Valve Rule Configuration for Gas Network

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Abstract: “Theoretical Configuration” mode is advanced for valve configuration according to principal of “Isolating Section by Section” of gas network to deal with section fault raised in gas network. “Valve Configuration Theorem（Yan’s Theorem）” is mentioned, and the relations between number of configuration valves and network structure parameters are revealed.

Furthermore, “Regular Configuration” mode based on principal of “Isolating by Area” is put foreword. “Calculating Formula of Valves Quantity” and “Valve Configuration Formula” is given thereby.

With domestic engineering practices and the relations between valve density and various factors with certain average length of network sections, “Valve Regular Configuration” method is described.

The article possesses a high sense of both theoretical and practical significance. It will be helpful for promoting the level of knowledge of gas engineering and from as a mater of experience turning to that of scientific realm.

Key words gas network, valve, valve configuration, safety of network, network fault

The pipes and valves are basic constitution parts for network. This article will discuss the valve configuration of gas network. With the principal of ‘Isolating Section by Section’ principle of network, the valve configuration theorem has been proposed. And the ‘valve rule configuration’ pattern is set for practice engineering. Accordingly, both the formula for estimating the quantities of posited valves and formula of configuration grade are established.

1. Valves and sections of pipe in gas network

The basic components of network are pipes and valves of great quantity. Cut-off valves are most applied in network. The valve types include gate valve, reed valve, ball valve and so on. When a section of pipeline appears to be breakdown, either has to be carried on maintenance or renewal, the section should be isolated from the network by shut off of relevant vales. For convenience, this article will mention the valve as Cut-off valve for abbreviation.

Considered from the comprehensive technical and economy aspects, that in the network both the valve establishment way and the establishment density must be suitable arranged, so that break down of network function will be as slightly as possible while pipe default arises. The scope of users which are isolated temporarily and the sections of network involved are to be as few as possible. For this reason, quantity of posited valves is as more as well; but from reducing expense of valves, quantity of posited valves is as less as well. Therefore, must carry on the suitable valve configuration to the network to achieve better technical economic effect.

The ratio of valve number and total length of network pipes is defined as valve density of network (in symbol k, unit for set/km). Then for China existing gas network, common valve densities k=0.4~1.5.We will be aware that the valve density with the scope of isolated is not of simple inverse relation.

Definition: A part of pipe with certain length for gas network is defined as section. So, section is not a strict concept. Regarding a pipe with more great length can be divided into number of sections.

A valve located in the main pipe spot or in branch terminal is to be called the 'End valve'.

2. Valve theory configuration of gas network and valve configuration theorem—Yan's Theorem

The principle which network valve configuration used is called "principle of isolating section by section", when any section of pipe network breaks down, the section can be isolated from other connected sections by shutting down the valves which are relevant with the section. According to this principal, there is "Theory configuration" pattern. It is refers with Necessary and sufficient (i.e. enough also not unnecessary) valves configuration for the network; the quantity expression of Theory configuration pattern is:

$$f_v=n_v-1 \quad (1)$$

where f_v——valve number which established in connected pipes of some node v;

n_v——node number of degree (graph theory concept), namely is the number of connected pipes of the node *v*.

To the network branch vertex, must establish the End valve in the branch terminal, therefore regarding the branch vertex:

$$f_v=n_v=1 \tag{2}$$

For explanation of theory configuration with direct-viewing, gives Figure 1.

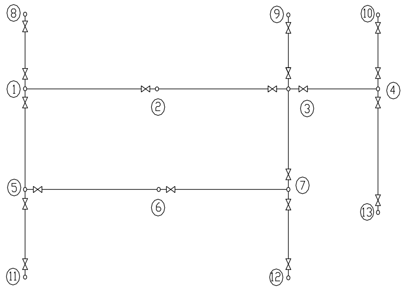

Fig. 1 valve theory configuration of network

Valve Configuration Theorem (Yan's Theorem) for theory configuration: For a network, the sections number is *B*, the ring content is *H*, in condition of conducting the valve theory configuration, and then valve quantity is:

$$J=B+H-1 \tag{3}$$

Where J——valve number of gas network under valve theory configuration, besides end valves;

B——number of sections for network;

H——network ring content, the concept of ring in gas network is equal to the concept "mesh" in graph theory.

