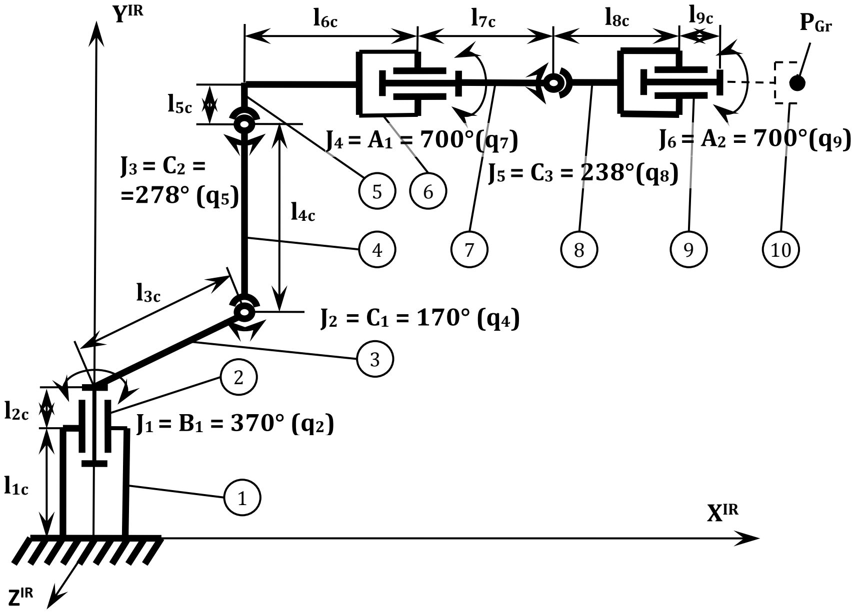


Fig. 7. The kinematic structure of the IR handling system model KUKA KR-30

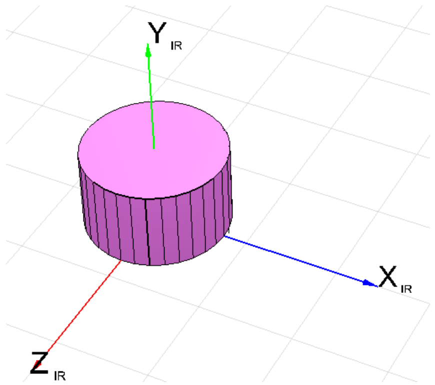


Fig. 8. The link L1 3D-solid-state model of the IR handling system model KUKA KR-30

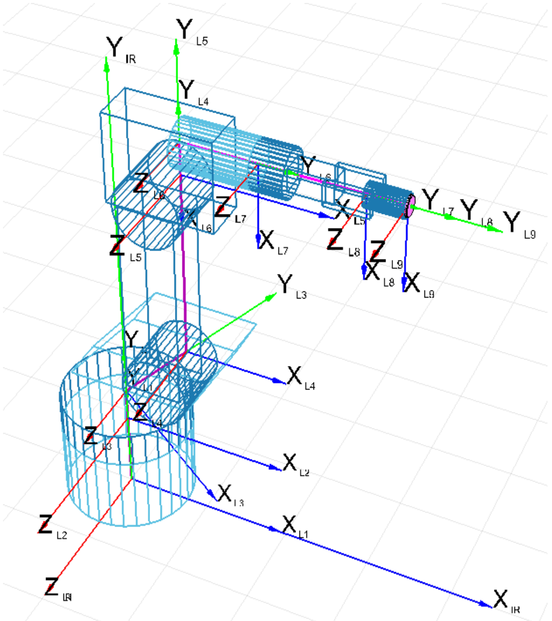


Fig. 9. The L1 – L9 3D-solid-state models of the IR handling system model KUKA KR-30

