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Overview of Free Point – Stuck Point Determination Methods and Back-Off/Pipe Severing Methods

Calvin Kessler, Jim Hill, and Mauro Arrambide – Halliburton Wireline & Perforating

Abstract

This paper reviews the commercially available methods used to determine free point and stuck point locations in support of land-based and offshore drilling and well abandonment operations. The technologies used to determine the free point location include acoustic, strain-stretch, strain-torque, and the newly introduced magnetostrictive methods. This paper discusses the advantages and limitations of each method in gravity deployment or pumpdown operations for vertical, deviated, and horizontal wells. It also discusses methods for back-off and severing operations of tubing, drillpipe, drill collars, and casing that is manufactured with traditional carbon steel and other alloys. Both explosive and non-explosive pipe cutting and severing methods are presented, as well as the pressure and temperature limitations of each method. It also describes the new non-explosive methods used to create circulation holes in tubing, drillpipe, and casing. Data from case histories, lessons learned, laboratory and test well experiments, and well site safety procedures were used in the development of this paper.

Introduction

Free point determination and pipe recovery operations in the drilling environment can have different objectives and priorities from those in well abandonment operations. In well abandonment operations, the general objective is the maximum recovery of tubing and casing with minimal fishing and with compliance with all regulatory requirements. Locating the 100% free pipe depth for tubing or casing is generally the objective of the free point operation. Subsequent e-line back-off or pipe severing operations are usually performed above the 100% free point location. Pipe recovery in concentric casing string completions is a common industry practice.

In the drilling environment, the locations of both the 100% stuck point and the 100% free point is important information, especially when the drillstring includes expensive LWD formation evaluation tools.

Traditionally, the free point determination begins with manual calculations of the pipe stretch, or elongation, when a force is applied to the stuck drilling string with the rig's draw works. The calculations involve the elastic properties of the drillstring, and its weight and buoyancy effects. From these calculations of approximate depth to the stuck point, electric logging tools that respond to the application of strain or torque in the drillstring are used to determine the precise location of the stuck point. Traditional free point measurements to determine the stuck point require a series of stationary measurements with the pipe in a neutral weight condition, and then with the application of stretch or torque. The logging tool is repositioned many times in the drillstring until the sensors detect no pipe movement (torque or stretch) of the applied force on the drillstring, thus determining the stuck point. These stationary measurements require a great deal of rig time. They can also create possible HSE events because the strain gauge technology requires the pipe to be pulled/stretched or torqued above the neutral weight condition at each stationary depth measurement point.

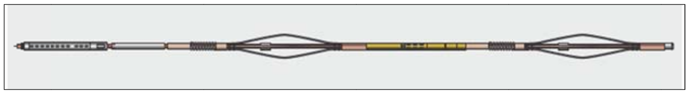

Fig. 1. Legacy Free Point Tool, a strain gauge is placed between two springs. The springs hold tension against the pipe interior. The strain gauge measures the changes that occur as stretch or torque is applied to the pipe. Magnets or 'dogs' are used in place of springs for some tools**.**

A new logging tool, available in the wireline service sector, has been globally deployed that cost-effectively identifies a free point.[1, 2, 3] The tool uses the property of steel called the magnetostrictive effect. When stress is applied to steel, the magnetization of the steel is modified. The procedure using the new tool requires two logging passes. The first logging pass records pipe magnetization information with the pipe in a neutral weight condition. The second logging pass records magnetization information with tension or torque applied to the pipe and then released. When torque or tension is applied to pipe that can be stretched or torqued, its magnetostrictive properties change. If a section of the pipe cannot be stretched or torqued, magnetization effects remain unchanged. On this basis, the free point, namely at the transition from pipe that can be stretched or torqued to pipe that cannot, is easily detected by comparing two logging passes.

The Halliburton Free Point Tool (HFPT) simply involves an overlay of two logging passes before and after the pipe has been stretched or torqued. With this new technology the basic procedures are one down logging pass with the pipe in a neutral weight condition. The rig applies and releases pipe stretch, returning the pipe to the neutral weight condition. And a second (up-logging pass) with the pipe in the neutral weight condition is generally all that is needed to provide a well log recording of the free pipe and stuck pipe depths. For back-off operations the free point tools need to be able to detect the application of torque applied to the drill string. A single down pass with the pipe in neutral weight and an up-logging pass following the application and release of the appropriate torque provides a continuous log recording of the torque effects on the drillstring. This is needed for successful back-off operations.

