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Applications of the systems theory to the designing of the sand preparation sub-system in foundry plants

R. Wrona[a,]*, A. Stawowy[b], A. Macioł[b]
[a]Department of Foundry Processes Engineering, Faculty of Foundry Engineering,
AGH University of Science and Technology, Reymonta 23, 30-059 Kraków, Poland
[b] Department of Applied Computer Research, Faculty of Management
AGH University of Science and Technology, Gramatyka 10, 30-059 Kraków, Poland
*Corresponding author. E-mail address: rwrona@agh.edu.pl

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Abstract

This study provides the basic principles for designing the functional structure of manufacturing systems and their components. The analysis of functional values is applied to create the technological and manufacturing model underlying the design of the foundry equipment with machine units and materials handling systems. Quoted examples illustrate the approved procedure to be applied to control the sand preparation process in a foundry.

Keywords: Foundry, Systems theory, Designing, Moulding sand

1. Introduction

This study is the continuation of the research work focused on applications of the theory of systems into foundry plant design. As it was mentioned in [1], each foundry plant can be treated as a system and, in accordance with the theory of systems, its components are regarded as sub-systems made from elements. Elements include machines, installations, transport and materials handling systems as well as process lines and work centres varying in a level of complexity. Elements making up the structure of the sub-systems vastly differ in terms of their construction, functional utility and reliability features. Despite this diversity of individual elements, attempts are made to build structures to enable the manufacturing activity of the whole system – a foundry plant. The design program involves:

- structural analysis, whereby a foundry plant is viewed in terms of schematic diagrams showing all flow relationships as well as technological processes,
- division of a foundry plant into systems and sub-systems to obtain simple and easy-to-analyse schemes,
- defining the function and role to be played by each component and defining the behaviour of the foundry plant when one component should change,
- defining the hierarchical structure of control.

The term "control' means the management of foundry processes and interactions so as to achieve the optimal values of performance and efficiency indicators. Typically, efficiency is understood as effective input-output transitions within the investigated system. For better illustration, an example shall be provided showing the sand mix preparation sub-system in the foundry plant.

2. Functional structure of the sand mix preparation sub-system

The fundamental principle of design requires that the analysis and synthesis of the solution be integrated, which means that every fragment of the process or the set of machines or transport units should play a clearly defined role in pursuing the main objective, specified in the foundry plant schedule. Accordingly, the following aspects have to be highlighted for identification:

- the entire process of sand mix components preparation, system sand preparation and the circulation of fresh and used sand mix,
- elements making up the above-mentioned process,
- relationships between process components and the process as a whole. It is required that input-output relationships be considered between process components and between the system and its surroundings.

Thus defined components in the shape of process and transport systems are interrelated, forming the coordinated technological- manufacturing structure. Development of such structure should help identify the series of quantities making up the relevant sets:

a) parameters controlling the process in a specified degree,
b) measured or controlled parameters, with the specified accuracy levels,
c) parameters associated with the working conditions of the foundry equipment.

For example, the sand mix preparation sub-system is characterised by the structure dependent on:

- the processes involved in mix components preparation (input)
- mould preparation processes (output)

The functional structure of the investigated sub-system with the parameters characterising the system's surroundings is shown in Fig 1.

Designations used:

Q_{m1}, Q_{m2},…,Q_{mn} - amount and type of mix components, efficiency of the materials handling installation feeding the storage bins above the mixing installation

Z_{m1}, Z_{m2},…,Z_{mn} - parameters of storage bins over the mixing installation

q_{m1}, q_{m2},…,q_{mn} storage bin loading, proportion of mix components in the function of operation time of the mixing installation

$W_{m(i)}(t)$ - efficiency of the mixing machine in the function of operating time t(i)

$t_{(i)} = t_{d(i)} + t_{m(i)} + t_{0(i)}$ – duration times of dosing, mixing and mix reception operations

$U_{m(i)}$- characteristics of the mixing machines

i- ordinal number of a machine

O_{max}- production capacity of the sand mix preparation sub-system, where: $O_{max}= \{W_{m1}, W_{m2},…,W_{mi}\}$,

