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ANALYSIS OF DYNAMIC-MATHEMATICAL MODEL OF INDUSTRIAL ROBOT AND ITS ENVIRONMENT IN THE ASSEMBLY PROCESS MODELLING

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ABSTRACT
In this paper we analyse dynamic-mathematical model of industrial robot. Also we analyse industrial robot environment. Also we give a model of insertion process and necessary equations. Dynamic – mathematical model is good to be analysed because it depends on all parameters not only on force and deformations whoch are the main parameters in quazi-statical model of insertion process.Insertion process is complex dynamic process, and it is under influence of insertion speed, insertion acceleration, friction, inertia, gravity.
Keywords: industrial robot, model, assembly, insertion process

1. INTRODUCTION
Considering that NC centres proved as very slow, robust and unsatisfactory for manufacturing it was necessary to have a studious, scientific admission in research of main principles of assembly. The main problem is phenomenon of part insertion which is the ground basis of assembly process. Starting basis in the part insertion theory heve been given by author [1] in the 1980-ies. Considering the fact that in the same time there were researches in some other institutes and laboratories we will list some of them: Prof. H.J Warnecke and Prof. R. Schraft, Prof. H. Makino, Prof. G. Boothroyd, Prof. H. Van Brussel. All those resarches have been made on the new concept basis of automatic assembly which means use of sensor systems, robot manipulators, artificial intelligence. In other words we can say it is concept of intelligent assembly. The researhers put great efforts in three directions which are: development of insertion process theory, development of robot manipulators and development of constructive solutions for automatic assembly of products. The research results in the area of assembly have got huge influence in the researches in the robotics, and so we get new scientific field called robotized assembly. In this field are very important the researches of concrete tasks and relations between robot and its environment. This paper will also give a modest contribution in that direction. Paper describes dynamic admission in modelling of insertion process.

2. DYNAMIC-MATHEMATICAL MODEL OF INDUSTRIAL ROBOT AND ITS ENVIRONMENT
In contrast to quasi-static model which takes into consideration mechanical characteristics like contact force and contact deformations and speed and acceleration are ignored (contact of physical objects is considered on aspect of contact geometry and contact force – insertion force), dynamic-mathematical model takes into consideration insertion speed, acceleration and inertial characteristics of physical objects which takes apart in insertion process. In dynamic admission of insertion process problem can be analysed as problem of dynamic relation between two objects in contact. Inertial researches and dynamic characteristics were analyzed in papers [6,7,8].
Physical model of robotized insertion process contents following parts:
- handling robot with necessary degree of movement,
- secondary handling robot with necessary active degree of movement on the top of robot,

- end-effector with pasive elements,
- objects to be assembled.

