Resistance Balance Simulation of Centralized Air Supplying and Dust Removing System for Cigarette Making and Tipping Machines

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Abstract: The operating stability of centralized air supplying and dust removing system (CASDRS) is the guarantee of efficiency and the quality of the cigarette making process. The pressure changing in the network, the value of the flow rate of the branch and especially the system resistance balance are the main evaluate indexes of the system. In this paper, a simulation model of CASDRS is built, as an evaluate tool of the system to analyze stability and energy saving potential. The simulation toolbox MATLAB/simulink is employed to analysis the resistance balance of the system, a pipe-net model is developed to the ventilation system. Through the connection of the blocks in the simulink toolbox, the operation of the matrixes which including constraining parameter input matrixes, the connection of the matrix and the calculation of the element of the matrix and the matrix itself, the system simulation model is obtained. The sensitivity result is given as the input parameters varied hourly and the result about energy consumption is more accurate.

Keywords: Air supplying, cigarette making and tipping machines, sensitivity analysis, simulink.

1. INTRODUCTION

The general cigarette making process in a cigarette factory is centralized air supplying and dust removing system (CASDRS). The centralized air supplying and dust removing system means working of several cigarette making and tipping machines, replacing the ancient high pressure fan and the dust removing equipment for a single unit, establishing the centralized suction convey station, applying to adjust the system resistance balance and to make the air distributed continuously, effectively and stably, see in Fig. (**1**). When the system is designed, the pipe is designed in such a manner that all machines operate on it. However, the pipe does not work on the design condition at most of the time. The number of operating machines vary with the production schedule; and when the cigarette making machine is under overhauling, the flow rate of the corresponding branch decrease to zero. When there is no cigarette on the machine, the flow rate of the corresponding branch is two times more than the normal.

Filip Johnsson, etc. modeled the flow and pressure fluctuations in the air plenum and the air flow into the fluidized bed by solving the continuity and momentum equations of the gas flow. The configuration of the air-feed system was changed by means of valves at two locations in the system [1]. J.A. SWAFFIELD, etc. combined model of physical characteristics of pipe junctions, terminations, trap seals and air admittance valves to a systematic provision of boundary condition

equations. The resulting entrained air jaw and the subsequent propagation of air pressure transients within both the system vertical stack and the associated vent network. The role of air admittance valves in limiting air pressure transient levels was discussed [2]. A typical ventilation unit was simulated by considering two major components: the thermal block and the airflow block. In airflow model, all its major parts such as the AC motor, frequency converter, air fan, air filter, pressure sensor, and temperature sensor was taken into account to develop a computational procedure based on the mathematical modeling of each part and to couple them together in an efficient manner. The model is implemented and a systematic analysis of the system is carried out, including its dynamic simulations in SIMULINK. The simulation results are compared with data obtained from analytical predictions as well as with experimental results available for a lab-scale ventilation unit [3-5]. Noval temperature control technique for a medicinal herb system powered by a photovoltaic array is a proportional integral (pi) controller. The control technique is investigated though simulation work by using MATLAB-SIMULINK [6, 7].

So, only through the check of all operating conditions, for example, the value of branch flow rate demand; whether the distribution can be obtained; the pressure drop of the network and the pressure of the fan, the design reliability can be confirmed, and the difference between the dynamics operating effect and the presume index under the static design can be reduced [8].

The system simulation model is obtained through the connection of the blocks in the simulink toolbox, the operation of the matrixes which include the calculation of the

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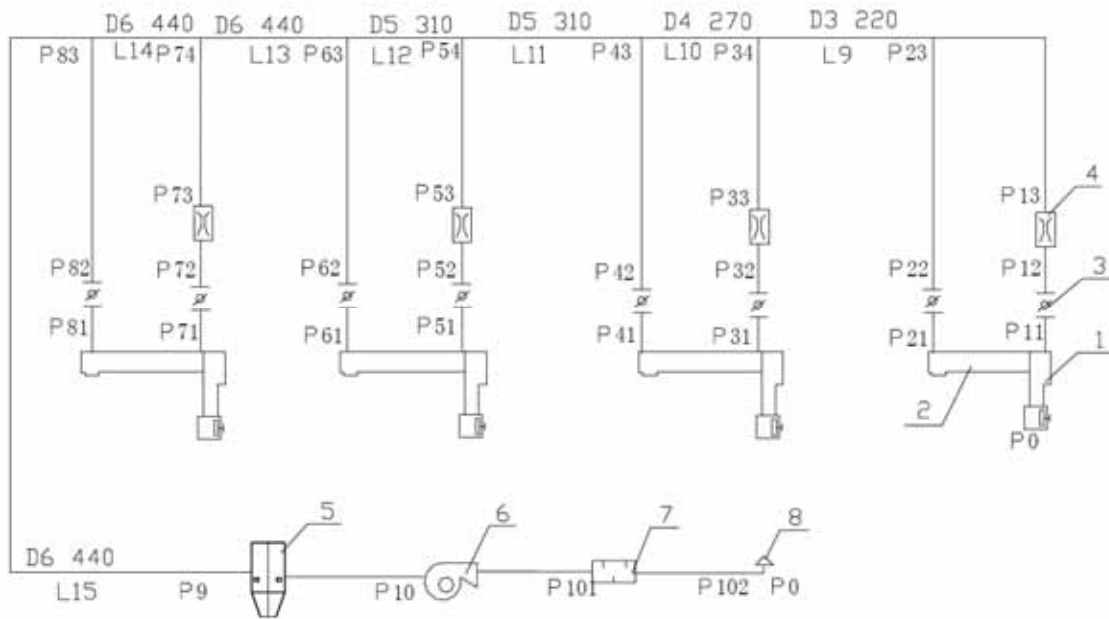
Fig. (1). The centralized air supplying and dust removing system.

