The three-dimensional simulation analysis of dynamic response on perforated strings

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The three-dimensional simulation analysis of dynamic response on perforated strings

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Abstract. It analyzes the dynamic response and stresses of perforating tubular string to detonating impact load in oil-gas well in ANSYS, obtains the response of vibration displacement, velocity and acceleration of perforating tubularstring caused by detonating impact load, finds the influence of the length and wall thickness of perforating tubular string to working stresses. The result shows that:when the detonating impact load exerts the perforating tubular string with compressive and tensile axial force alternatively;the vibration displacement, velocity and acceleration of perfora-ting tubular string change periodically at same cycle;the closer to the perforating gun, the larger the amplitude of vi-bration velocity and acceleration;the closer to the packer the smaller the vibration displacement, the larger the work-ing equivalent stress of perforating tubular string;the longer or the thicker the perforating tubular string, the smaller the working equivalent stress and the higher the strength safety. Therefore, it uses the damping tube between packer and perforating gun as well as thick walled tubing to increase the strength safety of perforating tubular string.

1. Introduction

In the HTHP deep wells, such as KS101 and WC1 which belong to CNPC, the fracture of the center pipe of the string of the packer which used to complete testing and perforation has occurred [1], and the accident of the strings broken off well was also occurred in a development well in the northeast of Sinopec [2]. With the view of understanding the impact of perforation detonation load on perforation string and downhole tool safety, engineers have carried out theoretical and experimental research. After nearly ten years of research, the Schlumberger has developed the optimization design technology of the perforated string. Through the prediction of the perforation detonation load and the strength safety of the string, the perforation parameters and the perforation string configuration are optimized to prevent the damage of the perforation string and the downhole tools [3]. Drawing lessons from the thought of Schlumberger, the relationship between the structure of the well and the length of the string and the stress strength of the string is analyzed in the case of the perforated string of a HTHP ultra deep well [4-6].

The influence of perforation on the strength of the string mainly lies in the vibration of the string which caused by perforation detonation, furthermore, the response of the string to perforation impact load. Due to the complexity of this problem, the current research mainly rely on finite element numerical analysis and experimental study [7,8]. Considering the inclination and azimuth, the finite element analysis model of horizontal well perforation was established, meanwhile, the relationship between vertical displacement and velocity of perimeter along the perimeter was analyzed [9], Puls Frac perforation engineering software and ANSYS finite element analysis software were used to analyze the implicit-explicit dynamic behavior of perforated pipe string. It was found that the stress of the pipe string at the lower end of confined packers was the highest when perforation was found. According to the existing research foundation, finite element model of perforation string is established by finite element analysis software ANSYS in this paper. The dynamic response and stress intensity of perforation string are analyzed. The vibration displacement, velocity and acceleration of perforation pipe string the response law of equivalent stress to perforation impact load, the effect of perforation length and wall thickness on the stress intensity of the string, and providing guidance for optimizing the configuration of perforation string.

2. Perforated section pipeline finite element model establishment and loading

To analyze the transient dynamic response of the string under the impact of fast changing impact load, the finite element analysis software ANSYS Workbench transient dynamic analysis module is applied to the finite element analysis of the perforated string. As shown in figure 1, the 20-m-long perforated section of the packer under the 88.9 mm × 9.52 mm P110 tubing-mounted perforating string is taken as the research object. The tubing material has a yield strength of 758 MPa, an elastic modulus of 206 GPa, a Poisson's ratio of 0.3 and the density of 7.85 g/cm^3. As shown in figure 2, the casing is a homogenous casing, the tubing can be regarded as an elastomer. Vibrates occurs under the combined action of perforating shock waves and percussive fluid pressure pulsation, the eight-node hexahedron entity unit is used to mesh the pipe string by using the mapping meshing method. The 20 m long pipe string is divided into 24,160 units with a total of 169,200 nodes.