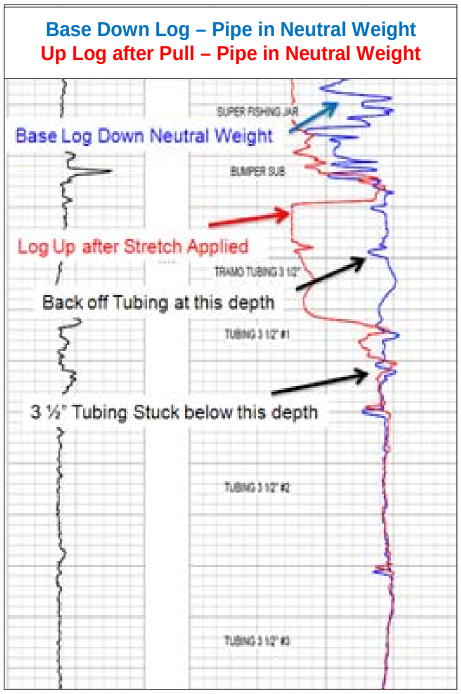

Fig. 2. Example of a HFPT Log

From a HSE standpoint, stretch, or torque are applied to the pipe one time and only for a few minutes..

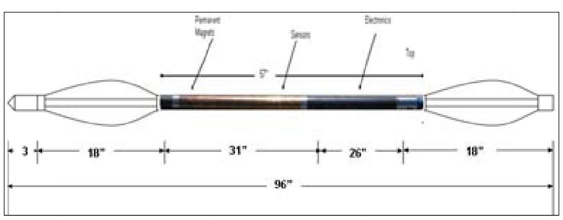

Fig. 3. HFPT with the addition of a rigid stinger and swab cups, the tool can be pumped down deviated and horizontal wells.

Acoustic cement evaluation tools can be used in certain conditions to help determine the free point and stuck point locations. In well abandonment conditions and casing recovery operations, cement evaluation services, such as rotating ultrasonic tools or radial cement bond logs, are commonly used to identify top of cement. In some applications, they can possibly identify hydrated mud or formation sloughing in the casing-formation annulus.

To support drilling operations, radial cement bond tools or rotating ultrasonic tools cement evaluation tools can also be used to identify stuck drillpipe and free drillpipe locations, and can identify multiple stuck points. The emphasis of the interpretation is the attenuation or reduction in amplitude of the pipe signal. In traditional bond logging operations, the casing is usually centralized, and the cement slurry is uniformly placed in the casing-formation annulus; when set, the cement slurry highly attenuates the acoustic signal. In the drilling environment, the drillstring is not centralized, and the drillpipe or drill collars may be in contact with the formation on the low side of the wellbore in multiple intervals. Differential sticking, key seating, or borehole stability issues will attenuate or reduce the amplitude of the acoustic pipe signal. The pipe signal will be reduced in these stuck pipe conditions, but not to the magnitude of attenuation or reduction in pipe signal encountered in well-bonded cemented pipe.

Pumpdown Operations

In highly deviated and horizontal well conditions, normal gravity deployment of free point determination logging tools may not enable the free point determination tools to reach the stuck point in the well. If the well can be circulated through the drillstring, then pumpdown operations of the free point tools can be used. Pumpdown operations are more economical than e-coil or tractor conveyance methods.

Basic pumpdown operations involve adding a stinger and swab cups above the free point tool and a side entry sub for e-line pack-off. A mud pump stroke rate to obtain a fluid velocity of generally 30 to 60 ft/min is used to initiate tool movement. Tool movement is monitored with the collar locator, and the pump stroke rate is adjusted as needed. Additional centralizers or rollers may be added to the logging tools to reduce tool-to-pipe friction. If the drillstring is plugged and normal circulation cannot be established, tractor or e-coil conveyance of the free point tools is required.

The Importance of Torque

The stuck point can be determined from either pipe stretch or pipe torque measurements. For successful back-off, surface-applied pipe torque must be detected at the proposed back-off point. If the torque cannot be detected, it is unlikely that the back-off operations will be successful.

Back-off Operations

A string shot is an explosive device used to create a depth-specific shock wave to assist in unthreading the downhole tubulars. A string shot rod with a predetermined length of detonating cord attached is run in the well to the planned back-off depth, as measured by the free point tool. The size and weight of the stuck pipe, as well as depth, temperature, and well deviation, and years of experience are used to determine the optimal amount of detonating cord.

In preparation for the back-off, the pipe has right hand torque applied and released until the string connections are tight. The string shot rod is then run to depth. Left hand torque is applied, the string shot is fired, and the pipe joint at that depth is loosened. This enables retrieval of pipe from this depth to be recovered.

