University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore technology/ Asset management	Spring semester, 2012 Open
Writer: Anders Grønnerød	…………………………………………… (Writer's signature)
Faculty supervisor: Tore Markeset, UIS External supervisor(s): Lasse Haugland, AWS	
Titel of thesis: Downhole cutting tool design concept for use with the AWS «Driller»	
Credits (ECTS): 30	
Key words: Cutting tool Condition monitoring AWS	Pages: 57 + enclosure: 3 Stavanger, 14.06.2012 Date/year

AkerSolutions™

University of Stavanger

Downhole cutting tool design concept for use with the AWS "Driller"

Anders Grønnerød

Master thesis Offshore Technology Industrial Asset Management in collaboration with Aker Well Service and UIS.

Abstract

Production tubing cutting operations is getting more and more common in the North Sea; this is a product of an increasing number of Plug and Abandonment operations and re-completions of old wells. The most common method of cutting production tubing has for a long time been explosive cutters. These cutters are relatively simple in use, cheap to produce and quite reliable. However, explosive cutters are as the name implies containing explosives. Explosive handling offshore should be kept to a minimum since the consequence of an explosion during handling of these types of cutters would most likely be fatal. Together with the other disadvantages of explosive cutters a non-explosive cutter should always be considered for the job.

The goal with this thesis was to design a non-explosive cutting tool that could be powered by an already existing Electro-Mechanical AWS tool. A part of this task it has been to present some of the already existing cutting tools on the market.

Further basic well design is described to give a better understanding of why downhole cutting tools are needed. Different completion parts are described together with some examples of why the production tubing needs to be cut and removed.

An interview with 3 different oil companies has also been conducted. This interview indicates that these three operator companies are positive with running Electro-Mechanical cutting tools in the future.

There is also a chapter in this thesis where it is discussed how condition monitoring can be implemented in the between-job maintenance of the cutting concept. These techniques could be used by any other tool suitable for condition monitoring.

It is in this thesis concluded that this design concept can be a developed into a functioning cutting tool, if an appropriate centralization mechanism is developed. It does also conclude that condition monitoring should be implemented in the between run maintenance of downhole tools suitable for condition monitoring.

Acknowledgements

This thesis is the finishing task of my master's degree in offshore technology on UIS. The thesis is written for Aker Well Service, a part of Aker Solutions which delivers well intervention services, a company which I have been working for since January 2011.

The need for downhole cutting in the North Sea and in the rest of the world will continue to grow. There are thousands of wells that are going to be abandoned, and in most cases one or more cuts have to be made to pull different components from the well to surface. A growing market for cutting tools will probably lead to increased competition to deliver the safest, precise and most reliable cutting tool on the market.

I want to thank my UIS instructor Tore Markeset for constructive feedback during this semester. Lasse Haugland and Espen Osaland at AWS for providing me with relevant information about the Driller tool

I also want to thank my friend Simon Bruset for helping me with the problems I ran into when drawing the tool concept. Special thanks also go to my colleague and friend Hugo Taskila for reading my thesis and asking critical questions.

Table of content

1. Introduction

1.1. Background

Well intervention services are more and more common in the North Sea. The increasing complexity of the oil wells is one of the reasons. Water, gas and chemical injection in the reservoir is the other reason. However, an oil well can't produce forever, and instead of abandoning these fields several years ago, the oil companies are now facing a P&A (plug and abandonment) boom. Providers of plug and cutting services can during the next years increase their workload drastic.

Many of Statoil's fields on the Norwegian continental shelf (NCS) are reaching the end of production. More than 1000 wells need to be abandoned due to field decommissioning over the next 5 to 25 years. Of these, almost half are subsea wells. (Statoil.com, 2012)

Thousand wells to abandon with conventional abandoning methods means approximately 2000 production tubing cuts within the next 5-25 years (2 cuts per well, one above the PBR, and one to collapse the production packer). This is only on Statoil platforms on the Norwegian continental shelf.

The market for effective cutting tools is definitely increasing. Many of the oil fields in the North Sea have been producing for over 20 years, and some for more than 30 years. Some wells has gone dry, and shall either be sidetracked or plugged permanently, some of them are still good producers which "only" needs a re-completion. Some wells are producing oil, but don't have enough pressure to get the oil to surface and needs to be re-completed with gas lift mandrels and some of them with downhole pumps. There could be relatively new wells which have problems with the downhole safety valve that cannot be fixed from the surface.

What these different cases have in common is that the production tubing needs to be pulled, and there might be a great possibility that it is necessary to make one or more cuts to accomplish this task.

1.2. Introduction

Aker Well Service or AWS is a part of Aker Solutions. AWS offers well intervention services both offshore and onshore. In Norway all the Oil and Gas is produced offshore, so in Norway all the operators are working offshore on different rigs in the North Sea. Aker Well Service also have offices in USA, Canada, Denmark and Azerbaijan.

Aker Well Services major business area is wireline services, both Slick lining and E-line operations. This includes; changing Safety valves, pulling and setting gas lift valves and fishing operations. Cased hole logging and Tractor services is also offered by Aker Well Service. These operations are performed with a braided wire with one or more inner conductors. Different tools are attached to the bottom of the cable and the wire is deployed into the well. In a well with a horizontal section a wireline tractor is used to get to target depth. A wireline tractor can be described as a surface controlled electro- hydraulic/mechanical device on top of the tool string, pushing the tool string and pulling the wire/cable into the horizontal section of the well.

One of the operation Aker Well Service offer are cutting of production tubing. Production tubing is cut for two reasons; Plug and Abandonment (P&A) or re-completion. A (P&A) is preformed when a well is no longer profitable, or there is so much trouble with the existing well that the cost of fixing this would be higher than drilling a new well. With a re-completion on the other hand, it is cheaper fix the existing well than to drill a new one. There is also other factors that could influence if a well is re-completed or not, but this is not relevant for this thesis.

There are several tools available for cutting production tubing. Some of them are described in the chapter "Cutoff methods." Aker well service is currently developing a new high power down-hole tool designed for milling steel plugs. This tool is called "Driller". In theory this tool should be able to deliver sufficient force to power a cutting tool.

1.3. Problem description

Develop a cutting tool concept for use with the AWS driller that is better than the other cutting tools on the market with respect to reliability, maintainability and "user-friendliness"

The sub objectives are:

1. *Establish an overview over market standard (what is already on the market)*
2. *Find the need for this type of cutting tools in today's market*
3. *Define design criteria for a functional product*
4. *Develop a cutting tool concept.*
5. *Decide how condition monitoring techniques can be used in the process of servicing the cutting tool (and other tools) is the future*

1.4. Limitations

Since there is a relatively short time aspect with this thesis to develop a cutter, my focus has been on developing a cutting concept that could be taken further by the research and development department within the company. The calculations are reduced to a minimum since my master degree is not in mechanical constructions. I have spent more time focusing on different methods of implementing condition monitoring methods into between job testing of a cutter.

1.5. Buildup of thesis

This thesis is built up by an introduction of existing tubing cutting practices. I have chosen not to go deeply into the practices of cutting tubing with drill pipe and coiled tubing since this is a totally different area than tubing cuts done by a wireline deployed tool.

A chapter is dedicated to basic well completion. This chapter is for ease the understanding of the next chapter which explains why production tubing is cut.

An interview of well intervention engineers in 3 different operator companies in the North Sea was held and is summed up briefly with the author's comments. This is for evaluating the operator companies' view of choosing electro-mechanical cutting tools over cutters that contains hazardous materials.

The next chapter is dedicated to the design of the cutting concept. In this chapter the Drillers function is described. Some of the most critical calculation is presented and the cutting concept is described by text and figures.

In the next chapter 3 basic condition monitoring techniques for use in between run maintenance of the driller is presented. How these 3 methods can be implemented is described. This chapter also describes the basics about condition monitoring.

At last there is a discussion and concluding remarks.

2. Existing methods of cutting tubing

There are several methods to cut tubing down hole. A tubing cutter can be deployed on pipe, coiled tubing or wireline. In this thesis the focus will be on cutting mechanisms that can be ran on wireline, but the other methods at summed up very briefly in the next chapter.

- Explosive cutters
- Chemical cutters
- RCT
- Split shot
- Electro mechanical cutters

These wireline deployed cutting methods are explained in the following chapters, the meaning of these chapters is to get a better overview over which methods that's available before the design concept for the new cutter is explained.

2.1. Drill pipe cutters and coiled tubing cutters

Mechanical cutters: A mechanical cutter cuts the tubing by simply rotating the drill pipe and the cutting blades is forced out and into the tubing wall, the push force against the wall is determined by the pump pressure. Carbide covered cutters tears through the tubing wall after X revolutions.

Hydro-mechanical cutters: Same system as with the mechanical cutter but the rotation comes from a pump motor that is placed above the cutter.

Abrasive cutting: Abrasives are pumped down the pipe with a high velocity and cut the tubing wall. Works like an extremely powerful sand blaster.

When cutting production tubing, regular drill pipe can't be used because of its big OD compared to the tubing's relatively small ID, it's therefore necessary to use pipe with a smaller OD, this pipe is called "through tubing pipe or spaghetti pipe.

Hydro mechanical cutters are used on coiled tubing as well as on drill pipe. Abrasive cutters are also in use with coiled tubing.

Wireline deployed cutters

Different cutter types are deployed on an E-line cable, several different types of cutters are available. Some cutters contain explosives, some a chemical mixture.

There are also cutters with a small electrical engine that cuts tubing mechanically available on the market.

2.2. Explosive cutters

Explosive cutters and chemical cutters has for a long time been the preferred, method of cutting stuck cut drillpipe and tubing. *(Schiaci,R et al, 2009)(Fanini O.N et. Al, 2009)* Maybe this is because this type of cutters has been on the market longer than the other cutting alternatives. "Why change a winning team".

The explosive cutters are constructed as a linear shaped charge formed into a circle around the body of the cutting tool. When the cutter is placed on the right depth, either by using a CCL or placed on a NO-GO, the field engineer sets of the cutter, by sending an electrical impulse to a detonator, witch again sets of the charge.

Figure 1 Explosive Cut, G.E King. 2009

There are several problems that arise when using an explosive cutter. After the cut is made, the pipe that is cut, usually "flares up" *(figure 1)*, and if an overshot is used for pulling the tubing, the top of the pipe needs to be dressed before an overshoot can be placed over the fish.

Another problem is that an explosive cutter can damage the pipe outside the pipe that is cut, this is typically in cases when a too great charge is used to cut a certain wall thickness, or the tubing is worn down so the actual tubing wall thickness is less than expected. The ideal size for an explosive cutter is approximately 80 % of the tubing ID, this might be a problem in some wells with partially collapsed tubing and scale buildup. Centralization is also important for an explosive cutter to work optimally; with the cutter lying on low side in a well, you might not be able to cut the tubing. The cut of an explosive cutter will also be affected by the metallurgy of the pipe and coating.

Most of the cuts done by an explosive cutter are not "100% cuts", there is often some metal left that keeps the tubing over and under the cut area together, this material needs to be yielded of when the upper section of the tubing is pulled. Cuts done by an explosive cutter has a higher success rate when the tubing is in tension. Tubing in tension will self-separate after the cut given that the tension pulled is great enough to apply tension all the way down to cutting depth, and the cross section area left of the tubing is small enough that the tension applied is great enough to separate it.

