Mathematical development of an efficient three-dimensional workflow for industrial manufacturing systems

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Abstract: The increasing rate of challenges and competitions that face industrial projects alongside the vast fluctuations in the various related variable, whether human, material or economic nature, have forced decision-makers and researchers to examine all the related technological production dimensions. The three-dimensional 3D array of technological production is formalized and examined in comparison with the relevant two dimensional 2D and one-dimensional 1D ones. The analysis of the general principals of conventional technological systems and the theoretical productivity of technological systems with different types of capacity technological areas were used as the base in order to develop a qualitatively new high efficient, continuous action, low-cost technological system. Flow-helical technological module FHTM was developed in order to ensure an effective solution for a complex automated production processes scheme that ensures sufficient rising of technical and economic indices of manufacturing for a wide range of industries.

1. Introduction

Scientific and technological advances constantly set some new and more complicated challenges before mechanical engineering that involve the design of a qualitatively new entirety of features and utility measures for the manufactured parts, improvement in production efficiency, automation of production processes, and ecological friendly [1], in order to meet the society’s demands, and the growing capabilities of science, engineering, and economy. One of the perspective directions for solving the problems that mechanical engineering is facing is the complex and complete automation of industrial processes, based upon the continuous action technologies [2]. Figure 1 illustrates some idiosyncrasies of continuous technological systems. Technological machines are divided upon their efficiency into groups; technological machines with normal efficiency, technological machines with high efficiency, and technological machines with ultra-high efficiency. These technological systems possess qualitatively new features and capabilities that make them widely used for complete complex automation of industrial processes in mechanical engineering for mass production of various machine parts. As normal production technological systems have already been thoroughly investigated and widely designed and implemented [3-5], this paper is aiming at the handling of the high and ultra-high productivity technological systems. Though, the ideas expressed herein, may, in general, be implemented on some technological systems with normal productivity, i.e. rotary and rotary-conveyor machines. The technological systems of continuous action with high and ultra-high productivity are referred to in this paper as three-dimensional 3D Technological Systems 'Workflow 3D TSW.'
A hypothetic model of the particularities of the reorganization of the treated object TO at complex automation of industrial processes is illustrated in figure 2, which demonstrates the input streams $V_1$, material $V_M$, power $V_E$, and $V_I$ and the corresponding output streams $W_1$, $W_M$, $W_E$, and $W_I$, without direct man-made contribution, due to whole automation. Studies have proved that the technological systems of continuous action, in which the process of objects continuous transportation motion, jointly with tools and means of processing perform the technological processing, perceptively to ensure the complex automation [6]. Increasing the technological capacity is to be tried in order to create the automatic technological system, hence, compact technological systems should be designed, possessing capacity arrangement of units of technological action with 2D or 3D technological areas, that are also described with continuous tools movement of and treating means, jointly with the objects, under treatment.

The goal of this paper is to develop general principles for the conception of qualitatively new technological systems with continuous action and to produce a general theoretical approach for the design of 3D TSW in order to synthesis specific alternatives of 3D TSW and the solution of the problems of automation of production processes.

2. Theoretical bases and analysis

Although the traditional rotary and rotary-conveyor technological systems possess qualitatively reliable capabilities, as well as high technical and economic indices, there are still needs for some new
opportunities in developing continuous technological systems that follow the 3D TSW new principles of design and functioning [7, 8]. The start would be in analysing the principle of transition from their 1D arrangement to 2D arrangement towards the 3D arrangement. These mentioned technological areas are demonstrated in figure 3. Transportation velocity of parts is designated with letters $v_{Tin}$, while $h_i$ stands for the parts step.

![Figure 3](image)

Figure 3. Technological area Models of a – 1D, b – 2D, c – 3D.