Because the string shot is an explosive device, well site explosive safety issues must be discussed and understood by everyone at wellsite. The RF Safe RED® detonator can be adapted for use with a string shot to enhance the safety of the explosives operation. The RED detonator eliminates the need for radio silence operations.

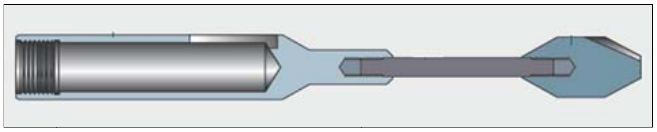

Fig. 4. String shot rod.

Establishing Circulation

Many of the pipe severing methods require drilling fluid circulation. If the bottomhole assembly is plugged off and circulation cannot be established, then the stuck pipe may need to be perforated to establish circulation. There are traditional explosive perforating methods and non-explosive methods to create circulation holes in the downhole tubulars. The smallest of the explosive perforating charges are tubing punchers, which will create a jet perforation in tubing. Tubing punch charges are designed for very shallow penetration to avoid damage to the second pipe string.

When perforating drillpipe, traditional small diameter through-tubing hollow steel carrier perforating guns can be used. For perforating drill collars, premium through-tubing capsule perforating gun systems are recommended. In deviated well conditions, zero degree charge-to-charge phasing (vertical charge alignment) and magnetic decentralizes to oriented the perforations to the low side of the well are recommended. This will enable circulation and spotting of surfactants at the pipe-formation interface to aid in minimizing differential sticking.

Non-Explosive Perforating Methods

In larger tubing sizes (4 in. +/-) or light weight low strength casing (J-55/K55) conditions the downhole power unit (DPU) electro-mechanical operated tubing/casing punchers can be used to create circulation holes.[4]

Fig. 5. DPU-Perforator in 4 ½ in. liner**.**

The radial cutting torch technology has been modified with a focused plasma nozzle to create the perforating torch system. The perforating torch is available in sizes from 1 ½ in. coiled tubing through 5 ½ in. casing.

Fig. 6. Example of a non-explosive perforating torch system**,** from MCR Oil Tools**.**

Chemical cutters have also had similar modifications of their nozzles to create a non-explosive perforation or slot.

Pipe Severing – Jet Cutters

Jet cutters are essentially a radial shaped charge specifically designed to cut a specific size and weight of pipe from 1 in. coiled tubing to 9 5/8 in. casing, and 3 ½ in. to 5 in. drillpipe. The jet cutters can be used in both carbon steel and high strength alloys. Circulation capabilities are not required for jet cutters, and they can be used in any borehole fluid (air/gas, water, mud, and completion fluids). Tubing cutters, coiled tubing cutters, and casing and drillpipe cutters are available for high temperature and high pressure operations.

The advantages of explosive cutters include the following:

- Sizes are available to fit most applications
- Available to all e-line pipe recovery contractors
- Inexpensive as compared to other methods
- Does not require fluid in the well
- High pressure and temperature capable
- RF Safe RED initiator compatible

The disadvantages of explosive cutters include the following:

- Restrictions in the pipe above the desired cut depth may not allow use
- May not provide a complete cut
- Will flare the pipe at the cut depth
- Explosives access and transportation may be difficult, depending on the local governmental regulations

Fig. 7. A jet cut showing the flaring of the pipe**.**

Table 1. Jet Coiled Tubing Cutter Specifications

Coiled Tubing Cutters		
Coiled Tubing OD (in.)	Pressure Rating (psi)	Temperature Rating (°F)
1.00	10,000	325
1.25	10,000	325
1.50	10,000	325
1.75-1.90	15,000	400

Table 2. Jet Tubing Cutter Specifications

Tubing Cutters		
Tubing OD (in.)	Pressure Rating (psi)	Temperature Rating (°F)
2 3/8	20,000 psi	400
2 7/8	20,000 psi	400
3 ½	20,000 psi	400

Table 3. Jet Casing and Drillpipe Cutter Specifications

Casing and Drillpipe Cutters		
OD (in.)	Pressure Rating (psi)	Temperature Rating (°F)
3 ½ drillpipe	12,500	400
4 ½ drillpipe	12,000	400
5 drillpipe	12,000	400
4 ½ casing	7,500	400
5 casing	9,000	400
5 ½ casing	9,000	400
5 3/4 casing	9,000	400
6 casing	9,000	400
6 5/8 casing	9,000	400
7 casing	9,000	400
7 5/8 casing	9,000	400
8 5/8 casing	8,000	400
9 5/8 casing	8,000	400

Pipe Severing – Radial Cutting Torch

The latest cutting technology is the MCR Oil Tools Radial Cutting Torch™ (RCT) tool. The RCT tool uses a thermite material which, when ignited, creates a super-heated plasma that exits the tool through a radial ceramic sliding port and cuts the pipe. There is no flare or swelling of the pipe. The thermite material is classified as a flammable solid, and because no explosives are used, transportation is not an issue.

