Research on Unsteady Operating Conditions of Natural Gas Transmission Pipelines

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Abstract

Simulation of the numerical value in the system can realize the prediction of the pressure and related flow information in the system to a certain extent. Therefore, it is necessary to simulate the selection of the pipeline first when the gas pipeline and performance parameters are selected. The first step is to select the pipeline structure. It is necessary to select the relevant parameters of the pipeline in the environment of gas consumption and gas supply. When the pipeline network is running, the simulation of the pipeline network can realize the pressure information and flow information of the pipeline during operation, so as to realize the pipeline Take control. Generally, the actual operation of the gas pipeline will result in changes in the gas load and related pressure due to changes in the actual number of users. Therefore, even if the system is simulated and calculated, it has great limitations, but it can be compared to the actual operation. The relevant situation of the pipe network attitude in the simulation. Therefore, when designing the natural gas pipeline network system, it is also necessary to simulate and analyze the actual operating state of the system.

Keywords

Natural gas pipeline, Unstable flow, Working condition analysis, Model establishment.

1. Overview of Unsteady Operating Conditions of Gas Transmission System

1.1 The Occurrence and Development Process of Unsteady Working Conditions

Under normal circumstances, the unsteady state in the natural gas pipeline system is mainly due to the phenomenon caused by the disturbance inside the system. The unsteady state during the operation of the system is due to the internal or boundary of the system. Unsteady working conditions caused by temperature changes and changes in intake pressure, etc. Generally, the unsteady working conditions that have more situations in actual operation are mainly caused by the change of the air supply flow at the midway split point [1].

Therefore, the urban gas distribution system is used as the research object when design optimization is carried out to analyze the process of unsteady working conditions and the reasons for the impact. In the process of analysis, the line pipe in a certain case is mainly used as the research object for research. When designing, it is necessary to set the lower limit of the inbound pressure to 2.0MPa and the outbound pressure to 1.8MPa according to the relevant design requirements.

As for the urban gas transmission system, the gas consumption of the gas distribution system will directly determine the amount of gas supplied at the gate of the city station. However, the compressibility of the gas is very large in actual operation. Therefore, in general, the city station The gas supply volume at the door is not equal to the gas supply volume of the city gas distribution system, although the change in the gas consumption of the city gas distribution system will directly affect the gas supply flow of the city gate station, but because of the gas distribution network.

When the gas consumption of the gas distribution network increases, the gas filling volume in the gas distribution trunk line at the door of the city station will be correspondingly reduced, and the pressure regulating device at the gate station will open up the pressure to ensure When this happens, maintain the pressure at about 1.8 MPa. At this time, the air supply at the city gate station will increase, but the pressure at the exit station will still be maintained at 1.8MPa.

When the gas consumption in the gas distribution network in the city decreases, adjust the pressure regulating device so that it can maintain the outbound pressure at 1.8MPa.

The above is mainly to analyze the situation when there is instability. At the same time, if there is a big difference between the air supply at the city gate station and the actual air consumption, the air supply pipe in the main line will change to a certain extent, which will cause the system to fail. Normal operation. However, when the system is in such an unstable situation, the operation plan of the main line system can be adjusted to ensure that the system can operate well under unstable conditions. For example, when the air consumption is less than the air supply, the compressor can be reduced. The speed of the compressor and the closing of some compressors can be used to adjust the pressure. At the same time, the excess gas can be transported to the gas storage for storage. When the gas consumption is greater than the gas supply, it can be provided by calling the gas in the gas storage The demand for gas, while adjusting the relative pressure by increasing the speed of the operating compressor.

1.2 Fast Transient Change and Slow Transient Change Process of Gas Transmission System

When the gas pipeline in the system is in an unsteady state, there will be two kinds of transients: fast transient and slow transient. Because the disturbance time is too long, the corresponding transient time will also occur. It is relatively long, so the process becomes a slow transient, and when the disturbance time is relatively short, the transient process will be accelerated, so the process becomes a fast transient. In general, the slow transient is the main cause The reason is the change of the weather; and the fast transient is mainly caused by the sudden change such as a gas leak or a pipeline break. This paper establishes related mathematical models during the analysis of the two transient processes to analyze the causes of natural gas instability and related influencing factors.

