Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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DAAAM Symposium

OPTIMAL LOCATION OF AN INDUSTRIAL ROBOT USED IN FORGE APPLICATIONS

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Abstract: *Industrial robots are used especially in sectors where the human body is in danger or is working in extreme conditions. One of these sectors is the forges sector where the manipulating objects are hot, and the vibrations and noise are big. The cooling of gripper and robot is realized passively in the movement phase, when no hot work piece is manipulated. So, the trajectory of movement is important and also the optimum position of robot with respect to the application positions. The proposed paper is dealing with the subject of moving the base of robot with respect to the application points so that an objective function representing the accumulated heat during a cycle to be minimum. A multi-criteria optimization approach is the best solution in this case.*
Key words: *Industrial Robot, Forge, Optimum Position*

1. INTRODUCTION

Industrial robots are used especially in sectors where the human body is in danger or is working in extreme conditions. One of these sectors is the forges sector where the manipulating objects are hot, and the vibrations and noise are big. The problem of manipulation the hot parts implies firstly the choosing of the right gripper mechanism in order to obtain the best cooling of it and of the robot itself. But the position of robot with respect to the application, by taken into consideration as an objective function the accumulated heat from work piece during the manipulation of it, it is also a very important problem.

An empiric solution of determining the position of robot base by computing only the three coordinates of the origin of the Cartesian coordinate system assigned to the robot base is given in (Kovacs & Cojocaru, 1982). This empiric solution is not taken into consideration the way of moving of robot between the application points, but is taken into consideration the weight of object that the robot is moving between these.

In (Tian & Collins, 2005) an optimization problem of placement of a simple two-link planar manipulator by using a genetic algorithm is presented. Also in paper (Mitsi et al., 2008) a hybrid genetic algorithm is used in order to determine the optimum location of the base of robot with respect to imposed discrete positions of end-effector.

The location of robot base with respect to the application is so that all the interest points of application to be situated in the working space of robot. An optimization of this location by taken into consideration the minimum time of movement was presented in papers (Ciupitu & Simionescu, 2007). In paper (Ciupitu et al., 2008) an optimum synthesis of motion law together with minimum time of motion was performed.

The mechanical structure of the industrial robot chosen by the manufacturers (Renault – France, Rahm – Italy), that are using it in forges sector is of articulate kind with 6 DOF. Sometime the opening area of forge makes difficult the inserting of hot part inside the forge even with 6 DOF. But an industrial robot with a mechanical structure of cylindrical type with at least 5 DOF may solve the problem too.

2. FORGING MANUFACTURING PROCESS

Usually the forged pieces are inserted from a bunker into a furnace in order to be heated. The hot part comes out from a medium frequency furnace (Fig. 1) with a random orientation or that can be fixed by using special mechanisms, depending of the shape of part. But because of temperature of part the individualization and orientation of part is difficult to be made with a good accuracy. So, a vision system to recognize the position of part and to communicate with the robot controller in order to make the position and orientation corrections of picking configuration, is necessary.

From delivering port of furnace the part is inserted by lateral into the forge and left down inside the forging mold. The inserting window is relatively small and requires a long final link of robot mechanism or long gripper fingers.

Sometimes another task of spraying the parts of forge is done by the same robot with the aid of a special dose fixed to the robot arm or to the gripper. Anyway, the different planes in which the pick-and-place operations are done, and the small window of forge where the robot arm must be inserted, impose a 6 DOF spatial mechanism for robot mechanism.

An industrial robot with a mechanical structure of cylindrical type with at least 5 DOF may solve the problem, but the prismatic joints are pretentiously even in case of cold manufacturing processes.

The end-effector could be cooled by the aid of a fan or by pressure air in some situations when the temperature of manipulating part is high and the heat cannot be eliminated by the movement of the robot during one cycle.

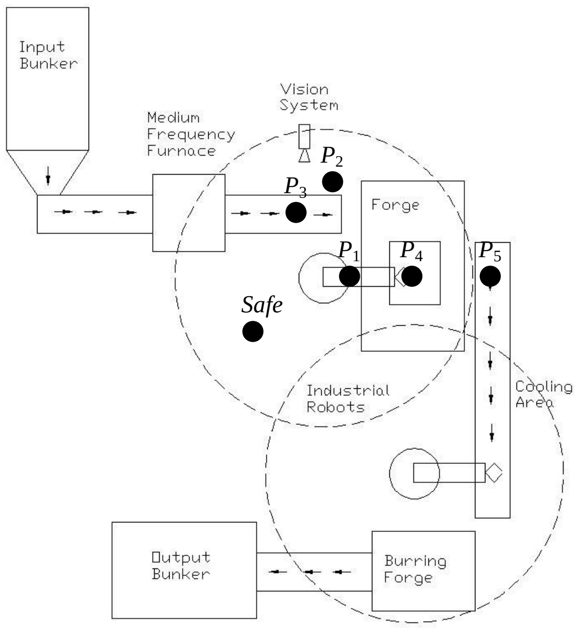

Fig. 1. Application scheme

3. OPTIMISATION PROBLEM

In order to formulate the optimization problem 2 models must to be known:

1) the mechanical structure model of robot with minimum and maximum acceptable values for each joint independent parameter and
2) the forge application given by: coordinates of positions (configurations) that the robot must reach, the trajectories and motion laws between these points, the temperature of work pieces and the weights of them.