A pressure path above and below the cut depth are required. The RCT tool can be used in any borehole fluid including dry pipe. The patented cutter does not use dangerous chemicals and does not require radio silence operations. This highly versatile pipe recovery tool is available in a wide range of sizes to enable cutting of coiled tubing, production tubing, casing, and drillpipe. The cut has no swelling or flaring, thus enabling easy pipe retrieval and subsequent overshot or spear fishing operations.

The advantages of the RCT tool include the following:

- Clean cut; no flaring
- Sizes to fit most applications
- Can cut stainless steel, Hastalloy, and chrome pipe
- Possesses medium pressure and temperature capabilities
- Better ability to pass restrictions and cut larger pipe than explosive cutters
- Does not require fluid in the well
- RF Safe initiator compatible or the non-explosive MCR Thermal Generator
- Non-explosive; eases storage, transportation, and other regulatory issues

The disadvantages of the RCT tool include the following:

- Requires the ability to circulate fluid at cut depth. A run with a tubing punch perforator may be required before the RCT tool is run.
- Expensive as compared to other methods
- Licensed technology; not available to all e-line pipe recovery contractors

Table 4. Radial Cutting Torch Specifications

Radial Cutting Torch Specifications			
RCT OD (in.)	Applications (in.)	Temperature (°F)	Pressure (psi)
¾	Coiled tubing to 1 ½	500	15,000
7/8	Coiled tubing to 1 ¾	500	15,000
1	1 ½ to 1 ¾ tubing	500	15,000
1 3/8	2 and 2 3/8 tubing	500	15,000
1 ½	2 3/8 tubing	500	15,000
1 11/16	2 7/8 tubing	500	15,000
2	3 ½ tubing	500	15,000
2 ½	3 ½ tubing – heavy weight	500	15,000
2 15/16	4 tubing 4 and 5 ½ drillpipe	500	15,000
3 3/8	5 and 5 ½ casing	500	15,000
4	5 ½ casing	500	15,000
5	6 5/8 to 7 5/8 casing	500	15,000

Fig. 8. Example of a Radial Cutting Torch Cut, from MCR Oil Tools**.**

Pipe Severing – Chemical Cutters

Chemical cutters use a bromine trifluoride chemical mixture that is expelled from the tool under pressure though a series of radial nozzles and can dissolve carbon steel. Chemical cutters operate in low pressure, low temperature environments, and are available in sizes ranging from coiled tubing through 8 5/8 in. casing. A static liquid-filled borehole is required, and they will not work in dry pipe conditions.

Bromine trifluoride is a hazardous chemical mixture; if exposed to organic materials, it reacts violently. A trained specialist is required for wellsite operations. Special precautions must be taken to prevent accidental exposure to the chemicals and fumes. In some instances, chemical cutters cannot be transported with explosive materials.

The advantages of a chemical cutter include the following:

- Clean cut with no flaring of pipe
- Sizes available to fit most applications
- Long history of successful use
- RF Safe initiator compatible

The disadvantages of a chemical cutter include the following:

- Must have a stable fluid column at the cut depth
- Low pressure ratings
- Chemical is hazardous
- Disposal of any miss run chemical materials
- Requires trained specialist to assemble and run
- Will not work in plastic coated pipe and high chrome content pipe
- Poor performance in zinc bromide completion fluids

Table 5 Chemical Cutter Specifications

Size	Pressure	Temperature
11/16” to 15/16” OD	5,000 PSI	275 DegF
1” to 1 1/4” OD	6,000 PSI	300 DegF
1 3/8” to 1 9/16” OD	7,500 PSI	300 DegF
1 11/16” to 7 ½” OD	10,000 PSI	300 Deg F

Fig. 9. Dyed water used to illustrate the radial pattern of the expelled fluid through the nozzles of a chemical cutter.

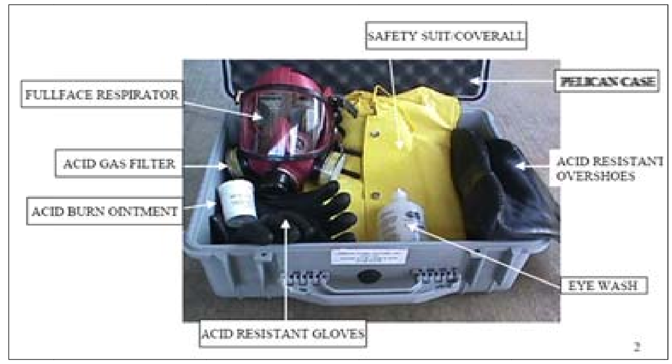

Fig. 10. Special personal protection equipment is required for chemical cutter operations.