element of the matrix and the matrix itself. The above operating conditions are simulated and calculated by the model.

2. THE RESISTANCE MODEL OF THE CASDRS

2.1. The Physical Model

In Fig. (**1**), there is branch 1 to branch 8, from the right to left. The diameter of the branch is standardized, the branch of the cigarette making machine is 130 mm, and the branch of the tipping machine is 159 mm. the pressure point distributing and the diameter of main pipe can be seen in the figure.

1-Cigarette making machine, 2-Tipping machine, 3-Valve, 4-Pressure balance valve, 5-Dust removing equipment, 6-Fan, 7- Muffler, 8-The outlet

2.2. The Math Model

The system is divided into power source and the resistance part, the part model is established according to their characteristic, such as the fan characteristic curve. Then, according to the relation of the power source and the resistance part, the system physical model and the calculating equation were obtained.

According to the mass equation:

$$\sum_{1}^{m} q_{m_i} = 0 \tag{1}$$

q_{m_i} - The flow rate of the i branch, inflow is positive and negative when it is outflow

According to the momentum equation [9]:

$$P_1 - P_2 = R \cdot q^2 \tag{2}$$

P_1 - The inlet pressure of the pipe

P_2 - The outlet pressure of the pipe

R - The resistance of the pipe

Because the equation has square monomial, the MATLAB cannot calculate directly, it should be linearization [10].

2.2.1. The Math Model of the Pipe

According to the equation (2):

$$q = \frac{1}{\sqrt{R}} \cdot \sqrt{P_1 - P_2} \tag{3}$$

In the equation,

P_1, P_2 - the pressure of pipe inlet and outlet;

R - the resistance of the pipe

Take the (3) as below:

$$q = \frac{1}{\sqrt{R}} \cdot \sqrt{P_1 - P_2} = f(\Delta p) \tag{4}$$

Disposes the equation (4) by tailor progression [11]

$$q = q_0 + f'(\Delta p_0)(\Delta p - p_0) + \frac{1}{2} f''(\xi)(\Delta p - \Delta p_0)^2$$

In the equation:

Min $(\Delta p, \ \Delta p_0) \leq \xi \leq$ max$(\Delta p, \ \Delta p_0)$

Ignore the square monomial [12]:

$$q = q_0 + f'(\Delta p_0)(\Delta p - p_0)$$

$$= \frac{\sqrt{\Delta p_0}}{\sqrt{R}} + \frac{1}{2\sqrt{R\Delta p_0}}(\Delta P - \Delta P_0)$$

$$\approx \frac{1}{\sqrt{R\Delta P_0}} \Delta P$$

$$= \frac{1}{\sqrt{R(P_1 - P_2)_0}}(P_1 - P_2)$$

Table 1. Loss in pipe of dust removing pipe.

Diameter(mm)	130	159	220	270	310	440
resistance per unit (mm water column)	0.176	0.135	0.090	0.070	0.059	0.038

Table 2. The resistance coefficient *vs*. the open degree.

Open Degree	1	0.89	0.78	0.67	0.56	0.44	0.33
resistance efficiency	0.2	0.52	1.5	4.5	11	29	108

So:

$$q = A \cdot (P_1 - P_2) \tag{5}$$

In the equation

ΔP - The pressure different of the pipe

ΔP_0 - The pressure different of the pipe at last period

$A = \dfrac{1}{\sqrt{R(P_1 - P_2)_0}}$ - The linearization coefficient of flow quantity.

The equation (5) is the linearization math model of the pipe.

According to the friction resistance:

$$R_0 = \frac{\lambda}{d} \cdot \frac{v^2 \gamma}{2} \ \text{(Pa)} \tag{6}$$

And:

$$(P_1 - P_2) = L \cdot R$$

There:

$$R = \frac{8L\lambda\gamma}{\pi^2 d^5}$$

According to the ventilation count Table **1**:

Consider the velocity in the pipe, use the least squares method, there is:

$$\lambda = 1.7d^2 - 1.37d + 0.31$$

The specific gravity of air:

$$\gamma = 0.0012 \ (Kg/m^3)$$

So:

$$A_{pipe} = \frac{1}{\sqrt{\dfrac{8L\gamma(1.7d^2 - 1.37d + 0.31)}{\pi^2 d^5}(P_1 - P_2)_0}}$$

2.2.2. The Math Model of the Valve

As the load of the system is changing, the flow rate in the branch is changing, so the network should be adjusted to keep the resistance balance of the system.

