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A generalized net model describing chromatically monitored and controlled arc plasma spraying

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Abstract: A Generalized Net (GN – an extension of the Petri net) model is constructed for spraying of materials by an arc plasma jet controlled by a chromatic sensing system.

Keywords: Chromatic sensor, Control, Generalized net, Model, Plasma, Spraying.

§1. Introduction

A major application area of low temperature plasmas [1] is in the production and modification of materials. Fig.1 shows the design of an apparatus [2] for plasma deposition (spraying) of thick layers (coatings), which uses a d.c. electric arc at high pressure to generate the plasma. The plasma spraying is now an established method in the machine-building industry to restore worn components, or deposit hard and/or protective layers on new parts and machining tools. This is also a promising technique for production of high-temperature super-conductive and ferromagnetic layers for the microelectronics [2].

Main parts of such a plasma spraying process (Fig.1) are (a) introduction of plasma-forming gas into the plasma generator (torch), (b) gas heating by the arc (generation of thermal plasma), (c) cooling of torch walls (power loss), (d) introduction of powder into the plasma flow, (e) plasma jet formation by the nozzle, (f) powder particles heating and melting, and (g) impact of molten particulate with substrate hence layer formation.

A disadvantage of all thermal plasma processes is the presence of instabilities that are due to various physical reasons. To overcome the difficulties in monitoring and controlling the plasma spraying it has recently been proposed [3] to use chromatic modulation techniques. These have been successfully deployed [4] in a wide range of industrial, biomedical and environmental applications. The essence of the chromatic methodology is to drastically compress the extensive amount of information describing the object to be monitored and/or controlled. Traditionally, optical emission spectra within a wide range of wavelengths have been used in plasma engineering as a diagnostic tool. Instead, the chromaticity method is based on the use of small number (typically 3) of broadband detectors having different, although significantly overlapping wavelength responsivities. Such a chromatic sensor is similar to biological systems such as human colour vision [5]. The three output signals - red, green and blue - are then converted to Hue, Lightness, Saturation (HLS) scale [6]. The HLS characteristics are more informative and less sensitive to disturbances in the signal path or noise.

Our plasma deposition device of Fig.1 is combined with a suitable chromatic monitoring system as shown in Fig.2. Preliminary studies of the response of the chromatic signals to plasma state variations have been reported [3]. The present paper is an attempt to describe the behaviour of the entire system of Fig.2 in terms of a generalized net (GN).

The definition of the concept of a GN is described in [7].

§2. 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 α, β, γ, δ, ε, ζ are placed in places l_1, l_3, l_5, l_{12}, l_{14}, l_{17} with initial characteristics, respectively:

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

"initial gas feed; parameters (massflux, etc.)",

"initial particles feed; parameters (massflux, number, etc.)",

"initial product; parameters (substrate position, substrate temperature, etc.)",

"monitor; parameters of measuring devices; number of time steps; number of sessions",

"criteria for correct operation; data (voltage, hue, saturation)".

$$Z_1 =< \{l_1, l_{18}\}, \{l_1, l_2\}, \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_1 & true & true \\ l_{18} & true & false \end{array}, \vee(l_1, l_{18}) > .$$

Token α obtains characteristic

$$\begin{cases} *, & \text{if a token has not arrived from place } l_{18} \\ \text{"new values of the parameters (electric current, voltage, etc.)"} & \text{otherwise} \end{cases}$$

in places l_1 and

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

in place l_2.

$$Z_2 =< \{l_3, l_{19}\}, \{l_3, l_4\}, \begin{array}{c|cc} & l_3 & l_4 \\ \hline l_3 & true & true \\ l_{19} & true & false \end{array}, \vee(l_3, l_{19}) > .$$