If taking the End valves to be included, then the number of valves for gas network will be:

$$J_S=B+H+T-1 \tag{4}$$

Where J_S—— gas network valve theory configuration, including End valves;

T——number of branch pipes for gas network (has T End valve).

For a network, a tree-branch of only one section, and in the section there is a valve near by the node is called ‘branch pipe’, for example, the section ⍰-⍰,⍰-⍰ and so on are branch pipes.

The theorem can be proved by method of Mathematical Induction.

This theorem may be examined, in Figure 1 with B=13, H=1, T=6. According to expressions (3), (4) there are:

$$J = B + H - 1 = 13 + 1 - 1 = 13$$

$$J_S = B + H + T - 1 = 13 + 1 + 6 - 1 = 19$$

“Valve Theory Configuration” is called 1st grade of configuration.

Obviously, the valve configuration theorem has given relations between the valves quantity and the network structure accurately. It has very strong theory and practical significance. It may grow practical result in valve configuration.

3. Valve rule configuration and rule configuration formula

(1) Factors as considering valve configuration from the engineering point of view

⍰ Because the price of valve being relative to the tube is more expensive, considered from the engineering economy aspects, for gas network, the valve configuration is impossible to use “principle of isolating section by section” to conduct a theory configuration; but is to adopt “principle of region isolating ”, namely, to take certain number of sections as an isolation object (sections group), consequently gas supply to be affected for limited range of region in situation of pipe failure;

② Because valve itself also has quite high failure rate, “principle of region isolating”, is suitable to perform from consideration of the network reliability and the network maintenance work;

③ Once a valve appears breakdown, the pipes in both sides of the valve are subjected its influence. Therefore, the section number inside an isolated sections group needs to be restricted.

Region isolation menns to shut down several valves in order to isolate several sections from the network with stopping certain area of gas supply, when section breakdown happens,

Through dividing all sections of the network into a number of sections group by carrying on valve rule configuration, it is possible to realize the region isolation.

(2) Valve rule configuration

Embarking from the theory configuration pattern, reduces valves, to divide sections of the network into groups with m sections inside a group, to delete valves of (m-1) with in the sections group to form “each m sections isolation” (i.e. “m section isolation” for short). It forms the region isolation (to be called grade m configuration). Thus, it enables the network to achieve one kind of suitable valve density. It is called “Valve complete rule configuration”.

To process “m section isolation” of complete rule configuration mode, there are fore steps. Firstly, to carry on the theory configuration to the entire network; secondly, to divide sections of the network into groups with m sections consistent; thirdly, to remove valves of (m-1) from each m sections group; and fourthly, to remove any excessive valves from sections group which consisted with equal or less then m sections, in this way to form grade m complete rule configuration.

Let us look at the Figure 2 to understand the procedure of complete rule configuration. It is a grade 3 configuration. There are 3 sections with in each group. And there is step to remove 2 valves from each group of 3 sections (deleted valves denoted by symbol-○-), in this way to form complete rule configurations of grade 3.