Usual the mechanical structure model of a robot is implemented into robot controller by using Denavit-Hartenberg formalism in order to find a transformation from tool tip to the base of robot. By choosing the axes systems in a special manner, the number of unknown parameters between 2 Cartesian coordinates systems chosen anyway on each link is reduced from six to four: a_i , s_i , α_i and θ_i , $i = \overline{1, n}$, where n is the number of degrees of freedom of robot.

The model of forge application is simplified composed only by the 5 points P_j , $j = \overline{1, 5}$, that the robot must reach during the motion, without any obstacles defined (Fig. 1): P_1 - in front of forge (waiting point), P_2 - upper the picking position, P_3 - picking position from the exit of furnace, P_4 - inside forge and P_5 - extreme position of eliminating the piece from forge to the cooling conveyer.

Also the order of reaching these 5 points in a complete cycle (composed by l = 8 intervals of motion: $P_1 \to P_2 \to P_3 \to P_2 \to P_1 \to P_4 \to P_1 \to P_5 \to P_1$) and the motions laws between these are supposed as known.

The heat accumulated by the robot during a cycle depends by the temperature of work piece T_l, $l = \overline{1, 8}$ and by the time when the work piece is manipulated by the robot. Finally, especially for optimization problems that is dealing with forces and energy or power consumption, the weights $\boldsymbol{G}_{jk}$, $j = \overline{1, 5}$, $k = \overline{1, 5}$, $j \neq k$, of objects moved by robots between application points, must to be known.

The unknowns of optimization problem are the parameters that are defining the position and the orientation of Cartesian coordinates system assigned to the base of robot $O_1X_1Y_1Z_1$ with respect to an inertial Cartesian system assigned to the "world of robot" (or to the application) denoted by $O_0X_0Y_0Z_0$. These parameters are composed by the 3 Cartesian coordinates of origin O_1 expressed in Cartesian system $O_0X_0Y_0Z_0$ (X_{0O1}, Y_{0O1}, Z_{0O1}) and the 3 independent angles that is giving the orientation of Cartesian system assigned to the robot base $O_1X_1Y_1Z_1$ with respect to fixed Cartesian system $O_0X_0Y_0Z_0$ from the cosines directories matrix.

The number of unknown parameters could be reduced by choosing the Cartesian system $O_0X_0Y_0Z_0$ in a Denavit-Hartenberg manner. So, by choosing the O_0Z_0 axis perpendicular to the O_1X_1 axis (chosen randomly perpendicular to the O_1Z_1 axis), only 4 parameters are enough: a_0, s_0, α_0, θ_0.

The objective function of optimization problem is a sum (or integral) of minimized parameter:

$$\boldsymbol{O} = \sum_{l=1}^{8} Q_l \tag{1}$$

where Q_i is the heat accumulated by the robot in each interval of motion from a cycle.

The process of finding the optimum set of parameters $\{a_0^*, s_0^*, \alpha_0^*, \theta_0^*\}$ is a numerical one. At the beginning of computation, starting by an initial set $\{a_0^{(0)}, s_0^{(0)}, \alpha_0^{(0)}, \theta_0^{(0)}\}$, a complete verification of application points P_j, $j = \overline{1, 5}$ so that to be into working space of robot is performed.

By inverse kinematics a set of joint independent variables $\{\theta_{1,j}^{(0)}, \theta_{2,j}^{(0)}, \dots, \theta_{6,j}^{(0)}\}$ is determined for each point P_j, $j = \overline{1, 5}$. A point P_j, $j = \overline{1, 5}$ is in working space of robot if all independent variables values are between minimum and maximum acceptable values for each joint:

$$\theta_{i\min} \leq \theta_{i,j} \leq \theta_{i\max} , \ i = \overline{1, 6} , \ j = \overline{1, 5} . \tag{2}$$

The Lagrange method for solving of the minimization problems is based on transforming a given constrained minimization problem into an unconstrained minimization problem. Finally results an un-linear system composed by 124 equations with 124 unknowns solved by numerical methods.

4. CONCLUSION

The optimum location of robot base depends to the robot structure and to the application. With same robot but different application positions and conditions results different locations for robot base.

The problem of finding the optimum location of robot base with respect to the application points according to an objective function is very important and could lead to major improvements (Ciupitu & Simionescu, 2007), (Mitsi et al., 2008). Sometimes the conditions of application impose special adjustments in order to protect the robot. The placing of robot base in an optimum location from the very first beginning is an essential initial task especially for large series productions. The economy of time or/and energy (money finally) for each product is decreasing it's price to almost a quarter (Feddema, 1996) but the protection of industrial robot parts is much more important because without robot no production.

A multi-criteria optimization approach, by taken into consideration the protection of industrial robot which is working in a hazardous environment and the economy of time and energy, is the future work of this research.

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