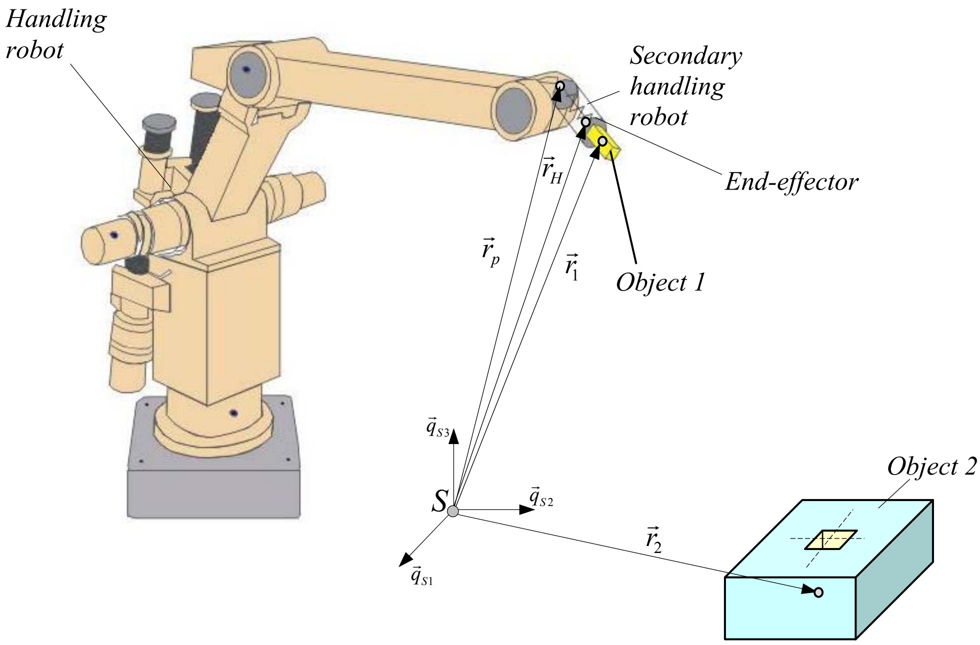

Figure 1: Structure of dynamic-mathematical model of industrial robot and its environment

Insertion process is geometry problem [9], and from the aspect of assembly important are only main and accessory contact surfaces and we can say that the description of whole geometry of object 1 and object 2 can be reduced on those surfaces (Figure 2). For analytic formulation of insertion objects contact surfaces it is necessary to define appropriated system coordinates just like in Figure 2: object 1 ($\vec{q}_{011},\vec{q}_{012},\vec{q}_{013}$) and object 2 ($\vec{q}_{021},\vec{q}_{022},\vec{q}_{023}$) which are connected to the mass centre and are collinear to main central axis, referent coordinate system ($\vec{q}_{S1},\vec{q}_{S2},\vec{q}_{S3}$) which is arbitrary in space.

