Flexible Production Systems (FPS) for Engineering and Technology Efficiency

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Keywords: Efficiency, Flexible Production Systems (FPS), Automation, Robotization.

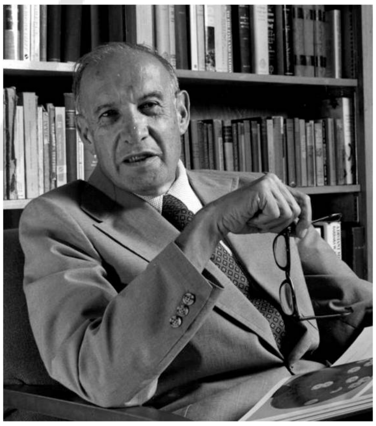
Abstract: This article presents essential elements regarding a new concept, Flexible Production Systems (FPS) which, if well applied, leads to increased efficiency in engineering and technology. The article subscribes to the quote "Efficiency means doing better what is already being done" (Peter Ferdinand Drucker). After defining the Flexible Production Systems (FPS), the article presents the characteristics of these systems and the correlations between them. The article also presents elements regarding complex management and automation within FPS. In this context, original elements are presented in the field of computer-aided management of the Electric Arc Furnace (EAF) and the automation of the electrical regime of this complex aggregate intended for the production of steels. The article also discusses FPS optimization through robotization, highlighting that the growth of flexible automation and the extensive use of industrial robots have a significant impact on all subsystems within economic units. To fully harness the benefits of robotic technologies, it is crucial to anticipate and understand these effects early on.

1 INTRODUCTION

Paraphrasing a well-known Romanian leitmotif, we can undeniably enunciate the following saying **"If there is no production, nothing is!".**

In this context, the authors subscribe this article to the following quote by Peter Ferdinand Drucker, also known as the Father of Scientific Management:

"Efficiency means doing better what is already being done."



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Canuta (Bucuroiu), I. L., Ioana, A., Mates, I. M., Semenescu, A. and Pollifroni, M.
Flexible Production Systems (FPS) for Engineering and Technology Efficiency.
DOI: 10.5220/0014399400004848

In *Proceedings of the 2nd International Conference on Advances in Electrical, Electronics, Energy, and Computer Sciences (ICEEECS 2025)*, pages 138-142
ISBN: 978-989-758-783-2

By definition, a Flexible Production System (FPS), or Manufacturing System (FMS) is an integrated set of numerically controlled, computer-controlled machine tools, served by robots and an automatic system for transporting, handling and storing workpieces, finished parts and tools, equipped with automated measuring and testing equipment and which, with a minimum of manual interventions by the human operator and with reduced adjustment times, can achieve simultaneous processing or successive use of different parts, belonging to a specific family of parts, with morphological and/or technological similarities, within the limits of a capacity and according to a pre-established manufacturing program, (Niculescu-Mizil, 1989), (Ioana, 2016), (Panc, 2020).

An FPS has the ability to allow for automated re-tuning/tuning for the production of parts from a variety of nomenclature, within set limits of their characteristics. FPS are intended for "families" of products that need to be manufactured in increased production volumes, which justify the investment.

The current manufacturing systems are the result of a long evolution and are a way of responding to the changes in the economic environment (internal and external) in which they operate, (Ioana, 2016).

In advanced production systems, the manufacturing process adapts its response to different tasks while maintaining efficiency and competitiveness.

A flexible manufacturing system is not a universal solution suitable for all circumstances, but rather an answer to particular needs. Such a system can adjust to diverse production requirements, whether related to product shape, size, or the technological processes involved.