Z_{f1}, Z_{f2},…,Z_{fi} - parameters characterising sand hoppers

q_{f1}, q_{f2},…,q_{fi} - sand hopper loading- sand mix demand to the moulding stand in quantitative terms

F_1, F_2,…,F_i characteristic of the moulding plant, where: i- ordinal number of the machine

$W_{f(i)}(t)$ - efficiency of the moulding installation in the function of operation time T(i), where:

$t(i) = \sum_{i=1}^{Z} \sum_{1}^{j} t_{ij}$ - sum of duration times of subsequent operations required for moulding

$M_{f(i)}$ - moulding capacity in the unit of time,

where: $M_{f(i)} = \{W_{f1}, W_{f2},…,W_{fi}\}$,

$W_{s(i)}(t) = W_{f(i)}(t)$ – storage capacity on the sand maturing field, C_s- production capacity of the mould storage, where:

$$C_S = \left\{ \frac{Wf1 + Wf2}{2}, \frac{Wf2 + Wf3}{2}, …, \frac{Wf(i-1) + Wfi}{2} \right\}$$

$M = m * C_s$, where: m – number of castings in a mould, M – production capacity of the moulding sub-system, the number of castings.

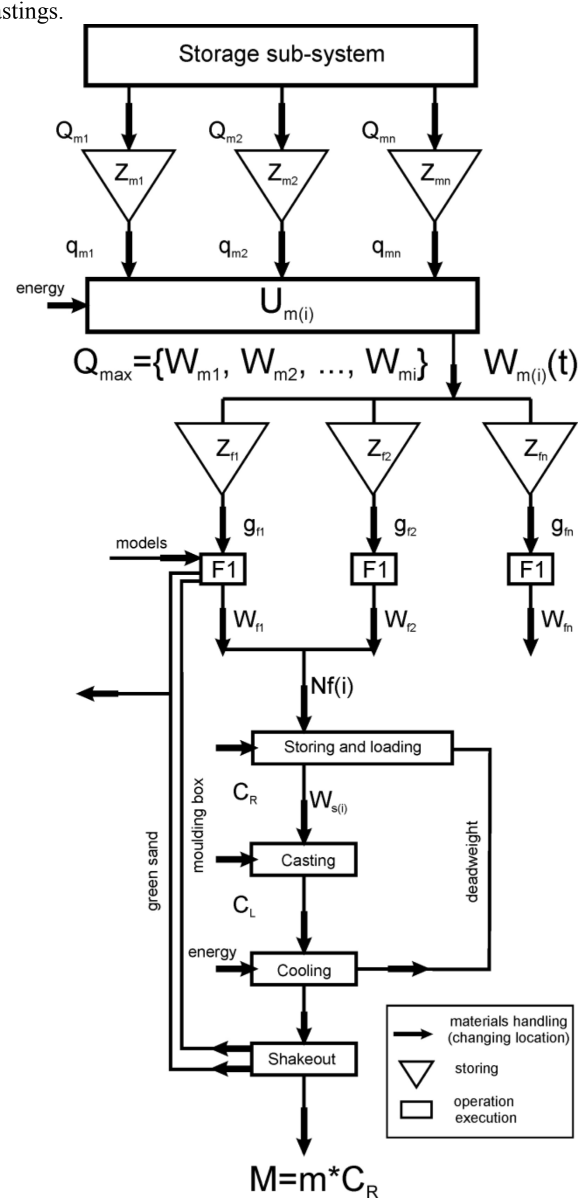

Fig. 1. Model of the process in the sand storage and preparation sub-systems

The graphic form of the sub-system is in line with the principles and methods of value analysis and offers us a better insight into the structure of the process, no matter what the sand mix preparation technology. Structural modifications, necessary to account for technological options, are introduced to adapt the structure to different process requirements. In the structure given here, the sub-system implements particular functions through processing the information from the surrounding sub-systems, enabling the process control such that the amounts and type of prepared sand mix be in line with the demand, at the same time ensuring the stability of sand parameters.

Application of the methods of the value analysis, particularly the function analysis yields the further procedure to define the sets of process installations (machines, transport and materials handling systems) executing the functions making up the given process. In the first place the function is defined and then machines and installations duly assigned. This procedure is applied to avoid confusion between the manner the given function is executed and the function itself.