As the linearization method of the pipe, the liner model of the valve:

$$q = A \cdot (P_1 - P_2)$$

According to the resistance coefficient table, assume the open degree is zero when the valve is close, is 1 when it open entirely, set the open angle is 90 when the open degree is 1.

With the least squares method, the

$$\varepsilon = 475K^2 - 733K + 285$$

So:

$$A_{valve} = \frac{1}{\sqrt{\dfrac{8(457K^2 - 733K + 285)}{\pi^2 d^4 g}(P_1 - P_2)_0}}$$

2.2.3. The Math Model of the Fan

According to the characteristic curve of the fan, the linearization model of the fan (type: 10-19-8D):

$$q = A'_{fan} + A_{fan} \cdot (p_2 - p_1) \tag{7}$$

In the equation:

$$A'_{fan} = -0.5 \cdot C_2 \cdot N$$

$$A_{fan} = \sqrt{\frac{0.25(C_2 \cdot N)^2 - C_1 \cdot N^2}{\Delta P^2_0} + C_3 \Delta p_0}$$

C_1, C_2, C_3 - the characteristic date of the fan

Put in the coefficient of flow quantity, the network calculation equation is obtained. See in appendix 1. Combine equations to A*X=B, X means the pressure and flow to calculated, A is the coefficient matrix, while B is the constant matrix.

2.3. Establish the Simulation Model

2.3.1. The Simulation Model of the Pipe

The block of the pipe (branch 1): according to the value of flow rate and pressure calculated by last period, the $(P_1 - P_2)_0$ can get through the operation of the matrix, then put the value multiply the corresponding location matrix, and
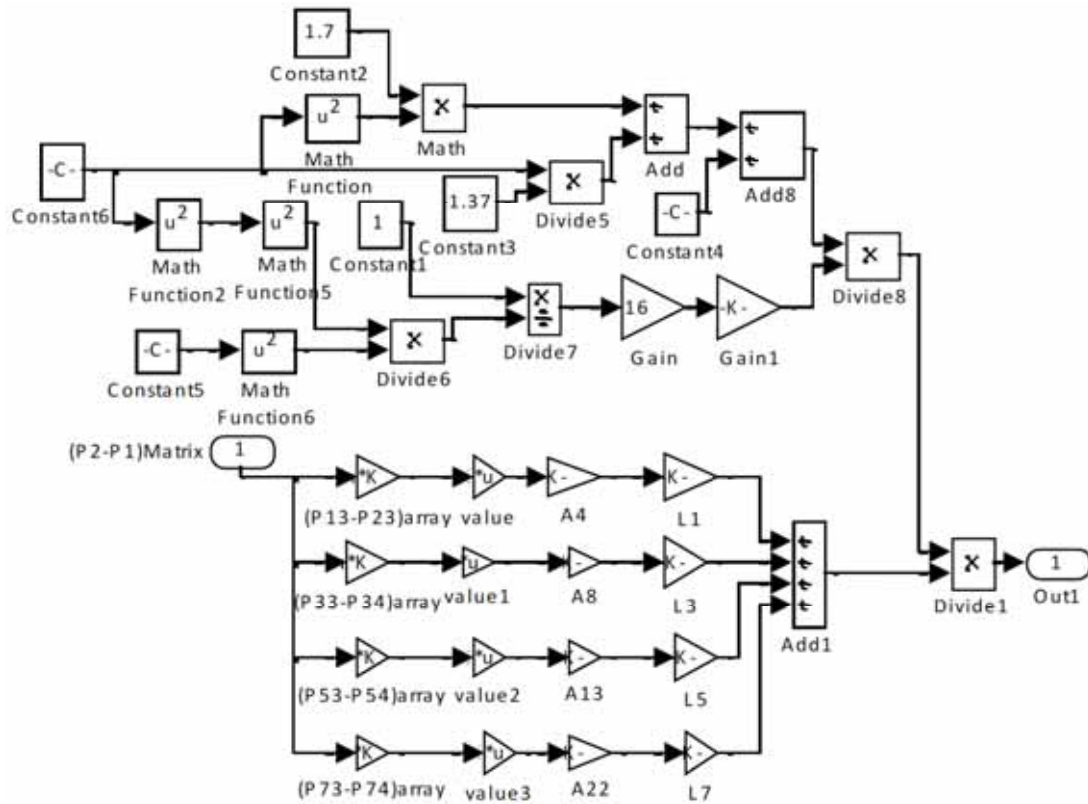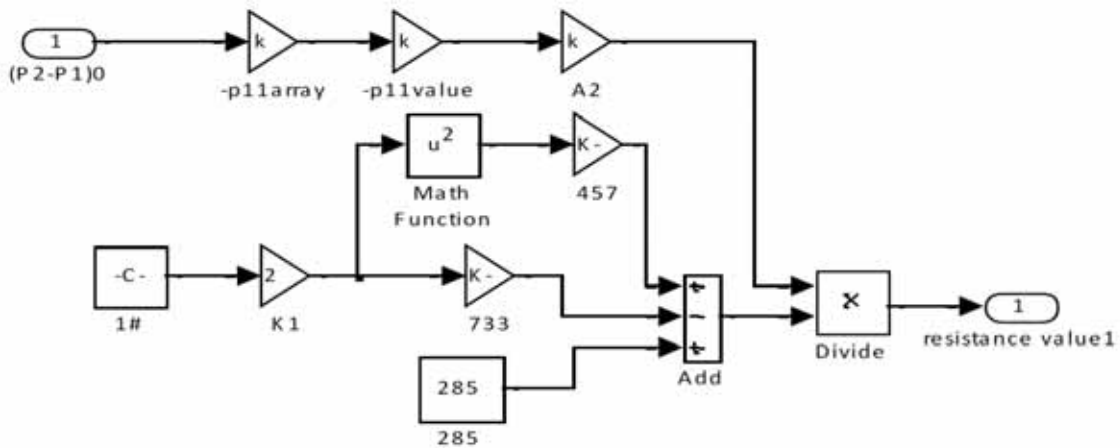
Fig. (2). The block of the pipe.

