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Generalized net modelling for the control of material processing with a flow reactor[1]

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Abstract: A Generalized Net (GN – an extension of the Petri net) model is constructed for monitoring and control of allow reactor for materials processing.

Keywords: Control, Flow reactor, Generalized net, Model, Monitoring

§1. Introduction

A common form of material processing is based on the flow reactor principle (Fig.1). At various stations of the carrier (gas or liquid) flow, materials (reactants) $G_1, G_2, G_3, ...$ and energy W are injected. Due to heating, mixing and, possibly, chemical reactions, the resultant flow acquires certain properties such as temperatures, densities and velocities of its components. As these in most cases are not directly measurable, indicators for the reactor operation are parameters $M_1, M_2, ...$ measured by a special device (monitor). The monitor gives out information to the "operator" (human or automation) which provides feedback for control purposes (Fig.1).

Reactors of this scheme have been employed in a number of technological processes [1,2]. Some of them process multi-phase flows e.g. gaseous carrier flows with dispersed powder particles, as in the thermal spray technology [3]. The resultant flow in this case carries molten particles which, upon striking a cold surface, condense thus forming a layer. In large scale industrial applications inspection of each individual coating is not an option. The alternative is to use the monitor output $M_1, M_2, ...$ (Fig.2) after *preliminary tests* made in order to correlate these with the end product quality. Other tests that find relations to the inputs $G_1, G_2, G_3, ..., W$ are to be run regularly, in particular for arc plasma spray torches [4,5] *(regular tests)*.

The definition of the concept of a GN is described in [6].

Our first GN model of arc plasma spray torches [5] describes in detail the flows of materials, energy and information in a chromatically monitored plasma spray system. The

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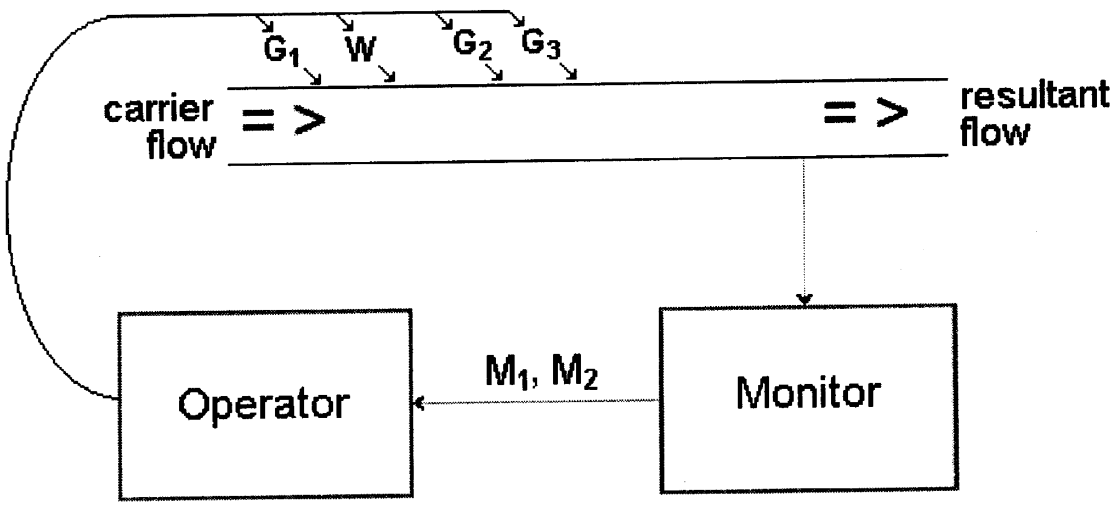

Fig.1 Flow reactor system: schematic diagram.

