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A new matrix-based mathematical model for determining unidirectional circuits in a ventilation network*

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Abstract The occurrence of local circulating ventilation can be caused by many factors, such as the airflow reversion during mine fire, the improper arrangement of local fan or underground fan station and the man-made error input of raw data before network solving. Once circulating ventilations occur, the corresponding branches in the ventilation network corresponding to the relevant airways in ventilation system form circuits, and all the directions of the branches in the circuits are identical, which is the unidirectional problem in ventilation network. Based on the properties of node adjacent matrix, a serial of mathematical computation to node adjacent matrix were performed, and a mathematical model for determining unidirectional circuits based on node adjacent matrix was put forward.

Keywords fluid network, unidirectional circuit, adjacent matrix

Introduction

Multi-stage fan station ventilation is adopted in many mines, such as Jinchuan Nonferrous Metal Company, Nanjing Meishan Iron Mine. This ventilation style is paid much attention to and is popular for it has many advantages, such as saving energy resources, easy to regulation and management. If the positions of fan stations or the choice of fan power are not rational, the side air branches can be reversed, and this phenomenon is what is called circulating ventilation. Moreover, the airflow reverses during mine fire period[1] and the unapt setting of local ventilator can also lead to the appearance of local circulating ventilation. The existence of circulating ventilation in a ventilation system means the existence of unidirectional circuits in the ventilation system. So-called unidirectional circuit is a circuit whose branches have uniform directions. If unidirectional circuits exist in a ventilation system, the law of air quantity equilibrium in a node and the law of resistance equilibrium in a circuit are correct, but all the path based algorithms including searching paths will fail [2,3]. Many algorithms are based on path algorithm, such as the path algorithm for network regulating, the path algorithm for automatic assigning initial values of air quantity by using a computer in natural air distribution algorithm, the independent path algorithm for determining network extremal flow, the path algorithm for determining diagonal structures and the path algorithm for network simplification [2]. The determination of unidirectional circuits in a ventilation network is discussed, and a new algorithm based on matrix is put forward in the paper.

1 Interrelated theory of node adjacent matrix

A ventilation network graph can be recorded as $G=(V, E)$, here, V is the node set, $V=\{v_1, v_2, \cdots, v_m\}$; m is the node number, $m=|V|$; E is the branch set, $E=\{e_1, e_2, \cdots, e_n\}$; n is the branch number, $n=|E|$.

For a directed graph $G=(V, E)$, we can construct an $m=|V|$ order square matrix $\boldsymbol{A}=(\boldsymbol{a}_{ij})_{m\times m}$, where:

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$$a_{ij}=\left|\left\{e_k \mid e_k=\left(v_i,v_j\right)\in E\right\}\right|, \tag{1}$$

where, A is the adjacent matrix of graph G.

The k power of A is recorded as $A^k=(a_{ij}^{(k)})_{m\times m}$, where:

$$(a_{ij}^{(k)})=\sum_{h=1}^{m} a_{ih}^{(k-1)}a_{hj}. \tag{2}$$

If and only if $a_{ih}\neq 0$ and $a_{hj}\neq 0$, then $a_{ih}\times a_{hj}\neq 0$, namely there are at least 1 branch from v_i to v_h and from v_h to v_i. Therefore, the value of $a_{ij}^{(2)}$ express the number of path from v_i to v_j via another node v_h, or we can say that the value of $a_{ij}^{(2)}$ express the number of path from v_i to v_j via 2 steps. In like manner, the value of $a_{ij}^{(k)}$ express the number of path from v_i to v_j via k steps. $a_{ij}^{(k)}=0$ express that there is no such path[4,5].

Theorem 1: If $\sum_{k=1}^{m-1} a_{ij}^{(k)}\neq 0$, there are at least one path between node i and j.

2 A new mathematical model for determining unidirectional circuit

From the point of view of graph theory, a unidirectional circuit is a path with the same start node and end node.

According to the definition of a unidirectional circuit, i.e. a circuit whose branches has uniform directions, once there is a unidirectional circuit, means that to any node v_u in the unidirectional circuit, there is a path whose start node and end node are v_u, and then the path with the same start node and end node is a unidirectional circuit. So, if there is a path has the same start node and end node, a unidirectional circuit is determined. According to Theorem 1, it can be concluded that if $\sum_{k=1}^{m-1} a_{ii}^{(k)}\neq 0$, namely if there is a nonzero element on the diagonal line of $A^k=(a_{ij}^{(k)})_{m\times m}$, $v_i(v_i\in V)$ must be a inner node of a unidirectional circuit.

According to the saying all above, a new matrix based mathematical model for determining unidirectional circuits is put forward in the paper.

(1) To determine the node adjacent matrix A of a given ventilation network.

(2) To calculate A^2, A^3,···, A^{m-1}. As the limit length of a path is $m-1$ (when all the nodes in a ventilation are in a line), A^m need not be calculated.

(3) If nonzero elements appear on the diagonal line of $A^k(k=1, 2, \cdots, m-1)$, a unidirectional circuit appear. All the nodes corresponding to nonzero elements on the diagonal line and the branches between the nodes will construct a unidirectional circuit.

To the ventilation network shown in Fig.1, the determining process by using the above mathematical model is showed as following.