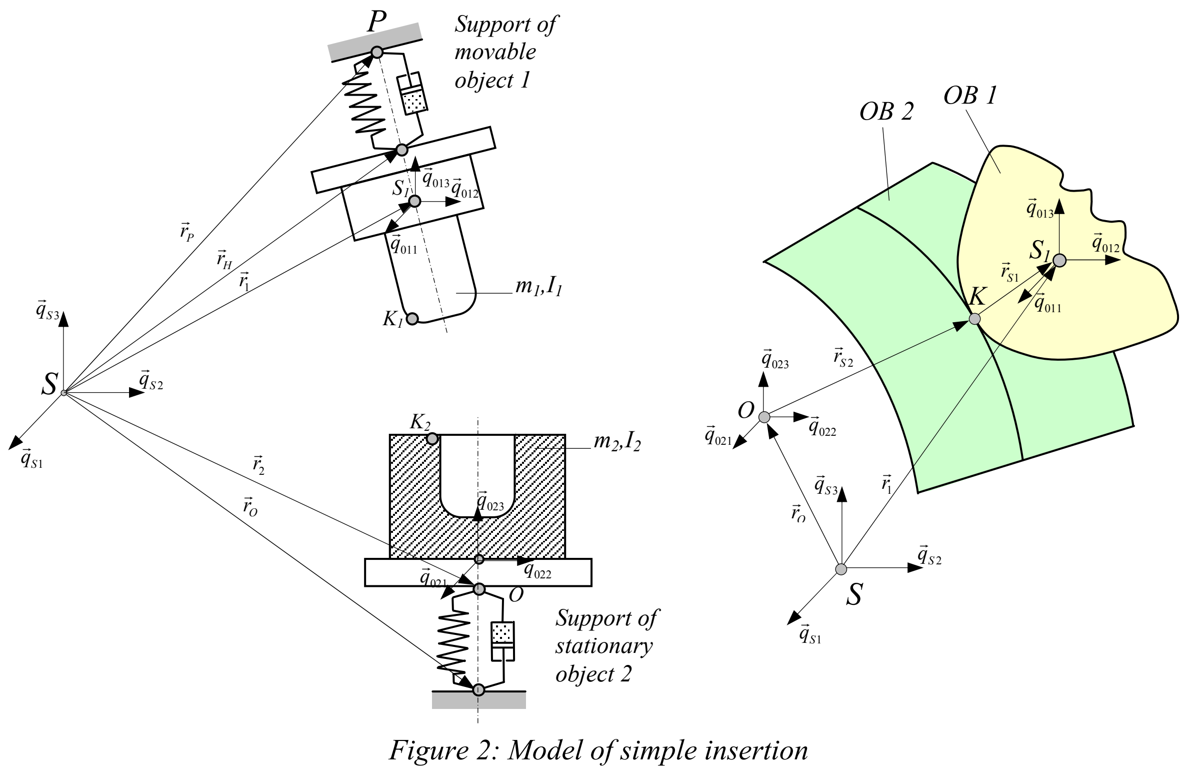

Figure 2: Model of simple insertion

Dynamic equations of movement are to be defined for each point of material system. For system showed in figure 2 it is rational to put movement equations only for some characteristic points: mass centrres S_1 and S_2, points of kinematic relations K_1 and K_2 and centres of compliance H and O. Inertal forces and kinematic reactions can be determined if geometric and kinematic characteristics of objects which takes part in assembly process are known and with help of main dynamic laws of stiff object.

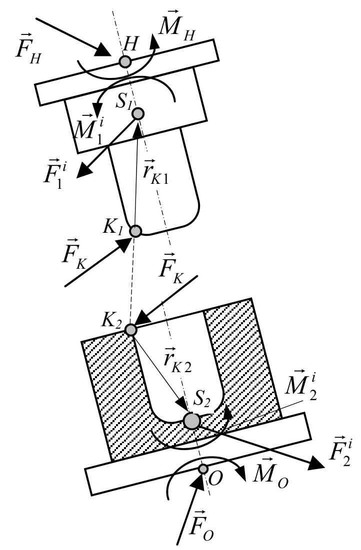

Figure 3: Load in stage of contact between two elements

Applying D'Alamber principle dynamic equations of movement are:

$$\begin{aligned} &\vec{F}_1^i + \vec{F}_K + \vec{F}_H + G_1 = 0 \\ &\vec{M}_1^i + \vec{r}_{K1} \times \vec{F}_K + \vec{r}_H \times \vec{F}_H = 0 \\ &\vec{F}_2^i + \vec{F}_K + \vec{F}_O + G_2 = 0 \\ &\vec{M}_2^i + \vec{r}_{K2} \times \vec{F}_K + \vec{r}_O \times \vec{F}_H = 0 \end{aligned} \qquad (1.1.)$$

Equations (1.1.) are calculated according to reference coordinate system S $\vec{q}_{S1}, \vec{q}_{S2}, \vec{q}_{S3}$, showed in figure 3. Inertial forces and torques in equations (1.1) can be expressed by Newton-Euler dynamic equations:

$$\begin{aligned} &\vec{F}_1^i = -m_1 \frac{d\vec{v}_1}{dt} \qquad \vec{F}_2^i = -m_2 \frac{d\vec{v}_2}{dt} \\ &\vec{M}_1^i = -I_1 \frac{d\vec{\omega}_1}{dt} + \vec{\omega}_1 \times \left(I_1 \vec{\omega}_1\right) \\ &\vec{M}_2^i = -I_2 \frac{d\vec{\omega}_2}{dt} + \vec{\omega}_2 \times \left(I_2 \vec{\omega}_2\right) \end{aligned} \qquad (1.2.)$$

where: m_1, m_2 –mass of assembly objects, $\vec{v}_1, \vec{v}_2$ - velocity vector of mass centre, I_1, I_2 – inertia torque Reactions in points H and O can be defined by position vector of secondary handling robot peak in relation to primary handling robot peak (Figure 4).

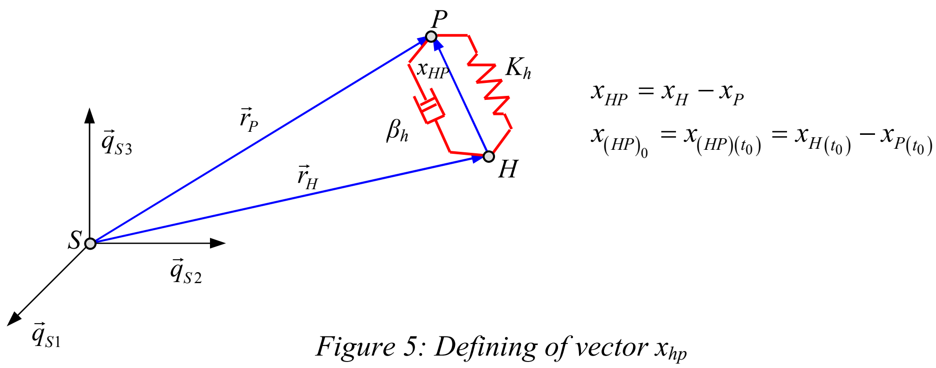

Figure 5: Defining of vector x_{hp}

Reaction of support H:

$$F_H = F_{He} + F_{Hv} = K_h(x_{HP} - x_{(HP)_0}) + \beta_h \frac{d}{dt}(x_{HP}) \qquad (1.3.)$$

