DYNAMIC MODELLING OF AUTOMATIC TOOL CHANGER SYSTEM FROM MACHINE-TOOLS USING LAGRANGE EQUATIONS

CLAUDIU OBREJA†, GHEORGHE STAN†, ADRIAN GHENADI†

†“Vasile Alecsandri” University of Bacau, Engineering Faculty, Calea Marasesti 157, Bacau, 600115, Romania

Abstract: In the field of cutting processes, the current trend is to produce more and more in the shortest time. A solution to this consists of shortening the total machining time by increasing the motion speeds of the tool supply systems that equip the machining centers, thus minimizing the idle time needed for replacing the tools during the machining process. Actual idle times needed for replacing the tools through the supply systems are high, especially for machining housing type work pieces on boring and milling machining centres. With the help of the method being proposed through this work, the motion times of the moving elements in the structure of the tool supply systems can be decreased, by following up, at the same time, their dynamic behavior.

Keywords: dynamic modelling, Lagrange, supply system, tool, tool changing mechanism

1. INTRODUCTION

Nowadays trends to produce more and more in the field of cutting processes have led to increasing the machining speeds [1, 2]. Currently, the scientific researches in the field of cutting processes, aiming at minimizing the tool replacement idle times, have been directed mostly to solutions to reconfigure the automatic tool changer systems [3], by minimizing the number of motions [4, 5]. A method of structural synthesis of the automatic tool changer systems, based on tree graphs may reduce as much as possible the number of motions needed for replacing the tools into the spindle and vice-versa, by starting from the type of the machining center [6]. Turkay, in [7], has developed a new method, based on the Genetic Algorithms of redistributing the input sequence of the tools for machining, in order to minimize the idle machining time, whilst Ecker and Gupta have presented a method for minimizing the machining idle time based on level-headed graphs, in [8]. Through the dynamic modelling being proposed in this work, lower time rates than the initial ones may be obtained on the supply systems.

2. DYNAMIC MODELLING

2.1. Functional Analysis of the Tool Supply System

The motions performed by the tool changer system (Figure 1), being proposed, that may equip the boring and milling machining centers for replacing the tools while cutting, may be divided into two large categories, as follows [9]:

* Corresponding author, email: claudiu_obreja@yahoo.com
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a) A transfer motion that brings the tool from the tool magazine to the waiting position. Theoretically, this motion does not affect the tool change time because it happens while the machine is cutting. In other words, the machining time is not affected.

b) Motions of effective replacement of tools into the spindle.

In Figure 2 is presented the geometrical model of the tool supply system obtained on the basis of the physical model presented in Figure 1.

Fig. 1. Tool supply system equipping a boring and milling machining centre [1]: 1- tool changing arm; 2- slide; 3- cylindrical guide way; 4- hydraulic cylinder; 5- oscillating motor; 6-axis, 7- radial-axial bearing; 8- buffer.

Fig. 2. Geometrical model of the tool supply system: D- motion directions of the elements; q- robot coordinates; G- gravity forces of the elements.

2.2. Principle of Dynamic Modelling

The dynamic behavior mathematical model of a mechanism used in the manipulator structure makes the connection between the torsos of forces and torques acting on the composing kinematical elements and the motion applied to these elements [10]. The mathematical model is based on generating the Lagrange equations of the type:

\[
\frac{d}{dt} \left( \frac{\partial E}{\partial \dot{q}_i} \right) - \frac{\partial E}{\partial q_i} = \frac{\partial W}{\partial q_i} = Q_i
\]

where: \(i = 1 \ldots m\), where \(m\) means the number of freedom degrees; \(E\) – kinetic energy at the level of the entire mechanism; \(q_i\) – relative position coordinate (or robot coordinate); \(\dot{q}_i\) – parameter of generalized relative speed; \(W\) – virtual mechanical work; \(Q_i\) – generalized force.

The logic diagram with a view to the dynamic modelling of the tool supply system is shown in Figure 3.

For particularizing the dynamic equations it will start from the dynamic balance equations of the mechanical structure (obtained by applying the Lagrange formalism). These are completed with the terms characterizing the forces or specific torques in case of the hydraulic drive. Further to particularizing the global balance equations and second range integration of the latter for each robot coordinate of the tool supply mechanism, the systems of equations associated to the transient duties and to the permanent running duty are:

\[
K_{M1}q_1 - \frac{1}{2}(K_{p1} + K_{M1})t^2 + C_1t + C_2 = 0
\]

where: \(K_{M1}\) – sum of the inertia moments by the coordinate \(q_1\); \(K_{p1}\) – force reduced on the shaft of the oscillating hydraulic motor; \(K_{M1}\) – sum of the resisting torques.
where: $K_{m2}$ - sum of the masses in motion by the robot coordinate $q_2$; $K_{p2}$ - force reduced on the shaft of the driving piston; $K_{F2}$ - force reduced on the shaft of the driving piston.

Further to imposing several time rates corresponding to the transient and permanent duties it has been possible to draw the variation laws of the kinematical parameters: distance, speed and acceleration, for each robot coordinate of the supply system (Figures 4, 5, 6 and 7).

![Diagram](image.png)

**Fig. 3. Logic diagram of the proposed dynamic modelling.**

\[
K_{m2}q_2 + \frac{1}{2}(K_{p2} + K_{F2})t^2 + C_1t + C_2 = 0
\]  \hspace{1cm} (4)

\[
K_{m3}q_3 - \frac{1}{2}(K_{p3} + K_{M3})t^2 + C_1t + C_2 = 0
\]  \hspace{1cm} (5)

\[
K_{m4}q_4 + \frac{1}{2}(K_{p4} + K_{F4})t^2 + C_1t + C_2 = 0
\]  \hspace{1cm} (6)

![Graphs](image.png)

**Fig. 4. Variation of the kinematical parameters for the robot coordinate $q_1$, rotation coupling A.**

**Fig. 5 Variation of the kinematical parameters for the robot coordinate $q_2$, translation coupling B.**
3. CONCLUSIONS

This model settles the connection between the input parameters of the hydraulic motors and the kinematical parameters of the automatic supply system. By assuming that the motions of the supply system are successive, the variation laws of space, speed and acceleration for each axis have been determined. In case of the acceleration duty, the space has a parabolic variation in function of time, speed is linear with positive slope and acceleration is positive as well, having a constant value.

In case of the permanent duty the space has a linear variation in function of time, speed is constant and acceleration is zero. In case of the deceleration duty the space has a parabolic variation in function of time, speed is linear with negative slope and acceleration is negative as well, having a constant value. This dynamic modelling may be implemented for other structures of tool supply systems as well, in order to determine their dynamic behavior.

REFERENCES