Fig. (3). The block of the pipe.

put the diameter 0.13m as the input parameter, A_{pipe} is obtained. The other coefficient of flow quantity are obtained through the element added to the matrix, and then get the pipe friction loss block, see in Fig. (**2**).

2.3.2. The Simulation Model of the Valve

According to the relation of the unit resistance and the open degree, through the operation of the simulink block, then the resistance coefficient block of the valve is obtained, then multiply the $(P_1 - P_2)_0$, and then extraction; put the result divided by constant block 1#, the A_{valve} is obtained. See in Fig. (**3**).

2.3.3. The Simulation Model of the Fan

The A_{fan} block: first, the C_2 multiply the N, gained $(C_2 \cdot N)$, then squared the result through a math block, and multiply with the const block (0.25, Constant 1), obtained $0.25(C_2 \cdot N)^2$, then after a serious operations, the $A_{fan} = \sqrt{[0.25(C_2 \cdot N)^2 - C_1 \cdot N^2]/\Delta P_0^2 + C_3 \cdot \Delta P_0}$ is obtained. At last, put the A_{fan} multiply with locality matrix, see in Fig (**4**).

The cigarette machine, dust removing equipment, and the muffler consist the matrix B. Put the constant matrix B divided the coefficient matrix A, the flux, pressure is obtained.