3. Parametric analysis of machines and plants making up the structure of the sub-system

Of particular interest are characteristic parameters of units and assemblies designed for implementation of the set of functions (operations) involved in the sand mix preparation. Technological units in the sub-system's structure include:

- processing units: transforming the physico-chemical conditions of materials (for example mixers characterised by operators governing the manner in which input quantities (sand mix components) are transformed into output quantities (sand mix with specified properties). The degree of transformation depends on the design and operating principle of the device,
- storage units: storage bins used to control the flow rate of mix components and sand mix between particular installations, their flow capacity being particularly hard to define. This issue is of key importance when the production processes are scheduled in series, per shits, and after periodic dosage of the given component,
- dosing units: used to carefully measure (by weight or by volume) the amount of component required in the subsequent stage of the process,
- materials handling: used to handle the materials and components between the source and reception points, without changing their parameters.

To attempt a more detailed characteristics of the sub-system in relation to the process involved, a formal description is required, revealing the input-output relationships characterising the states of the system at the specified moments of its operation. The process is characterised by the continuous flow of information and materials and by the changes of the "form of information" between the given elements of the sub-system which are subject to changes. Input –output relationships are classified as follows:

a) inputs:
- operational-technological relationships: the flow of materials depends on the type of equipment, specifications of the power system and installations, process control,
- spatial and building structure: location, division into zones in accordance with functional relationships, the block levels, compactness of the structure,

b) outputs:
- technological relationships: type of process, type and number of machines, production capacity, power demand, organisational structure of the process,
- architectural and constructional data, spatial structure, load-bearing structures.

For illustration, a parametric description of the sand mix preparation process is shown in Fig 2.

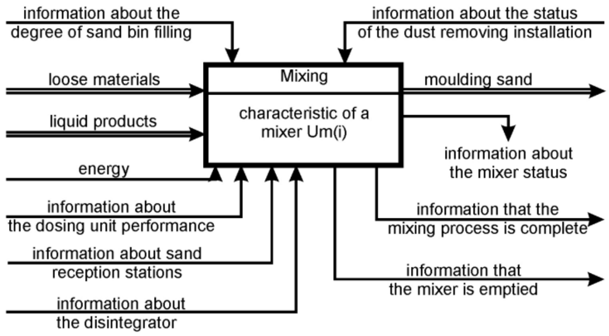

Fig. 2. Storage sub-system

The parameters make up the static characteristic of the process and plants, without any time relationships. These are mainly manufacturer's data found in catalogues, enabling the selection of particular machines and installations for the project. Of major importance are:

a) Efficiency of the machine: basic information enabling the selection of the machine for the process. This parameter expresses the machine performance per unit amount of material handled and in the function of time. It is a well-known fact that the real efficiency level differs from that quoted in the manufacturer's catalogue. The difference between the theoretical and real efficiency is associated with the way the machine is utilised, which in turn depends on the work organisation system.
b) Installed power: this parameter defines the power supplying system and enables us to find the power consumed by particular machines during the process.
c) Geometry and dimensions: this parameters is useful in designing of the spatial structure of the sub-system, to put the system components in their positions and in handling the load-bearing structures. This parameter is absolutely necessary at the stage of development of the spatial structure on the basis of an approved technological model.
d) Balancing of the exhaust air: the sand mix preparation sub-system incorporates machines that require dust removal. The flux of exhaust air affects the air balance in the ventilation and dust control system.

4. Conclusions

Adopting the systemic approach implicates a procedure targeted at integrated design. The systemic approach does not lead to formulation of a set of rules or hypotheses, but should be regarded as a standpoint to view the designed object or plant. The approach involves the analysis of key relationships between the system elements, followed by inferring based on the developed model. This study explores the technological model showing the functional structure of the sand mix preparation sub-systems. Underlying the model are input-output relationships and feedback loops. Feedback relationships are based on the sequence of information, mass and energy flows. It is reasonable to conclude that a system or a sub-system is an abstract term whilst the object or plant- for instance a foundry plant, is a real, concrete entity. The relationship between the system and the real object is interpreted such that the system as a property of a material object constitutes the principle of its operation.

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