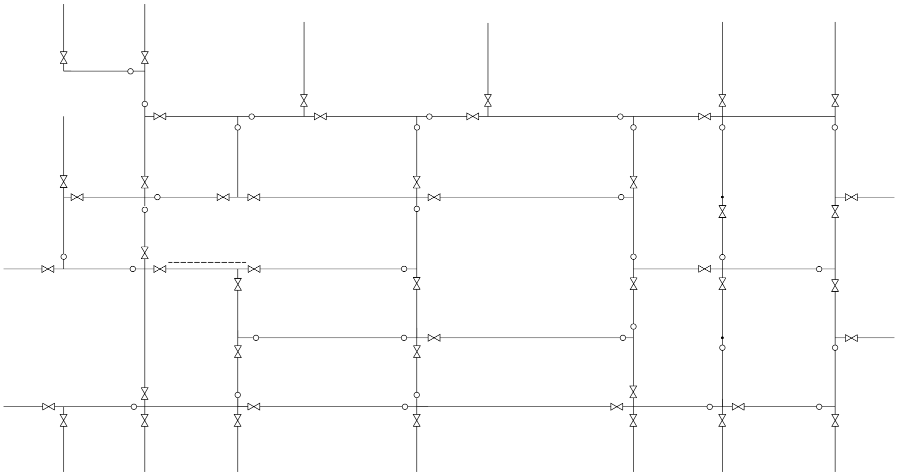

Fig. 2 network with grade 3 valve rule configuration.

To carry on complete rule configuration of grade m to the network, theoretically the number of sections group may be obtained is:

$$Z = \left\lfloor \frac{B-T}{m} \right\rfloor \qquad (5)$$

Where $\lfloor\ \rfloor$——symbol of floor function.

Actually, the number of sections group may be obtained is Z_E, owing to being not complete rule configuration, for instance, the 13 sections of branch and a section with sign of dashed line in Fig. 2 are not included in group counting. Thus:

$$\Delta Z = Z - Z_E \qquad (6)$$

where ΔZ——group quantity difference of disposed in complete rule configuration vs. in real existed in rule configuration；

Z_E——group quantity real existed in rule configuration.

It is sure that number of valves disposed for real rule configuration is less than that of for theory configuration. The number of valves can be subtracted are from 3 items of valves of basic deduction, odd valve (valves in odd group), and surplus valves. Obviously, number of valves not deducted with calculating by ΔZ has to be added.

⍰ The number of basic deduction valves is:

$$\Delta J_m = (m-1)\left\lfloor \frac{B\text{-}T}{m} \right\rfloor \tag{7}$$

Where ΔJ_m——number of deducted valves owing to complete rule configuration;

m——rule configuration grade, it is natural number: 2, 3… .

⍰ The number of odd valves.

Definition: It is called odd group, when number of sections in group is less than *m*（grade）.

$$B_R = \sum_{i=1}^{n} R_i \tag{8}$$

$$\Delta Z = \left\lfloor \frac{B_R}{m} \right\rfloor \tag{9}$$

式中 B_R——number of sections in odd groups of network；

R_i——number of odd valves in i^{th} odd group；

n——number of odd groups。

The number of odd valves, which can be subtracted from odd group:

$$\Delta J_R = \sum_{i=1}^{n} (R_i - 1) \tag{10}$$

where ΔJ_R——number of odd valves；

In Figure 2, there are 19 odd groups: 18 group of branch sections and the section with dashed line sign nearby it, ($\Delta J_R = \sum_{i=1}^{19} (R_i - 1) = 19(1-1) = 0$).

⍰ The number of surplus valves.

Definition: valve which appears non-isolation function in a group is called surplus valve.

Definition: In case of existing rings in a group, it becomes a ring with no valve on its sections by removing surplus valve from the rings; the ring is called net-ring.

There is possibility of existing surplus valves during rule configuration with grade m≥3. As processing rule configuration, once existing rings of h within a group, always to process the theory configuration by just positing valves of *m*+*h*-1 belonging to the group, then removing valves of（*m*-1）from the group. In this situation, there still are valves of *h* can being removed from the group, those are surplus valves, look at Fig 3.