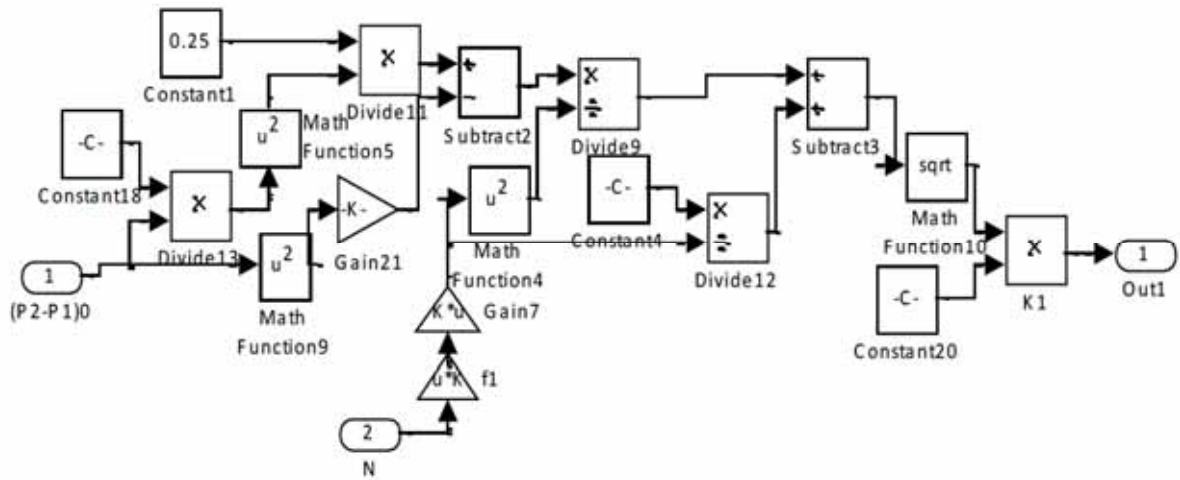
Fig. (4). The A_{fan} of the simulation model of the fan.
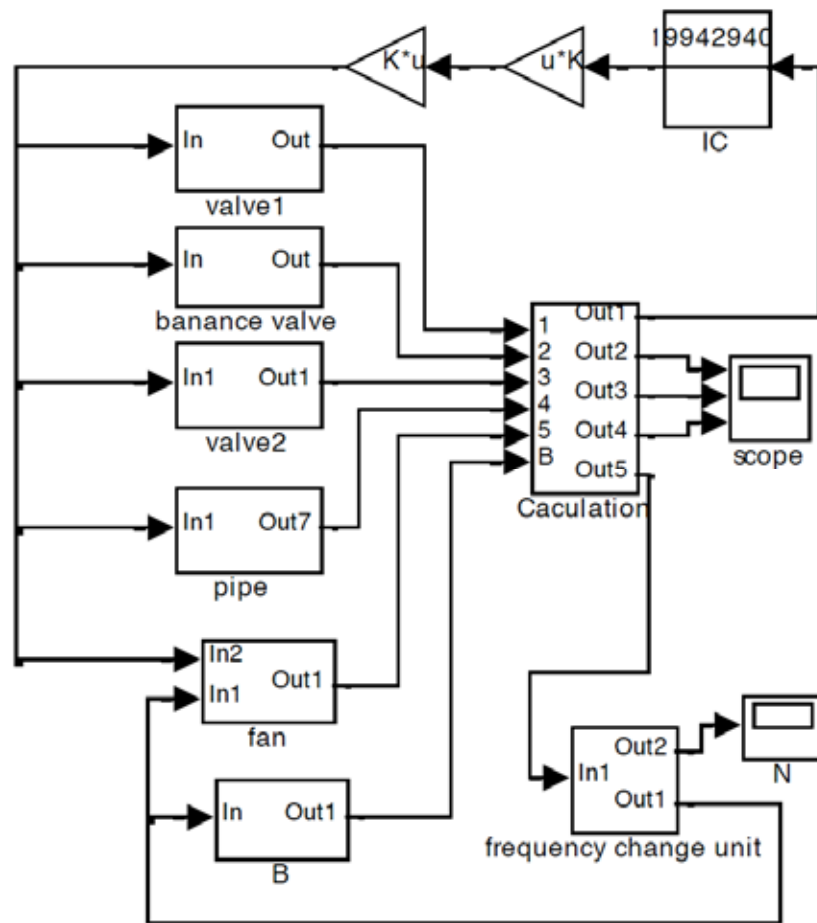

Fig. (5). The simulation model of the system.

Then use the function of algebra loop, put the last result as the input of the next period, the system respond result is gained, see in Fig. (**5**).

3. RESULTS AND DISCUSSIONS

Because the probability of the two machines stopping at the same time is very small, the condition is that four machines are in operation and the stopping of one machine is confirmed. Suppose open degree of the valve1 in branch 1 from 1 to 0. Fig. (**6**) illustrates the response of the branch flow rate to the open degree of the valve 1 from 1 to 0.

Fig. (**7**) indicates the response of the pressure of the node with the open degree of the valve 1 from 1 to 0. The pressure difference of the valve 1 can be obtained by $(P_{21} - P_{11})$, so the pressure characteristic of the valve in the system is simulated.
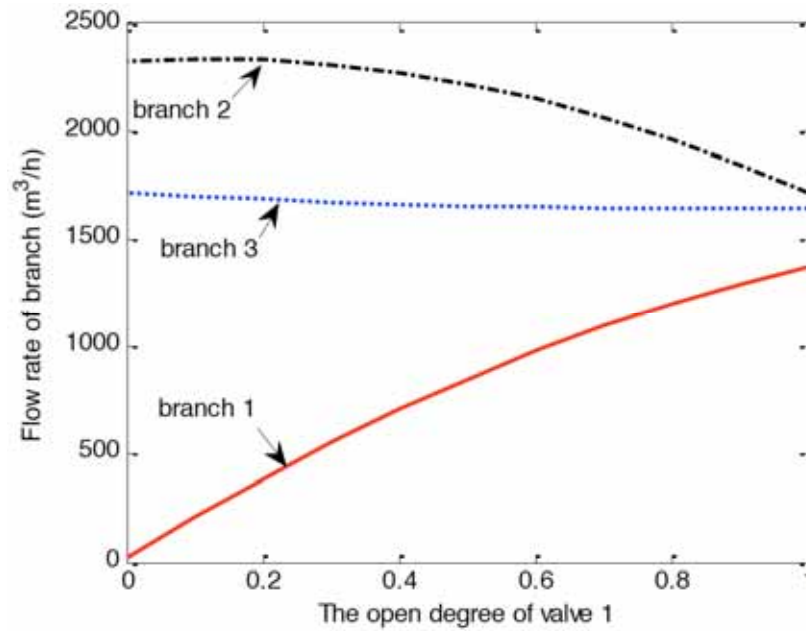
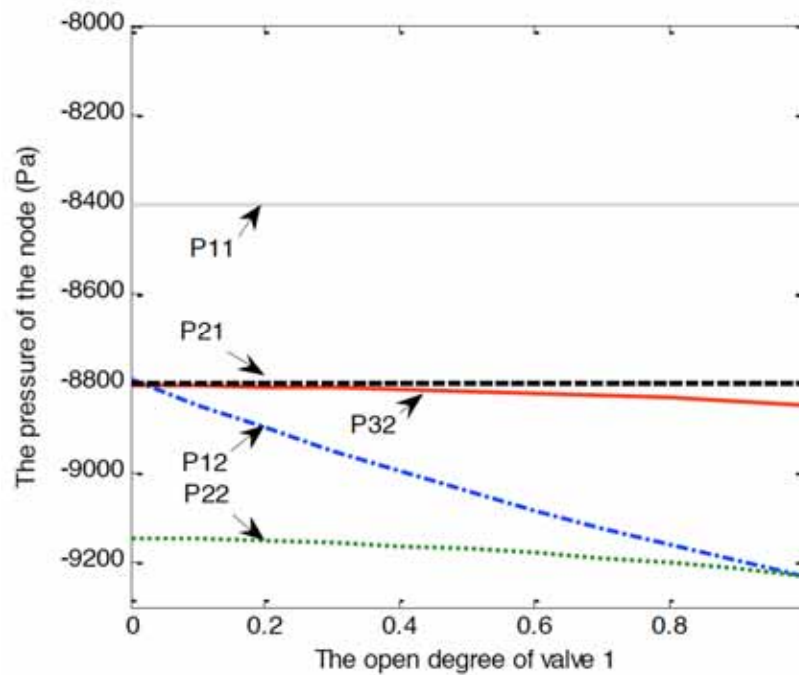**Fig. (6).** The branch flow rate *vs.* the open degree of valve 1.

