Application of turbine generator in pipeline for transporting natural gas

Liang Zhang and Jiyu Zheng

School of Mechanical Engineering, Southwest Petroleum University, Chengdu, Sichuan, 610500, China
E-mail: zhangliang@swpu.edu.cn

Abstract. Turbine generator is a kind of small power generation equipment widely used in drilling, military, and other fields, but there is no practical application in pipeline for transporting natural gas at present. In this paper, the working principle and technical characteristics of turbine generator are expounded, indicating that the way of using the kinetic energy of natural gas transported in the pipeline to convert to mechanical energy to generate electricity has a good prospect in engineering application. Based on design theory of turbine blade and VB language programming, 3d blade model is established. CFD software is used to simulate the flow field of the blade, and the distribution of velocity and pressure in the single periodic flow path of stator and rotor is obtained, providing feasible technical means for testing turbine hydraulic performance in practical engineering.

1. Introduction
Natural gas was transported in long distance pipeline, the natural gas contains some moisture and when the temperature of natural gas falls below its dew point (under the condition of gas pressure and water vapor content, cooled to the temperature at which the water vapor condensation beginning of the formation of liquid water), the moisture in the gas began to precipitate, and generated with some of the components in natural gas, a white crystalline hydrate the hydrate easy to jam in pipeline. In order to ensure the natural gas pipeline unimpeded, it is necessary to build transmission and distribution management station on the transmission line to heat the natural gas. At present, it is widely used to burn some natural gas to heat the natural gas in the pipeline with water jacket heater. However, it needs a lot of equipment, and its operation and later maintenance are tedious, which is difficult to achieve in the mountainous area, desert and other areas of single well or small gathering and transportation station. However, electric heating method is simpler than water jacket furnace heating equipment, easier to maintain and more accurate to control. But power transmission in remote areas is extremely inconvenient. Therefore, it is of great significance to use simple power generation equipment to provide power for transmission and distribution management stations. At present, turbine power generation is widely used in underground mud power generation, underground drilling tools, pipeline power generation, wind power generation, military and other fields. Elbatran A H et al.[1] systematically analyzed the hydraulic performance of turbine drill cascade by CFD technology, and provided a feasible scheme for testing turbine hydraulic performance. Velasco D et al.[2] presents two-dimensional numerical simulations of the flow around a cross-flow vertical-axis water turbine (straight-bladed Darrieus type) using active flow control by means of synthetic jets. [3-9] introduces the application of rotating machinery in different fields, studies the structure and hydraulic performance of blades through numerical techniques and experiments, and optimizes the design of blades from different angles.
X D et al.[10] conducted optimization analysis on downhole turbine generator blades, and verified the correctness of optimization through CFD method.

2. Operation principle and technical features
Turbine generator of natural gas pipeline is a device which converts the kinetic energy of natural gas into mechanical energy, its working principle is: natural gas enters the turbine drive module through the excessive pipeline, and drives the turbine rotor to rotate through the turbine stator growth rate, the turbine stator speed increases to drive the rotation of turbine rotor turbo wheel shaft to be transmitted to the generator module. The electromagnetic induction is used to cut the magnetic induction line to generate electricity. The generated current is regulated by the electric voltage regulator module to meet the applicable requirements. Natural gas in the process of transportation needs good sealing, magnetic drive to achieve the industrial machinery torque contactless transmission, dynamic seal power transmission, its sealing effect is very good.

Figure 1. Schematic diagram of turbine generator in pipeline

Since the whole set of device is integrated into a pipeline, the natural gas flow rate in the pipeline is used to drive the turbine rotation, and the turbine directly drives the generator behind to generate stable electric energy. As long as there is natural gas transmission in the pipeline, the power generation device can continuously provide electricity for the management station. Moreover, due to its compact structure and convenient maintenance in the later stage, it is very suitable for the use of management station in remote areas.

Natural gas generator of pipeline has the following advantages:
(1) It’s suitable for use of natural gas power for spontaneous transmission of remote gathering stations;
(2) It is suitable for the domestic electricity demand of gas transmission and distribution stations along the long natural gas transmission pipeline;
(3) The method of electricity-heating replaces the traditional production problem of gas-fired water jacket furnace, which saves the cost.

3. Simulation the flow field of the blade
3.1. Geometric model of blade
The most critical part of turbine generator is blade. The structure of blade directly affects hydraulic performance and thus the efficiency of the whole turbine generator. Good blade structure is conducive to improving the rate of energy conversion. There are many factors that affect hydraulic performance of turbine, among which the most important part is the profile of blade. There are many types of linear blades. At present, the combination forms of blades include arc line and hyperbolic spiral line, parabola and arc line, and single combination of arc line or parabola; methods of blade linear modeling mainly include fourth-order spline, non-uniform rational B spline (NURBS) curve modeling, Bezier curve modeling and fifth-order polynomial curve modelling.

