Bulletin of the *Transilvania* University of Braşov
Series I: Engineering Sciences • Vol. 6 (55) No. 2 - 2013

THE DETERMINATION OF THE OPTIMAL CONTROL LAW FOR A MANUFACTURING SYSTEM IMPLEMENTED ON FLEXIBLE LINE FMS 200

A.D. MOROȘAN[1] **A. DĂNILĂ**[1] **F. ȘIȘAK**[1]

Abstract: *We consider the problem of optimal control of flexible manufacturing systems. We study the process production on a flexible manufacturing line from SMC, with different workstation. Each workstation performs a work lead. The objective is to determine the optimal time for the production rate at each workstation from the system. We exhibit that each workstation situated in the head of process production is characterized by a set of deferral time. The head workstation initially stays idle for a period equal to their deferral time. The optimal time for production makes each workstation to adopt a just-in-time production.*

Key words: *flexible manufacturing systems, production process, optimization.*

1. Introduction

Flexible manufacturing systems - FMS and flexible manufacturing cells - FMC represent modern reconfigurable systems, which can be composed by different modules connected in different ways [3].

The main characteristic of these systems is the speed with which can modify their production technology, which means manufacture of medium series which may be subject to minor variations in large variations of shape, size and structure [1].

Flexible manufacturing systems have been developed in order to combine the flexibility concept with the productivity of fabrication lines.

Manufacturing systems consist of processing subsystems composed by numerical machining centers - CNC, automated material handling systems and a network connected to a computer which controls the functioning process flexible manufacturing system [5].

For flexible manufacturing systems, production process optimization problem leads to the development of algorithms in order to find an optimal solution to reduce production time, reduce costs and other characteristics which can occurs in process.

Flexible manufacturing line optimization problem is equivalent to the problem of minimizing a criterion function.

Hindi and Ruml [3] show a way of optimizing the production process of a flexible system by maximizing the amount of pieces per unit time which the entire system can produce.

Bogdan et al. [1] shows a system for supervisory and control of a flexible line, based on a network of matrices whose elements are logical variables. The authors

[1] Dept. of Automation and Information Technology, *Transilvania* University of Braşov.

demonstrated that the proposed method significantly reduces the computational effort and ensures efficient operation of the line.

In order to obtain the minimum time necessary for passing from an initial state to the final state, by a product, Zaslavsky et al. [7] propose in their paper algorithms based on fluency models widely used.

Algorithms are developed in order to determine the optimum time controllability and a strategy programming from point of view of the optimum time.

Perkins and Kumar [6] approaches optimization problem from the viewpoint of minimizing the costs associated with the waiting time of pieces at the entrance stations and associated cost of manufacture interruption due to a lack pieces from the entrance of the station.

Optimization manufacturing processes requires modelation of the main characteristics of manufacturing systems and their control.

The paper proposes optimization of production process on a flexible manufacturing line through online identification of parameters of the dynamic model of the line.

The paper is structured as follows. Section two provides a brief description of flexible manufacturing systems and flexible system FMS 200 from SMC. Third section presents the implementation of the optimization principle on flexible line. Then are presented experimental determinations, and finally conclusions and future work.

2. Flexible Manufacturing System

2.1. Definition and Flexible Manufacturing Systems Architecture

The trend which manifests regards the organization of modern production processes is to develop production activities (design, planning, scheduling and control) which can adapt quickly to global market demands and enabling the achievement of competitive products, with costs optimal production.

From this perspective flexible manufacturing systems represents a modern and efficient solution that satisfies the requirements for adaptability and efficiency of manufacturing systems. Flexible Manufacturing systems have been developed since the seventh decade of the last century; the first flexible manufacturing system was developed in 1968 by Molins Company under the name of "System 24" and was a flexible system that can operate without human operator intervention, 24 hours, but under the control of a computer. Nowadays use of flexible manufacturing systems is very common.

A flexible manufacturing system represents a group of CNC machine tools, connected together by an automatic transmission and handling system of parts and tools which are controlled by a computer; the system performs automatic processing in small and medium series of parts belonging to a technology, based on an algorithm of production.

The inputs of a flexible manufacturing system are represented by (a) the raw materials used in the technological process (elements, components, substances), (b) the energy necessary to perform the process in optimal conditions, (c) piece configuration information, (d) machining process, (e) the number of finite parts and (h) information concerning the evolution in time and space of the manufacturing process.