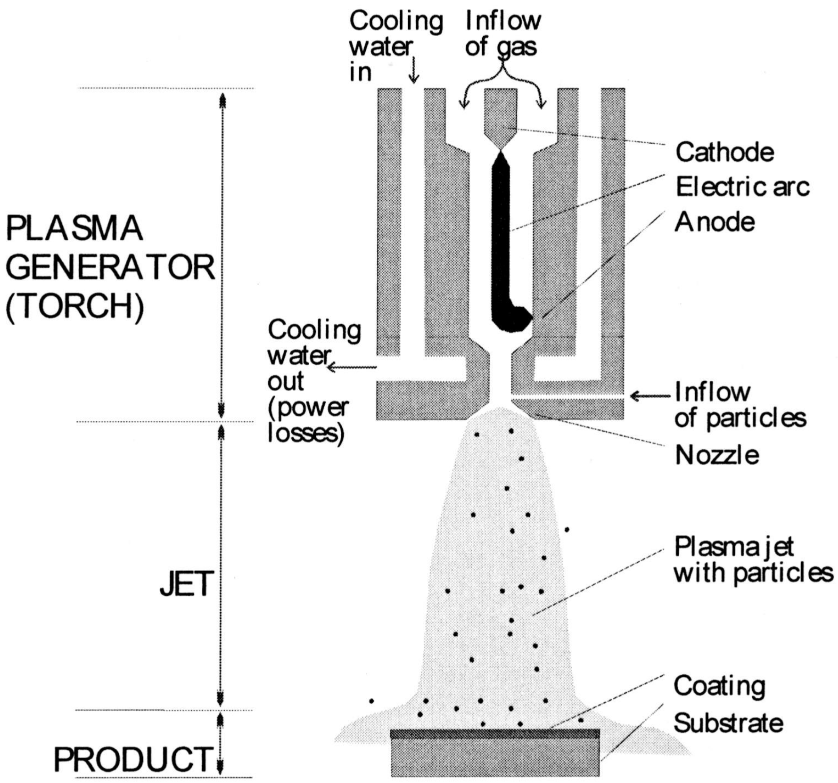

Fig.1 Longitudinal cross section of a plasma spraying system.

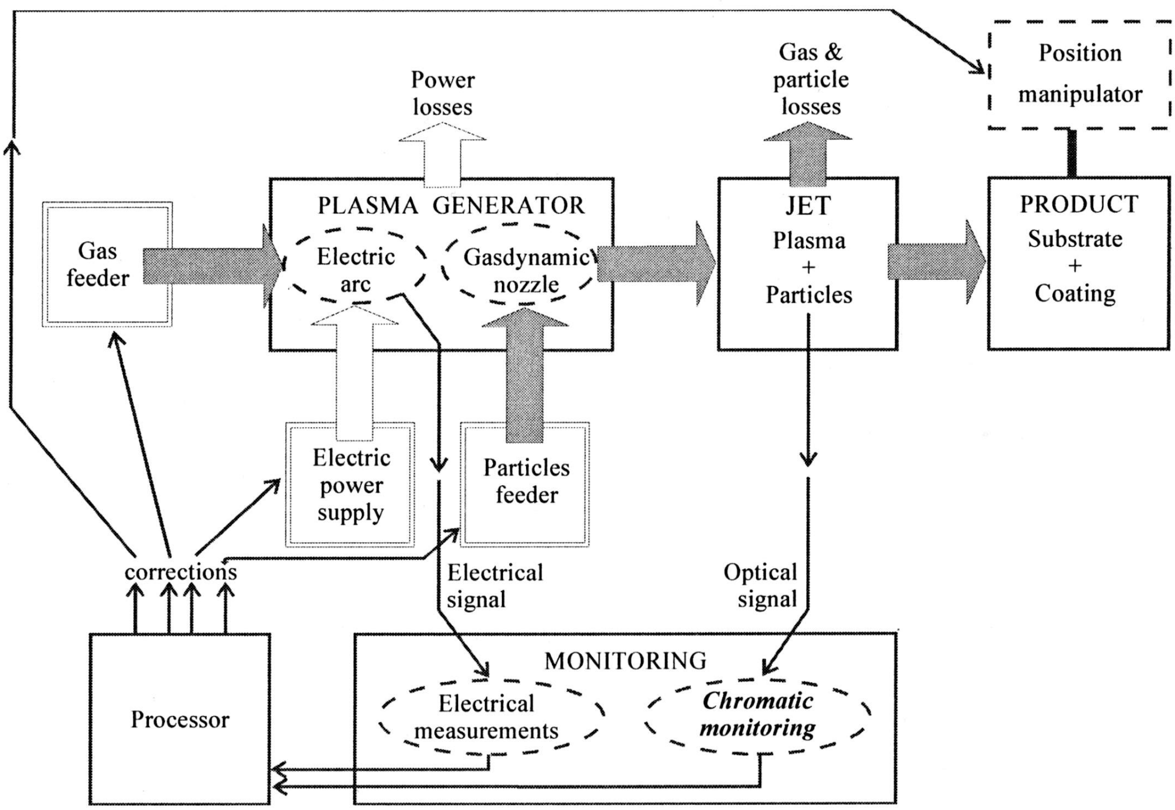

Fig.2 Outline of an arc-torch facility for plasma spraying equipped with chromatic monitoring and control