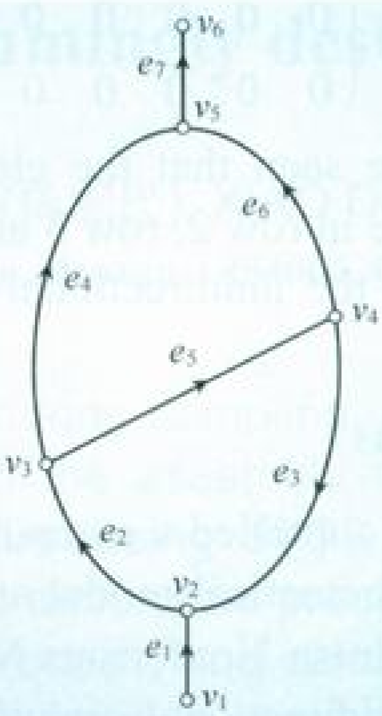

Fig.1 Ventilation network

(1) The node adjacent matrix of the ventilation network in Fig.1:

$$A=\begin{pmatrix}0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&1&0\\0&1&0&0&1&0\\0&0&0&0&0&1\\0&0&0&0&0&0\end{pmatrix}.$$

(2) A^2, A^3, A^4, A^5

$$A^2=\begin{pmatrix}0&0&1&0&0&0\\0&0&0&1&1&0\\0&1&0&0&1&1\\0&0&1&0&0&1\\0&0&0&0&0&0\\0&0&0&0&0&0\end{pmatrix},$$

$$A^3=\begin{pmatrix}0&0&0&1&1&0\\0&1&0&0&1&1\\0&0&1&0&0&1\\0&0&0&1&1&0\\0&0&0&0&0&0\\0&0&0&0&0&0\end{pmatrix},$$

$$A^4=\begin{pmatrix}0&1&0&0&1&1\\0&0&1&0&0&1\\0&0&0&1&1&0\\0&1&0&0&1&1\\0&0&0&0&0&0\\0&0&0&0&0&0\end{pmatrix},$$

$$A^5 = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}.$$

(3) It can be seen that the elements on the diagonal line that lie in row 2, row 3 and row 4 of A^3 are not zero, namely the unidirectional circuit is $\{e_2, e_3, e_4\}$.

3 Applications

Author have complied a computer program based on the above mathematical model and used it to No.2 mine area of Jinchuan Nonferrous Metal Corporation. There are two unidirectional circuits are determined. The unidirectional circuits are shown in Fig.2.

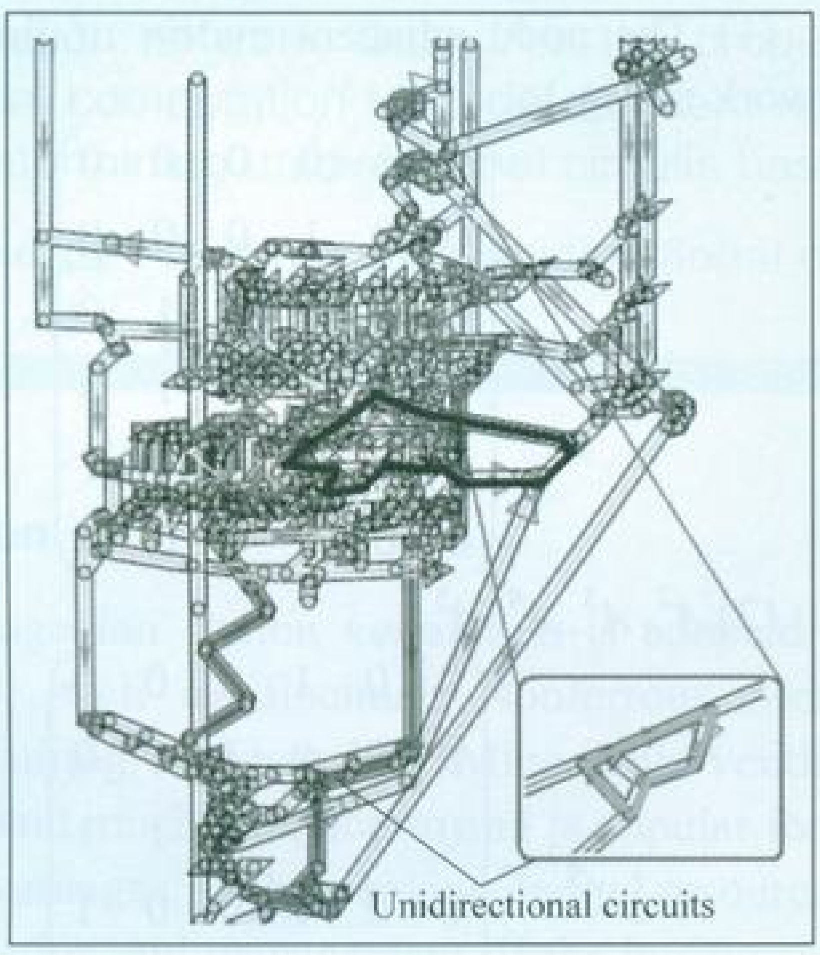

Fig.2 The unidirectional circuits in the ventilation system

4 Conclusions

(1) The formation reasons of unidirectional circuit are analyzed.

(2) A theorem is put forward, namely if $\sum_{k=1}^{m-1} a_{ij}^{(k)} \neq 0$, there is at least one path between node i and node j.

(3) A new node adjacent matrix based mathematical model for determining unidirectional circuits in a ventilation network is put forward and is used in an actual mines.

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