System outputs are (1) the final pieces with different configurations and properties, (2) loss of energy, or (3) waste (scrap).

2.2. Flexible Manufacturing System - FMS 200

The system FMS 200 manufactured by SMC Japan is a configurable flexible manufacturing system consisting of a maximum of 10 manufacturing cells, Figure 1. The system can perform sorting operations, assembly and quality technical inspection. The system is completely automated. The processing stations are connected by a conveyor with a length of 4 meters, equipped with stopped and position sensors designed to carry prefabricated parts between different workstations.

Each processing station is equipped with its own electric panel. Components and devices that compose electrical installation are visible positioned so that, it is possible to add new elements when it is necessary to modify the system. The command of electric and pneumatic actuators is performed with programmable logic controllers (PLC), type Siemens S300.

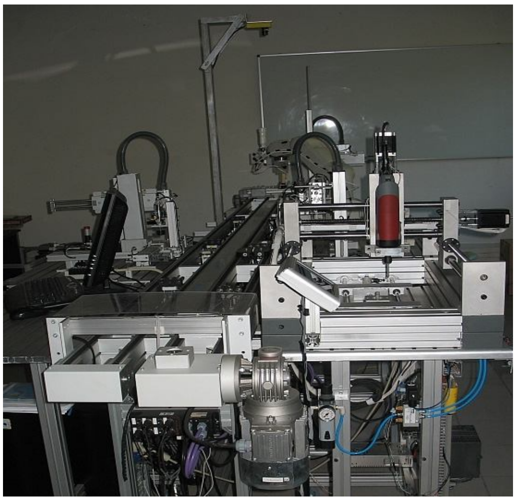

Fig. 1. *Flexible processing line - FMS 200 at the ProDD Research Institute; overview*

The programmable logic controller of the stations and programmable logic controller of the conveior are connected to a Profibus network communication. The overall control of the subsystems manufacturing line is designed by PLC master station - the conveyor PLC.

Flexible manufacturing system FMS 200 has a rectangular arrangement (Figure 2), so the four stations components are located in length transfer system, type conveyor.

Flexible manufacturing process takes place modular system passing through following processing stations:

- processing station 1: feeding prefabricated warehouse capacity 12 pieces semi double acting pneumatic actuators, sensors magnetic proximity type;
- processing station 2: fitting assembly organs station - bolts, screws magazine capacity 38 pieces, double acting pneumatic actuators, proximity sensors and pneumatic griper;
- processing station 3: fixing station of the four screws - robot type MELFA RV - 2AJ MITSUBISHI with 5 degrees of freedom;
- processing station 4: station vision visual inspection by camera type COGNEX DVT515.

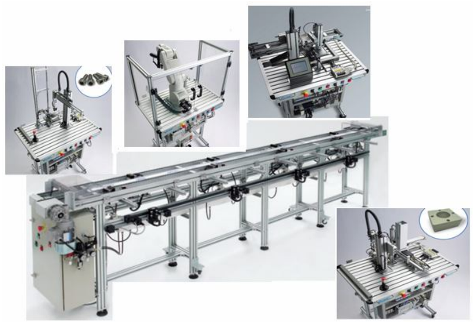

Fig. 2. *The layout of processing stations on flexible line FMS 200; ProDD Institut Braşov*

The manufacturing process consists of installation of a roller bearings equipped with ball bearing, shaft and fixing cap.

First workstation supplies the system with components bearing frame subassembly that take it from magazine and places it on the palette which is located in the system transfer/conveyor.

The station is provided with a mechanism to control the presence of bearing. The control mechanism checks the presence of bearing and rejects subassemblies which are not provided with bearing or which have another type.

The second station from flexible manufacturing line technology performs the operation of placing the screws in threaded holes friction bearing body.

Robot station is the third station FMS 200 system. The technological process that he carries it consists in placing shaft on the inner ring of the bearing, bearing retainer cap placement and fixing screws in bearing body.

Last station manufacturing line is designed to check the quality of technological operations performed on the flexible line. The station is equipped with a manipulator who takes piece and positioned for inspection. Piece inspection is performed using calibrated vision camera connected to a PC, equipped with dedicated software.