Reaction of support H defined by equation (1.3) contents two components $\vec{F}_H$ and $\vec{M}_H$ explained in equation (1.1). Reaction of support O:

$$F_O = F_{Oe} + F_{Ov} = K_O(x_O - x_{(O)_0}) + \beta_O \frac{d}{dt}(x_O) \qquad (1.4)$$

Contact force $\vec{F}_K$ appears as result of interaction from object 1 to object 2 in insertion process. To determine this force it is necessary to know friction characteristics of contact zone.
Contact force has got two components:

$$\vec{F}_K = \vec{F}_K^n + \vec{F}_K^t \qquad (1.5)$$

Components of contact force are mutual dependent and on this level of modelling of assembly process it can be established feedback between partial dynamic models of ortogonal and tangential surfaces.

3. CONCLUSION

Presented dynamic-mathematical model of assembling object 1 with object 2 is for simple exception of surface type. But in this case we also have comlex exception of surface type. The main differnce between those two surface types is not dynamic but kinematic character. Complex exception of surface type takes additional degrees of movement which means that it is needed to use suitable strategy of movement to keep continuity of relativ movement of object during the contact. In the case of simple exception of surface type this problem theoretically does not exist and that can be seen in this paper. By complex exception of surface type during the free movement of object in general case causes jamming which means stopping of relative movement of object and one of the irregular condition in insertion process. This is one of the main problems and to solve this problem it is necessary to use special strategy of active adaptive movement of secondary handling robot which is nowadays still subject of a research.

4. REFERENCES

[1] Whitney D.E.: „Quasi-static assembly of compliantly supported rigid parts“, Trans. ASME, J. Dyn. Systems Measur. And Control (104) pp:65-77, 1982.

[2] Warnecke H.J., Schraft R.D.: „Industrial robots and assembly automation“ Internal report, FhG – IPA – Division 330, 1989

[3] Makino H., Furuya N.: „Selective compliance assembly robot arm“, Proceedings of the 1st international Conference Assembly Automation, pp 77-86, 1981.

[4] Boothroyd G.: „Design for assembly Handbook, Design project“, Department of mechanical Engineering, University of Massachusetts, Amherst, Massachusetts, USA, 1983.

[5] Van Brussel H., Simons J.: „The adaptable compliance concept and its use for automatic assembly by active force feedback accomodations“, Proceedings of the 9th International Symposium on Industrial robots, pp 167-191, 1979

[6] Vukobratović M., Potkonjak V.: „Applied dynamics and CAD of manipulation robots“, Springer Verlag, Berlin, FRG, ISBN 3-540-13074-8, 1979

[7] Asada H., Kakamuto Y.: „The dynamic analysis and design of a high speed insertion hand using the generalized centroid and virtuall mass“, Trans. ASME J. Dyn. Systems Measurements and Control (112) pp: 646-652, 1990

[8] Asada H.: „Teaching and learning of compliance using neural nets: representation and generation of nonlinear compliance“, Proceedings IEEE International Conference Robotics Automation, pp: 1237 – 1243, 1990

[9] Whitney D.E.: „Historical Perspective and State of the Art in Robot Force Control“, Int.J. Robotics Res. 6(1) pp: 235 – 241, 1987

[10] Nevins J.L., Whitney D.E.: „The force vector assembler concept“, Proceedings of the 1st CISM IFToMM Symposium on Theory and Practice of Robots and Manipulators, Vol II, 1974, pp: 273-288.

[11] Petrović P.B.: „Inteligentni sistemi za montažu“, Mašinski fakultet Beograd, 1998.