Other problems with an explosive cutter is the risk of handling explosives, this requires skilled personnel and safe working environments. Several precautions must be made when rigging up an explosive cutter. Always connect the detonator to the tool string before you connect the explosives to the detonator this principle is called EBBA (electric before ballistic). This can be challenging on rigs/vessels/locations with limited rig up height. Explosives must be stored in a dedicated place on the rig, and transported to the rig in dedicated containers

2.3. Chemical cutters

Chemical cutters are also a well-tested method for cutting stuck tubing. The chemical cutter working method is that an electrical igniter set of a reaction inside the cutter which creates a pressure build up in the upper part of the tool. The pressure forces a set of anchors out that holds the tool in place during the cutting process, when the anchors reaches the wall and centralizes the tool, another chamber inside the tool opens and a bromine trifluorid mixture is exposed to a mixture of oil and in some tools; steel wool.

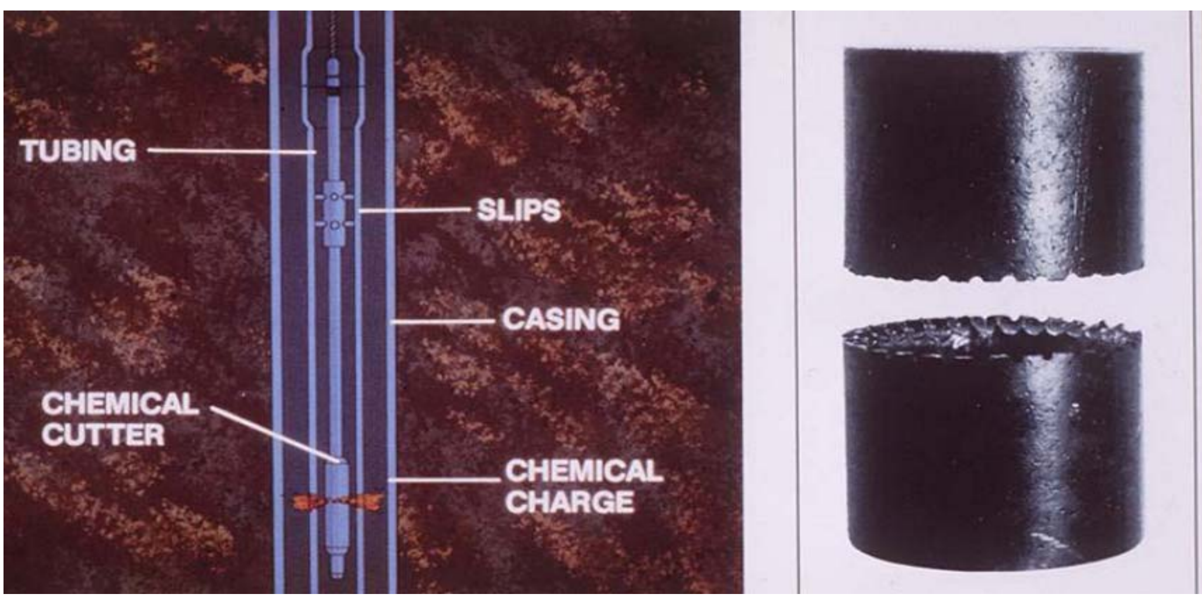

Figure 2 Chemical Cut, G.E King. 2009

When these substances starts to react with each other pressure and temperature will rise, and when this pressure reaches the well pressure the corroding mixture is sprayed out onto the tubing wall and cut the tubing.

The main advantage of running a chemical cutter compared to an explosive cutter is that the chemical cutter don't flare up the tubing, if an overshoot is used for fishing it will not require any dressing.

As with the explosive cutter there are several setbacks of using a chemical cutter. The fluid in the tubing must preferably have a low viscosity. The tubing is preferably cut in tension. Most cuts done by a chemical cutter are not 100% cuts and the tubing must be yielded off by pulling with the rigs top drive. Chemical cutters is also more sensitive to a differential pressure inside and outside the tubing, it is preferred to punch a hole or open a sliding sleeve in the tubing before running in with the chemical cutter.

The chemicals in a chemical cutter are highly reactive. *(Chemistryblog.net, 2012)* It must therefore be transported and stored according to a procedure for dangerous chemicals. The handling and rig up problems is the same as with an explosive cutter.

2.4. Radial cutting torch

The radial cutting torch is another type of cutter which contains material that's not classified as explosives or chemicals. Radial cutting torches is often referred to as a RCT. The energy created from the RCT to cut the tubing/pipe/casing is created from termite pellets which consist of a proprietary mixture of powdered metals. *(mcroiltools.com, 2012)*

The RCT works like this: The operator applies power to an "igniter" that is placed on top of the cutter. This igniter is called thermal generator.

The thermal generator heats the termite pellets until they start a chemical reaction witch turns the termite pellets into a molded plasma with a temperature 6000 deg. Celsius. The heat produced inside the cutter builds up an internal pressure in the torch, when this pressure exceeds the wellbore pressure, a sleeve in the bottom of the tool shifts down and the high energized molded plasma is sprayed onto the tubing wall, this action can be compared to a 6000 deg C. high pressure sand blaster.

Figure 3 RCT Cut, MRC Oiltools. 2011

Since the RCT is not classified as a dangerous chemical or an explosive it can be transported with a passenger aircraft which significantly reduces the mobilization time. The RCT as the explosive and the chemical cutter have a better chance of success if the tubing is in tension when the cut is made.

Even though the RCT is not classified as an explosive or a dangerous chemical you don't need much experience in medical practice to understand that personnel exposed to a 6000 deg. Celsius high pressure sand blaster wouldn't have good odds to survive, therefore the RCT should be handled with the same precaution as explosive cutters.

2.5. Split shot

Split shots are linear shaped charges which are used for splitting joint couplings. The system uses a detonator and the same type of explosives as the explosive cutter. Unlike the other cutters where you want to avoid the couplings, this charge is placed inside a coupling using a CCL to determine depth. This might be a problem since the joint is approximately 30 cm long and the charge can't be made much longer than that, otherwise the fishing operation could be problematic.

Another problem is the use of hook wall threads which are illustrated on the figure below together with a picture of a male and a female coupling after a split shoot.

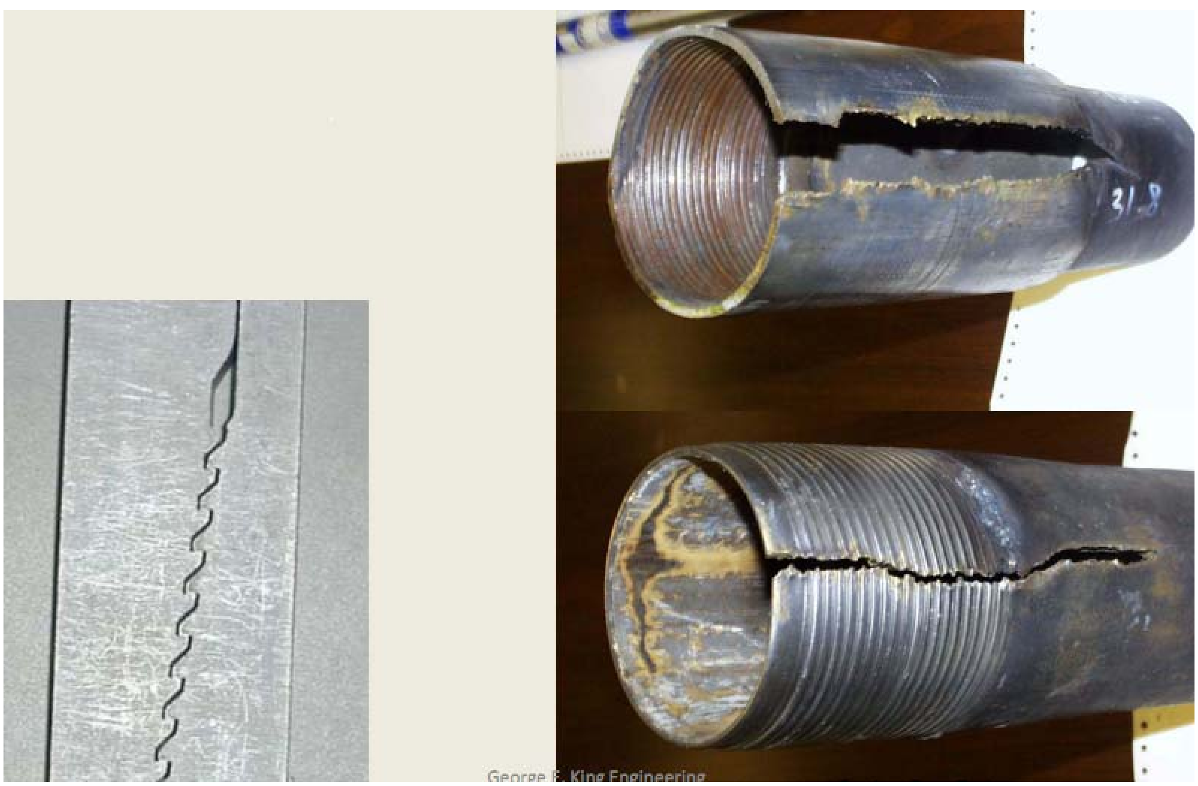

Figure 4 Hook wall threads and split shot, G.E King, 2009

2.6. Electro-mechanical cutters

Electro-mechanical cutters are the newest type of cutters on the market. They are the only type of cutters that don't contain any hazardous materials and no extra safety precautions needs to be taken before running an electro mechanical cutting tool.

The easiest way of explaining electro mechanical cutting tools is to say that this is tools that cuts the tubing mechanically, powered from surface through the E-line cable, there are several electro mechanical cutting tools on the market but only one of them has been a real success for use in the North sea, this is the Sondex DECT. This tool is briefly described below together with two other electro mechanical cutting tools available on the market.

2.6.1. Sondex DECT

Sondex is a GE owned company which develops and produces downhole logging equipment for the oil industry. One of their developments is the DECT (Downhole Electric Cutting Tool)

The cut made by the DECT can be compared to a lathe cut, and is therefore the perfect "fit" for an overshoot or a spear when it comes to fishing operations. Flaring of the cut pipe is not a problem with this type of cutters.

The DECT functions as a lathe, where the upper part of the tool is anchored to the tubing wall with steel anchors. The bottom part of the tool which contains the cutter blade rotates. For each revolution a cutting blade starts to travel from inside the cutter body and moves outwards (this movement is fixed, when the cutter have rotated 360 deg, the cutter blade will have moved e.g 0.1mm outward).

The tubing will be cut when the bottom part of the tool have had enough revolutions to get a radius from the center of the DECT to the tip of the cutting blade which is greater than the outer diameter of the tubing divided by two.

Figure 5 Sondex DECT. ge-engergy.com 2012

2.6.2. Weatherford MCT

The MCT (Motorized Cutting Tool) is a cutting tool developed by Weatherford. This is another Electro mechanical cutting tool. This tool has a smaller OD than the DECT 1 -11/16 compared to the DECT's 2 ¾, this is positive for deployment in smaller id tubing's. What's negative with this cutter is that the maximum cutting diameter gets reduced to such a level that cutting standard "North Sea Tubing" of 4 ½'' - 5 ½'' is not possible. *(Campel.S et.al, 2009)*

Figure 6 Pizza cutting wheel. Weatherford.com 2012

The MCT's method of cutting is similar to a pizza cutter (fig 6), the bottom of the tool rotates and hydraulic pressure forces an arm with the pizza wheel outwards against the tubing wall. Before the tool starts its rotation the anchor are pushed out against the tubing wall by hydraulic pressure and centralizes the tool.

The operator monitors the Ampere Value on a screen as the tool is rotating, and is able to monitor when the pizza wheel has parted the tubing. Ampere value will increase or decreases depending on the tubing state (compression or tension). If the tubing is in tension, the pizza wheel will rotate without any resistance. If the tubing is in compression, the tubing will collapse over the coned "cutting area" of the pizza wheel and squeeze it so the operator will see a drastic ampere increase.