2.3. Principles and Methods for Optimization of Flexible Manufacturing Lines

Optimization of an industrial process represents a selection of solutions in report with a predefined criterion, from a lot of possible solutions.

In order to achieve optimization performance of a flexible manufacturing system necessary to implement planning techniques based on performance criteria.

By applying performance criteria is obtained a maximum or minimum size of the system, depending on requirements.

To apply performance criteria is necessary to pass through a series of steps. The first step is to establish a criterion of efficiency. The second step consists in selecting a set of possible alternatives. The last two steps is to determine the model and parameter values in determining alternative process that optimizes the criterion defined in the first stage.

Flexible manufacturing systems modeling can be performed either through theory or through demonstrations.

In a manufacturing process of a flexible system, after establishing the model and the measurements that occur in the process and after data acquisition and process control is performed, can be applied to their optimization criteria. The sizes that can be optimized in such a system are the sizes involved in the process, namely: production times, energy consumption, processing costs.

Hsu and Shamma [4] propose a method of optimizing operating costs in a production system, using constraints. Based on a linear dynamic system, applied constraints to obtain approximations of costs and thus be able to obtain an optimum. They proposed method can be used both offline and online.

Zaslavsky et al. [7] propose a solution to the problem of determining the starting time of a cycle manufacturing and machine work so that the system starts from an initial state and reach to a final state in a minimum time. In order to obtain an optimal control and a minimum time of production, it uses deterministic models of flows with delays.

To optimize the operation of a flexible manufacturing system and reduce costs, Bogdan et al. [1] proposed a system of logical matrices for manufacturing process control.

Chang [2] proposed to optimize a manufacturing process by maximizing the use of workstations. It develops a deterministic algorithm based on the estimated time of production and flow of pieces. In the manufacturing process, according to this algorithm are powered with pieces the workstations.

For modeling flexible manufacturing system FMS 200 is necessary to obtain optimal control of production rate for each workstation in the system, thus optimizing production time. In the system upstream workstations can be an obstacle for stations downstream from these.

Beginning station of the process can be characterized by a series of delay times, because the workstation from upstream operates according to the principle just-in-time. If the workstation from the beginning of the process running at normal capacity the work pieces it will accumulate in a buffer because the upstream station has not completed execution. In order to avoid the accumulation of a large number of parts in the buffer is necessary that the head station to be inactive for a period of time equal to the time delay. Thereafter the station will start producing until the initial deficit will be eliminated. By eliminating this deficit it will find the optimal time of production.

3. Implementation of the Principle of Optimization on Flexible Manufacturing Line FMS 200

In order to implement the principle of optimization need to be addressed following problems: (a) independent command of the two motors of the conveyor belt of the station, and (b) acquisition on real-time the information regarding the position of each flexible line work tasks. For solving these problems, the following were made:

(1) an experimental installation consisting of electrical module, Figure 3 and a command panel which has been inserted on the electrical structure of transportation module of flexible line; this subassembly has allowed the PC command to start of the two drive motors of the conveyor belt, independent;

(2) two software applications for communication with master PLC through Profibus network and for the handling and processing respective information on the status of the line of the actuators flexible, real-time location of all work tasks at any time on the production line.

For communication with the Profibus network elements was used KepSeverEx driver. This driver is a 32-bit application for Windows, used as a means of taking data and information from various client devices in industrial applications. KepServerEx fall into the category applications that can be used as OPC server.

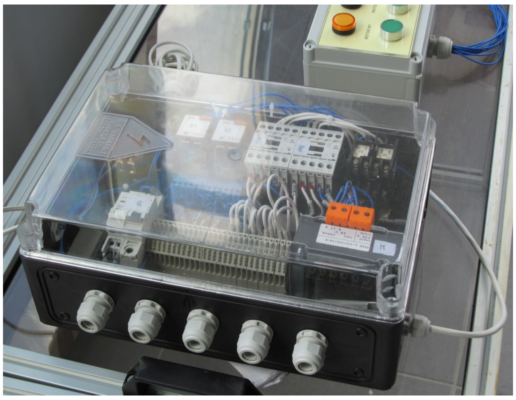

Fig. 3. *Electrical module for independent command of conveyor belt engine of flexible line FMS 200*

The technologies to share data between applications for client/server may be:

(1) technology data sharing DDE - Dynamic Data Exchange; this is a method through which a program can inter-communicate or control another program;

(2) OLE - Object Linking and Embedding technology; this technology allows an application to export a part of a document to another application and then import it with additional content;

(3) SOA technology - Service Oriented Architecture, which allow exchange of information between several interconnected computer through a cloud network through communication service.