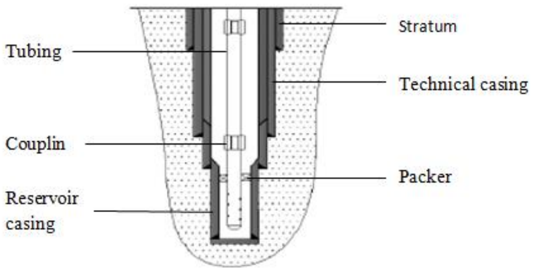

Figure 1. Schematic diagram of tubing conveyed perforating string.

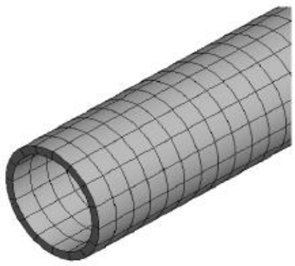

Figure 2. Local diagram of finite element model of the perforated strings.

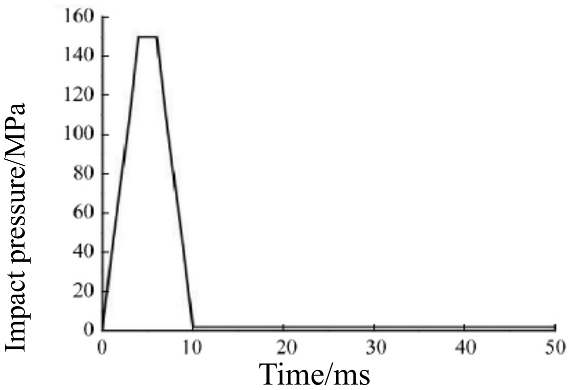

Figure 3. Axial shock load by perforating.

The simplified perforation impact load-time curve is shown in figure 3 [7], the peak pressure is 150 MPa and the loading time is 50 ms. The impact load that ia shown in figure 3 is applied to the finite element analysis model of perforated pipe string which is shown in figure 2, and the finite element analysis of dynamic response of perforated pipe string can be used to obtain the vibration displacement, velocity and acceleration of perforation string. In addition, we can know the dynamic response of perforation pipe string to perforation impact load from the law of equivalent stress changing with time.

3. Dynamic response analysis column vibration displacement perforations

Figure 4 is the curve of the displacement-time of the pipe string at 5 m, 10 m and 20 m from the packer. It can be seen from the diagram that the vibration displacement of string at different locations varies periodically with time, similarly to the sine curve, and the cycle is the same, which is about 16 ms. The peak vibration displacement of the distance packer which located at 20 m is 22 m, the peak vibration displacement of the distance packer is 13 mm, and the peak vibration displacement is 8 mm at the distance packer 5 m, which indicates that the closer the distance packer is, the smaller the vibration displacement of the string is.

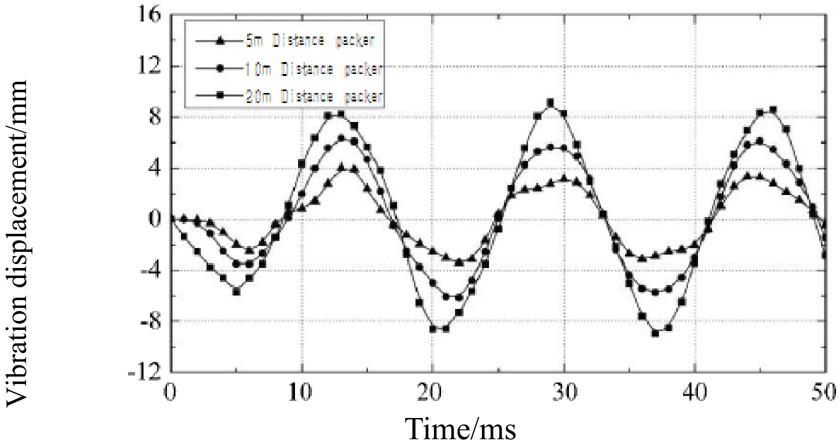

Figure 4. Vibration displacement of perforating string at different positions.