Fig. (7). The pressure of the node *vs.* open degree of valve 1.

Fig. (**8**) illustrate the N of the fan with the frequency changing unit.

Fig. (**9**) illustrate there is no cigarette on the machine, the flow rate of the corresponding branch is goes up, while the flow of the other branches is reduced.

The fan airflow is increased, and the power of the fan is increased, see in Fig. (**10**).

Through the analysis of these simulations data, we can get the following conclusions:

(1) The simulation model can simulate different operating parameters under different conditions, such as the different operating number of the machines, the influence to the flow rate of the system, the pressure drop, pressure of the branch, the operating stability, the power of the fan, and the energy consumption of different machines which have different location.

(2) The characteristic of the valve in the system is different from the valve itself, the resistance of the valve can be obtained by simulation method.
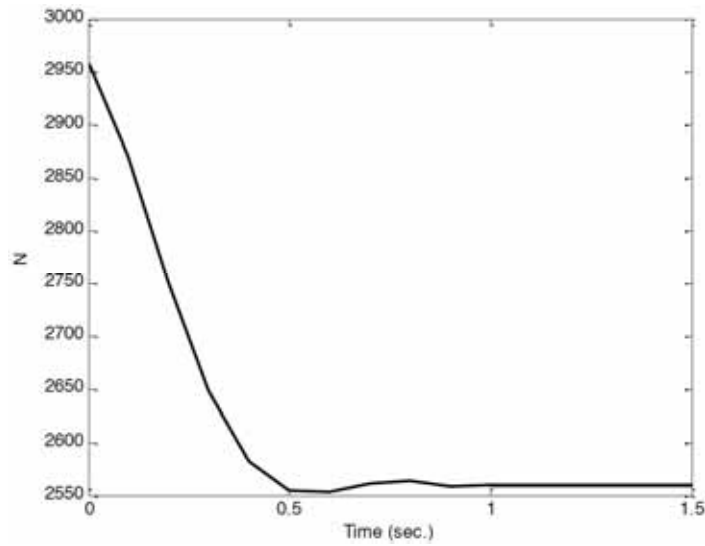
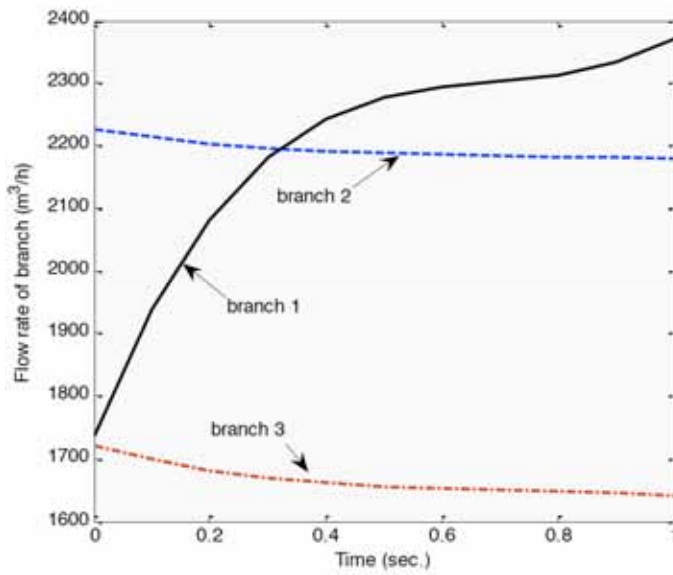**Fig. (8).** The N of the fan *vs.* open degree of valve 1.