2. Mathematical Model for Dynamic Simulation of Gas Pipeline

2.1 Establishment of Dynamic Simulation Mathematical Model

When the gas pipeline is in actual operation, its operation is changing all the time, so the related thermodynamic parameters and flow parameters in the pipeline will change accordingly due to the change of its state. In the analysis, the change of the gas in the vertical flow direction can be ignored, so when analyzing the flow direction, it can be determined that the direction of natural gas transmission during the transmission process is unique, so it can be obtained during the transmission process. Correlation function relationship between the pressure, density and velocity of the gas in the gas [2].

When natural gas has an unstable flow in the pipeline, you can describe it, as shown in the figure below. When analyzing, use the mass conservation equation and the momentum and energy conservation equations to establish the related mathematical model to get The equations related to the unstable flow of natural gas in the pipeline.

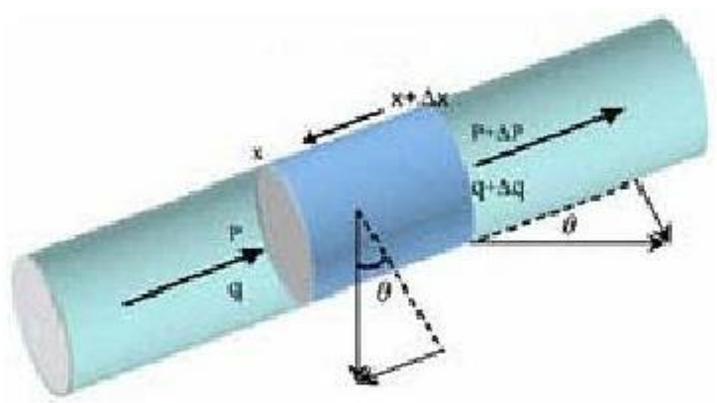

Fig. 1 Flow through the control body

The above figure mainly includes the gas density ρ(x,t), pressure P(x,t), velocity v(x,t), temperature T(x,t), internal energy U (x,t) and enthalpy h(x,t)6 The relationship function between each variable and time. According to the relevant theoretical knowledge, it can be found that there are six squares when solving these six unknowns, so in the process of analysis The enthalpy equation of the gas and the gas state equation and internal energy equation are also needed to form an equation set and then establish the relevant mathematical model [3].

$$A\frac{\partial \rho}{\partial t}+\frac{\partial(\rho vA)}{\partial x}=0 \tag{1}$$

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial(\rho v^2)}{\partial x}=-g\rho\sin\theta-\frac{\lambda}{D}\frac{v_2}{2}\rho \tag{2}$$

$$-\rho vA\frac{\partial \Omega}{\partial x}=\frac{\partial\left[\rho A\left(u+\frac{v^2}{2}+g\right)\right]}{\partial t}+\frac{\partial\left[\rho vA\left(h+\frac{v^2}{2}+g\right)\right]}{\partial x} \tag{3}$$

$$\rho=\rho(P,T) \tag{4}$$

$$u=U(P,T) \tag{5}$$

$$h=h(P,T) \tag{6}$$

Among them: P means absolute pressure of gas, Pa; v means flow velocity of gas, m/s; t means time variable, s; x—variable along the tube length, m; g—acceleration of gravity, m/s^2; A means the cross-sectional area of the gas passing through the pipeline, m^2; D means pipe inner diameter, mm; u means gas internal energy, J/kg; h means the gas's h, J/kg; s means the height of the pipeline position, m.

2.2 Simplification of Mathematical Model

The mathematical model established this time is mainly to describe the problem accurately. At the same time, when the model is established, the answering process of the model needs to be very simple. Therefore, although the model established above can achieve an accurate description of the problem, However, the process of solving equations is relatively complicated and therefore does not meet the relevant requirements. Therefore, it is necessary to simplify the mathematical model on the basis of the mathematical model established above, so as to obtain a solution that can describe the problem accurately and simply Solve it.

2.2.1 Isothermal flow assumption [6]

First of all, it is more complicated to solve the balance equation in the above expression.

In theory, there will be two extreme cases of adiabatic flow, and isothermal flow, T=constant,. The former is mainly related to the process of rapid transients in the tube, so the impact of this situation can be ignored, while the latter mainly occurs in the process of slow transients, but in the process of transients due to The temperature change caused by heat conduction is very small, so the temperature change can be ignored, that is, the variable is not considered. Assuming that the temperature is constant, then the tube function of the temperature relationship between internal energy and enthalpy can also be used Think of it as a constant.