Token β obtains characteristic

$$\begin{cases} *, & \text{if a token has not arrived from place } l_{19} \\ \text{"new values of the parameters} & \\ \text{(massflux, etc.)"} & \text{otherwise} \end{cases}$$

in place l_3 and

"corrected gas feed, parameters (massflux, etc.)"

in place l_4.

$$Z_3 =< \{l_5, l_{20}\}, \{l_5, l_6\}, \begin{array}{c|cc} & l_5 & l_6 \\ \hline l_5 & true & true \\ l_{20} & true & false \end{array}, \vee(l_5, l_{20}) > .$$

Token γ obtains characteristic

$$\begin{cases} *, & \text{if a token has not arrived from place } l_{20} \\ \text{"new values of the parameters} & \\ \text{(massflux, number, etc.)"} & \text{otherwise} \end{cases}$$

in place l_5 and

"corrected particles feed, parameters (massflux, number, etc.)"

in place l_6.

$$Z_4 =< \{l_2, l_4, l_6\}, \{l_7, l_8, l_9, l_{10}, l_{11}\}, \begin{array}{c|ccccc} & l_7 & l_8 & l_9 & l_{10} & l_{11} \\ \hline l_2 & true & true & false & false & false \\ l_4 & false & false & true & true & true \\ l_6 & false & false & true & true & true \end{array},$$

$$\wedge(l_2, \vee(l_4, l_6)) > .$$

The tokens obtain the characteristics

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

in place l_7,

"power losses; parameters (amount of losses)"

in place l_8,

"particles parameters (mass flux, temperature, etc.)"

in place l_9,

"plasma parameters (mass flux, temperature, number, etc.)"

in place l_{10} and

"losses of materials; parameters (mass flux, temperature, etc.)"

in place l_{11}.

$$Z_5 =< \{l_{12}, l_{21}\}, \{l_{12}, l_{13}\}, \begin{array}{c|cc} & l_{12} & l_{13} \\ \hline l_{12} & true & true \\ l_{21} & true & false \end{array}, \vee(l_{12}, l_{21}) > .$$