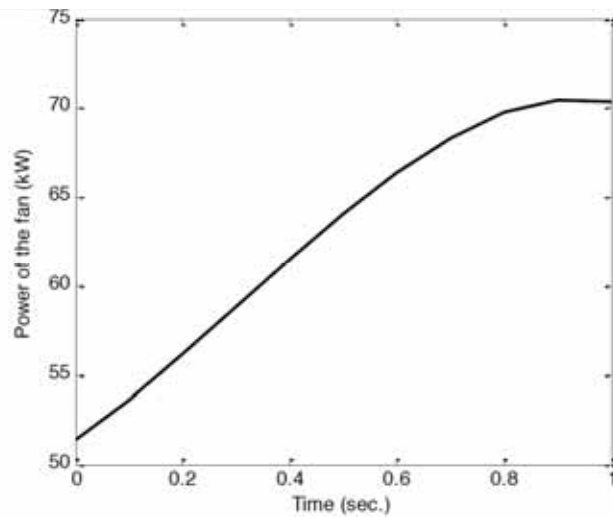**Fig. (9).** Flow rate of branch *vs.* Time.

Fig. (10). Response of the power of the fan with no cigarette in the machine one.

(3) The energy can be saved by the frequency change of the fan in the system.

(4) A pipe-net model is developed to the ventilation system, through the advantage of the resolve matrix of the MATLAB/simulink, this should not demand complex programming.

(5) The traditional static calculation method should be checked in the real condition, plot a serious responding graph as a parameter, then can be solve the couple relation, it waste a lot of time and power, and the precision is low. Through the simulink function of algebra link, the dynamics responding result can be obtained as several parameters vary at the same time.

(6) When compared with the ancient economy characteristic calculation, the dynamics calculate that the energy consumption method is more relational and accurate.

CURRENT AND FUTURE DEVELOPMENTS

In this paper, MATLAB/Simulink toolbox is used to forecast the CASDRS resistance loss in order to enhance its working efficiency. In the future, tobacco production process will be realized by remote control monitoring, data acquisition, enterprise network communication function, etc.

Through an automatic analysis system, the results will be directed to the CASDRS and then be analyzed to realize the intelligent control of Pneumatic conveying system and then to promote production more efficiency and less energy consumption.

CONCLUSION

In this paper, the different operating conditions of the system are studied to provide an index for choosing the fan. At the same time, using this method can restrain the disturbance quickly, make the pressure of the system stable and improve the efficiency and the quality of the machine. It provides a reference for engineers to find the perfect design, the perfect operation condition and control plan.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

APPENDIX 1:

$$
\begin{cases}
P_0 - P_{11} = P_{make} \\[2mm]
q_1 = \dfrac{1}{\sqrt{R_{F1}(P_{11} - P_{12})_0}} \cdot (P_{11} - P_{12}) \\[4mm]
q_1 = \dfrac{1}{\sqrt{R_{P1}(P_{12} - P_{13})_0}} \cdot (p_{12} - p_{13}) \\[4mm]
q_1 = \dfrac{1}{\sqrt{\dfrac{8L_1\lambda\gamma}{\pi^2 D_1^{5}}(P_{12} - P_{13})_0}} \cdot (P_{13} - P_{23}) \\[6mm]
P_0 - P_{21} = P_{join} \\[2mm]
q_2 = \dfrac{1}{R_{F2}(P_{21} - P_{22})_0} \cdot (P_{21} - P_{22}) \\[4mm]
q_2 = \dfrac{1}{\sqrt{\dfrac{8L_2\lambda\gamma}{\pi^2 D_2^{5}}(P_{22} - P_{23})_0}} \cdot (P_{22} - P_{23}) \\[6mm]
q_1 + q_2 = \dfrac{1}{\sqrt{\dfrac{8L_9\lambda\gamma}{\pi^2 D_3^{5}}(P_{23} - P_{34})_0}} \cdot (P_{23} - P_{34}) \\[6mm]
P_0 - P_{31} = P_{make} \\[2mm]
q_3 = \dfrac{1}{\sqrt{R_{F3}(P_{31} - P_{32})_0}} \cdot (P_{31} - P_{32}) \\[4mm]
q_3 = \dfrac{1}{\sqrt{R_{P2}(P_{32} - P_{33})_0}} \cdot (P_{32} - P_{33}) \\[4mm]
q_3 = \dfrac{1}{\sqrt{\dfrac{8L_3\lambda\gamma}{\pi^2 D_1^{5}}(P_{33} - P_{34})_0}} \cdot (P_{33} - P_{34})
\end{cases}
$$