For example, the control polygon vertex of the fourth-order Bezier curve on the suction surface is $P_1(x_1, y_1), P_2(x_2, y_2), P_3(x_3, y_3), P_4(x_4, y_4)$ and $P_5(x_5, y_5)$, Vertices P1 and P5 are respectively the
tangential points of the front and rear wedge edges on the suction surface. Parametric equations of suction surface can be obtained according to Bezier curve formula, the parameters is $\lambda$, the range of $\lambda$ is $[0, 1]$.

$$x(\lambda) = (1-\lambda)^4 x_1 + 4\lambda(1-\lambda)^3 x_2 + 6\lambda^2(1-\lambda)^2 x_3 + 4\lambda^3 (1-\lambda)x_4 + \lambda^4 x_5$$

$$y(\lambda) = (1-\lambda)^4 y_1 + 4\lambda(1-\lambda)^3 y_2 + 6\lambda^2(1-\lambda)^2 y_3 + 4\lambda^3 (1-\lambda)y_4 + \lambda^4 y_5$$

With the help of mathematical software, the linear equation of the pressure surface of stator and rotor and the curve equation of the pressure surface of suction surface are obtained respectively.

Pressure surface:
$$y_p = 8.6699689 + 0.0408969*x - 0.0137012*x^2 + 0.0050610*x^3 + 0.0001091*x^4 - 0.0000105*x^5$$

Suction surface:
$$y_s = 7.1514306 - 0.3421726*x + 0.0183867*x^2 - 0.0122172*x^3 + 0.0019067*x^4 - 0.0000577*x^5$$

Through VB language programming, basic parameters of turbine torque, flow rate, blade tip diameter and fluid density that have been calculated are input. Then the program automatically calculates blade installation Angle and draws the following profile:

![Figure 2. Linear curve of the blade](image)

3.2. Flow field simulation of blade

According to map the blade profile curve according to the calculation, will draw the model of the blade, then get the calculated model of stator and rotor, through pretreatment to single cycle turbine stator flow model, in order to avoid backflow, the inlet and outlet respectively extend the distance, the computational model was meshed and the area near the blade was locally encrypted. figure.3 shows the mesh and boundary condition setting of single-period flow.

![Figure 3. Mesh and boundary condition setting of single-period flow](image)
3.2.1. Establishment of analytical model. After the computational grid model is obtained, boundary conditions and computational parameters need to be set as follows:

(1) There is no relative sliding between the flow passage boundary of turbine stator and rotor and the flow passage boundary of blade of stator and rotor, so they are no slip wall surface;

(2) Periodic boundaries of stator rotor are all rotating boundaries;

(3) The stator is fixed, while the rotor is rotating at a speed of 300rpm; interaction between stator and rotor will occur. To express the interaction between stator and rotor, the frozen rotor hybrid interface model is adopted at the interface of stator and rotor;

(4) The inlet of the flow passage is set as the velocity inlet, and the outlet is the pressure outlet. By default, under normal pressure environment, the flow direction of the flow passage is the negative direction of Y-axis, and the rotor flow passage rotates around the negative direction of Y-axis.

3.2.2. Analysis of flow field results. Through the qualitative analysis of the flow field simulation results of the single periodic flow passage of turbine blades, the pressure in the flow field presents a downward trend from the inlet of stator to the outlet of rotor, and the pressure on the pressure surface and suction surface of the rotor and stator of blades presents a certain gradient change. It can be seen from Figure 4 and Table 1 that the pressure drop of the flow field on the Y axis is small, and the pressure difference between stator and rotor blades is extremely small, less than 1%.

| Minimum pressure (Pa) | Maximum pressure (Pa) | Range of pressure (Pa) | pressure difference (Pa) |
|-----------------------|-----------------------|------------------------|--------------------------|
| 99990                 | 105700                | 99990～105700           | 5710                     |

Figure 4. Pressure distribution nephogram of single-period flow of blades

Figure. 5 shows the velocity distribution in the X, Y and Z directions of the flow passage of a single-period blade. It can be seen that the velocity in the X direction increases on the stator-rotor joint surface and can reach the maximum value in the X direction. The velocity along the Y-axis is obviously smaller on the suction surface of stator and rotor but larger on the pressure surface of stator and rotor. The velocity along the z-axis is smaller near the outlet of the stator pressure surface and larger on the suction surface between the stator and the rotor.
4. Conclusion

This paper introduces the application and technical characteristics of turbine generator in pipeline for transporting natural gas, and puts forward an effective method to solve gas blocking and freezing in remote areas by using natural gas kinetic energy generation in pipeline, which has a very good prospect in practical engineering. In addition through programming and 3D modeling software to establish the turbine blade geometry model of stator and rotor. As the working medium of natural gas turbine generator is gas, but the working medium of common turbine generator is mud, the pressure and speed of the flow passage inside the turbine will be greatly different due to the different media. Through CFD numerical simulation, the pressure and velocity distribution of the flow passage of a single-period blade of natural gas pipeline turbine generator are obtained, because the pressure drop and velocity distribution of turbine blade are mainly concerned. Through numerical simulation, it can be seen that the pressure drop of turbine generator in natural gas pipeline exists in the flow direction, but its value is smaller than mud generator; the stator increases the flow of natural gas in the pipeline. The feasibility of using natural gas kinetic energy generation in natural gas transportation pipeline is illustrated. CFD numerical simulation can provide feasible technical means for testing turbine hydraulic performance in practical engineering and provide data reference for optimizing structure of blades.

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