Testing String Dynamics When Jarring Stuck Packer

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Abstract. The jar, as a standard down-hole tool in oil well testing string, is widely used in order to free the packer when stuck. But its efficiency is not satisfied. Based on stress wave propagation theory, testing string dynamic behavior is studied during jarring process. Model analysis is performed with practical string parameters to investigate impact force and impulse. It is found that the triggering force, which is usually called overpull, is the most important parameter. Both impact force and impulse would increase in response to overpull. Both collar string length and jar stroke length have little influence on the maximum dynamic force transmitted to packer, but they have large influence on impulse delivered to the packer: longer collar or stroke will produce higher impulse value. While the ratio of impact force to overpull is not a sound factor to evaluate jarring effect.

Introduction

A lot of researches have been made on how to free stuck strings during oil well drilling and workover, but there is no report on jarring stuck packer. Jarring is one of the practical methods in oil fields[1,2]. Prior work on jars indicates that the amplification coefficient of maximum dynamic force to jar triggering force ranges from 2 to 10[3,4,5]. And the coefficient is regarded as an important parameter for evaluating jar efficiency. The reasons of large coefficient span come mainly from two aspects: dimensions of working string and theories used in discussion. Jarring process is usually treated as three stages: storing up strain energy by tensioning string, converting strain energy to kinetic energy after triggering, and transmitting dynamic force and impulse to stuck point after impact. The first stage is easy to describe, but the others are described by different theories. Skeem[1] and Jin Jiefang[6] simulated jarring stuck drillstring with wave propagation theory, the drillstring is idealized as a one-dimensional, piecewise constant elastic medium with large length-to-diameter ratios. While Zhang Zhaode[7] and Sun Renfu[3] calculated impact force on workover string by principle of mechanical energy conservation. And principle of momentum conservation was also used by Skeem[1] and Zhang[2].

Testing string has clear structure and packer position, its dynamic behaviors when jarring stuck packer should be similar to drillstring. But only about 30% stuck packers can be freed by jarring directly. Comparing with drillstring and workover string, testing string dynamics in jarring process is more suitable to be analyzed with wave propagation theory[6,8]. Basing on actual dimensions and working conditions of offshore testing string, jarring effects are investigated in this paper. The impact speed, impact time, and maximum dynamic force and impulse delivered to the packer are calculated and compared in detail. The results could be used for optimizing testing string structure.

Theoretical Discussion on Jarring Process

Characteristics of Testing String

A real testing string has many tools and most of them are distributed in a short section above the jar. These tools and their crossovers would change pipe stiffness obviously. Even so, within this discussion the string can be idealized as four parts from bottom to top:
**Packer**  Locked with casing tightly for withstanding large differential pressure and axial load of pipe. In some instances, it cannot be unpacked by normal method, so the jar will be activated to free it by jarring, and this is the destination of this study.

**Jar**  Installed just above the packer. Its only function is to free the packer in need. Its anvil can be regarded as rigid connection with the packer, and this is the most obvious difference from other models.

**Collar string**  Important pipe section connecting jar and drillpipe. It contains many functional tools in response to technological procedures. Normally, its total length ranges from 100m to 150m. During jarring the collar is supposed to convey waves and increase impact speed.

**Drillpipe**  Making up the great portion of testing string in length. It is usually over one order of magnitude longer than collar and in the mean time, its cross sectional area of wall is less than collar. So in jarring process, stress wave propagation and reflection in drillpipe is not discussed, whereas the reflection at pipe-collar interface is considered.

Figure 1 illustrates the highly simplified jarring configuration.

![Figure 1. Configuration of testing string.](image-url)

### Jarring Process and String Dynamics

Foundation of stress wave in elastic long rod is used to discuss testing string jarring dynamics. The whole jarring process is assumed to be perfect and dispersionless. Main dynamic behaviors in the process are as follows.

**Storing Strain Energy by Tensioning String.** Applying hook load until a specific tensile force is produced at the jar. This force equals to the top force minus pipe weight from jar to ground, is the triggering force of the jar and is called overpull. The overpull produces tensile strain energy in the string. Part of the energy will convert kinetic energy after triggering. Considering the time-lag effect, the whole string is nearly in a static equilibrium state.

**Hammer Speed at Release Stage.** Based on the theory of stress wave in elastic long rod, compatibility equation between hammer speed and collar strain is \( dv=\pm C\Delta e \). So, the initial hammer speed after jar triggering, at time \( t=0 \), can be written as

\[
v_c = \frac{F_0 C}{A_c E} .
\]

Where \( v_c \) is initial hammer speed triggering, m/s; \( F_0 \) is overpull, kN; \( C \) is stress wave speed in steel, m/s; \( A_c \) is cross sectional area of collar wall, m\(^2\); \( E \) is elastic modulus of steel, kPa.

It can be found that the hammer speed at release is defined by the overpull and collar cross section.

**Speedup Process of Hammer.** After jar triggering, compressive stress wave caused by \( F_0 \) propagates upward along the collar, collar segment where wave passed will have the unique speed \( v_c \).

Due to the cross-sectional discontinuity at the interface of drillpipe and collar, at time \( t=L/C \) (where \( L \) is the length of collar), this compressive relief signal is partially reflected as a tensile signal back toward the jar. The reflection coefficient is

\[
\lambda = (\alpha - 1)/(\alpha + 1).
\]
Where $\alpha = A_c/A_p$, dimensionless; $A_p$ is cross sectional area of drillpipe wall, m$^2$.

The speed of the collars passed over by the reflected signal becomes $v = v_c (1+\lambda)$.