Fig. 11. A chemical cut of 5 ½-in. casing.

Pipe Severing – Drill Collar Severing Tool

Drill Collar Severing Tools (DSCT) are used for severing drillpipe, heavyweight drillpipe, and drill collars with more explosive power than normal drillpipe cutters. The DCST uses a unique dual-end firing system (detonation achieved by firing from two directions, top and bottom) that simultaneously initiates both ends of the explosive column. The detonation wave fronts collide at a centrally located cartridge, which shapes the high energy into effective severing action.

DCSTs are high energy devices intended as the last resort for pipe recovery. The drill collar severing tools are to be used to sever pipe or collars in open hole. High temperature and high pressure DCSTs are available.

The advantages of DCST include the following:

- Sizes to fit most applications
- High pressure and temperature rated
- Does not require fluid in the well
- RF Safe initiator compatible

The disadvantages of DCST include the following:

- Requires trained specialist to assemble and run
- Cut is very destructive; recovery of downhole cut unlikely

Fig. 12. Drill collar 2 in. severing tool cut of 5 in. spiral heavy weight drillpipe.

Table 6 Drill Collar Severing Tool Specifications

Drill Collar Severing Tool Specifications					
Tool OD (in.)	**1 3/8**	**1 3/4**	**2**	**2 5/8**	**2 1/8**
Temperature Rating	HMX - 400°F (204°C)				
	HNS - 460°F (238°C)				
Pressure Rating (psi)	20,000 for 1 hour				26,000 for 1 hour
Length (in.)	36	36	36	36	37.8
Explosive Weight (g)	589.2	842	1488	2520.4	1487.8
Designed to Sever up to (OD in.)	3 1/2 DC	6 1/2 DC	8 DC	11 DC	8 DC

Pipe Severing – Split Shot Severing Tool

The Owen Oil Tools Split Shot® tool is a linear jet explosive designed to perforate a longitudinal slot across the tubing or casing collar. The slot will relieve thread stress enabling retrieval of the pipe. The Split Shot cutter can be run in heavy mud, paraffin, collapsed tubing, or restrictions.

The advantages of the Split Shot severing tool include the following:

- Small OD enables passing through restriction
- No flaring of the pipe
- Does not require fluid at the shot depth
- High temperature rated split shot available
- RF Safe initiator compatible

The disadvantages of the Split Shot tool include the following:

- Low pressure rating
- Magnetic decentralization required
- Does not work well in chrome or similar pipe

Fig. 13. Split Shot tool in 3 ½ in. tubing, from Owen Oil Tools LP a subsidiary of Core Laboratories.

Table 7. Split Shot Specifications

Split Shot Specifications			
Size OD (in).	**Pressure Rating (psi)**	**Application**	
		Min OD (in.)	**Max OD (in.)**
0.875	9,500	1.315	2.375
1.00	10,000	1.315	2.375
1.375	18,000	1.66	2.87
1.375	18,000	2.375	4.50
2.00	18,000	2,875	7.00
2.00	18,000	3.50	16.00

Summary

Pipe recovery is a service that covers all phases in the life of a well, including the following:

- Drill support operations
- Tubing strings and packers during intervention
- Tubing and casing during abandonment

The basics of pipe recovery include determining where the string is stuck and providing a recovery solution.

Operations segments include the following:

- Free Point tools, such as
  - Mechanical
  - Acoustic
  - Magnetostrictive
- Back-off tools, including
  - Explosive
  - String shot
- Cutters, including:
  - Explosive
  - Chemical
  - Plasma

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About the Authors

Calvin Kessler is responsible for commercialization and technical marketing of Cased Hole E-line mechanical services. He has been employed with Halliburton since 1973. Calvin holds a Bachelor of Science degree in petroleum engineering and a Masters degree in mining engineering. He is a member of SPE, API, AADE, and SPWLA.

Jim Hill is the Cased Hole E-Line Product Manager for Halliburton Wireline and Perforating. Jim has more than 30 years of experience in both domestic and international wireline operations, and management. Jim joined Halliburton through an acquisition in 1988. He is a member of SPE and AADE.

Mauro Arrambide is the Pipe Recovery Manager for North America Land Operations with Halliburton Wireline and Perforating. Mauro has more than 30 years of pipe recovery operations and management experience. He is a member of AADE.