4. Dynamic response analysis of vibration velocity of perforated pipe string

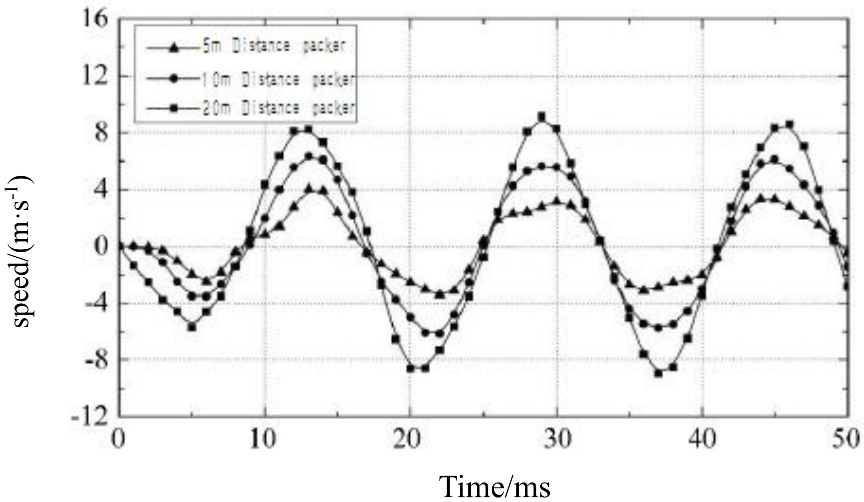

Figure 5. Vibration velocities of perforating string at different points.

Figure 5 is a curve of the vibration velocity from 5 to 10 and 20 m away from the packer. It can be seen that the vibration velocity of the column varies with time periodically with the same period. The peak vibration velocities of the columns at 5 m, 10 m and 20 m were 4 m/s, 6 m/s and 9 m/s respectively, that is,the farther the distance packer is, the greater the amplitude of the vibration velocity.

5. Dynamic response analysis column vibration acceleration perforations

Figure 6 shows the curve of vibration acceleration of a string at 5 m, 10 m and 20 m from the packer with time. It can be seen from the diagram that the vibration acceleration of the pipe string at different positions alos changes periodically with time, and the cycle is the same. The peak vibration acceleration at 20 m, 20 m, 5 m distance packers are respectively 3500 m/s^2 (about 350 g), 2200 m/s^2 and 1600 m/s^2, that is, the farther the distance from the packer ,the great the vibration acceleration.

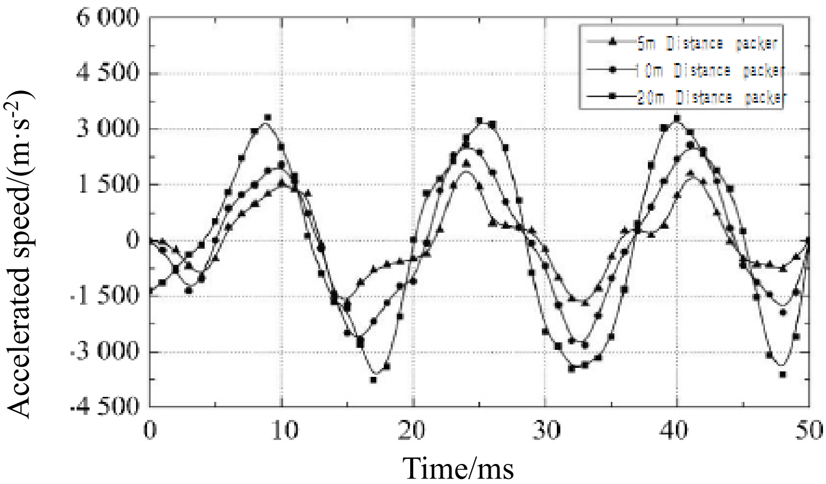

Figure 6. Vibration velocities of perforating string at different points.