$$\begin{array}{c}
(\text{KUKA KR}-30)\ =\ \{\text{L1: (D: 0,1,0; S: 350; M: 250; GP: [CR: 0, 0, 0, 300, 350;]);}\\
\text{L2: (D: 0,1,0; S: 150; M: 137; V: 140; }Q_{min}: -0.044, 0, -0.999, 0;\\
Q_{max}: -0.044, 0, 0.999, 0;\ \text{GP: [CR: 0, 0, 0, 300, 150;]);}\\
\text{L3: (D: 1,1,0; S: 450; M: 92;}\\
\text{GP: [TZ: 220, 220, }-100\text{, 200, 400, 600, 500, 300,0, 0.924, 0, 0, 0.383;]);}\\
\text{L4: (D: }-1\text{,1,0; S: 850; M: 60; V: 126; }Q_{min}: 0.462,0,0,-0.887;\ Q_{max}: 0.924,0,0,0.383;\\
\text{GP: [CR: 0,0,0,150,300, 0.707,0.707,0,0; PD: 0,0,200,850,250,200;]);}\\
\text{L5: (D: 0,1,0; S: 145; M: 40; V: 140; }Q_{min}: 0.829,0,0,-0.559;\ \text{Qmax: }-0.259,0,0,0.966;\\
\text{GP: [CR: 0,0,0,150,300, 0.707,0.707,0,0; PD: }-50,-150\text{,0,400,500,200;]);}\qquad (4)\\
\text{L6: (D: 1,0,0; S: 350; M: 20; GP: [CR: 0,0,0,100,350;]);}\\
\text{L7: (D: 0,1,0; S: 465; M: 10; V: 260; }Q_{min}: -0.996,0,-0.087,0;\ Q_{max}: -0.996,0,0.087,0;\\
\text{GP: [CR: 0,0,0,100,150; PD: 0,150,0,200,100,100;}\\
\text{PD: 0,310,}-60\text{,200,100,30; PD: 0,310,60,200,100,30;]);}\\
\text{L8: (D: 0,1,0; S: 170; M: 5; V: 245; }Q_{min}: 0.508,0,0,-0.862;\\
\text{Qmax: 0.508,0,0,0.862; GP: [CR: 0,0,0,50,170;]);}\\
\text{L9: (D: 0,1,0; S: 10; M: 1; V: 322; }Q_{min}: -0.996,0,-0.087,0;\\
Q_{max}: -0.996,0,0.087,0;\ \text{GP: [CR: 0,0,0,40,10;]); },
\end{array}$$

where L9 is link 9 in the IR handling system;

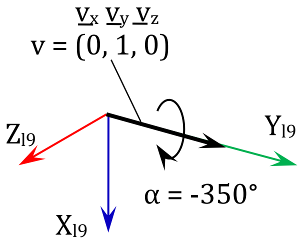
D: 0,1,0 – vector of the direction of a link of L9 in the system of coordinates of L8 link
arrangement along an axis Z_{L8}
arrangement along an axis Y_{L8}
arrangement along an axis X_{L8}

S:10 is the geometric amount of wire representation of a link
L9 └ L9 link length, in mm

M:5 is mass of a link of L9

V:245 is the maximum speed of movement of a link of L9, in °/s

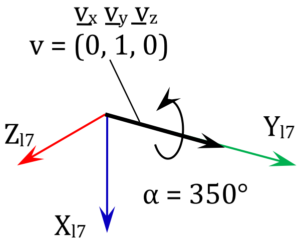
Q_{min}: -0.996,0,-0.087,0 is the minimum quaternion of the restriction of the magnitude of movement (rotation) of the L9 link coordinate system.



