Application and design of virtual reality technology in wellbore oil production process of pumping unit system

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Abstract: This paper describes the virtual simulation system based on digital computation aided design (CAE) and visual simulation technology. The pumping unit wellbore 3d visualization platform developed by this system can display the three-dimensional wellbore track, simulate the three-dimensional wellbore work string statically, simulate real motion and the whole life cycle of wellbore string by establishing a dynamic three-dimensional model . Using virtual reality technology can realize the total life cycle management of oil well such as optimization design of producing wells , the construction risk assessment, dynamic analysis and prediction of the operation process. This technology is of great significance to guide the design of construction parameters of the wellbore rod and pipe string.

Introduction

Virtual reality technology is one of the frontier research fields in contemporary information science. It combines computer graphics, computer visual, psychology, artificial intelligence, sensor and network communication , and other aspects of technology. It creates a virtual environment in the computer. It makes users to produce immersive real sense through real-time, three-dimensional graphics display, sound simulation, human and virtual environment of natural real-time interaction. At present, virtual reality technology has become an important technical means and tools in the whole life cycle of the system.

Simulation Model

Simulation model of axial vibration and axial movement of sucker rod string.

The wave equation of axial vibration of sucker rod string is described:

$$\begin{cases} r_{\mathrm{r}} A_{\mathrm{r}} \dfrac{\partial^2 u}{\partial t^2} - E_{\mathrm{r}} A_{\mathrm{r}} \dfrac{\partial^2 u}{\partial x^2} + n \dfrac{\partial u}{\partial t} + d\, h N = r_{\mathrm{r}}^{'} A_{\mathrm{r}} g \cos q - r_{\mathrm{r}} A_{\mathrm{r}} \dfrac{\partial^2 u_0}{\partial t^2} - n \dfrac{\partial u_0}{\partial t} + d\,(x-L) P_p(t) \\ N = \sqrt{(P \dfrac{dq}{dx} - q_r \sin q)^2 + (P \sin q \dfrac{dj}{dx})^2} \end{cases} \tag{1}$$

Where

$$r_{\mathrm{r}}^{'} = r_{\mathrm{r}} - r_{\mathrm{L}} \tag{2}$$

ν is damping coefficient of wells liquid to sucker rod column, 1/s;ρ_r is density of rod material, kg/m3;ρ_L is density of well liquid, kg/m^3;E_r is elastic material of sucker rod material, N/m^2; A_r is the cross-sectional area of the sucker rod, m^2;θ is wells angle;ψ is hole azimuth angle; P is axial force, N; h is coefficient, h= f/ A_r *ρ_r; f is friction coefficient between rod and tube; u*(t) is motion displacement of suspension point, m; P_p is the liquid load on the pump plunger, N;δ is a Coefficient, depending on the direction of the motion of the pumping rod.

At present, more than 90% international mechanical products and equipment are analyzed by using finite element method. The basic idea of the finite element method for sucker rod is that at first disperse the suck rod string into a number of spatial beam element , and then establish the element equilibrium equation with any single beam unit as the research object based on the principle of virtual work， finally establish the whole equilibrium equation of the sucker rod string through the whole stiffness matrix and load matrix.It is shown in figure1.

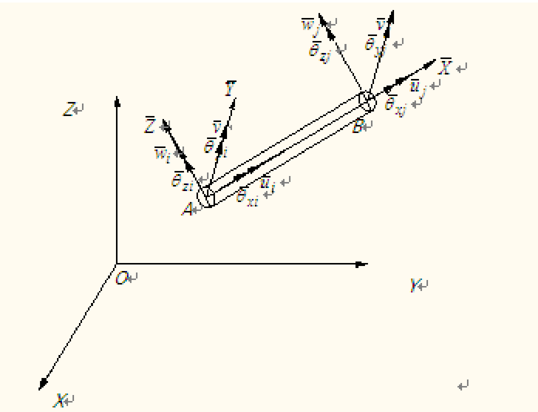


Fig. 1 node displacement and diagram of space beam element

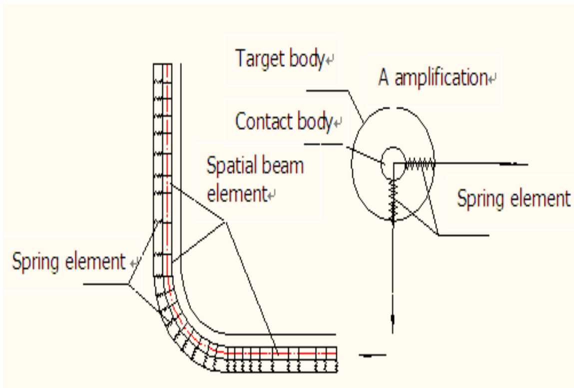


Fig. 2 schematic diagram of space beam element

The basic idea of the spring element method is that at first disperse target sucker rod into a number of spatial beam element with the general finite element method, and then place two spring element which are convenient and accurate simulation of rod and pipe contact state along the element local coordinate system y axis and Z axis, finally nonlinear mechanical problems of rod and pipe contact are solved by the spatial beam element and spring element combination .