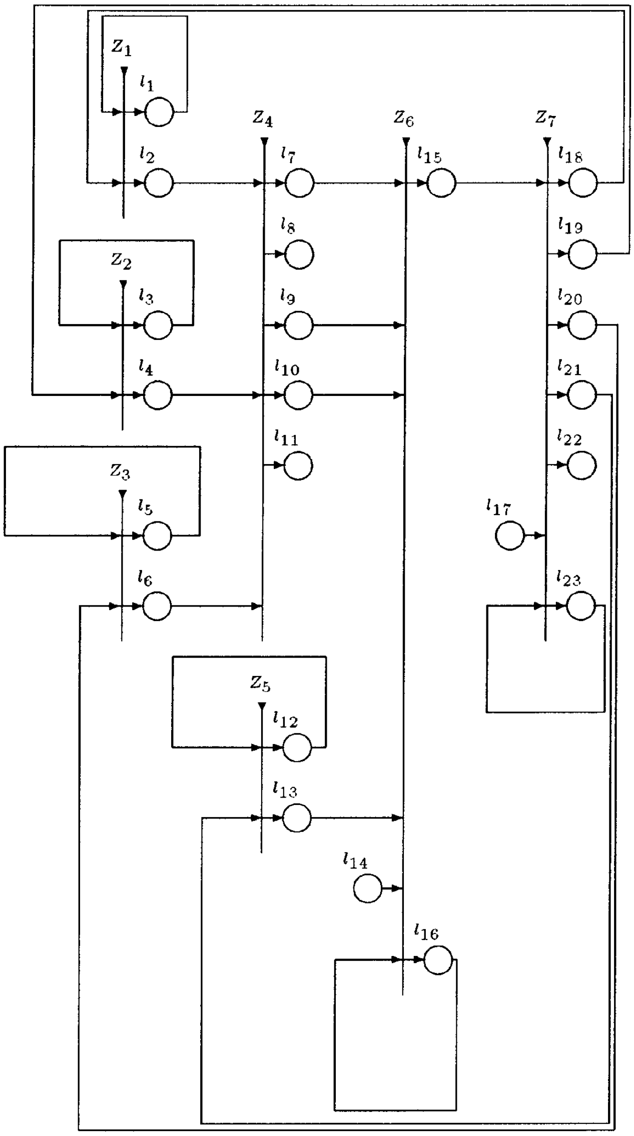

Fig. 1: A GN-model

The tokens obtain the characteristics

"product; parameters (new position, temperature, etc.)"

in place l_{12} and

"product; parameters (corrected position, temperature, etc.)"

in place l_{13}.

$$Z_6 =< \{l_7, l_9, l_{10}, l_{13}, l_{14}, l_{16}\}, \{l_{15}, l_{16}, \},$$

	l_{15}	l_{16}
l_7	*false*	*true*
l_9	*false*	*true*
l_{10}	*false*	*true*
l_{13}	*false*	*true*
l_{14}	*false*	*true*
l_{16}	$W_{16,15}$	*true*

,

$$\vee(\wedge(l_7, l_9, l_{10}, l_{13}), \wedge(l_{14}, l_{16})) >,$$

where
$W_{16,15}$ = "current time (within current session) = acquisition time".
The tokens obtain the characteristics

"output data (voltage, hue, saturation, etc.)"

in place l_{15} and

"current data (voltage, hue, saturation, etc.)"

in place l_{16}.

$$Z_7 =< \{l_{15}, l_{17}, l_{23}\}, \{l_{18}, l_{19}, l_{20}, l_{21}, l_{22}, l_{23}\},$$

	l_{18}	l_{19}	l_{20}	l_{21}	l_{22}	l_{23}
l_{15}	*false*	*false*	*false*	*false*	*false*	*true*
l_{17}	*false*	*false*	*false*	*false*	*false*	*true*
l_{23}	$W_{23,18}$	$W_{23,19}$	$W_{23,20}$	$W_{23,21}$	$W_{23,22}$	*true*

,

$$\wedge(l_{15}, \vee(l_{17}, l_{23})) >,$$

where
$W_{23,18} = W_{23,19} = W_{23,20} = W_{23,21}$ = "current session number < number of sessions",
$W_{23,22} = \neg W_{23,18} \wedge \neg W_{23,19} \wedge \neg W_{23,20} \wedge \neg W_{23,21}$.
The tokens obtain the characteristics

$$\begin{cases} *, & \text{output data are identical with criteria for operation} \\ \text{"corrective for input electric power"}, & \text{otherwise} \end{cases}$$

in place l_{18},

$$\begin{cases} *, & \text{output data are identical with criteria for operation} \\ \text{"corrective for gas feed"}, & \text{otherwise} \end{cases}$$

in place l_{19},

$$\begin{cases} *, & \text{output data are identical with criteria for operation} \\ \text{"corrective for particles feed"}, & \text{otherwise} \end{cases}$$

in place l_{20},

$$\begin{cases} *, & \text{output data are identical with criteria for operation} \\ \text{"corrective for product position"}, & \text{otherwise} \end{cases}$$

in place l_{21},

"total estimation of system operation"

in place l_{22} and

"time record of monitor"

in place l_{23}.

The tokens from places l_{18}, l_{19}, l_{20} and l_{21} unite with tokens α, β, γ and δ in places l_1, l_3, l_5 and l_{12}, respectively, and the latter tokens obtain as next characteristics the last characteristics of the first tokens.

§3. Conclusion

The GN approach could be used sucessfully for the description of variety of technological and intellectual problems. In the present paper the authors have made an attempt to apply this approach to the description of a specific plasma technology process and a means for its monitoring and controlling. This problem requires:

(a) knowledge of overall characteristics of the plasma system such as relations between output and input parameters;

(b) suitable algorithms for monitoring and control, and

(c) experience concerning the technological process in terms of criteria for:

 (i) correct operating point,

 (ii) tolerable deviations from this, and

 (iii) faulty situations.

Further studies are needed to gain more such expertise and incorporate this in our GN-model.

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