6. Dynamic response analysis of equivalent stress of perforated pipe string

Figures 7 and 8 show the equivalent stress contour of the string at the packer at 6 ms and 10 ms respectively. It can be seen that the stress wave has not been transmitted to the packer at 6 ms and the equivalent stress of the string at the packer. The maximum equivalent stress is about 182 MPa. With the propagation of percussion shock waves, the equivalent stress of the column at the packer gradually increases and reaches 441 MPa at 15 ms. In addition, it can be seen that the equivalent stress distribution on the pipe section is not uniform, and the maximum equivalent stress always appears at the outer wall of the pipe string. Figure 9 shows the curves of the maximum equivalent stress of the packer processing column and the perforating section with time.

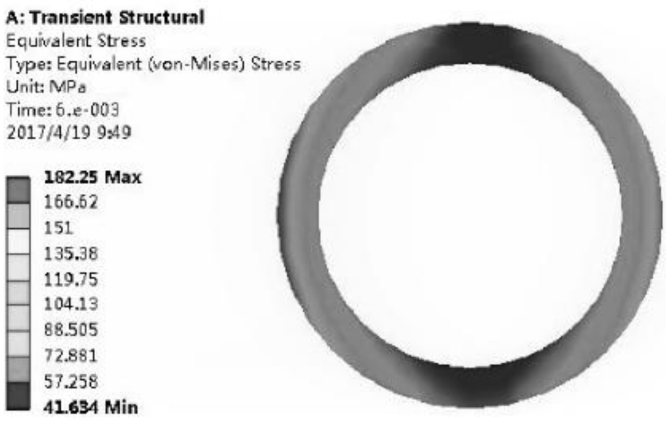

Figure 7. Equivalent stress distribution near packer at 6 ms.

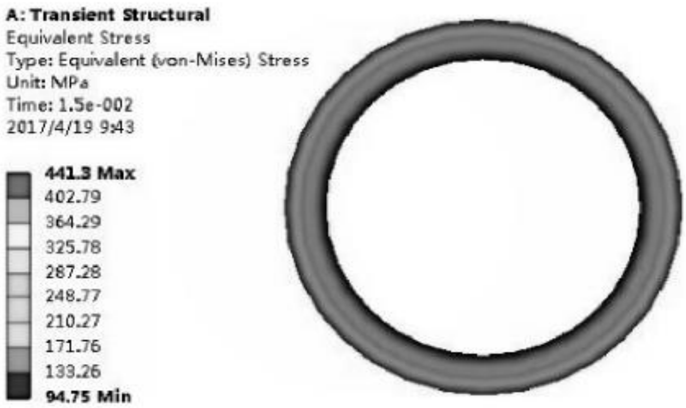

Figure 8. Equivalent stress distribution near packer at 15 ms.

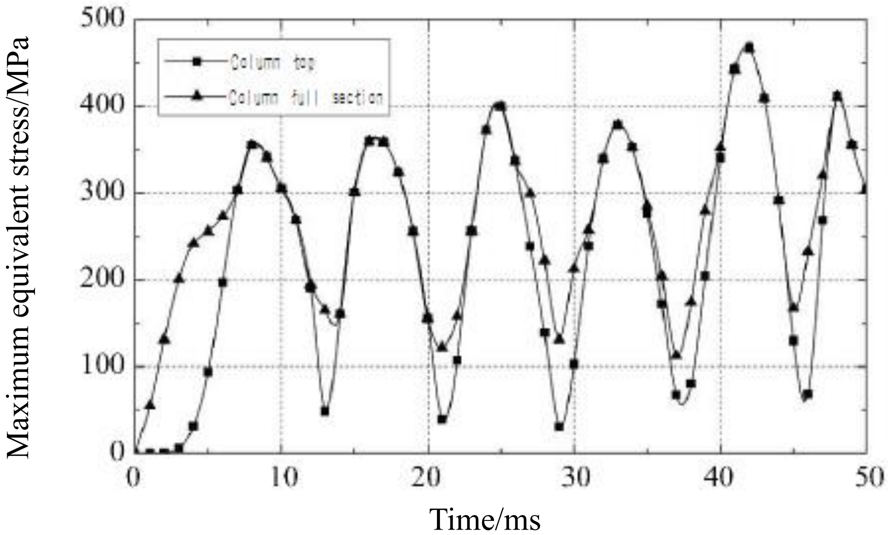

Figure 9. The maximum equivalent stress of string versus time.