$$\mathbf{Qmin} = (\mathbf{s},\mathbf{v}) = (\mathbf{s},\mathbf{v_x},\mathbf{v_y},\mathbf{v_z}) = \left(\cos\frac{\alpha}{2}, v_x\cdot\sin\frac{\alpha}{2}, v_y\cdot\sin\frac{\alpha}{2}, v_z\cdot\sin\frac{\alpha}{2}\right)= \left(\cos\frac{-119^\circ}{2}, 0\cdot\sin\frac{-119^\circ}{2}, 0\cdot\sin\frac{-119^\circ}{2}, 1\cdot\sin\frac{-119^\circ}{2}\right) = \\ = \left(\cos(-59{,}5^\circ), 0{,}0, \left(\sin(-59{,}5^\circ)\right)\right) = (-\mathbf{0.996}, \mathbf{0}, -\mathbf{0.087}, \mathbf{0})$$

Fig. 10. The illustration of the rotation of element L9 by axis Y by α = m – 350°

Q_{max}: +0.996,0,0.087,0 is the maximum quaternion of restriction of the magnitude of movement (rotation) of a link of L9



$$\mathbf{Qmax} = (\mathbf{s},\mathbf{v}) = (\mathbf{s},\mathbf{v_x},\mathbf{v_y},\mathbf{v_z}) = \left(\cos\frac{\alpha}{2}, v_x\cdot\sin\frac{\alpha}{2}, v_y\cdot\sin\frac{\alpha}{2}, v_z\cdot\sin\frac{\alpha}{2}\right)= \left(\cos\frac{-350^\circ}{2}, 0\cdot\sin\frac{-350^\circ}{2}, 0\cdot\sin\frac{-350^\circ}{2}, 1\cdot\sin\frac{-350^\circ}{2}\right) = \\ = \left(\cos(-175^\circ), 0{,}0, \left(\sin(-175^\circ)\right)\right) = (-\mathbf{0.996}, \mathbf{0}, \mathbf{0.087}, \mathbf{0})$$

Fig. 11. The illustration of the rotation of element L9 by axis Y by α = +350°

GP: is the identifier of the group of geometric primitives that describe the IR handling system link form.

CR:0, 0, 0, 40, 10 –“cylinder" geometric primitive
L – length of the cylinder, mm
R – radius of the cylinder, mm
CR arrangement along axis Z in SK of link L9, mm
CR arrangement along axis Y in SK of link L9, mm
CR arrangement along axis X in SK of link L9, mm
identifier of primitive CR (Cylinder) – “cylinder”.

2.3. Versatility of the Proposed Drawing Up

Also other FMC components are similarly described: objects of manipulation and barriers (motionless components, the group of elements C), IR grippers [9, 10, 11, 12] and devices [13] containing both motionless, and mobile elements (groups of C and V elements).

The IM components are used in the automated determination of the technological parameters of service [11], in research on the power consumption related to robotic trajectories [21], in the consideration of the solutions of problems of kinematics for the kinematic excess of IR handling systems [22].

3. Conclusion

As a result of the research presented and discussed in this paper, the following features of information models for the development of flexible manufacturing cell components can be specified:

– a single mathematical apparatus in case of IM creation is the theory of quaternions. The description of all components as single semantic units – quaternions – owing to these providing a scalar and vector component, allows describing both the motionless structural components, and mobile ones displaying linear and rotary movements. It is especially important for the description of relative movements of mobile links of the handling system, gripper elements, mobile elements of each working post device;

– utilisation in the quaternion description of components of geometric primitives allows the recreation of 3D models as separate parts of each component and their arrangement in sequence. It is important in the case of the solution of a number of tasks of technological content, for example, for the determination of the trajectory parameters of the gripper movements in case of technological operations of unloading and loading of each working post;

– including into the information model of the CFR of parameters used for “connecting” separate cells determined by features of the described component for the display of their ordered sequence; for example, in the case of the description of the ordered sequence of links of the handling system, gripper, and devices is universal;

– other parameters (weight and speed of the relative movement of links) brought into the IM allow the further solving of direct and inverse problems of kinematics and dynamics necessary for determining the temporary and dynamic parameters of synthesizable gripper trajectories, and also the determination of the link control laws for the automatic implementation of the synthesized optimum trajectory of gripper movements.

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