2.6.3. Baker Hughes MPCT

Bakers Hughes MPCT is an electro mechanical cutting tool that cuts tubing and pipe with a circle saw principle, a circular blade rotates with x- revolutions per minute. The rotating blade is then moved radially against the tubing wall. At the same time the cutting blade is rotating, a swivel placed in the cutter body above the cutting blade rotates 360 deg. to make the cutting blade cut the tubing equally.

Figure 7 MPCT Cutting Head. Bakerhughes.com 2012

The MPCT comes in 3 different sizes and can cut pipe with dimensions from 2 7/8 – 7'' *(Bakerhughes.com, 2012)* the MPCT is not available on the Norwegian market in these days.

3. Basic well design

An oil well is a complex mechanism, and before you can see the use for a down hole cutter it is important to understand the basic buildup of an oil well. This chapter will give the reader a better understanding of how an oil well is build up, and what different components that's in the production tubing

3.1. Drilling and completion

The most common way of drilling and completing an oil well is:

- **Drill top hole 30" -36"**
- **Set conductor 30''**
- **Drill surface hole 26''**
- **Set surface casing 20''**
- **Cement surface casing**
- **Drill intermediate hole 16''**
- **Set intermediate casing 13 3/8**
- **Cement intermediate casing**
- **Drill 12 ¼ hole**
- **Set casing 9 5/8**
- **Cement**
- **Drill 8 ½ hole**
- **Set liner**
- **Cement liner**
- **Run production tubing**
- **Set packer**

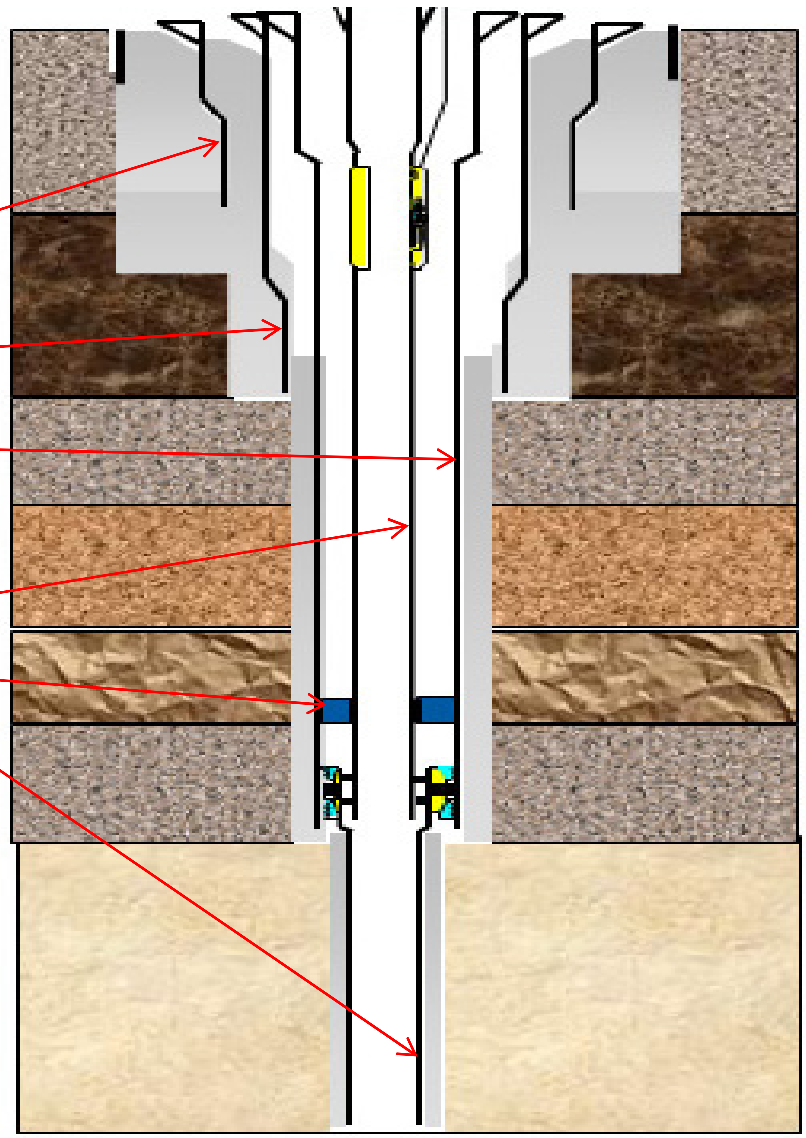

Figure 8 Basic well completion., AWS internal compendium 2010

The production tubing is the "part" of the well that is most likely to be cut, this is because the production tubing is the part of the well that is most likely to be pulled out several times during the lifecycle of a well. It is the only pipe in a well that is not cemented either to the formation or to other "pipes/casings".

The production tubing is not just a regular straight pipe, but has many different parts with different functions. Some of the most common parts are listed below; failure of these parts is also a great contributor to many well intervention operations offshore (and onshore).

3.2. Down hole safety valve

The down hole safety valve (DHSV) is a flapper valve controlled by a control line that has a fail-safe system, this means that there always must be applied hydraulic pressure in the control lines to the valve to keep it open.

There are two types of down hole safety valves, tubing retrievable safety valve (TRSV) and wireline retrievable safety valve (WRSV). The TRSV is an integrated part of the production tubing, to remove this one you need to pull the tubing and replace the joint with the TRSV integrated. If the TRSV fails you can run down with wireline and land the WRSV in a landing profile inside the TRSV, the TRSV is constructed in a way that when you set the WRSV (usually by jarring down) you establish contact between the control line and the flapper valve control system inside the WRSV. You can now control the WRSV through the TRSV control line. The negative effects of having a WRSV in the well compared to just a TRSV is that you will get a smaller ID in the tubing that might restrict the production.

3.3. Side pocket mandrel

A side pocket mandrel is a pocket in the tubing where a valve can be placed. This valve provides communication between annulus and production tubing. In reservoirs with low pressure it is common to pump gas down the annulus and in to the tubing through the SPM to help the oil flow.

There are three types of valves that is common dummy valve, gas lift valve, and chemical injection valve.

- A dummy valve is a solid piece of metal that is placed in the side pocket so you have the opportunity to change it out with either a gas lift valve (GLV) or a chemical injection valve if well conditions require one or both for optimal production.

- A gas lift valve is a one way valve that opens when the pressure in the annulus is greater than the pressure in the tubing. The GLV requires no communication line from surface to inject gas.

- Chemical Injection Valves is used for injecting chemicals into the tubing if there is a need for that.

- To operate a chemical injection valve you need to have a control line down from surface, which you pump down what chemical that is needed to solve the well problem

These valves can be set and pulled down hole. To do this you need a wireline string with a tool that can pull one type of valve, and in the next run set the new preferred type of valve. This tool is called a “kick over tool” (KOT). The side pocket is designed in such a way that the winch driver can place the kick over tool correctly in the side pocket with no electrical components needed.

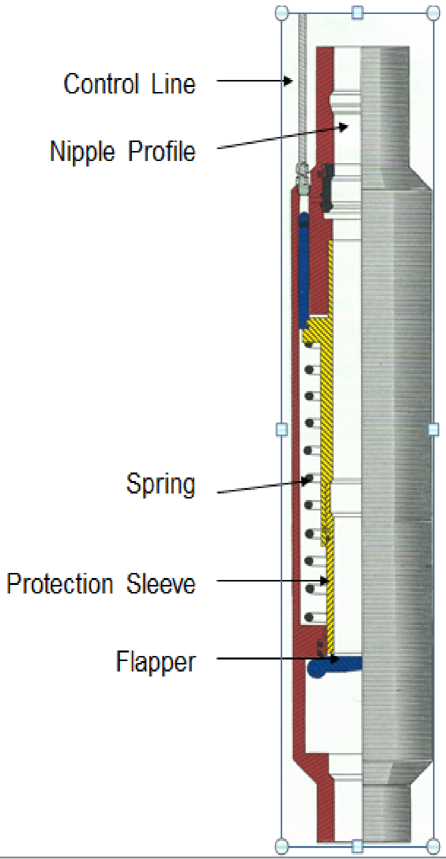

Figure 9 DHSV, AWS internal compendium,. 2010

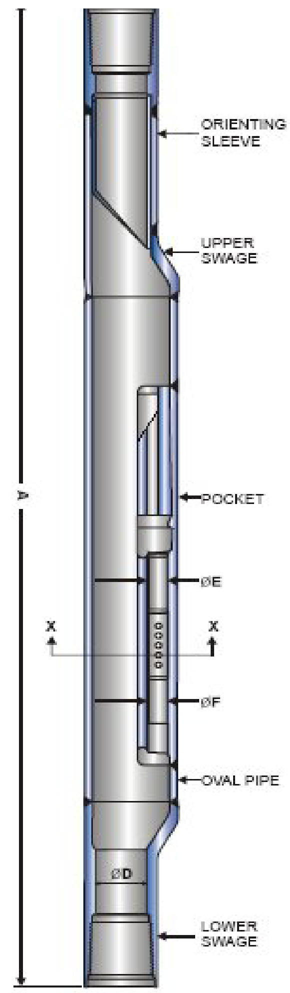

Figure 10 SPM, americancompletiontools.com, 2012

3.4. Sliding sleeve

A sliding door is a mechanic door in the tubing that can be opened and closed. In open position there is communication between the tubing and annuls, and in closed position there is no communication. The sliding doors can be left open when the tubing is ran into the well for maintaining the same pressure inside the tubing and in the annulus. It can then be closed once the tubing is in place

The sliding doors also comes in handy when there is a need to circulate out gas with fluid, and you have no possibility to go down with coiled tubing or some sort of pipe system (subsea wells where a LWI workover system is used). When a well needs to be killed to change out the completion this can be a time saving component to have included in the tubing. The sliding doors can be operated either from surface through a control line or with a stroker with a shifting tool ran on wireline.

3.5. Travel joint

A travel joint is often referred to as a Polished Bore Receptacle (PBR). The PBR is made out of two pipes with different dimensions, where the pipe with the greatest dimension has a polished inside, and the smallest has a polished outside. The smooth sides slide against each other with minimal friction.

The PBR is placed just over the production packer and its function is to take up movement caused by temperature fluctuation in the well. When deployed in the well the PBR is locked in mid position by shear pins. These shear pins is designed break when the movement exceeds a certain travel length.

3.6. Tubing hanger

The tubing hanger is what attaches the tubing to the wellhead, or in other words what the tubing is hanging from.

3.7. Production packer

The production packer is the barrier that prevents well fluids/gas to enter annulus. This packer is a part of the tubing that is lowered into the well, and is usually set by pressuring up the tubing with a plug below the production packer, the pressure will cause the slips to be set and the packer elements to swell.

3.8. Wireline re entry guide

The wireline re entry guide is often referred to as a mule shoe, this is the lower part of the upper completion where the oil flow comes from the liner and enters the production tubing. The mule shoe is an oblique cut pipe that makes it easier for the wireline tools to reenter the production tubing.

