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## Supervisory system of integrated spray booths

### Abstract

Authors present a real time supervisory system for two cooperating spray booths, which are elements of the production line. The supervisory system enables a constant observation of such physical parameters like: temperature, pressure, air flow, concentration of styrene etc. The system also warns workers inside spray booths about dangerous events like a critical level of styrene, too low overpressure, the air flow is not high enough, etc. The paper presents results of the hardware and software development.

**Keywords:** spray booth, supervisory control system, safety.

### 1. Introduction

A typical control system of spray booth demands a stabilization of the temperature and the overpressure inside the work chamber of the booth. Apart of above parameters the volume of air flow should be maintained at a given value. Unfortunately during a normal activity of spray booths unwanted events may happen, which eventually provide to accidents. According to that both the temperature and the pressure stabilization algorithms should be connected with a supervisory algorithm, which enables the safe stop of the spray booth. The most dangerous event is related to the overpressure and the under pressure. In both cases operator's life is in danger, additionally the construction of the spray booth could be damaged. Another serious problem could be an insufficient air flow as a result of: filters clogging or an inlet/outlet channel clogging. Too low volume of air flow inside the spray booth may cause poisoning of operators, according to the Volatile Organic Compounds (VOC) influence e.g. styrene. Air flow disturbances may be related to technical problems with inverters that control fans of blowing and extracting units. For instance it can be: an overcurrent, too high temperature, a communication failure, etc. The last source of critical events is an actuator in the temperature stabilization loop i.e. the burner and the heat exchanger. An excessive temperature inside the heat exchanger or in the inlet channel can damage both the heat exchanger and the inlet channel.

Similar problems may occur at the factory, which specializes in the bathtubs production, where two cooperating spray booths were built.

Based on the analysis of critical events in the real time control systems the supervisory system was developed and applied. This system improves safety conditions inside the spray booths. The system also enables collecting data of working parameters and about dangerous occurrences.

### 2. General description of the plant

Discussed installation consists of two dedicated booths. The booths have a different construction parameters and functionalities. A view of installation is presented in the Figure 1. The smaller booth 1 is dedicated to work as a preparatory station and it is connected to spray booth 2 by the gate with shutter. Each booth has two units with fans: air makeup unit (supply unit) and extraction unit. The spray booth 2 has a larger cubature so it has higher performance fans. Circulated air is supplied inside the booth 1 from air make unit by a duct 3 and the plenum 4. The plenum is located over the working chamber. Then the polluted air is extracted from the booth by extraction unit and further ejected to the atmosphere by the exhaust duct 5. Similarly the air makeup unit 6 supplies a fresh air to the plenum 7 and next

to the spray booth 2. The extraction unit 8 draws air and eject to the atmosphere. The air inside the booth 2 is contaminated with overspray particles. Pulled air is purified by two stage filtering system located in the wall of the booth. Each booth has own independent shutter gate and there is additional shutter gate located between booths. All gates are controlled automatically and synchronized with external conveyor system. Each booth has an individual control system that stabilizes work parameters of booth. The main controlled parameters are: air velocity and overpressure. The air makeup unit at the booth 2 is equipped with heating unit (one stage gas burner).

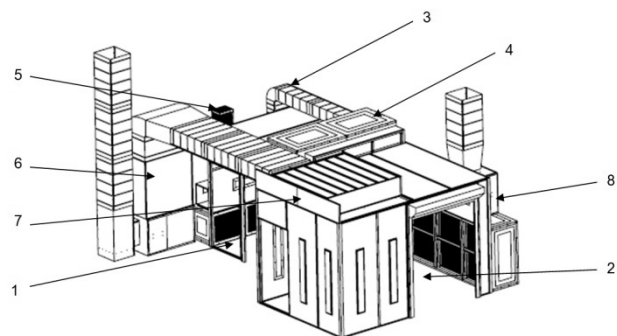


Fig. 1. A view of integrated booths

The overpressure inside the booths is stabilized by individual PID controllers. The volume of air flow is adjusted by performance of blowing fan. Then the exhaust fan follows blowing fan and keeps the overpressure on the set value. The main problems of overpressure control are the number of gates, connection between two booths with different cubature and fan performances, no communication between PID controllers. The hazardous situations may occur at the moments when gates are being opened and closed, mainly a gate between booths. The different performance of fans can cause unexpected conditions. Dynamic of fans is low enough to stabilize disturbances, but in case to analyze unforeseen conditions the work parameters have to be continuously recorded. Nowadays PLC controllers in addition to automatic control give the possibility of parameters registration. Registration data can be stored directly at the PLC or shared on the network for other devices by OPC server. Shared data can be visualized or stored on time using PC computer via local network or internet. Data access by internet allows remote analysis and diagnostics.