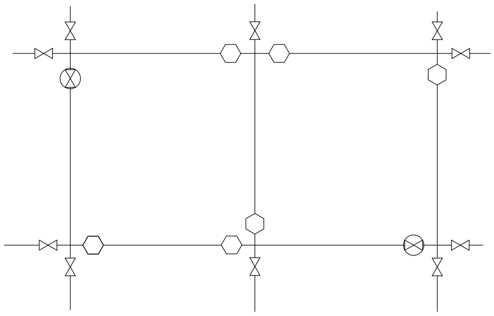

Fig 3 basic deduction valves by rule configuration and surplus valves

（*B*=*m*=7，*J*= *m*+*h*-1=7+2-1=8, ΔJ_m=6， $\delta J_m = \Delta H_m$=*h*=2）

⋈—valve outside group； ⬡ —basic deducted valve by rule configuration；

⊗ —surplus valve

Therefore, we have a pre-theory: the number of surplus valves equals to the number of net-rings for a rule configuration:

$$\delta J_m = \Delta H_m \tag{11}$$

where δJ_m——number of surplus valves；

ΔH_m——number of net-rings。

□ Number of having not be removed valves in rule configuration:

$$\Delta J_Z = \Delta Z \times (m-1) \tag{12}$$

$$\Delta J_Z = \left\lfloor \frac{B_R}{m} \right\rfloor \times (m-1) \tag{13}$$

(3) Calculating Formula of Valves Quantity of rule configuration

For valve rule configuration, total number of valves disposed for whole network is:

$$J_m = J - \Delta J_m - \delta J_m - \Delta J_R + \Delta J_Z$$

From expressions（3）,（5）,（6）,（7）,（10）, we have：

$$J_m = B + H - 1 - (m-1)\left\lfloor \frac{B-T}{m} \right\rfloor - \Delta H_m - \sum_{i=1}^{n}(R_i - 1) + (m-1)\left\lfloor \frac{B_R}{m} \right\rfloor \tag{14}$$

In case of involving end valves: :

$$J_S = J_m + T \tag{15}$$

Expressions（14）,（15）are called valve counting formula of rule configuration.

Taking network of Fig. 2 as an example（number of sections *B*=67, number of rings *H* =14, number of branch pipes *T*=18, number of sections in odd groups B_R=1）, rule configuration grade m=3).

Number of valves in theory configuration:

J＝*B*+*H* -1 =67+14-1=80。

The number of basic deduction valves is:

$$\Delta J_m = (m-1)\left\lfloor \frac{B\text{-}T}{m} \right\rfloor = (3-1)\left\lfloor \frac{67-18}{3} \right\rfloor = 32,$$

The number of odd valves, which can be subtracted from odd group:

$$\Delta J_R = \sum_{i=1}^{n}(R_i - 1) = \sum_{i=1}^{1}(1-1) = 0$$

The number of surplus valves:

$$\delta J_m = \Delta H_m = 0$$

Number of having not been removed valves in rule configuration:

$$\Delta J_Z = \Delta Z \times (m-1) = \left\lfloor \frac{B_R}{m} \right\rfloor \times (m-1) = 0 \times (3-1) = 0$$

Thus, number of valves for rule configuration:

$$J_m = B + H - 1 - (m-1)\left\lfloor \frac{B-T}{m} \right\rfloor - \Delta H_m - \sum_{i=1}^{n} (R_i - 1) + \Delta Z \times (m-1)$$

=67+14-1-32-0-0+0=48

In result, the number of valves for rule configuration is less than that of for theory configuration by 32 in grade 3 configuration.

(4) The rule configuration characteristics

① Rule configuration is not only one pattern for a network. There are lots of patterns. May form the *B* grade configuration at last. Namely, there is no any valve in the network besides the end valves;

② The grade for formation rule configuration, may be any natural number 2,3...*B*.

③ It is possible to use rule configuration with mixed different grades for a network.. Namely, divides the network into some parts, each part to a network adopts different configuration grade;

④ For most actual network, when rule configuration is adopted with grade used being not great than grade 3 (m≤3), so, number of surplus valve is 0 in generally. Therefore, this nature will be advantageous for us to use the formula (14), (15) to counter the valve number of a configuration network.

(5) Rule configuration formula

Definition: Ratio of valve number posited in the network to total pipeline length of the network is called valve density. The valve density unit is generally (set/km).