KepSeverEx application has the ability to be implemented for communication with industrial devices can be used for communication with the PLC master station witch monitors and controls PLC on each workstation by DDE technology and OLE technology also.

PLCs from each station communicate with master through a PROFIBUS network. Thus, only the station master can initiate a communication, while the slave's (the workstations) respond to requests.

In order to monitor and control the status of the master station via PROFIBUS network must initiate a communication with master through OPC's KepServer. This requires that on the server communication channel to create a device with a certain number of tags or a group. These tags represent the system status capable of being monitored and controlled. Once communication with master has been established by the application mentioned above, the status of each station can communicate of a resident application on Matlab programming environment.

The application made within the experiment aimed to processing production times from each workstation in order to optimize the process of flexible manufacturing line.

Signals taken from the PLC master, relating to execution elements of subassemblies flexible line stations have a diverse form: some signals are defined on the floor and others are set on the front.

To obtain a unified software structure defined on the landing signals were converted to front-defining signals. For this purpose, an outside function has been implemented on MatLab programming environment, called Bistabil1. In Figure 4 is the result of an instantiation of this function. The user interface of the application for optimizing flexible line carried out within this experiment is shown in Figure 5.

The application displays and monitors moments when workloads from flexible manufacturing line, are during the four stages of the manufacturing cycle, respectively moments of start/stop cycle and manufacturing cycle.

Acquired data are stored in text format and are available for processing.

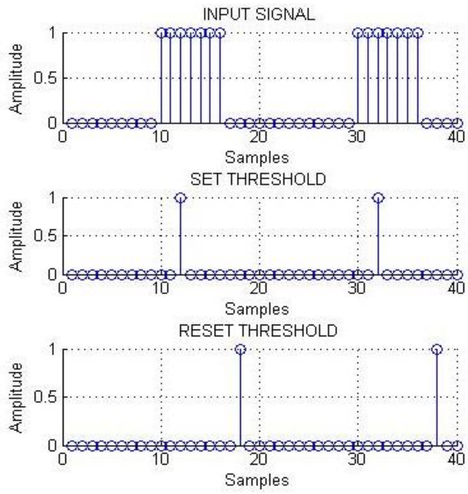

Fig. 4. *Implementation results of Bistabil function on a sampled input signal, active on the landing*

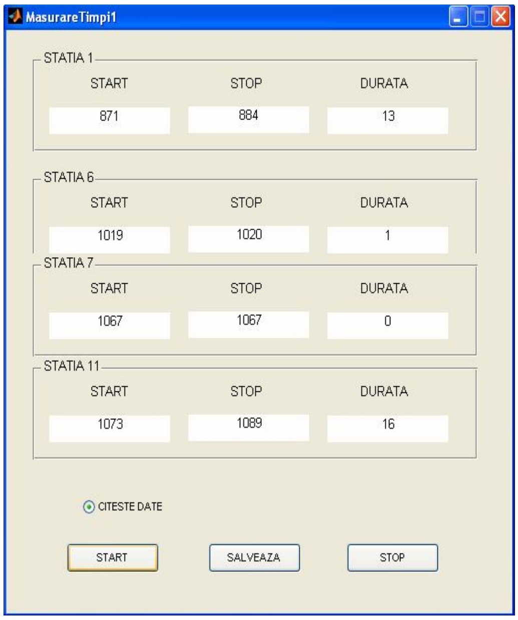

Fig. 5. *The main application user interface for optimizing flexible line FMS 200*

4. Experimental Determinations on Flexible Manufacturing Line FMS 200

In the experiment were tested a total of eight groups consisting of 12 pieces elements. It was not simulated the effect of uncertainties due to faults semifabrications or uncertainties due to damage stations. Experimental results are presented in Table 1 and control strategies tested in within the experiment are presented in Table 2.