On the basis of the general finite element method, the space beam element and spring element assembled is shown in figure2.

Pumping wellbore 3D visualization platform based on VR Technology

Development model and Platform architecture. System uses B/S+C/S mixed development model and the current popular.NET development platform for the development of the project. Platform have typical three layer structure which are the interface presentation layer, business logic layer, model data layer. Multi core integration management mode, each core to complete the independent function of the virtual simulation system, the core of the integration through the database technology to achieve the unified management and call of the system. platform architecture is shown in figure 3.

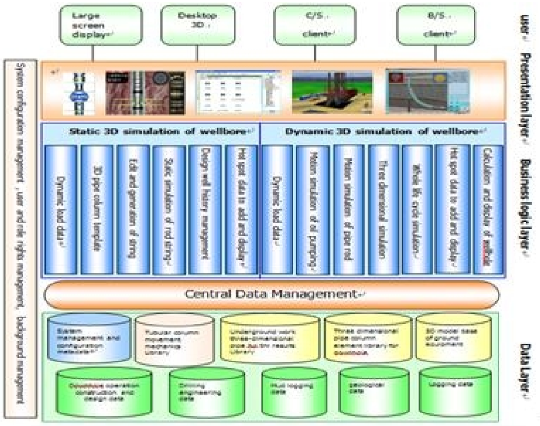
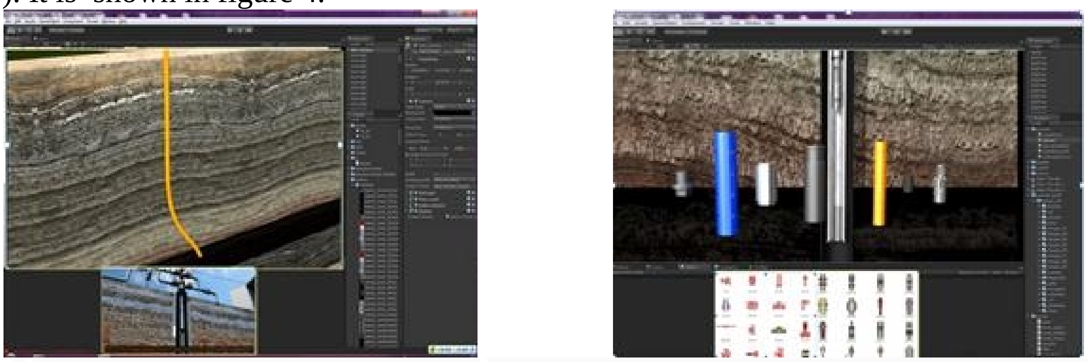


Fig .3 software layered architecture diagram

Major function. The main functions of the system are divided into three parts: static 3D simulation of wellbore, Dynamic 3D simulation of wellbore.

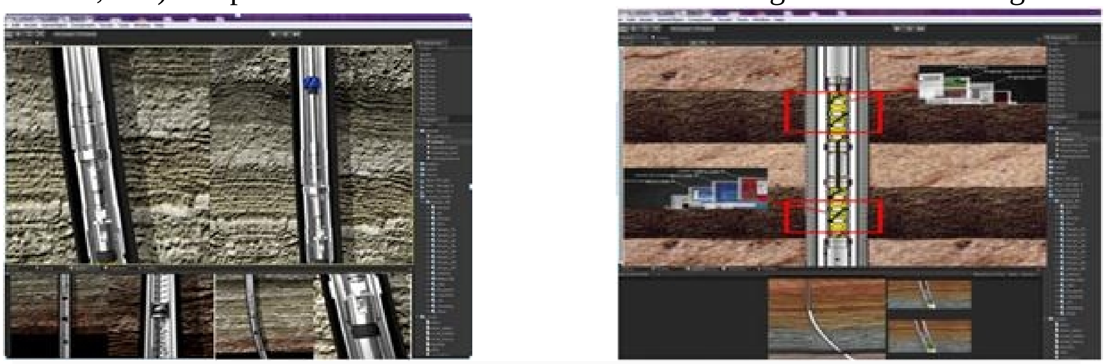
Static 3D simulation of wellbore based on the Virtools platform development, combining VSL script programming language and SDK software development package to realize the 3D well trajectory generation, tools and components edition, including tool drag, rotate and zoom, synchronous display function, including: well trajectory data information (sounding, deviation angle, azimuth angle, full width change rate), based data information (types of tools, specific parameters, etc.). It is shown in figure 4.