From equation (14), for certain average section length of the network *L*, ignoring δJ_m， ΔJ_Z， ΔJ_R ,the relation between configuration grade *m* and valve density k_{LP} can be derived according to the definition of valve density k_{LP} ：

$$k_{LP} \approx \frac{(B-T)\frac{1}{m}+H-1}{BL} \qquad (16)$$

$$m = \frac{1-\frac{T}{B}}{k_{LP}L-\left(\frac{H-1}{B}\right)} \qquad (17)$$

式中 *m*——configuration grade of rule configuration ；

k_{LP}——valve density of the network, excluding end valves;， set/km ；

L——average section length of the network, km/section。

Equation （17） is called rule configuration equation. In condition of certain *L*, characteristic of network construction $(H-1)/B$, *T*/*B* the configuration grade can be decided with given valve density k_{LP} . By referring to *m*, that what is the proper valve configuration can be aware. We have to recognize that *m* is just a reference, and is not an exact number.

It is obviously that mL is presentation of isolation length and scale of isolation area as well:

$$L_{IA} = mL \qquad (18)$$

Where L_{IA}——isolation length。

From equations（17）， （18）, it is aware that the proportions of isolation area is not just in inverse proportion to the valve density.

（6）Analysis on factors of influence upon rule configuration

By using equation（16）,curves in Figs.4, 5,6,7 are drawn.

⍰ Shape of network. In condition of same *m*, *L*, there are different valve densities with square shape, rectangular shape, branch shape in decline order.

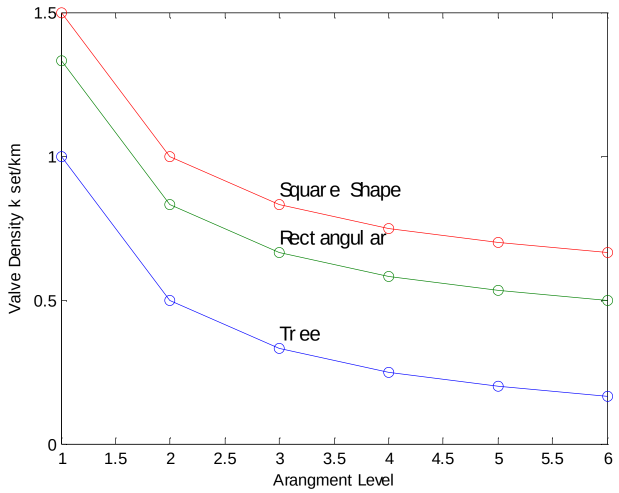

Fig. 4 relation between valve density and section average length with references of shape of network

② ring density of network. The greater the ring density（*H*/*B*）, the greater the valve density.

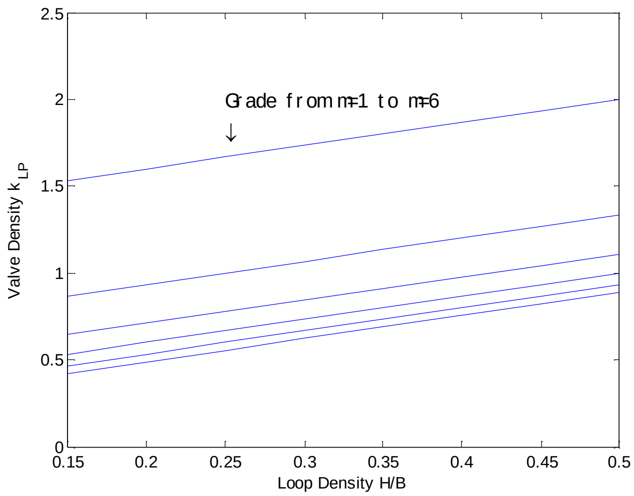

Fig. 5 relation between valve density and ring density with references *m*

③ Average section length. The greater the length, the less the valve density.