A flexible manufacturing system is considered to have the following main characteristics, (Ioana, 2014), (Nitulescu, 2019):

- Adaptability
- Integrability
- Suitability
- Structural dynamism

In practice, it is not possible to speak of absolute characteristics, but rather of varying degrees of integrability, structural dynamism, and so on, since these features cannot all be achieved at the same time. Compared to rigid production systems, Flexible Production Systems (FPS) offer several advantages:

- High adaptability to changes, requiring minimal effort, as adjustments are made through modifications of computer programs rather than altering the machinery itself.
- Extensive use of numerically controlled machines, robots, automated conveyors, and control systems.
- A wider range of processing options and order variations.
- Functional autonomy across three shifts, without the need for direct and continuous human intervention.
- The ability to evolve and be gradually improved in line with production requirements.

Figure 1 shows the characteristics of the flexible production system (FPS) and the correlations between them.

Specialized research identifies three levels of flexible manufacturing systems, which vary in terms of complexity and scope:

a) **Flexible Processing Unit** – Typically a sophisticated machine tool (such as a machining center) equipped with a multi-pallet magazine and an automatic tool manipulator, capable of operating autonomously.

b) **Flexible Manufacturing Cell** – Consists of two or more flexible processing units, with machines directly controlled by computer systems.

c) **Flexible Manufacturing System** (FMS) – A larger-scale system that integrates several manufacturing cells connected through automated conveyor systems, which transfer pallets, parts, and tools between machines. The entire process is centrally and/or locally computer-controlled, overseeing storage systems, automated measuring, control and testing equipment, as well as CNC machine tools. This level incorporates all subsystems of a manufacturing process, including production, logistics, control, and scheduling.

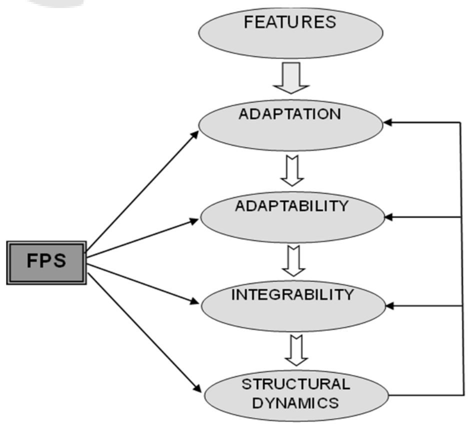

Figure 1: Characteristics of the Flexible Production System (FPS) and the correlations between them

2 COMPLEX MANAGEMENT AND AUTOMATION IN FPS

The new concept of flexible manufacturing system implies a total integration and coordination of the subsystems by means of computers, (Ioana, 2013), (Nicolescu, 2000), (Ioana & Nicolae, 2002).

Figure 2 provides a clear example of computer-assisted management applied to the technological process of steel production in electric arc furnaces (EAF).

Because of the process's complexity, its management relies on a computer system equipped with two independent computing units (CU1 and CU2).

However, since most EAFs in the country lack AMCR systems capable of operating continuously and in real time, operator involvement remains necessary.

The actual management of the EAF involves providing for the computing unit (CU1) two sets of input quantities, as follows (Ioana & Nicolae, 2002):

- $\sum i_1$ – input quantities extracted from the process from its output quantities $\sum y1$ possible to be quantified by direct measurements provided by the measuring elements ($\sum$ME).
- $\sum i_2$ – input quantities provided through the operator (these are the quantities that cannot be measured continuously and in real time).

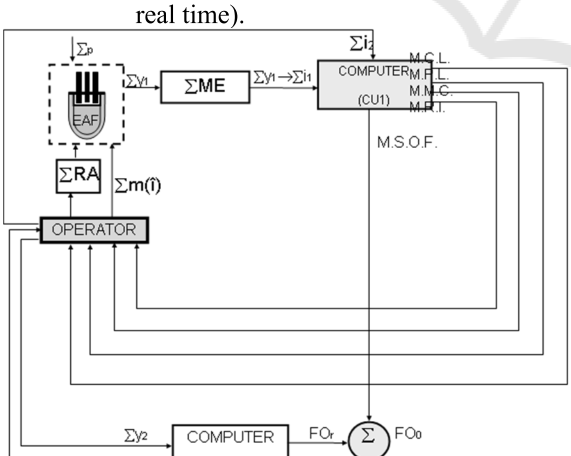

Figure 2: Principle Scheme of computer-aided control at EAF.