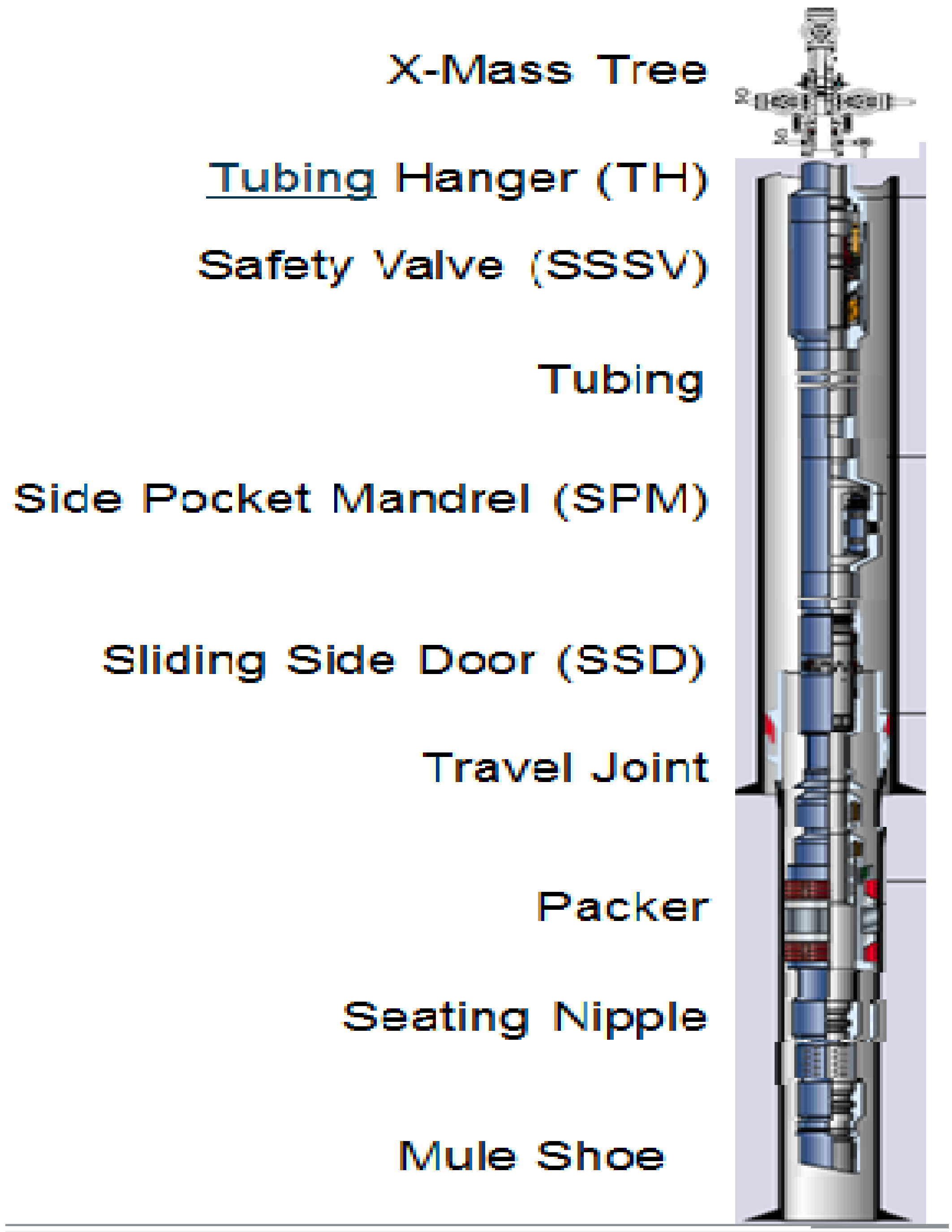

Figure 11 Completion parts overview. AWS internal compendium, 2010

4. Possible reasons for cutting production tubing, and where the cut is made.

There are several reasons for cutting production tubing but it if a cut is made, the tubing needs to be pulled from the well. The tubing must then either be replaced, or the well must be permanently plugged,

These two alternatives are called:

- Re completion
- Plug and Abandonment

4.1. Plug and Abandonment

A Plug and Abandonment operation takes place when it is no longer profitable to produce the well. The production tubing then needs to be removed for the well to create an approved barrier between surface and the reservoir

4.2. Re-completion

A re-completion is conducted when there is believed to be enough hydrocarbons left in the reservoir, to still profit from producing the well. Some wells are re-completed a few times during its lifecycle. When a well is re-completed depends on the condition of the tubing, the condition of the well barriers, and the reservoir conditions.

Tubing condition includes the condition of different tubing parts and the tear of the tubing (corrosion, abrasive tear). The Down Hole Safety Valve is often a problem, since it contains mechanical moving parts that are operated from surface through a control line. If the DHSV flapper valve or the seal area the flapper valve closes against is too worn to match the criteria's of an inflow test, the DHSV needs to be changed out. This can be done either by pulling the tubing, or running an Insert valve.

If there are problems with the control line that can't be solved from surface the tubing must be pulled. Same if the seal areas for the Insert valve are to worn to match leaking criteria's. The SPM's (Side Pocket Mandrels) also have a potential of failing if the seal areas witch the packer element on the insert mandrel can't seal properly.

Another tubing part that has a great potential of leaking is the PBR, the packer element moves up and down regulated by the temperature in the well. If this element or the polished metal area which it slides upon is destroyed, the tubing will start to leak and it must be changed out.

Well barrier condition is another reason to re-complete a well. A leaking production packer, or tubing with uncontrolled leakage between flow path and annulus will require a re-completion or intervention services to regain control over the tubing-annulus path. It's important to know that a re-completion is a heavy investment and there can be done a lot of well intervention services to match the cost of a re-completion.

What is meant by "reservoir conditions" in this thesis is the size of the production zone (how much hydrocarbons is left in the reservoir) and the pressure in the reservoir (is the pressure high enough to" lift" the oil to surface).

If there is lots of hydrocarbons left in the reservoir but the reservoir pressure is not high enough to lift the oil to the required level, sea bed on subsea installations and surface on platform wells, you have three choices;

- It can be injected gas and/or water into the reservoir to increase reservoir pressure
- The well can be completed with tubing that contains side pockets which allow insertion of gas lift mandrels
- The well can be completed with downhole pumps

There are almost as many ways of re-completing a well as there are wells drilled. In this case we will imagine a re-completion of a type of well that is showed in figure 8. Since this thesis objective is to develop a cutting tool concept the information around the re-completion will be reduced to what involves the choices on where to cut the tubing.

A common way of re-completing such a well would be to pull out the upper section of the PBR. In an ideal world this could be done from surface with the top drive, but in many cases the PBR is not even sheared from its midsection and most top drives is not capable of pulling what is required to "loosen" a PBR that have been standing in the same position in the well for 10-20 years.

The easiest solution is then to make a cut somewhere just above the PBR, go down with an appropriate fishing string and jar the upper section of the PBR loose. A jar functions as a mechanical hammer that gives a great impact on the "tubing parts" that is attached to the fishing string

Newer oil wells are often not completed with a PBR, but here are several wells in the North Sea that needs to be re completed. In some of this cases, it's possible to pull the upper section of the PBR, sting inn with a new upper section and set an extra production packer above the old one. The barriers in the well are then satisfactory.

When pulling the tubing from the well the production packer elements and slips need to be retracted. A common collapsing system for the slips and element is to make a cut inside the packer.

In some deep/long wells there are production tubing running all the way down to the production zones. To "push" this tubing down through the casing might not have been a great problem when the well was relatively new. When the tubing and casing have been down hole for 10-20 years, the outside of the tubing, and /or the inside of the casing might be corroded. The friction factor will then have increased to such a level that the top drive is unable to pull the tubing out in one piece. Also in this case it is necessary to cut the tubing to be able to get the tubing out.

In this chapter some of the most common failure methods in an oil well are presented. There are of course several other problems that can occur in an oilwell that could lead to either a Plug and Abandonment operation, or a Re-Completion.

5. What type of cutting tool are preferred by the Operator Companies

Today's situation in the North Sea is not the same as it was 30 years ago. The HSE focus has increased exponentially since they found the first oil on block 2/4 in 1969. There are a lot more regulations on what's allowed to do and what's not allowed, The Norwegian government through the instances of OD an PTIL can take a lot of this credit.

PTIL's influence on the North Sea activities have forced the Operating companies to make the working environment more safe by applying different risk reducing activities like "tool box talks" and pre job meetings. The operating companies also sets stricter demands to the service companies on personnel training and safe working methods, this restrictions also includes different tools, and handling and use of potentially dangerous materials.

Part of this thesis is to locate the need for an electro mechanical cutting tool for use in the North Sea 5 questions was sent to the well intervention department in 3 operating companies in the North Sea; Talisman, BP and Statoil. To determine what their thoughts and experience are with other electro-mechanical cutting tools, and what their policy are for keeping and running cutting tools which contain potentially hazardous materials.

The questions are stated below, together with a brief "answer sum up". The complete answers can be found in the appendix.

1. **When tubing is cut on a BP installation, either for recompletion or Plug and anbandonment, which wireline deployd cutting tool is prefered?**

   Answer summary:

BP: *Sondex DECT is prefered*

Statoil: *Sondex DECT, SLB Power Cutter, MCR RCT are used by Statoil.*

Talisman: *MCR RCT and Sondex DECT are prefered by Talisman.*

My comment: The DECT is mentioned by all three companies as a possible cutting option. This tool is explained previously in the thesis. The DECTs advantage over the other "familiar" cutting tools is that it doesn't contain any explosives or chemicals, and the flaring created by these types of cutters is not an issue with a rotating mechanical cutter. The outer string is also not damaged when using a mechanical cutter.

The RCT cutter is also mentioned by two of the companies. The propellant in this cutter is not rated as explosive or hazardous material, and can therefore be transported with helicopter. The problem with the RCT is that it could damage the casing and “weld” the tubing to the casing.

SLB Power Cutter is an Explosive cutter, with all its benefits and advantages. When that is said, Schlumberger that delivers the Power Cutters have got the majority of the logging contract with Statoil, and availability could be a matter in this case. This applies also with BP and Talisman when it comes to the RCT (Aker well service had the logging contract with both Talisman and BP when this interview took place)

With the DECT the case is a bit different. Schlumberger can’t deliver an electro mechanical cutting tool. In that case Statoil is free to choose which Company that has the best cutting tool for their purpose.

2. **Is there any special risk evaluation that is run if there is decided to use a cutting tool that contains explosives or dangerous chemicals? Is it prefered to use other cutting methods to avoid keeping hazardous materials on the rig?**

BP: *Alternative tools are preferred over explosive cutters*

Statoil: *All the cutters that are used on Norweegian sector have gone through excessive risk evaluations before they are approved for use. Non Explosive cutters are preferred over explosive.*

Talisman: *It is never an optimal situation to have Explosives onboard.*

My comment: In Norway the procedures for handling explosives are pretty strict compared to the rest of the world. Field engineers that are responsible for explosive handling offshore must go through excessive training before becoming in charge of explosive handling. A list over the amount of explosives onboard in always updated.

When that is said, even if the possibility that something goes wrong when handling explosives is extremely low the consequence is enormous, no matter how many barriers the service company and the operator company has there is always a possibility for human mistakes, and equipment failure.
"Three monkeys hitting keys at random on typewriters for an infinite amount of time will almost surely produce Hamlet ". (Ives, 1987)

3. **Which factor is the most critical when deciding what cutting tool that is chosen for the job? Safety, reliability or price.**

Answer summary:

BP: *Safety-reliability-price.*

Statoil: *All the cutters are qualified safety wise. Reliability is most important.*

Talisman: *Reliability, all the cutters are qualified.*

My comment: The answers to these questions are seen "isolated" a bit varying, but if you see them together with the other questions they land on the same conclusion. As Statoil say, "all the cutters we use are qualified for use in the north sea". This includes both reliability and safety.

There is a safety aspect concerning the reliability of the tool, if an explosive cutter needs to be rigged down after being ran in the hole without firing, or the cut is insufficient, to pull the tubing free, a new cutter must be rigged up. This increases the time of human contact with a "live gun". This is a safety issue itself.