$$\left\{\begin{array}{l}
q_1 + q_2 + q_3 = \dfrac{1}{\sqrt{\dfrac{8L_{10}\lambda\gamma}{\pi^2 D_4^5}(P_{34}-P_{43})_0}} \cdot (P_{34}-P_{43}) \\[4mm]
P_0 - P_{41} = p_{make} \\[2mm]
q_4 = \dfrac{1}{\sqrt{R_{F4}(P_{41}-P_{42})_0}} \cdot (P_{41}-P_{42}) \\[4mm]
q_4 = \dfrac{1}{\sqrt{R_{P4}(P_{42}-P_{43})_0}} \cdot (P_{42}-p_{43}) \\[4mm]
q_1 + q_2 + q_3 + q_4 = \dfrac{1}{\sqrt{\dfrac{8L_{11}\lambda\gamma}{\pi^2 D_5^5}(P_{33}-P_{34})_0}} \cdot (P_{43}-P_9)
\end{array}\right.$$

$$\left\{\begin{array}{l}
P_0 - P_{51} = p_{make} \\[2mm]
q_5 - \dfrac{1}{\sqrt{R_{F5}(P_{51}-P_{52})}} \cdot (P_{51}-P_{52}) = 0 \\[4mm]
q_5 - \dfrac{1}{\sqrt{R_{P5}(P_{52}-P_{53})}} \cdot (P_{52}-P_{53}) = 0 \\[4mm]
q_5 = \dfrac{1}{\sqrt{\dfrac{8L_1\lambda\gamma}{\pi^2 D_1^5}(P_{53}-P_{54})_0}} \cdot (P_{53}-P_{54}) \\[4mm]
q_1 + q_2 + q_3 + q_4 + q_5 = \dfrac{1}{\sqrt{\dfrac{8L_{12}\lambda\gamma}{\pi^2 D_5^5}(P_{54}-P_{63})_0}} \cdot (P_{54}-P_{63}) \\[4mm]
P_0 - P_{61} = p_{make} \\[2mm]
q_6 - \dfrac{1}{\sqrt{R_{F6}(P_{61}-P_{62})_0}} \cdot (P_{61}-P_{62}) = 0 \\[4mm]
q_6 = \dfrac{1}{\sqrt{\dfrac{8L_6\lambda\gamma}{\pi^2 D_2^5}(P_{62}-P_{63})_0}} \cdot (P_{62}-P_{63}) \\[4mm]
q_1 + q_2 + q_3 + q_4 + q_5 + q_6 = \dfrac{1}{\sqrt{\dfrac{8L_{13}\lambda\gamma}{\pi^2 D_6^5}(P_{63}-P_{74})_0}} \cdot (P_{63}-P_{74}) \\[4mm]
P_0 - P_{71} = p_{jom} \\[2mm]
q_7 = \dfrac{1}{\sqrt{R_{F7}(P_{71}-P_{72})_0}} \cdot (P_{71}-P_{72}) \\[4mm]
q_7 = \dfrac{1}{\sqrt{R_{P4}(P_{72}-P_{73})_0}} \cdot (P_{72}-P_{23}) \\[4mm]
q_7 = \dfrac{1}{\sqrt{\dfrac{8L_7\lambda\gamma}{\pi^2 D_6^5}(P_{73}-P_{74})_0}} \cdot (P_{73}-P_{74}) \\[4mm]
q_1 + q_2 + q_3 + q_4 + q_5 + q_6 + q_7 - \dfrac{1}{\sqrt{\dfrac{8L_{14}\lambda\gamma}{\pi^2 D_6^5}(P_{74}-P_{83})_0}} \cdot (P_{74}-P_{83}) = 0 \\[4mm]
P_0 - P_{81} = p_{jom} \\[2mm]
q_8 - \dfrac{1}{\sqrt{R_{F6}(P_{61}-P_{62})}} \cdot (p_{81}-p_{82}) = 0 \\[4mm]
q_8 - \dfrac{1}{\sqrt{\dfrac{8L_2\lambda\gamma}{\pi^2 D_2^5}(P_{82}-P_{83})_0}} \cdot (P_{82}-P_{83}) = 0 \\[4mm]
q_1 + q_2 + q_3 + q_4 + q_5 + q_6 + q_7 + q_8 - \dfrac{1}{\sqrt{\dfrac{8L_{15}\lambda\gamma}{\pi^2 D_6^5}(P_{83}-P_9)_0}} \cdot (P_{83}-P_9) = 0 \\[4mm]
P_9 - P_{10} = P_{dustremove} \\[2mm]
q_1 + q_2 + q_3 + q_4 + q_5 + q_6 + q_7 + q_8 - A'_{10} - A_{10}(P_{101}-P_{10}) = 0 \\[2mm]
P_{101} - P_{102} = P_{muffler} \\[2mm]
P_{102} - P_0 = P_{outlet}
\end{array}\right.$$

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