### 3. Hardware and software synthesis of the monitoring system

A general scheme of the monitoring system is shown in the Figure 2. The main element is the programmable controller with Intel x86 200 MHz-compatible CPU with integrated I/O processor. The PLC controller is also a data source for the supervisory level control, based on the OPC technology. In case of presented solution authors used OPC UA type instead of OPC DA to avoid well known problems with the DCOM configuration at the HMI station, what sometimes makes data exchange impossible.

The HMI station could be a selected office computer with SCADA software. This station enables a constant observation of all variables configured as OPC tags. Apart of the HMI station there are two touch panels installed directly in spray booths to warn operators about alarm and critical events inside spray booths. Both the HMI station and touch panels share measured data but only touch panels are elements of the safety system, which can provide real time responses to critical events, described later.

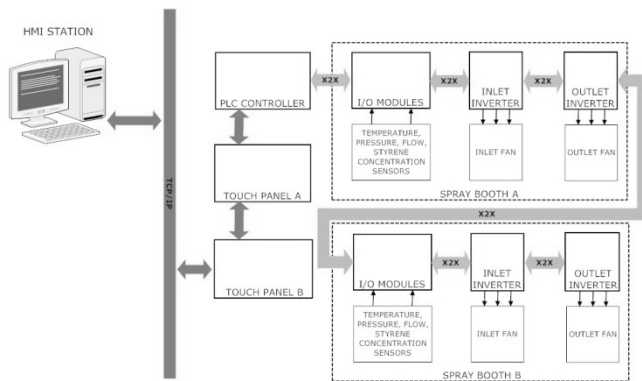


Fig. 2. A block diagram of the monitoring system of integrated spray booths

The Figure 3 shows the physical structure of the monitoring system. The blue line means the Intranet inside of the production factory, the orange line means a serial communication network, which is directly connected with the sensors and actuators level. The serial network named X2X [9] enables building distributed structures in a relatively easy way. It is important that I/O data may be transmitted in the real time based on 2000 μs cycle time.

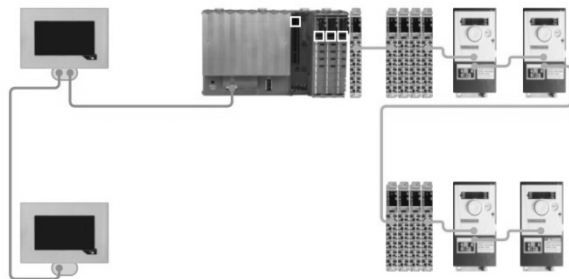


Fig. 3. A physical structure of the monitoring system of integrated spray booths

In both spray booths the same devices were used to control the process and to collect I/O data. The first I/O segment consists of the bus receiver (X20BR9300), the temperature module (X20AT4222), the analog inputs module (X20AI4622) and the bus transmitter module (X20BT9100). The bus receiver is the element of the link between the PLC and the I/O segment. The temperature module is responsible for reading data from resistance sensors, in this case PT1000 sensors. The analog inputs module enables reading data from the flow air transducer and from the pressure transducer using a current signal standard i.e. 4-20 mA to remove an influence of the electromagnetic field. Additionally based on this standard it is possible to detect a cable break or a failure of transducers when the signal is equal 0 mA. In the Figure 4 the exemplary physical connection between sensors and modules has been shown.

The last element of the I/O segment i.e. the bus transmitter enables extension of the serial network for additional elements. In case of spray booth both the inlet and the outlet inverters were next elements of the serial network. A single inverter is equipped with a bus receiver and a bus transmitter and then any additional network isn't needed to integrate inverters with a serial network.

An advantage of it is also opportunity of reading additional parameters like load current, inner temperature and diagnostics information about inverter's failures e.g. overcurrent, too high temperature, power line error etc.

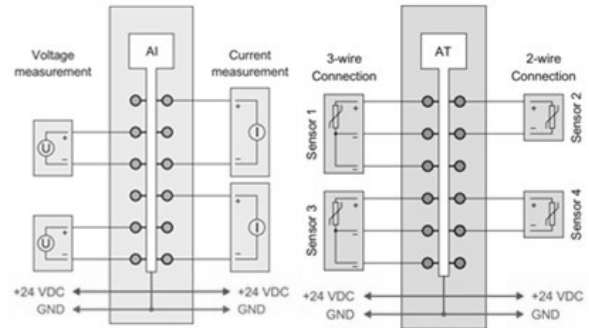


Fig. 4. A physical connection between sensors and modules [2, 3]

All monitored variables from the spray booth A are presented in the Table 1. The same group of variables will be collected from the spray booth B.