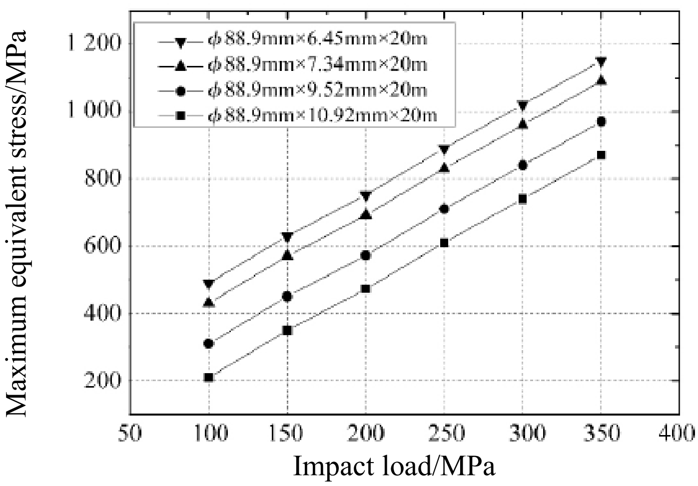

Figure 10. Maximum equivalent stress of columns with perforations of different wall thicknesses under different amplitude perforation impact loads.

7. Influence of length and wall thickness of perforated pipe string on stress intensity

Using the above-mentioned finite element analysis model and method, the impact load amplitude of perforation is assumed to be 100, 150, 200, 250, 300 and 350 MPa respectively. Observing the effect of the length and wall thickness of the perforation section on the maximum equivalent stress is investigated, as shown in table 1 and figure 10.

Table 1. Under different amplitude impact load of different lengths perforation section of the maximum equivalent stress.

Tubing length/m	**Impact load**/MPa					
	100	150	200	250	300	350
20	248	398	498	677	798	857
30	217	369	469	649	769	826
40	203	357	456	637	758	812
50	195	351	448	629	752	805

As can be seen from table 1 and figure 10, the maximum equivalent stress is positively correlated with the amplitude of perforating impact load. The longer the column of perforation or the thicker the wall, the smaller the maximum equivalent stress is. Therefore, setting the shock-absorbing tubing between the perforating gun and the packer (increasing the length of the perforating section), or increasing the thickness of the perforating section can improve the strength as well as safety of the perforating section's string.

8. Conclusion

- Under the percussive detonation impact load, the pipe string under perforation is subjected to alternating compressive and tensile impact loads. The vibration displacement, vibration velocity and vibration acceleration around the string periodically change with time as well as the period. The farther away from the packer (the closer to the detonation source of the perforation), the greater the amplitude of the vibration displacement, the vibration velocity and the vibration acceleration is, the peak of the vibration acceleration of the string caused by perforation impact can reach hundreds of gravitational accelerations, and go through a dynamic load.
- The closer to the packer, the smaller the displacement amplitude of the string is, but the larger the equivalent stress is, the equivalent stress of the packer at the beginning of the perforation is smaller, in addition, as the time increases, the propagation of the detonation wave, the equivalent stress of the column at the packer gradually increases, and the column at the packer is the dangerous point of stress in the column of the perforation section. As a result, perforation strings often experience plastic buckling near the packer even cause damage to the packer core tube.
- Under the same perforation impact load, the longer the column of perforating section or the thicker the wall of the column, the smaller the maximum equivalent stress is and the safer the column. Therefore, it is possible to provide a damping tube between the perforating gun and the packer (to increase the length of the perforating section string), or to increase the wall thickness of the perforating section column to improve the strength and safety of the perforating section string.

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