The mass flow rate in the above model is represented by a velocity variable, and it is regarded as a constant temperature process, then the gas will satisfy the equation (2) in this case. After the above transformation, when the gas becomes unstable, the basic equation can be simplified to the partial differential equation shown in (3) [4].

$$q=\rho vA=\rho Q \tag{7}$$

Among them: q represents the gas mass flow.

$$\rho c^2=P \tag{8}$$

In the formula: c represents the propagation speed of sound waves in the gas, m/s.

$$\frac{A}{c^2}\frac{\partial v}{\partial t}+\frac{\partial q}{\partial x}=0 \tag{9}$$

$$\frac{\partial P}{\partial x}+\frac{\partial(\rho v^2)}{\partial x}+\frac{\partial(\rho v)}{\partial t}+\frac{\lambda \rho v^2}{2D}+\rho g\sin\theta=0 \tag{10}$$

2.2.2 Fast Transient Model for Unsteady Conditions

When determining the relevant parameters during pipeline operation, the quantitative estimation results can be obtained after estimating each part of the equation. When estimating the equation (4), some items need to be ignored, so that the The equation is simplified. The first equation in the above equation represents the continuity equation, which mainly describes the balance of gas flow, and the second is the equation of motion, which mainly refers to the continuity equation in the first equation in equation (4), which represents The gas flow balance relationship; the second equation is the equation of motion, which mainly describes the loss of gas energy and the related change energy loss. Therefore, it is necessary to estimate the size of each item in the following expression when analyzing, so that those factors can be ignored.

$$\frac{\partial P}{\partial x}+\frac{\partial(\rho v^2)}{\partial x}+\frac{\partial(\rho v)}{\partial t}+\frac{\lambda \rho v^2}{2D}+\rho g\sin\theta=0 \tag{11}$$

After integrating the above formula in the range of x=0 and x = L, (12) is obtained. In this expression, Z(L) and Z(0) respectively represent the end and beginning of the pipeline. Calculating the following equations can realize the simplification of the above equation, and δ1 represents the loss of energy when overcoming the change of kinetic energy, δ2 represents the loss when energy is overcoming inertia, and δ3 represents When consuming the energy loss of friction, δ4 represents the loss of energy when overcoming the pipeline elevation difference [5].

$$p(L,t)-p(0,t)+(\rho v^2)_{x=1}-(\rho v^2)_{x=0}+\int_0^L\frac{\partial(\rho v)}{\partial t}dx+\int_0^L\frac{\lambda\rho v^2}{2D}dx+g\rho[Z(L)-Z(0)]=0 \tag{12}$$

$$\delta_1=\frac{(\rho v^2)_{x=1}-(\rho v^2)_{x=0}}{\Delta p}\times 100\% \tag{13}$$

$$\delta_2=\frac{\int_0^L\frac{\partial(\rho v)}{\partial t}dx}{\Delta p}\times 100\% \tag{14}$$

$$\delta_3=\frac{\int_0^L\frac{\lambda\rho v^2}{2D}dx}{\Delta p}\times 100\% \tag{15}$$

$$\delta_4=\frac{g\rho[Z(L)-Z(0)]}{\Delta p}\times 100\% \tag{16}$$

2.2.3 Slow Transient Model for Unsteady Conditions

For slow transient conditions, it is actually a very slow process of boundary conditions. Therefore, the establishment of the mathematical model for this situation can ignore the term in the above formula. Which simplifies to:

$$\frac{\partial P}{\partial t}=-\frac{c^2\rho_n}{A}\frac{\partial Q_n}{\partial x} \tag{17}$$

$$\frac{\partial P}{\partial x}=-\frac{\lambda c^2 \rho_n{}^2 Q_n{}^2}{2DA^{2\rho}}-\frac{g\sin\theta}{c^2}P \tag{18}$$

2.3 Determination of Initial and Boundary Conditions

After corresponding analysis of the above related conditions, the mathematical models of fast transients and slow transients can be obtained. The establishment of this mathematical model describes the law of flow in the tube, so for unstable conditions, the change is the relevant laws mainly depend on the initial conditions and boundary conditions [6].