The price aspect of the cutter comes way behind the reliability when it comes to the selection process, the rig rates these days is so high that the operator companies simply can't afford to save "pocket money" on a cutter. Scarabeo 5 that Operates for Statoil in the North Sea costs 400.000 dollars per day. *(na24.no,2009)*

4. **Amongst the electro mechanical cutting tools that are used, it seems like the Sondex DECT is the most used cutting tool on Norwegian sector. Have you got experience with other el. mech. cutting tools like Weatherfords MCT or Baker Hughes MPC?**

Answer summary:

BP: *Just have experience with the DECT.*

Statoil: *The DECT is the only electro mechanical cutting tool approved in the Statoil system.*

Talisman: *MCR RCT and Sondex DECT are prefered by Talisman.*

My comment: There is no doubt that the electro mechanical cutting tool that has been the greatest success on the Norwegian market is the Sondex DECT. When 2/3 well intervention engineers don't know or is not familiar with the other el. mech. cutting tools than this tool. I will say that Baker Hughes and Weatherford that is two of the Great 4 Service companies (Schlumberger, Halliburton, Baker Hughes, Weatherford) has done an extremely bad job offering their product to operator companies on the Norwegian continental shelf.

The Weatherford tool is obviously not suited for the North Sea because of the measurements of the tool and the cutting range, but if Weatherford have got a product that works with cutting smaller tubing, it should not be a problem to scale up this tool and make it suitable for cutting typical North Sea size tubing (4-5 ½''). The Norwegian shelf is the midpoint in to oil world when it comes to utilizing advanced technology.

The Baker Hughes MPCT can cut the same dimensions as the DECT can. And I can't see the reason why Baker Hughes haven't made this tool available for the Norwegian market already. Baker Hughes Atlas is already 1 out of 4 established Wireline companies in the north sea together with AWS, Deepwell, Schlumberger, so there is no reason for them to stay out of maybe the most valuable market in the world.

5. **What is yours/the companies experience with running electro mechanical cutting tools rather than explosive/chemical or RCT?**

Answer summary:

BP: *Good experience with el. mech. cutting tools*

Statoil: *Positive experience with el. mech. cutting tools*

Talisman: *Better control with an electro mechanical cutting too when it comes to precision than an explosive.*

My comment: All the three operator companies have had good experience with electro mechanical cutting tools, in this case the DECT. There was some problems in the beginning, like problems of getting stuck if the tubing collapses after the cut is made and squeezes the blade; this is now fixed with a "breakable blade"

Final conclusion for the questions

My conclusion from these five questions is that these three operator companies representatives have got positive experiences with the Sondex DECT. If there was other available electro mechanical cutting tools that were just as good, or better than the Sondex DECT. These three operator companies would be positive to run these tools before cutters which contains hazardous materials.

6. Design of the Cutter

Aker Well Service is under development of a high power downhole rotation engine called "Driller". This tool is actually designed for milling steel plugs. The Driller has unlike other wireline deployed milling tools a "self-feeding" mechanism, this means that the milling progress does not depend on the progress of a well tractor.

Before the cutting tool and the different components in the cutting tool is explained. It is suitable to have a simple drawing that shows how the cutting tool concept will look when deployed in the well. The different parts in the "toolsting" will be explained later in this chapter

Figure 12 shows the function of the "cutter toolstring". The cutters different "conditions" are described below

1: Driller and cutter in deployment position.

2: Cutter blade is placed on the desired depth, and the operator engages the Driller anchors.

3: The Driller is activated, the cutting tool starts to rotate, the knife is pushed against the tubing and starts to "turn down" the material in the tubing wall.

4: The Cutting Tool has cut the tubing. Now the knife has to be retracted. This is achieved by running the Driller back to Deployment position. Then the operator can release the anchors in the driller, and pull out of hole.

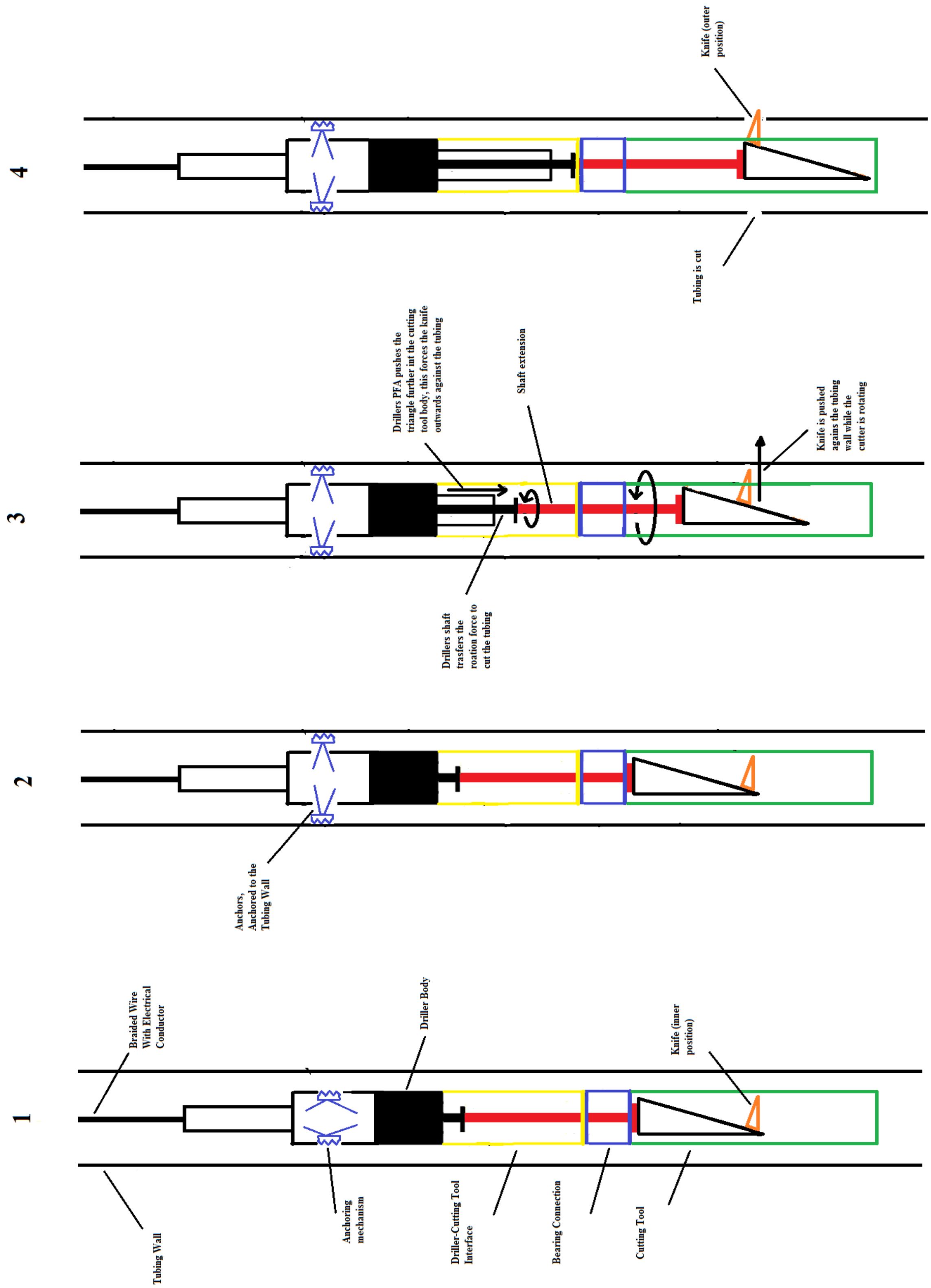

Figure 12 "Cutter Toolstring"

6.1. The Driller Tool

Due to internal restriction on what is allowed to publish about the driller yet. I have chosen just to make a sketch of the bottom of the driller to explain witch parts that is rotating and witch parts that forces the bit forward, the internal mechanism internal in the Driller is irrelevant for this thesis.

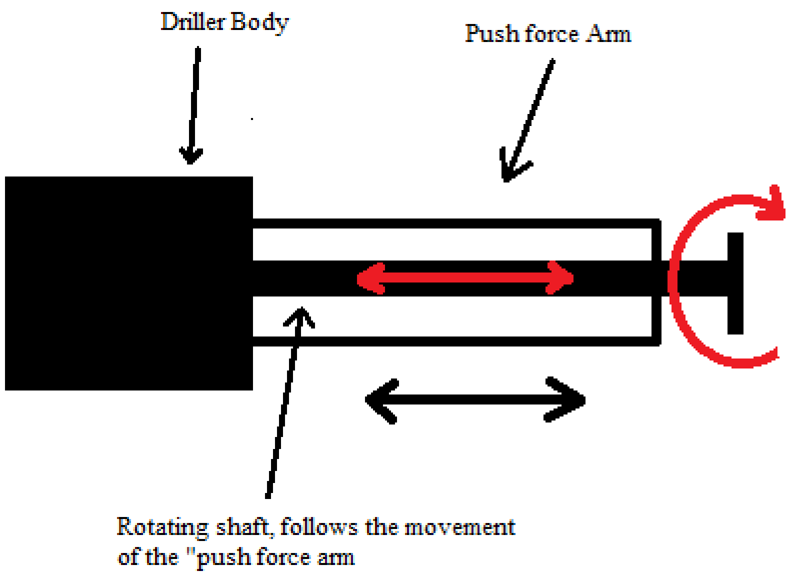

Figure 13 Driller sketch

The push force arm (PFA) moves from inner position to outer position as shown in figure 13. This movement takes 6 minutes. Inside the PFA there is a rotating shaft (figure 12) which follows the movement of the push force arm. If the PFA moves out 20cm the axle moves 20cm in the same direction. The PFA has an elliptical shape and does NOT rotate along with the axle.

When the driller is used for what it is made to do, a milling bit is attached to the end of the axle. The PFA is in inner position while the tool is deployed into the well. When reaching the desired depth, which in this case will be a steel plug, run slowly down and tag the plug carefully, then pick up carefully and place the driller a short distance above the plug. Anchors in the Driller body are anchored to the tubing wall when engaged by the operator. The operator will then start up the driller. At first the milling bit will rotate with no resistance, but as the push force arms moves further out of the driller body along with the rotating shaft, the mill will engage the steel in the top of the plug.

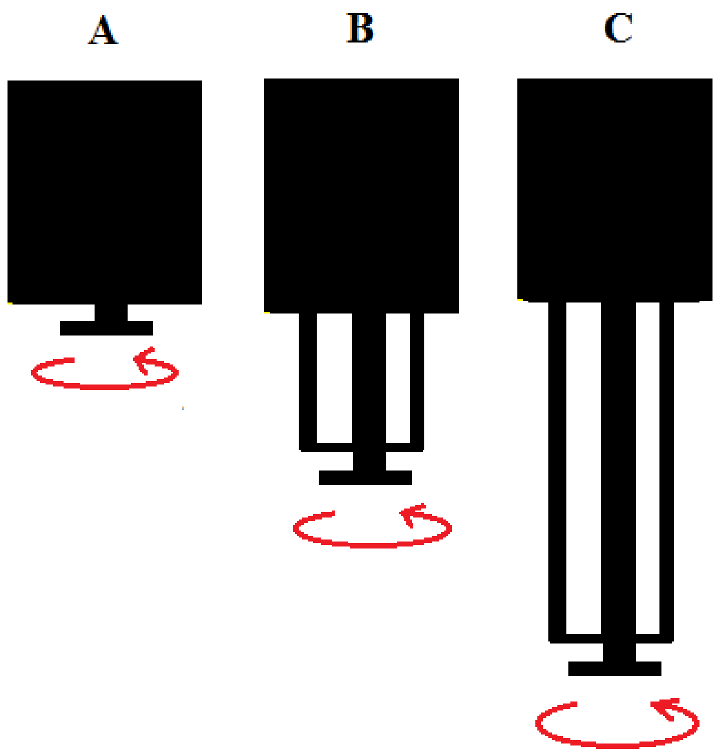

Figure 14 Driller in inner, mid and outer position

The figure above shows the driller in A; inner, B; mid and C; outer position. The tool is deployed into the well in inner position and anchored to the tubing wall with the Drillers slips. During the cutter process the PFA moves from inner to outer position; it is this movement along with the rotation that will be used to power the cutter.