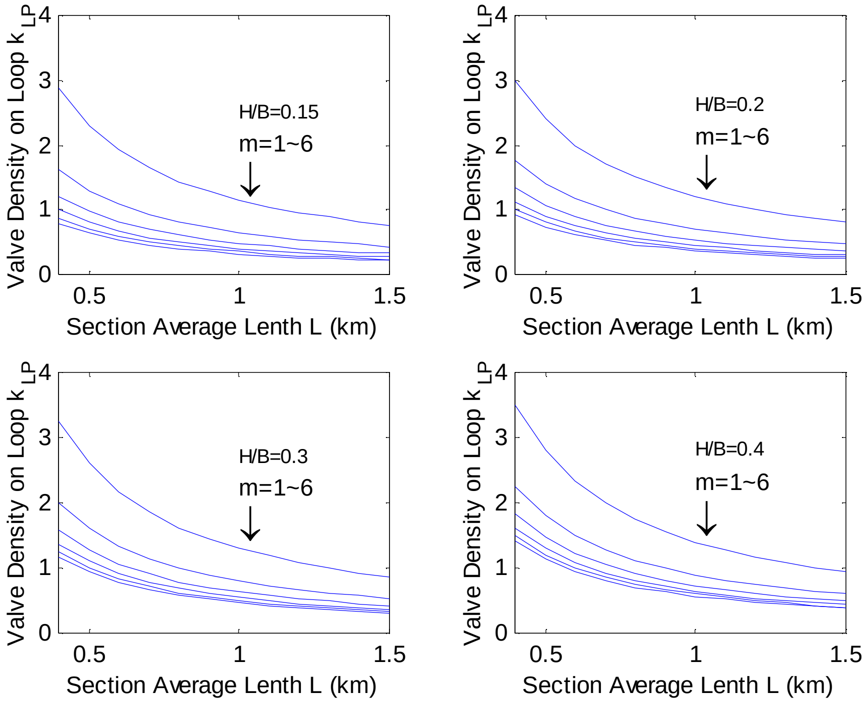

Fig. 6 relation between valve density and section average length with references *m* and *H*/*B*

④ Configuration grade. The greater the grade, the less the valve density. But in condition of $m \geq 4$, the trend is much week. Can be seen from Figs.5, 6.

⑤ Scale of network. The greater the Scale, the less the valve density.

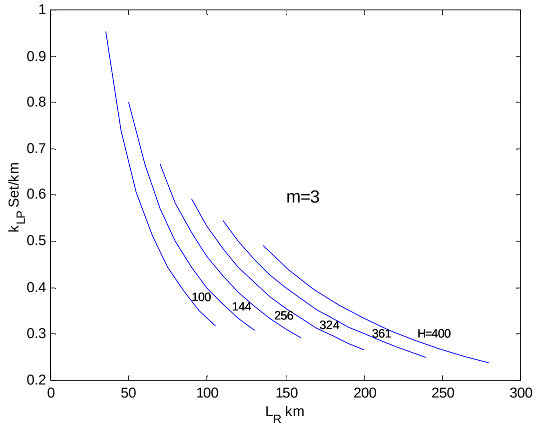

Fig. 7 relation between valve density and scale of network with references *m*

4. Discussions

① Owing to $2\times m$ of sections are influenced as a valve in fault, configuration grade should not be too great, usually $m=2, 3$;

② Several configuration grades can be adopted for a network;

③ For section of longer length, it can be divided into several sections with average section length;

④ Some notifications. For a node, preferring disposition valve in pipe with smaller diameter; to configure sections group as far as possible nearer in valve configuration are of advantageous for the management. In order to form better rule configuration (to close to complete rule configuration), it is suggested to make certain adjustments to the actual configuration.

5. Conclusion

①Valve Configuration Theorem (Yan's Theory) has set the scientific foundation for gas network valve disposition problem.

② Rule configuration method and the valve configuration formula provide engineering principle and practical method for valve configuration of gas network.

③ With different treatment for different scale network, according to hypothesis average length of section L, network structure characteristic $(H-1)/B$, T/B considering to use proper valve density k_{LP}, the suitable configuration grade m value may obtain.

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