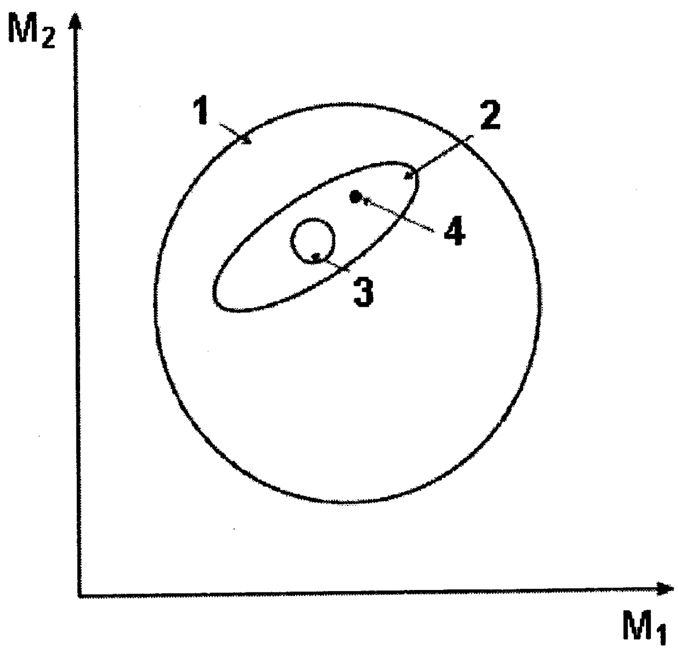

Fig.2 Monitor output space: 1 failure region, 2 operating region, 3 correct operating region, 4 current operating point.

present model is suitable for a wider, generic class of systems (Fig.1) with an emphasis on decision making.

§2. Control strategy

Let the monitor output variables $M_1, M_2, \ldots$ vary within region 1 of Fig.1 (for the system modelled in [5] this region is a circle defined in the polar co-ordinate system by

$$0 \leq H < 2\pi, \ 0 \leq S \leq 1,$$

where H, S are chromaticity parameters). The actual co-ordinates $M_1, M_2, \ldots$ read by the monitor define a "current operating point", 4 in Fig.2. According to the *preliminary tests,* high quality end product is obtained when $M_1, M_2, \ldots$ are within a small region called "correct operating region", 3, surrounded by the wider region where operation is still possible without endangering the system but with defective product ("operating region" 4). Being further outside would mean faulty operation (for the system [5] this would mean gas or cooling water leakage, or excessive electrode erosion).

The operator response depends on the position of the current operating point

1. if this is in region 3, no action is needed;
2. if this is in region 4 and outside 3, adjustment of $G_1, G_2, G_3, \ldots, W$ (corrective) is undertaken in order to restore position in 3;
3. if this is in region 1 and outside 4, the operation is terminated and the system is repaired (for the system [5] a typical repair is electrode replacement).

Action ii. leads to adequate results so far as the *regular tests* have provided the current dependence of $M_1, M_2, \ldots$ on $G_1, G_2, G_3, \ldots, W$.

§3. Construction of the model

Below we shall construct a reduced GN (Fig. 3) without temporal components, without transitions, places and tokens priorities and without places and arcs capacities, and for which the tokens keep all their history.

The system operates discretely in sessions, consisting of a number of time steps. At each time step data is acquired; at the end of each session output signals for correction of the input parameters ("correctives") are generated, if needed.

We shall describe the transition condition predicates and the tokens characteristics not fully formally for easier understanding of the formalism in use.

Initially, tokens β and γ are placed in places l_1 and l_3 with initial characteristics, respectively:

"initial input electric power; parameters (electric current, voltage, etc.)",

"initial flow state; parameters (mass fluxes, temperature, etc.)",

The transitions have the following forms.

$$Z_1 = < \{l_1\}, \{l_1, l_2\}, \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_1 & true & true \end{array}, \vee(l_1) > .$$

Token β obtains characteristic

"new values of the parameters (electric current, voltage, etc.)"

in place l_1 and

"current input electric power; parameters (electric current, voltage, etc.)"

in place l_2.

$$Z_2 = < \{l_3\}, \{l_3, l_4\}, \begin{array}{c|cc} & l_3 & l_4 \\ \hline l_3 & true & true \end{array}, \vee(l_3) > .$$