Facts about the driller:

OD (outer diameter): 85mm
Stroke length: 430mm
Time for push force arm to move 430mm: 6 minutes
Push force: 150kg
RPM: 200
Moment: 220 N/m
Motorsize: 5 Kw
Power Supply: 600V 8.3 Ampere

The idea of making a cutter for use down hole came to me the first time I heard about the Sondex DECT and all the problems that was related to the maintenance of this cutter. I thought that there must be an easier way to cut a tubing if you have enough power available than to use this relatively complex tool, that requires many hours of redressing between each run. When I first heard about the driller I thought that this has to be a tool that it is possible to attach some sort of a cutting mechanism to. There are definitely many other ways to design a cutter for use with the Driller. My concept is not unique by any means, but for use in this context it's unlike anything I have seen.

6.2. Driller – Cutter Interface

The Driller is designed in a way that makes it impossible for my given design to function properly. The rod that produces the push force (PFA) has an elliptical shape with a maximum OD of 6cm. Maximum OD that fits into the cutting tool body can't be greater than 30mm. I have created an interface that will solve this problem.

The driller body is extended 43 cm. When the driller is in outer position, the end of the rotation rod (PFA) will be lying flush with the "bottom" of the driller body.

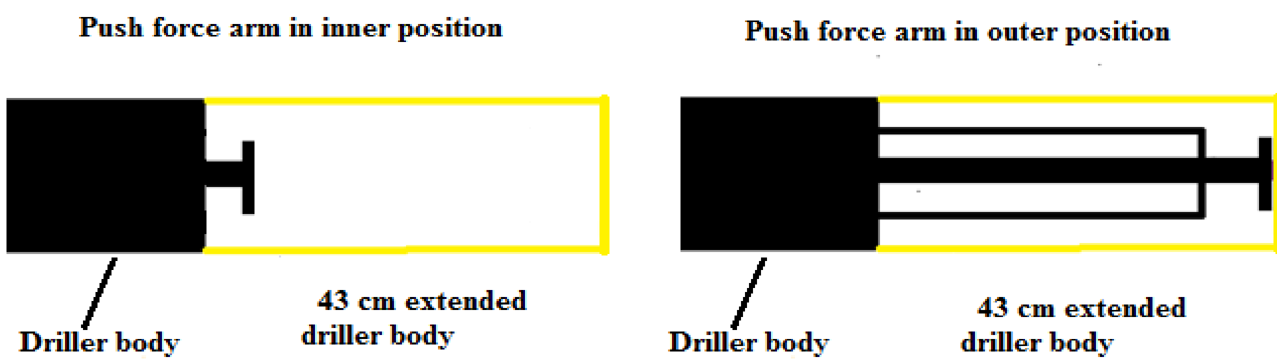

Figure 15 Driller – Cutter interface

The bottom of the extended driller body is attached to a 15cm long bearing connection with the same OD as the driller and cutting tool, this will allow the cutting tool to rotate along with the rotation of the Shaft.

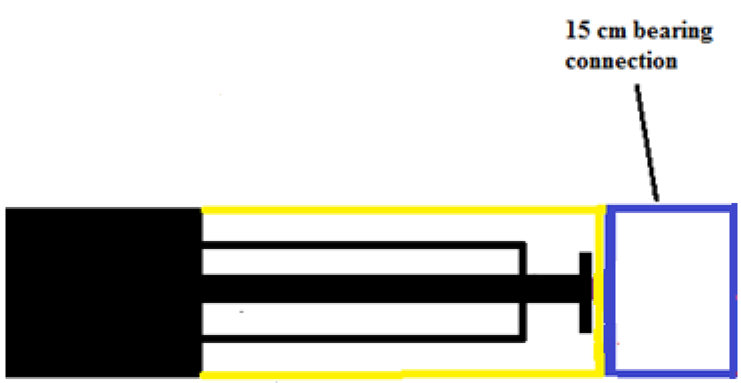

Figure 16 Driller – cutter interface with bearing connection

The rotating shaft is extended with a 43+15cm shaft which will fit inside the cutting tool body. The rod has a diameter of 25 mm and a length of 580mm

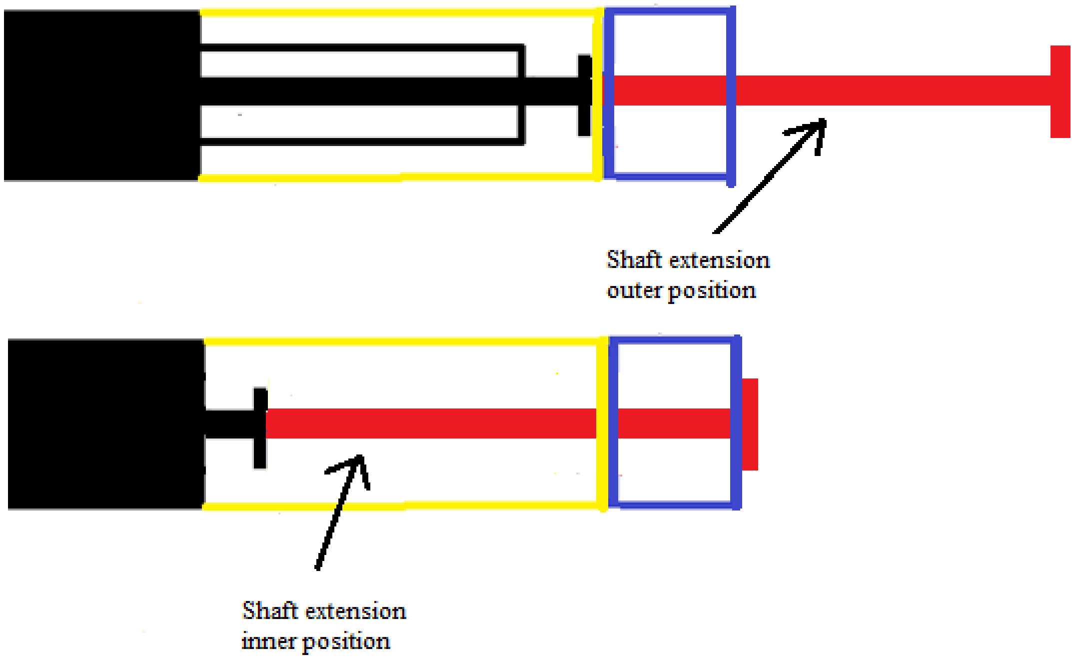

Figure 17 Driller - cutting tool interface with bearing connection and shaft extension

The steel rod will be the weakest link in the interface, since the OD of this rod is limited to 3cm max. The most critical force that will act on this rod is the shear force caused by the torque, if the tool is rotating and the knife is "locked" in outer position.

$\boldsymbol{\tau}$ = Max torque from driller = **220** Nm = **220 * 10^3** Nmm

r = Radius = **72**mm (from center of the cutter to the tip of the knife)

F = Force (N) =Unknown

F = $\boldsymbol{\tau}$ / r = 220 *10^3Nmm / 72mm = 3055.55 = 3056N

$\boldsymbol{\tau_v = M_v / w_v}$

$\boldsymbol{\tau_v}$ = Shear stress caused by torque = unknown

$\mathbf{M_v = \tau = F * r}$

$\mathbf{w_v}$ = cross section module = $\pi d^3 / 16$ (for a circular cross-section area)

We will first try with a rod diameter of 30mm

$\mathbf{\tau_v = 220*10^3\ Nmm / ((3.14 * 3^3)/ 16)\ mm^3 = 41\ N/mm^2}$(MPa)

If we compare this number with table NS 13205 we will find that we are not near the yield strength limit, of St 50 (Shaft steal) that is: 285Mpa *(Gelgele, 2008)*

Rod diameter of 25mm

$\mathbf{\tau_v = 220*10^3 Nmm / ((3.14 * 25^3)/ 16)\ mm^3 = 71\ N/mm^2}$ (MPa)

There is no point of having a rod with a smaller diameter than 2,5cm because of the internal dimensons of the cutter; 71Mpa < 285 Mpa, this size is OK

6.3. Cutter design.

The main goal with the design of this cutter is of course to make it as reliable as possible. A tool that fails downhole is extremely costly, mainly because the operation is so time consuming, and the day rates are extremely high.

Since my knowledge of how the driller is built up inside is limited, the idea with this tool is to use the "push" force and rotation from the driller to rotate a cutting blade and force it outwards to cut the production tubing. This has been a time consuming task to accomplish. I have some restrictions of what I shall not focus on in this thesis, but it would i.e. be meaningless to design a cutter that would have been impossible to pressure compensate. During the process I have had to re-design the cutter several times because the product might work properly on surface, but fail down hole because the design would make it impossible to i.e. pressure compensate or to centralize.

Main design criteria:

Should be able to cut tubing from 4 ½ Inch with weight 15.10 LB/FT to 5 ½ inch weight 23 LB/FT 4 ½ inch, weight 15.10 LB/FT in one run with the same setup of the cutter.

4 ½ Inch, weight 15.10 LB/FT have an ID in metric units of: 95,6mm and OD 114,3mm

5 ½ Inch, weight 23LB/FT have an ID in metric units of: 118,6mm and OD 139,7mm

Metal to cut: (139.7mm – 118.6mm) / 2 = 10,5mm *(Aker Well Service Talley Book, 2012)*

Secondary design criteria's:

- Tool OD can't exceed 85mm
- Must be possible to pressure compensate and centralize

6.4. Idea for cutter design

The cutter is based on the "lathe" principle where the desired part is cut by a rotating knife. In a lathe as known from a workshop, the part is turned around its own axe and a knife is slowly approaching the material. For this cutting tool it is the cutting tool that is rotating, but the principle is the same. The Sondex DECT is also based upon the "lathe" principle.

A critical factor with this method of cutting steel is to get the knife to approach the material with a suitable speed. This speed is referred to as "feed" in machining operation. If the feed rate is too high the knife could break.

The feed rate will be given by the speed of the push force arm; this speed is with today's set up 6min from inner position to outer position. The cutting tool OD is 85 mm and the maximum tubing OD to cut is approximately 140mm. a knife has to be lifted approximately 30mm for the tubing to be cut. The cutting tool will use the full length of the push force arm to lift the knife 30mm. 6min to lift the knife 30mm = 1 min to lift the knife 5 mm, if we assume an absolute minimum cutting RPM of 20 rev/min, the feed rate will be 5/20 = 0,25mm/rev.

According to Chandima Ratnayakes lecture notes from the course "production technique" at UIS a roughening cut has a feed from 0.4-1.25mm/rev. A roughening cut are used to remove large amounts of materials as rapid as possible. A maximum feed of 0.25mm/rev I will therefore consider acceptable. If the cutting RPM is increased the feed will decrease. Optimal feed rate and cutting speed is something that has to be analyzed further, if developing this tool is considered.

The time it takes for the push force arm to move from inner to outer position can easily be reduced/increased by minor adjustments on the driller in a workshop, the drillers setup when this thesis is written is the optimal setup for milling. If the driller also will be used for cutting tubing, 2 different standard setups need to be established.

6.5. Cutting tool design

The cutting tool without the driller and the interface consists of 5 main parts.