The theoretical productivity of technological systems with the various types of capacity technological areas is determined by means of the relations in table 1.

| Technology area | Relations | Terminology |
|-----------------|-----------|-------------|
| 1D area         | $TP_{ul} = \frac{l_i}{t_o u_l}$ | (1) \* TP; theoretical productivity, $l_i$, $s_i$, $a_i$: length, area, and volume of 3D technological area. |
| 2D area         | $TP_{le} = \frac{a_i}{t_o a_{el}}$ | (2) $u_e$, $a_e$, $v_e$: length, area, the volume of a singular technological area. |
| 3D area         | $TP_{el} = \frac{v_i}{t_o v_{el}}$ | (3) $t_i$: time. |

New generation technologies and flow-capacity continuous technological systems may be developed based on the determination of the system of qualitatively new principles for development of highly efficient technologies (S), and technological systems lying on crossing of the new S1 and the well-known S2 design principles and on the system of designing qualitatively new technologies and technological systems that ensures the possibility of working with highly sophisticated multi-level hierarchal items, as illustrated by figure 4.
Another important step in the structure synthesis process is the system’s elements organization into a compact capacity structure. This task requires the increase of the amount of technological capacity according to the following equation (4):

$$ T_{Cr} = \frac{C_T}{C_{or}} $$

where:
- $T_{Cr}$: the amount of the use of technological capacity at r-level;
- $C_T$: The capacity volume, where the technological equipment is installed;
- $C_{or}$: The overall capacity volume.

3. Results and discussions

The dependence of the relative productivity $P_{rel}$ of technological modules with different capacity technological areas on their relative overall dimensions $e_o$ of the capacity technological area was determined on the bases of the equations 1-3 and illustrated in figure 5. Analysis of these results prove that as overall dimensions of capacity technological area increases, the productivity of technological systems also increases, in agreement with the following consistencies: for the 1D technological area; in a direct proportional dependence, for the 2D technological area; in square dependence and for 3D technological area; in cubic dependence. Thus, technological systems with 2D and 3D technological areas are characterized as qualitatively new, much higher technical and economic indices in comparison with 1D technological area that were developed on the basis of rotary and rotary-conveyor machines and lines.

$$ \text{Figure 5. Dependence of the system’s productivity on the technological area’s dimensions for the: 1: 1D, 2: 2D, 3:3D.} $$
These findings made it important to increase the technological unit density in order to alleviate the efficiency of the structural design for a technological system. Also, with \( n \)-technological modules, it is essential to compact them in capacity, via grouping into cells of production as illustrated in figure 6 that represents a formalized 3D production cell. These cells need to be organized in capacity groups all over the whole workshop so as to confirm the capacity arrangement and hence, to raise the quotient of the use of capacity and the environment as shown in figure 7. A formalized diagram of compacted capacity production volume that is organized inside the coordinate system \( X, Y, Z \) thru production cells. The modulation of the progress of technological systems permits the implementation of the automated production principles, such as the flexibility, continuity and high technical and economic manufacturing indices.

![Figure 6. Formalized 3D technological workflow.](image)

The design of a real-time technological systems algorithm for the general method of continuous 3D TSW synthesis was introduced in addition to the methods for optimization synthesis of their design, as illustrated in figure 8. The following is shown there: Objects for treatment and Flow-screw technological module FSTM are supplied with an incoming flow \( V \), they are discharged with an outgoing \( W \) flow. The direction of the rotary motion of FSTM sub-systems is designated with arrows.
Figure 8. A principal-structural model of 3D technological workflow.

4. Conclusions
The major characteristics of the various dimensions of production technologies were demonstrated in the context of their addition to the final productivity measures and their do ability under different work environments. Then, the development and design of new qualitative high-efficiency technological systems for continuous action were analysed and implemented on the basis of the commonly practiced mathematical and analytic models of the various dimensions of the general arrangement principles of the classic types of technological systems. The FHTM variables including the technological capacity and unit compaction were good tools in order to guarantee to overcome the problems with complete and sophisticated self-maintained production processes and sufficiently raised the technical and economic indices of the manufacturing process and hence made it available to be broadly used for various industrial branches.

5. References
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