Based on these two sets of input sizes ($\sum$i1) and ($\sum$i2), the computing unit (CU1) elaborates the general driving procedure based on specific mathematical models. In this regard, the results of the five mathematical models are used:

- The mathematical model for prescribing the objective function (MSOF).
- The mathematical model for calculating the load (M.C.L.).
- The mathematical model for effective melt conduction (MMC)
- The mathematical model for load preheating (MPL)
- The mathematical model for reactive dust injection (MRI)

The operator then receives the parameters from the general EAF management procedure. For certain categories, commands are transmitted to the chain of automatic regulators ($\sum$AR), which handle process control, while in other cases the operator intervenes directly through execution variables ($\sum$m(î)), for instance when manually dosing the charge.

At the same time, CU1 establishes the prescribed value of the objective function (OF_0).

After the completion of the technological stage (in this case, steel elaboration), the operator collects output data from the process ($\sum y_2$) that could not be continuously or in real time measured. These data are then processed by a second computing unit (CU2), which—together with CU1—determines the actual achieved level of the objective function (OF_r).

The comparator ($\sum$) compares the prescribed (OF_0) and the achieved (OF_r) values of the objective function, calculating their deviation (ΔOF):

$$\Delta OF = OF_0 - OF_r \qquad (1)$$

Based on this deviation, the operator (technologist) decides whether to adjust the overall EAF management procedure. Using the two computing units, a new management strategy can then be developed.

Due to the inherent complexity of steelmaking in electric arc furnaces, comprehensive management of this system requires the systematic execution of the following stages:

- Quantifying and maintaining a prescribed technological state (inertia state) of the furnace, which can be ensured by conventional automation methods.
- Implementing advanced automation of the EAF, aimed at process management to maximize the objective function OF, as defined by specialized mathematical models.

Conventional automation of the EAF focuses primarily on:

- Electrical regime automation

- Thermal regime automation

The main goal of electrical regime automation (Figure 3) is to regulate the electrical power absorbed from the network on each phase, corresponding to each electrode. For this, the algebraic sum via the algebraic adder (AA), of the signals from the current transformer (TRI) and the voltage transformer (TRU) serves as the input for the drive motor driver (DMD).

The adjustment of electrode positions, with the aim of keeping the arc impedance constant (Za = const.), is carried out by the drive motor (DM) through the electrode position adjustment device (EPAD).

Electrode position regulators can also operate based on alternative algorithms, such as:

- Constant arc voltage regulation (Ua = const.)
- Constant arc current regulation (Ia = const.)

Figure 3 illustrates the principle diagram of EAF electrical regime automation and regulation.

Intelligent, real-time production control systems, which use simulation technology to predict the subsequent impact of short-term production decisions, are a highly effective production management tool.

There is currently a large market for simulation-based analysis in production. This market is represented by the demand for products from the metal materials industry, in a continuously diversified typo-dimensional range, most of which are designed and used mainly for long-term design applications (predictive analysis). Other products are designed and used primarily for short-term planning and programming applications and limited capabilities.

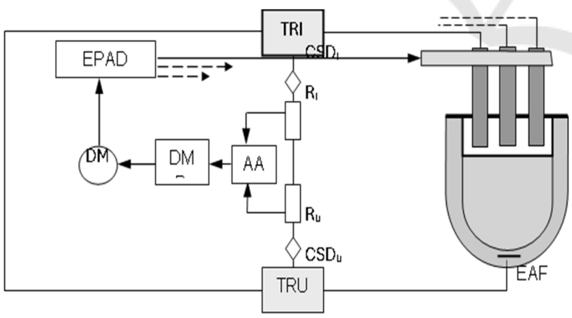

Figure 3: Diagram of the principle of the automation of the electrical regime of the EAF.