Tab. 1. Monitored variables from the spray booth A

| Device                     | Variable          | Data type | Physical range/Unit |
|----------------------------|-------------------|-----------|---------------------|
| PT1000 (3)                 | aiTemperature1..3 | INT       | -10 – 60 /°C        |
| Flow transducer            | aiFlow            | INT       | 4-20 /mA            |
| Pressure transducer        | aiPressure        | INT       | -50 – 50 /Pa        |
| Inverter of Air Supply Fan | aiSpeed           | INT       | 0 – 50 /Hz          |
|                            | aiCurrent         | UINT      | 0-10/A              |
|                            | uiError           | INT       | 0-55/-              |
| Inverter of Extraction Fan | aiSpeed           | INT       | 0 – 50 /Hz          |
|                            | aiCurrent         | UINT      | 0-10/A              |
|                            | uiError           | INT       | 0-55/-              |

Based on measured data the developed system constantly supervises pressure, air flows, temperatures values and parameters of inverters and takes actions when one of them reaches the alarm or the critical value. Those actions are connected with: displaying a specific info-window in touch panels (TP), stopping a production process (S) and saving information in the data base (DB). Selected events demand the acknowledgement (ACK) of the operator or the administrator of the production line. In the Table 2 are presented possible events with actions.

Tab. 2. Critical events and corresponding actions in spray booths supervisory control system

| Event                  | Actions |     |     |     |
|------------------------|---------|-----|-----|-----|
|                        | TP      | S   | ACK | DB  |
| Overpressure           | Yes     | Yes | No  | Yes |
| Under pressure         | Yes     | Yes | No  | Yes |
| Too low air flow       | Yes     | Yes | Yes | Yes |
| Alarm styrene level    | Yes     | No  | No  | Yes |
| Critical styrene level | Yes     | Yes | Yes | Yes |
| Inverter's failure     | Yes     | Yes | Yes | Yes |
| Burner's failure       | Yes     | Yes | Yes | Yes |
| Too high temperature   | Yes     | Yes | Yes | Yes |

The most suitable algorithmic construction to develop events recognition and starting proper actions is the step sequencer, which is a construction with a number of subprograms. Authors developed the step sequencer by means of the SELECT function, from the system Bernecker&Rainer library. The SELECT function

is based on the STATE keyword and the WHEN keyword which represents the action which has to be taken in a specific state according to specific conditions i.e. events. This function could be realized by means of IF-THEN statement, but the SELECT function is clearer and easier to expand. The first stage of the development such a step sequencer is the definition of all possible states in which a machine can work, then all conditions of jumping from one state to another should be determined. In the Figure 5 authors presented the supervisory control algorithm of the complex spray booths in a form of the step sequencer.

```

SELECT
    STATE <START> //Waiting for the start
        <instruction_list>
    WHEN <START Condition>
        <instruction_list>
    NEXT <BOOTH RUN>
    STATE < BOOTH RUN> //The normal working mode
        <instruction_list>
    WHEN <Normal STOP Condition>
        <instruction_list>
    NEXT <START> //Go to the Start state
    WHEN <Overpressure Condition>
        <instruction_list>
    NEXT < START >
    WHEN <Underpressure Condition>
        <instruction_list>
    NEXT < START>
    WHEN <Too low flow Condition>
        <instruction_list>
    NEXT < ACKNOWLEDGEMENT >
    WHEN < Alarm styrene level>
        <instruction_list>
    NEXT < VENTILATION>
    WHEN < Critical styrene level>
        <instruction_list>
    NEXT < ACKNOWLEDGEMENT >
    WHEN < Inverter's failure Condition>
        <instruction_list>
    NEXT < START>
    WHEN < Burner's failure Condition>
        <instruction_list>
    NEXT < START>
    WHEN < Too high temperature Condition>
        <instruction_list>
    NEXT < START>
    STATE < VENTILATION> //The ventilation working mode
        <instruction_list>
    WHEN <Accepted styrene level Condition>
        <instruction_list>
    NEXT <BOOTH RUN>
    WHEN <Normal STOP Condition>
        <instruction_list>
    NEXT <START> //Go to the Start state
    STATE <ACKNOWLEDGEMENT> //Waiting for the operator's action
        <instruction_list>
    WHEN <Acknowledgement Condition>
        <instruction_list>
    NEXT <START> //Go to the Start state
ENDSELECT

```

Fig. 5. The supervisory algorithm in a form of the step sequencer

## 4. Conclusions

The developed supervisory algorithm introduced in the control system of complex spray booths is the important element of the safety system, which automatically stops the whole system, when a selected critical event happens (Tab.2). The process of development of this algorithm was easier by using the SELECT statement from the system Bernecker&Rainer library. Additionally the algorithm can be easily rebuilt by adding next states and next conditions, according to the end user's demands. The possibility of algorithm extension allows in case of

connecting additional elements for instance heat recovery units. The heat recovery units should be monitored in case of energy efficiency decrease caused by overspray sediments [7, 8].

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