- Body (*fig 19*)
- Triangle (*fig. 20)*
- Knife *(fig. 21)*
- Lid *(fig. 22)*
- Knife-slider with bolt *(fig. 23)*

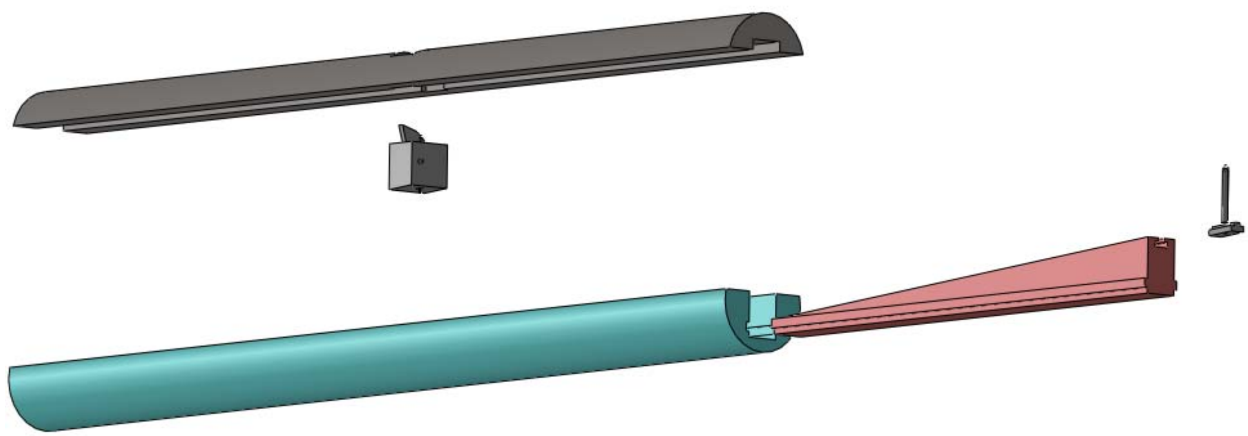

Figure 18 Exploded view of the cutting tool

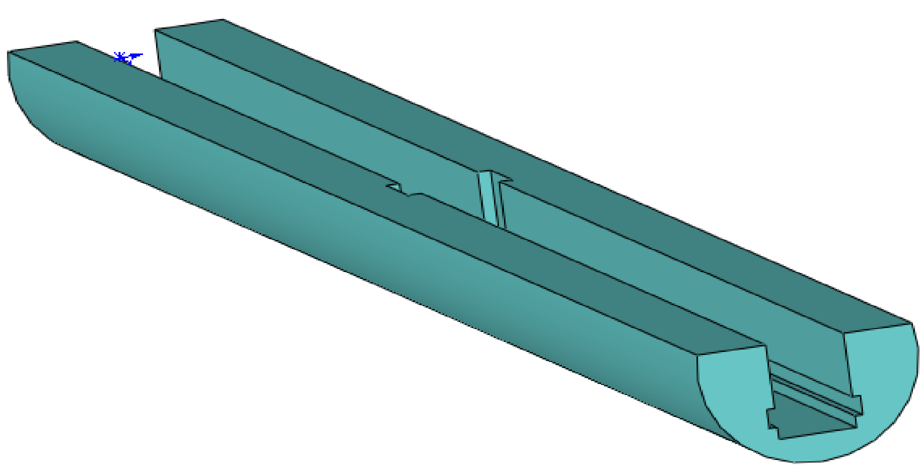

Figure 19 Body

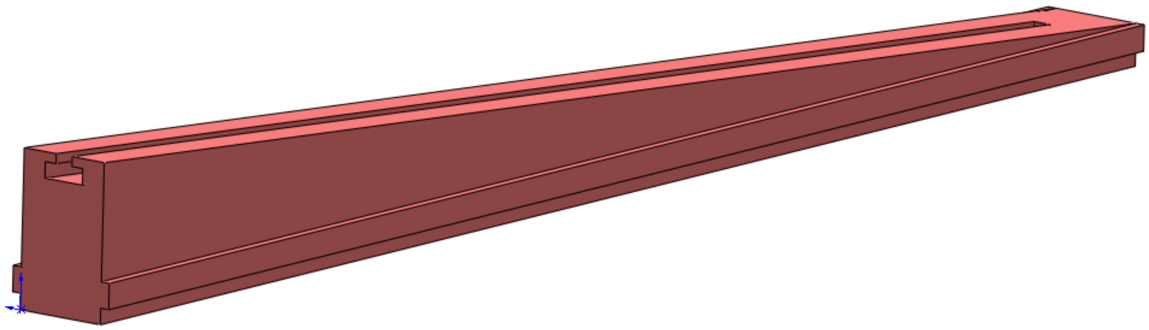

Figure 20 Triangle

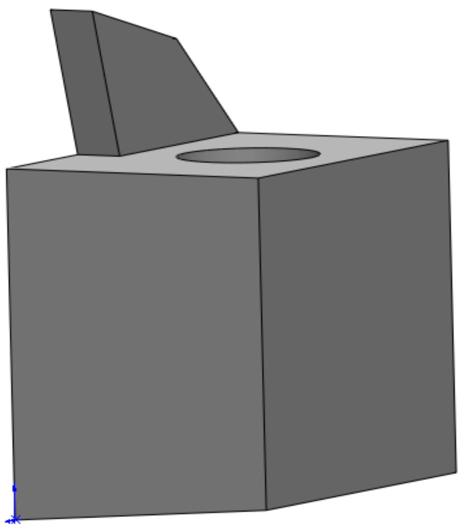

Figure 21 Knife

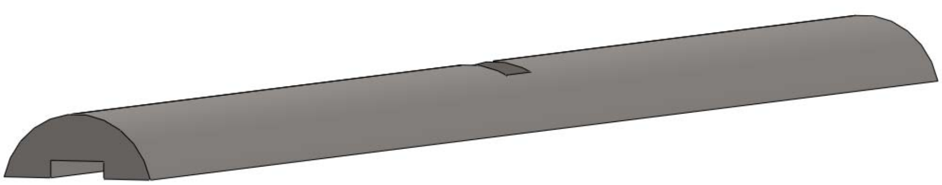

Figure 22 Lid

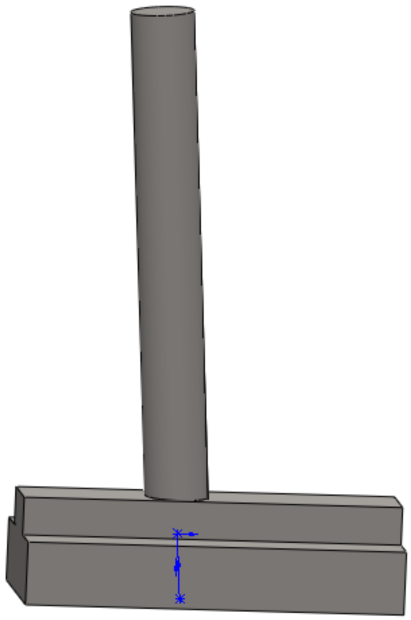

Figure 23 Knife-slider with bolt

Assembling of the cutter happens in this order.

- Slide the triangle into the body
- Install the knife slider in the groove in the triangle
- Slide the knife into the vertical groove in the body. When the knife slider is placed in the center of this grove, the bolt enters the hole in the knife.
- Place a nut on top of the bolt and tighten up the connection.

In closed position the knife blade is protected by the cutter body (Lid). The figure below shows this.

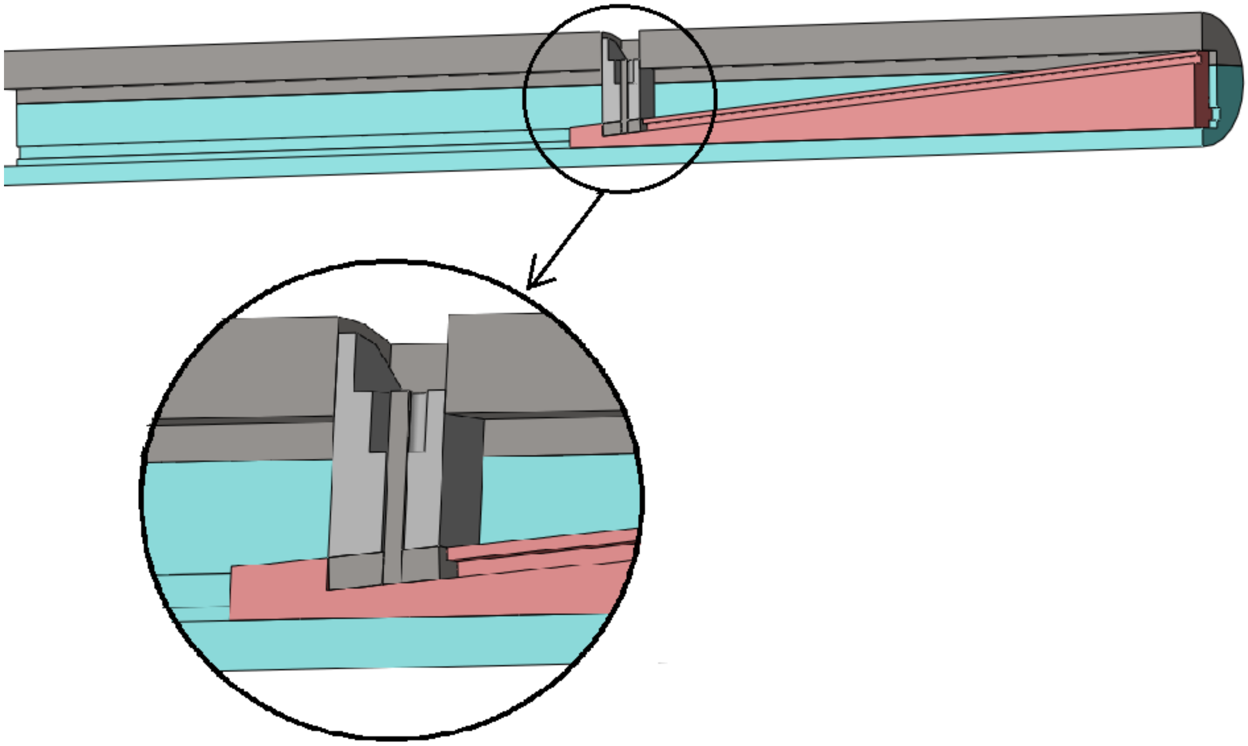

Figure 24 Knife in deployment (inner) position

The triangle is attached to a 2.5cm (diameter) rotating shaft which transfers rotation and push force from the driller to the cutting tool (red. The cutting tool body is attached to the driller body through a bearing connection. The triangle starts to rotate inside the cutting tool body, the force from the rotating triangle forces the cutter body to rotate.

The shaft is also pushing the triangle further into the cutting tool body, forcing the knife outwards against the tubing. Figure 25 shows the knife in outer position. In this position the tubing should be cut given that the tool is satisfactory centralized.

It is of high importance that the forces through the knife during a cut are absorbed by the lid and the cutter body. The knife holder that fits in the triangle groove is designed just with the purpose of the retraction of the knife after the cut is made, and will most likely not stand the forces from the cutting process itself.