2.3.1 Initial Conditions

The initial conditions of the general system are mainly determined according to the current state of the pipeline when the system starts to run. It represents the stable state before the transient occurs. The conditions generally include the flow value and pressure at the initial moment. Distribution of:

(1)The flow value at the initial moment can be expressed as,;

(2)The pressure distribution law at the initial moment can be expressed as: When analyzing the pressure distribution at the initial moment, it can be determined according to the following expression:

$$P(x,0)=\sqrt{p^2(0,0)-\left[p^2(0,0)-p^2(L,0)\right]\frac{x}{L}} \tag{19}$$

After related analysis, it is found that the above expression can be transformed into the following two expressions, so as to realize the calculation of the pipeline with a slope, and (19) is mainly used to calculate the horizontal pipeline.

2.3.2 Boundary Conditions

The so-called boundary conditions indicate whether the pressure at both ends of the pipeline changes in the flow rate or the changing law. Generally, the actual area is different, so the following combinations appear. The main use in this paper is the third boundary condition [7].

(1) Given x=0 and x=L pressure changes with time:

$$p\ (0,\ t)=p_0(\mathrm{t}),\ \mathrm{p}\ (L,\ t)=p_L(\mathrm{t})$$

(2) Determine the pressure value at one end of the pipeline and its related laws that change over time, and calculate

$$Q\ (0,\ t)=Q_0(\mathrm{t}),\ Q\ (L,\ t)=Q_L(\mathrm{t})$$

(3) Determine the pressure value at one end of the pipeline and its related law of change over time, and calculate the law of change at the other end:

$$p(0,t)=p_0(\mathrm{t}),\ Q(L,t)=Q_L(\mathrm{t})\ \text{or}\ Q(0,t)=Q_0(\mathrm{t}),\ p(L,t)=p_L(\mathrm{t})$$

3. Numerical Solution of the Model

When solving partial differential equations and their performance, the solution methods can be divided into numerical methods and analytical methods. From the point of view of calculations, it is very complicated to use analytical methods to calculate. Therefore, analytical methods are different for this type of equations. This is not suitable, so the calculation method in this article is numerical method [8].

3.1 Analysis of Model Solving Method [13]

The process of using the characteristic line method to solve the equation is mainly to find a few lines past a certain point in the solution domain, so as to transform the partial differential equation into an independent variable according to this line Then you need to perform finite difference processing on the equation along this line to solve the unknown value of the equation. This method is very simple in the process of solving, but when taking the value In order to ensure the stability of the final result, only a small length of time can be used for analysis when calculating.

Use the implicit central finite difference method to solve the model. When using this method to solve the problem, you first need to use the network node to calculate the difference quotient of the function of the unknown number, and then obtain the difference equation of the function, and then according to these difference equations Solving the unknowns of the equation, but the amount of calculation performed by this method is relatively large, but the final value obtained using this method is more stable.

In general, the fast transient process is mainly to complete the entire transient process in a short time, but during the transient process, the transient process will change with time, but when calculating It needs to take a small period of time, and the relevant feature of the characteristic line method is that it needs to be calculated in a short time to ensure the stability of the final calculation [9].

The slow transient process is the opposite of the former, and its duration is very long. Therefore, when the entire transient process is analyzed, the amount of analysis is very large. Therefore, the analysis of the process is mainly done by selecting a longer It can not only reduce the amount of calculation to a certain extent. At the same time, relatively stable data can be obtained.

3.2 Characteristic Method for Solving Fast Transient Models

The following expression expresses the fast transient model, (20) expresses the evolution process based on coefficients, and (21) expresses the characteristic equation of the system.

$$\begin{cases} \frac{\partial p}{\partial t} + \partial_1 \frac{\partial Q_n}{\partial x} = 0 \\ \frac{\partial Q_n}{\partial t} + \partial_2 \frac{\partial p}{\partial x} + \partial_3 \frac{Q_n{}^2}{p} + \partial_4 P = 0 \end{cases} \tag{20}$$

$$C_+ \begin{cases} dx - cdt = 0 \\ -\alpha_2 dp - \alpha_1 \alpha_2 \frac{1}{c} dQ_n - \left(\alpha_3 \frac{Q_n}{p} + \alpha_4 P \right) dx = 0 \end{cases} \tag{21}$$

$$C_- \begin{cases} dx + cdt = 0 \\ -\alpha_2 dp + \alpha_1 \alpha_2 \frac{1}{c} dQ_n - \left(\alpha_3 \frac{Q_n}{p} + \alpha_4 P \right) dx = 0 \end{cases} \tag{22}$$