EAF –electric arc furnace for steel processing; TRI – current transformer; TRU – voltage transformer; CSD_I, DCS_U – control and separation devices; R_I, R_U – additional strengths; AA – algebraic adder; DMD – drive motor driver; DM – drive motor; EPAD – electrode position adjustment device.

The difficulties of implementing these systems in online planning, programming and control applications consist mainly of:

- **The design scheme is focused exclusively on its use by humans**, and not on the decision software usually found in computer-integrated manufacturing production control systems.
- **The system shall not use modelling units** or a scheme to facilitate the development of simulation models for real-time application. This includes inadequate support for modelling the complex decision logic element, where either the necessary units are not accessible or the decision logic modelling is integrated with physical features so that changes are difficult to implement. In addition, many systems do not incorporate units for real-time task coordination.
- The design scheme implicitly assumes that the designers of the simulation and the end users are the same, providing a single primary interface or a set of "rigid" interfaces (e.g. a "programming" interface and a "modelling" interface) for building models and running simulation experiments. However, in the context of online planning, programming and control applications, end-users are often represented by a variety of personnel (e.g. programmers, capacity planners, managers) who have not been directly involved in the development of the model, have no experience in the field of simulation, and wish to use only partially the simulation tool.

The usual shortcomings of commercial packages and the ever-growing interest in real-time online planning, programming and control indicate that an **effective scheme for online simulation systems is needed**. When creating important concepts for such a scheme, it is useful to examine the applications for online simulation technology.

Online simulation systems incorporate two powerful factors, namely:

- **The ability to forecast the subsequent behaviour of the application** based on the initial parameters (initial state).
- **The ability to faithfully reproduce and/or predict** the logical decision-making element of a manufacturing system.

These two capabilities offer possible benefits to a wide range of users within an economic production organization.

3 FPS OPTIMIZATION THROUGH ROBOTIZATION

The rise of flexible production systems and the adoption of robotization represent new organizational approaches that significantly affect all production subsystems. Anticipating and correctly understanding these potential impacts is essential for the proper integration and effective use of robotic technologies.

As flexible automation advances and industrial robots become more widely implemented, their influence on the various subsystems of economic units grows stronger, making early awareness of these effects crucial for their efficient application.

The robotization of production processes in the metal materials industry also has direct effects on the human factor, these mainly referring to the following aspects (Bălescu, 2004):

- The degree of human participation in certain technological processes.
- Avoiding the use of human operators in hazardous environments.
- Relieving operators of monotonous, repetitive, or stressful tasks.
- High requirements for worker qualifications and retraining.
- The importance of the human operator's role and status within the organization.

Consequently, any study of robotization's effects on economic units must also consider the human factor. Robots should be treated as resources that, like any other, require investment, operation, and maintenance, and can only be used effectively in conjunction with other resources. It is therefore important to understand the relationship between robots and other resources and how this interaction impacts the management system of the economic unit.

4 CONCLUSIONS

For industry, globalization brings new opportunities but also fierce competition. Industrial engineering companies are forced to improve their production systems so that they are able to react quickly and economically effectively to unpredictable market conditions, such as changing production volume, improving quality and decreasing costs, labour shortages, etc.

The implementation of industrial robots reduces the uncertainty associated with the human factor, thereby increasing the reliability of automated systems. This, in turn, enables more effective quality control within the manufacturing system and facilitates the transition to real-time production management. These developments have significant implications for the management methods and approaches employed..

A Flexible Production System (FPS) has the ability to allow automated readaptation/adjustment to new for the production of parts from a variety of nomenclature, within established limits of their characteristics. FPSs are intended for "families" of products that need to be manufactured in increased production volumes, which justify the investment.

In advanced production systems, manufacturing processes adapt their responses to different tasks, enhancing both efficiency and competitiveness. A flexible production system is not a one-size-fits-all solution; rather, it is designed to meet specific production requirements.

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