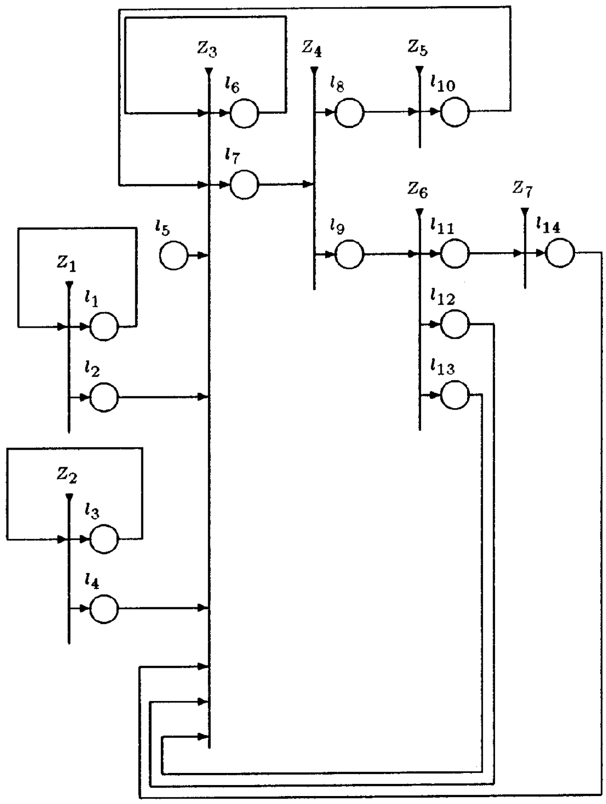

Fig. 3: A GN-model

Token γ obtains characteristic

"new values of the parameters (massfluxes, etc.)"

in place l_3 and

"current material feed, parameters (massfluxes, etc.)"

in place l_4.

Tokens that are designated below as α enter place l_5 with initial characteristic

"cstart of monitoring, parameter (time)".

$$Z_3 = < \{l_2, l_4, l_5, l_6, l_{10}, l_{12}, l_{13}, l_{14}\}, \{l_6, l_7\}, \begin{array}{c|cc} & l_6 & l_7 \\ \hline l_2 & false & true \\ l_4 & false & true \\ l_5 & true & false \\ l_6 & true & false \\ l_{10} & true & false \\ l_{12} & true & false \\ l_{13} & true & false \\ l_{14} & true & false \end{array},$$

$$\wedge(l_2, l_4, l_6, \vee(l_5, l_{10}, l_{12}, l_{13}, l_{14}) > .$$

Token α obtains characteristic

"new values of the parameters"

in place l_6 and

"current state of resultant frol, parameters"

in place l_7.

$$Z_4 = < \{l_7\}, \{l_8, l_9\}, \begin{array}{c|cc} & l_8 & l_9 \\ \hline l_4 & false & true \end{array}, \vee(l_7) > .$$

The tokens obtain the characteristics

"end product; quality parameters",

in place l_8 and

"resultant flow monitoring; monitoring parameters (coordinates of current operating point)",

in place l_9.

$$Z_5 = < \{l_8\}, \{l_{10}\}, \begin{array}{c|c} & l_{10} \\ \hline l_8 & W_{8,10} \end{array}, \vee(l_8) >,$$

where
$W_{8,10}$ ="end product test is needed".

The tokens obtain the characteristic

"end product; quality parameters",

in place l_{10}.

$$Z_6 = < \{l_9\}, \{l_{11}, l_{12}, l_{13}\}, \begin{array}{c|ccc} & l_{11} & l_{12} & l_{13} \\ \hline l_9 & W_{9,11} & W_{9,12} & W_{9,13} \end{array}, \vee(l_9) >,$$

where
$W_{9,11}$ ="the coordinates of current operating point are outside the operating region",
$W_{9,12}$ ="the coordinates of current operating point are in the operating region, but outside the correct operating region",
$W_{9,13}$ ="the coordinates of current operating point are in the correct operating region".

The tokens obtain the characteristics

"end of process; repear is needed"

in place l_{11},

"adjustment os operating point is needed; parameters (magnitude of adjustment)"

in place l_{12} and they do not obtain any characteristic in place l_{13}.

$$Z_7 =< \{l_{11}\}, \{l_{13}\},$$

$$\begin{array}{c|c} & l_{14} \\ \hline l_{11} & true \end{array},$$

$$\vee(l_{11}) > .$$

The tokens obtain the characteristic

"new status of system"

in place l_{14}.

§4. Conclusion

Along with the basic structure and behaviour of a flow-type material processing system provided with a means for monitoring and control, the present model incorporates knowledge-based decision making. The latter feature, however, needs further elaboration to take into account "training" sessions of the system which establish relations between input parameters and monitor output signals.

Decision making based on several monitor spaces (diagnostics) would also be of interest, as our regime adjustments and failure detection in some cases may depend on monitoring both at reactor input and output and/or both mean values and fluctuations, simultaneously.

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