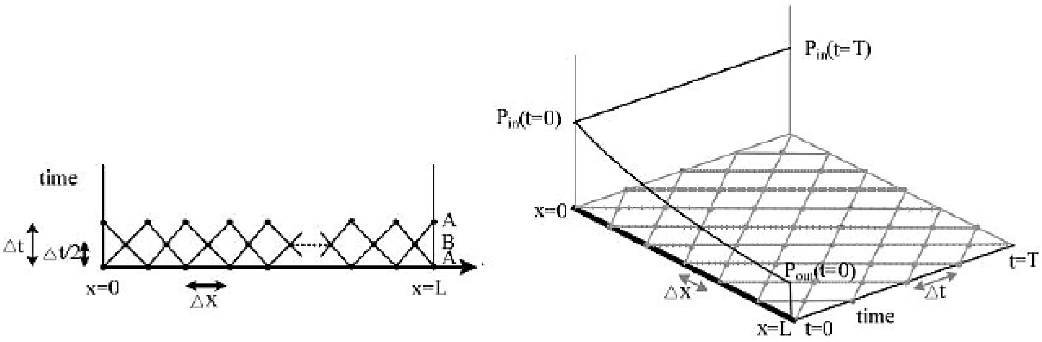

Fig. 2 The numerical solution method of the characteristic line method

3.3 Implicit Central Finite Difference Method for Solving Slow Transient Model

In the slow transient model, replace the first equation with $g=p^2$ to obtain (23), and then perform finite difference for each term in the expression. For the time derivative $\frac{\partial g}{\partial t}$ at the point (j, n) Forward difference, and get (25) and equation (26) after taking the average [10].

$$\frac{\partial^2 g}{\partial x^2}+\beta\frac{\partial g}{\partial x}=\alpha\frac{\partial g}{\partial t} \tag{23}$$

$$\left(\frac{\partial g}{\partial t}\right)_{j,n}=\frac{g_{j+1,n}-g_{j-1,n}}{2\Delta x} \tag{24}$$

$$\left(\frac{\partial g}{\partial t}\right)_{j,n}=\frac{1}{2}\left(\frac{g_{j+1,n}-g_{j-1,n}}{2\Delta x}+\frac{g_{j+1,n+1}-g_{j-1,n+1}}{2\Delta x}\right) \tag{25}$$

$$\left(\frac{\partial g}{\partial t}\right)_{j,n}=\frac{1}{2}\left(\frac{g_{j-1,n}-2g_{j,n}+g_{j+1,n}}{\Delta x^2}+\frac{g_{j-1,n+1}-2g_{j,n+1}+g_{j+1,n+1}}{\Delta x^2}\right) \tag{26}$$

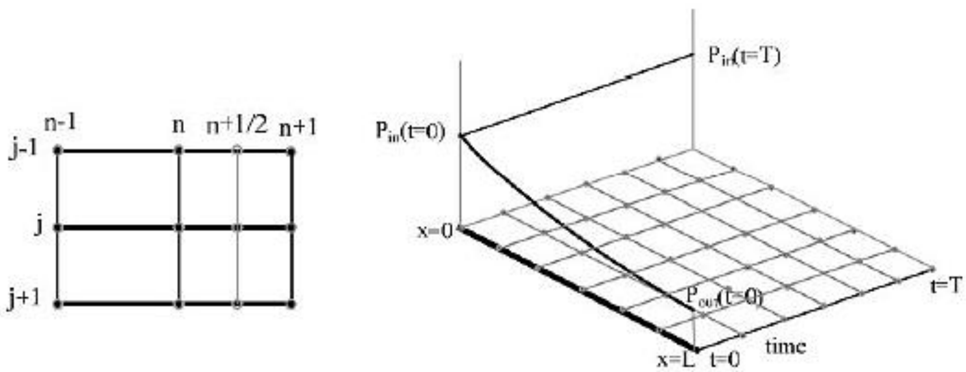

Fig. 3 The numerical solution method of the implicit central finite difference method

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