a display of 3D well trajectory scale b sketch map of 3D edit of process pipe column

Fig. 4 sketch map of 3D static simulation of wellbore

Dynamic 3D simulation of wellbore use Virtools to connect the Oracle database through the VT Server, the extracted wellbore motion data is used to drive the periodic movement of the shaft, and the simulation of the dynamic simulation of the three-dimensional wellbore pipe column is simulated. Including the simulation of motion process of the fluid in the wellbore, string motion of eccentric wear, bending, distortion, simultaneous display function well trajectory data information (sounding, deviation angle, azimuth angle, full width change rate), based data information(types of tools, specific parameters, etc.) and pressure data information of tube rod string . It is shown in figure 5.



a schematic diagram of stress deformation b schematic diagram of hot spot data

Fig. 5 sketch map of 3D dynamic simulation of pumping unit

Application examples.

As a guide pipe the rational selection of the parameters for the design and construction of rod string, by pumping oil wells virtual reality digital simulation system of Huabei Oilfield 10 wells are mechanical simulation calculation and the whole well deflection proof and abrasion proof analysis, the results carries on the comparison between the simulation result and the actual operating records are shown in Table 1. The system runs stably, the operation efficiency is high, the operation result conforms to the rate reach to 93.7%, the fault rate is 0.

Table 1 The comparison between the simulation result and the actual operating records

Well No	Calculation module	Calculation of eccentric wear	Eccentric wear	Actual operation situation
Test 25-14	Axial force calculation	1600-1800	serious	1、tubing placement 1458-1719；sucker rod replacement 913-1737；Sucker rod broken 1489 2、tubing placement 18-261，sucker rod replacement 849-1801，Sucker rod broken 1489
	Radial force calculation	375-1550	Not too serious	
Test 25-15X	Axial force calculation	1674-1988	serious	1、tubing placement 1359-1710，sucker rod replacement 889-1713 2、tubing placement 1917-2025, sucker rod replacement 862-1702
	Radial force calculation	374-1599	Not too serious	
Test 25-18X	Axial force calculation	1699-1924	serious	1、tubing placement 18-279, sucker rod replacement 317-409
	Radial force calculation	400-1649	Not too serious	
Test 31-14X	Axial force calculation	1624-1874	serious	1、pinch off 1121，sucker rod replacement 1121-1129
	Radial force calculation	349-1524	Not too serious	
Test 11-25	Axial force calculation	1625-1850	serious	1、Sucker rod broken 1565，sucker rod replacement 845-997、1414-1862
	Radial force calculation	125-1500	Not too serious	
Test 11-28	Axial force calculation	725-1225	serious	1、rod deformation 888-912，sucker rod replacement 1212-2308
	Radial force calculation	1275-2175	Not too serious	
Test 22-17	Axial force calculation	1600-1700	serious	1、tubing placement 753-1823, sucker rod replacement 444-1790 2、tubing placement 1204-1786，sucker rod replacement 1135-1175、1745-1785
	Radial force calculation	400-1500	Not too serious	
Test 22-32	Axial force calculation	1120-1245	serious	1、tubing placement 532-1303，sucker rod replacement 655-1303，Sucker rod broken 1015 2、tubing placement 722-1302，sucker rod replacement 30-1142
	Radial force calculation	145-1095	Not too serious	
Test 22-35	Axial force calculation	1500-1975	serious	1、release of eccentric wear 1574
	Radial force calculation	225-1175	Not too serious	
Test 814X	Axial force calculation	325-1050	serious	1、tubing placement 426-906 2、tubing placement 330-906，sucker rod replacement 800-906
	Radial force calculation	525-900	Not too serious	

Conclusion

The virtual simulation system which based on digital computing aided design (CAE) and the scene simulation of composite technology , finally establishes the digital simulation laboratory of mechanics through macro digital simulation and the micro rod and tube for the finite element analysis. Based on oil pumping machine, gas storage well bore research, it gradually realizes the production wells optimization design, risk assessment, dynamic prediction, accident reconstruction, and so production nodes of digitalization, visualization, and inallyrealized based on the virtual reality technology of oil and gas wells in the whole life cycle management, prediction and optimization through the late supplement other simulation models (such as injection, fracturing, overhaul and operation).

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