At time $t = 2L/C$, the reflected relief signal arrives at the hammer end of the collars, and then the hammer speed will be $v_c (1+2\lambda)$ and the wave becomes tensile.

The above cyclic process will repeat before the hammer impacting the anvil takes place. In the $N^{th}$ cycle, $2(N-1)L/C < t < 2NL/C$, the hammer speed is

$$v_N = v_c \left(1 + 2\sum_{n=1}^{N-1} \lambda^n \right).$$

**Impact Force.** At some time $t = t_I$, the hammer impacts with the anvil, a tensile wave travels upward collars, and the speed of collars passed over by the wave becomes zero.

According to impacting theory, impact force between hammer and anvil is

$$F_I = \frac{A \cdot E}{C} \cdot v_N = \frac{v_N}{v_c} F_0.$$  \hspace{1cm} (4)

The tensile wave by $F_I$ propagates just like that by $F_0$.

**Maximum Unstuck Force.** There will be a moment in which both signals by $F_I$ and $F_0$ are tensile and overlap together to form the maximum unstuck force at packer

$$F_{Max} = F_I + 2\lambda^{N+1} F_0.$$  \hspace{1cm} (5)

**Impulse to Packer.** The maximum unstuck force usually lasts a very short time and cannot be used as a credible parameter for evaluating the jarring effect. And as a remedy, impulse delivered to packer during jarring is introduced as

$$I(F,T) = \int_{t_I}^{t_I+2L/C} F(t) \, dt.$$  \hspace{1cm} (6)

Where $I$ is the impulse, as the function of unstuck force and time interval. The integration limit is from $t_I$ to $t_I+2L/C$.

Theoretical method above is accepted by most researchers in study jarring effect when unstuck strings during drilling or workover operation. Up to now, there is no report on jarring stuck packer during well testing. So, based on actual dimensions and working conditions of offshore testing string, jarring effects are investigated in the following part.

**Case Study**

**Basic Parameters**

Stroke length of jar is 101.6mm (4") or 152.4mm (6"). The longitudinal wave speed is $C = 5190\text{m/s}$; elastic modulus is $E = 2.1\times10^8\text{kPa}$. Parameters of drillpipe and collar are listed in Table 1.

<table>
<thead>
<tr>
<th>Pipe Style</th>
<th>Outside Diameter (mm)</th>
<th>Wall Thickness (mm)</th>
<th>Weight per Unit Length (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1/2” drillpipe</td>
<td>88.9</td>
<td>9.35</td>
<td>0.194</td>
</tr>
<tr>
<td>4-3/4” collar</td>
<td>120.7</td>
<td>34.95</td>
<td>0.683</td>
</tr>
</tbody>
</table>

Three assemblies are considered:

- 1#: Jar x 4” stroke length + 4-3/4” collar×100m+3-1/2” drillpipe×3000m
- 2#: Jar x 4” stroke length + 4-3/4” collar×150m+3-1/2” drillpipe×2950m
- 3#: Jar x 6” stroke length + 4-3/4” collar×150m+3-1/2” drillpipe×2950m

The first assembly (1#) is an actual string and the other two are for discussion. The results of computations for a variety of configurations are obtained as follows.
Impact Moment

First of all, the wave cycles from $F_0$ are given in Figure 2. The vertical ordinate is wave cycles and wave direction when the hammer knocked the anvil. For example, a cycle point in $[i-1, i-0.5]$ indicates that triggering wave is in its $i$'th cycles and travelling upward, a cycle point in $[i-0.5, i-1]$ means the wave is in its $i$'th cycles and travelling downward. The horizontal ordinate is overpull ($F_0$).

From Figure 2 the following conclusion can be drawn:
- Assembly 1# has great similarities with Assembly 3#, both the cycles and wave directions. This indicates that the impact moment is influenced by collar length and jar stroke length.
- Assembly 2# has less wave cycles when impact, which means impact speed may be lower.
- With the increase of overpull, $F_0$, wave cycles decrease.

Due to the wave speed $C$ is constant, data in Figure 2 approximately represent the interval from triggering to impact.

Impact Speed

The speeds of hammer at impact moments are drawn in Figure 3.

The following conclusions can be obtained from the data:
- Collar length, jar stroke length and overpull impose a complex influence on impact speed.
- With the increase of overpull, $F_0$, impact speed doesn’t always increase.
- Assembly 3# has a longer stroke length, but the impact speed doesn’t has obviously predominance.
- Both wave cycles and wave direction have great influence on impact speed.

Maximum Unstuck Force

The maximum unstuck forces calculated under idealized conditions are drawn in Figure 4. The following conclusions can be obtained from the data:
- Increasing collar length and jar stroke length have less effect on promoting maximum unstuck force.
- The so-called amplification coefficient of maximum dynamic force to jar triggering force is not a representative factor to evaluate jarring effect.

Impulse to Packer

Take the total impulse in $t_I+2L/C$ as a parameter, the relationship between impulse and overpull is shown in Figure 5. The following conclusions can be obtained from the data:
- The impulse has much clear trend line than other parameters.
- By increasing collar length, the impulse can be increased obviously.
- Prolong stroke length has little influence on impulse.
**Conclusions**

Trigger force is the most important factor for promoting testing string jarring effect. A higher trigger force can increase maximum unstuck force and impulse to packer.

Collar length has little influence on maximum unstuck force, but by increasing collar length the impulse to packer can be increased obviously.

Stroke length has little influence on maximum unstuck force and impulse to packer.

Current testing string structure has great rationality. It is not recommended to use fewer collars for obtain larger unstuck force.

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**References**