Table 1

Duration of workload on flexible manufacturing line FMS 200

Processing stage	**Average duration**
< - >	< s >
Processing on Station S1	14
Transport S1 - S6	22
Processing on Station S6	60
Transport S6 - S7	5
Processing on Station S7	42
Transport S7 - S11	5
Processing on Station S11	16
TOTAL	164

In the experiments, flexible line was supplied with elements at equal time intervals and was monitored time moments when worktashs have reached various stages of processing and the total required for processing whole lot of elements. From the analysis experimental results it can be seen that the total time required to process the whole lot of elements decreases with increasing frequency power line.

Starting with supply frequency of the line, 1 *semi-finished*/30 *s* total duration required tends to the constant value of 982 s. If the supply frequency is higher than the amount mentioned above, the buffer of the second station accumulates elements.

The number of elements which are accumulated in the buffer is higher as the line feed frequency is higher. For the case examined, the optimal frequency supply station corresponds to the value for which the total duration required and the number of elements which accumulate in the second station buffer is at most equal to a workload.

5. Conclusions

We have study a flexible manufacturing system. We have determined the optimal control for a process production, in order to reduce the time production. For this, we show that exist a moment when is necessary to put pieces on the flexible line for complete the process production and this moment represents the optimal time for production. This time of alimentation with pieces is determinated by workstation witch function longer and this is station 6. Also, we observe that for this optimal time, the second workstation from the flexible line work based on principle just-in-time, and the workstations which are situated after this, stay in an idle state for a period of time.

So, if we modify the speed of the conveyor belt we will increase the total

Strategy supply of flexible manufacturing line FMS 200 Table 2

Strategy supply of flexible line	**Total time of process**	**Piece in buffer**
< - >	< s >	< - >
Flexible line is fed at the end of a full cycle of production	2034	0
Flexible line is fed at the end of a cycle of production on station S7	1787	0
Flexible line is fed at the end of a cycle of production on station S6	1236	0
Flexible line is fed at the end of the intermediate mounting phasea of the third screw on station S6	1014	0
Flexible line is fed at the end of the intermediate mounting phasea of the second screw on station S6	936	0
Flexible line is supplied at equal intervals of 45 s	984	3
Flexible line is supplied at equal intervals of 45 s	935	7

time of production and the working time of each station is not affected. For future work we want to study the situation when the flexible manufacturing system function, like a stochastic system and based on signals generated by each station, to improve the production process, based on other parameter of the system.

Acknowledgements

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Guvernment under the contract number POSDRU/107/1.5/S/76945.

References

1. Bogdan, S., Lewis, F., et al.: *New Matrix Formulation for Supervisory Controller Design in Practical Flexible Manufacturing System.* In: Proceedings of the 1999 IEEE International Symposium on Intelligence Control/Intelligent Systems and Semiotics, Cambridge, September 13-17, 1999, p. 144-149.
2. Chang, S.C.: *Demand - Driven, Iterative Capacity Allocation and Cycle Time Estimation for Re-entrant Lines.* In: Proceedings of the 38th IEEE Conference on Decision & Control, Arizona, USA, December 1999, p. 2270-2275.
3. Hindi, H., Ruml, W.: *Network Flow Modelling for Flexible Manufacturing Systems with Re-entrant Lines.* In: Proceedings of the 45th IEEE Conference on Decision & Control, San Diego, USA, December 13-15, 2006, p. 1043-1050.
4. Hsu, C.H., Shamma, J.S.: *Receding Horizon Control for Manufacturing Systems*. In: Proceedings of the American Control Conference, New Mexico, June 1997, p. 1914-1918.
5. Jerald, J., Asokan, P., et al.: *Scheduling Optimization of Flexible Manufacturing Systems Using Particle Swarm Optimisation Algorithm.* In: International Journal Advanced Manufacturing Technology, London, March 2005, p. 964-971.
6. Perkins, J., Kumar, P.R.: *Optimal Control of Pull Manufacturing Systems*. In: IEEE Transactions on Automatic Control **40** (1995) No. 12, p. 2040-2051.
7. Zaslavsky, B., Rodriguez, A., Collins, D.: *Time - Optimal Control for Re-entrant Semiconductor Fabrication Lines.* In: Proceedings of the 36th Conference on Decision & Control, San Diego, USA, December 13-15, 1997, p. 102-107.