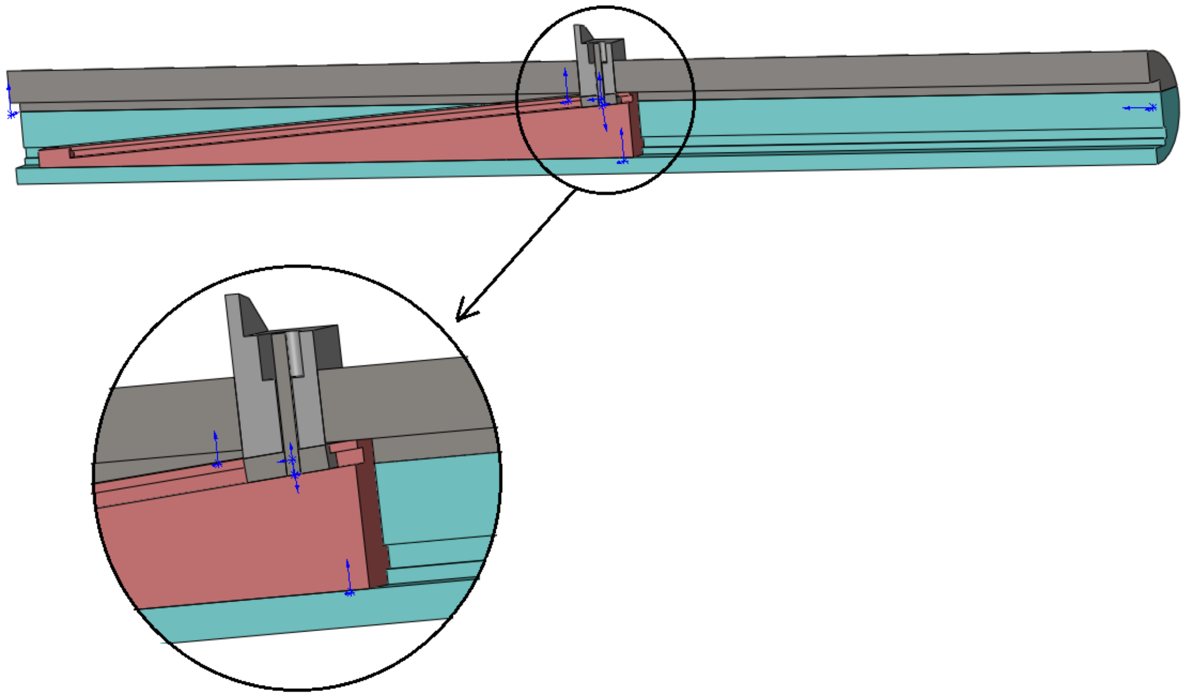

Figure 25 Knife in outer position

6.6. Comments to the drawings and further work with the cutting tool

There are no bolts and threads drawn into the figure. The purpose of the drawings is to explain the basic concept of how the driller can be used to power a cutting tool, and how such a cutting tool can be designed.

Except for the extended shaft no calculations of the driller are provided in this thesis. If there is decided to continue the work with this concept cutter, advanced calculations in a simulation program i.e. ANSYS should be carried out.

Knife (fig.21) cannot be machined as one solid part. A design for holding a cutting insert must be made and different steel qualities on both the insert holder and the insert itself must be considered. This could probably qualify as an own master thesis.

Further, the tool has to be closed and pressure compensated. The point of the knife stick up point will probably be the most challenging part to seal. This area requires both low friction since the knife must slide up and down, and sealing element. Rubber as a seal element is probably not the best choice at this point. A brass seal could maybe be an option. This requires further calculations.

The rotating shaft needs to be attached to the triangle with a connection that can transfer torque both clockwise and counterclockwise. This connection must also be able to transfer push and pull force.

A centralization mechanism is necessary for this tool to function properly. Since the push force for the driller is 150kg and can be increased if needed, it should not be a problem to use push force through the triangle and centralize the tool below the cutter.

6.7. Advantages and disadvantages with this cutting tool

There are a lot of things that has to be taken into consideration when discussing pros and cons with a cutting tool concept. The advantages don't need an explanation but it's important to divide the disadvantages into two different groups. A disadvantage caused by a problem that **can** be solved, and a disadvantage caused by a problem that **can't** be solved.

For this tool, the need for an extra centralization mechanism is critical for optimal tool performance. With this design concept there is no specific design suggestion. Still, the cutting tool is designed in such a way that it is possible to use the push force, through the triangle, to create a centralization mechanism. This is a problem that can be solved. It is still a disadvantage but not to that extent that the design concept should be discarded before possible solutions is looked upon.

Another problem with the design showed on the "concept drawings" is that if the knife gets locked in outer position, it could cause problems getting out of the well. This could be fixed by re designing the knife and give it a design that is possible to break, i.e. releasing the anchors and pulling the up (same principal as with the DECT's breakable blade).

A disadvantage witch can't be "fixed" with this design is the fact that the cutter is not placed in the bottom of the tool. If the tubing when cut parts and "scissors" (when the "upper part" of the cut tubing is placed on low side, and the "lower part" on high side) the parts of the tool that is below the cutting spot, could get squeezed, and the tool will be stuck. This is definitely a negative side with this cutter. How often this scissoring happens is unknown to me, but I do know that the RCT cutters setup is not with the cutter placed in the bottom, and it has not stopped the oil companies from planning jobs with this cutter.

Advantages:

- Easy redressing
- Simple design
- Only a minor re-design of an already existing tool is required to power the cutting tool

Disadvantages:

- The tool requires centralization
- If the tool is locked in outer position it could cause problems getting out of the well.
- Cutting mechanism is not placed in the bottom of the cutting tool

7. Maintenance of the cutting tool

When discussing pros and cons with this cutting tool, the need for good centralization came out to be a critical factor with this tool. If the tool is not satisfactory centralized it could lead to vibrations in the tool and tool failure. The importance of having a functional tool down hole is critical because of the time it takes to pull out and replace this tool.

The planning of the job and the testing of the tool before the job is therefore critical for success, not only this tool, but all sorts of tools that are used in an oil well. Pre job testing of tools in the work shop are part of Aker Well Service's routines before shipping certain tools offshore. For the testing of this cutting tool the requirement to centralization has to be very strict to minimize the risk for tool failure. A regular test were the tool are laid out on a bench and tested, running the knife from inner to outer position, and visually monitor the motions of the tool, would in my opinion be unsatisfactory. With this tool I believe we would get a much better overview over the cutters condition if we implement condition monitoring as a practice for pre job testing.

7.1. Condition monitoring

"Condition monitoring is a generalized method for establishing a machine's health using measured parameters which reflect changes in the machine's mechanical state"
(Markeset, T. 2010 "Introduction").

Condition monitoring is a well-known term in in the industry; it can be described as the usage of different fault finding tools to establish a certain baseline for what are acceptable parameters for the specific part or machine, and if the baseline changes to a level that is non-acceptable, action must be taken to reduce damage to the part or machine.

What type of condition monitoring that is suitable depends on the failure mode. Tore Markeset describes three failure modes in figure 25

- Instantaneous failure.
- Fast degradation process
- Slow degradation process

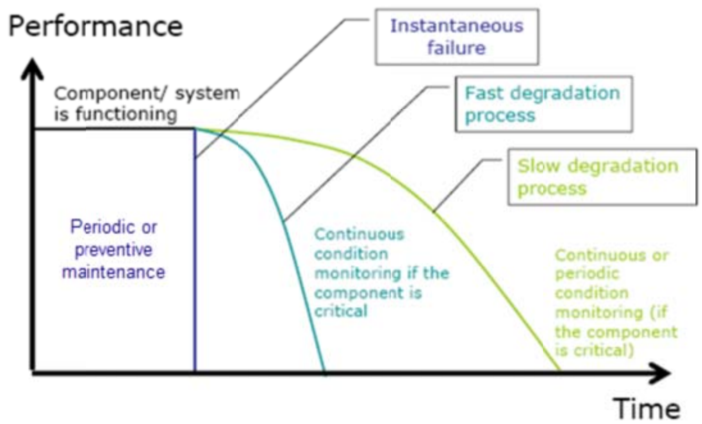

Figure 26 Different failure modes. Markeset. T., 2010" Introduction"

Instantaneous failure; best example is typically a light bulb either it works, or it does not work. This failure mode is not suitable for condition monitoring.

Fast degradation process; this affects the system in such way that the performance of the system will decrease drastically if the components condition falls below its normal condition. This type of system or the critical component within the system should be continuously monitored

Slow degradation process: same as fast degradation process but in this case some "wear" to the system or component can be accepted depending on how critical optimal function is. Can be monitored either periodic or continuous depending on how critical the component or system is.

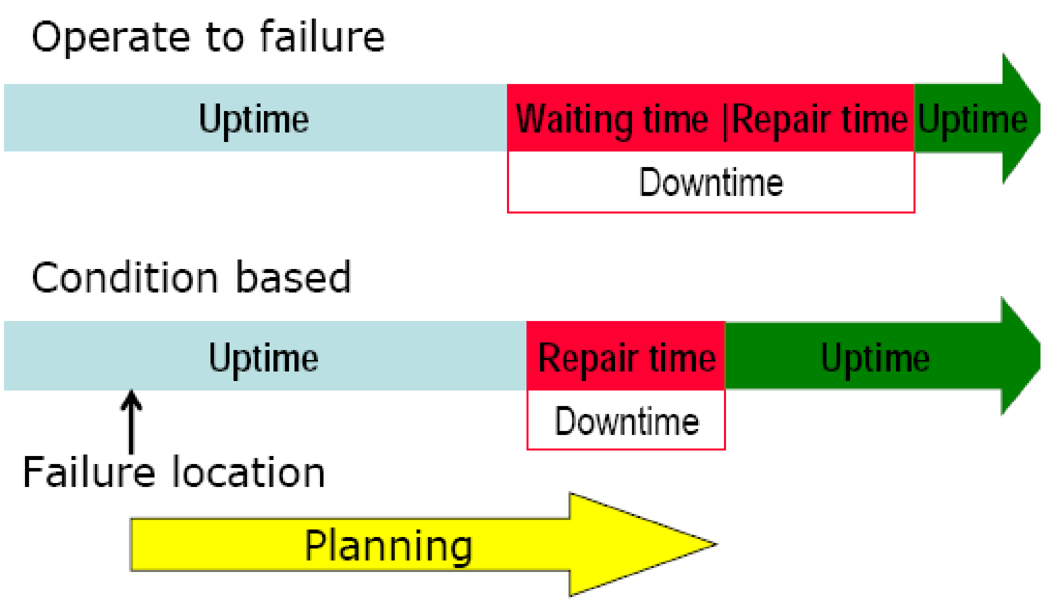

Figure 27 Operate to failure vs. Condition based. Markeset.T., 2010 "Introduction"

The figure above shows the relationship between **downtime** and **uptime** with or without condition based maintenance. For this type of tool this modell will not be accurate, since this tool is not suitable for condition monitoring during operation. But with the use of different condition monitoring teqniques between jobs the downtime could be reduced to 0.

How can this be acomplished by condition monitoring and not by just regular maintenace? Like most other mechanical devices, downhole tools have som sort of a service history. "O-ring X is canged for every downhole trip" or " valve Y is changed after 1000 hours". This is spesifications that is recommended eigther by the company that have created the tool, the O-ring or valve company or the service company that is running the tool. This is often experience based numbers, or numbers created by laboratory testing.

With these numbers not taken into consideratin is the uncertainty of the different spare parts functionallity or reliability. Lets say a bearing could have a estimated life of 400 hours. But it could also break down after 60 hours caused by i.e a minor missalignment. When the tool is in the workshop after a run, the service procedures are follewed, and the tool is in some cases tested. If missalignments in the bearing leads to great tool vibrations, the technicians can probably determine that something is wrong and investigate. If there is just a minor vibration and the technican is not that experienced with that spesific tool, it would probably be axepted and it would be sent offshore.

If the practice in the workshop have involved periodic condition monitoring, a vibration sensor would have been attached to the tool and the chance of finding the fault would have been much greater.

Condition monitoring could also be a great tool for prototype testing of the cutter. In this case the cutter would be ran from inner to outer position several times both with and without resistance applied to the knife blade, while monitoring the vibration parameters.

7.2. What type of condition monitoring techniques would be suitable for this type of tool

There are several different condition monitoring methods that a system which both includes rotation and a "sliding mechanism could benefit from". The three that I believe is the most suitable for this tool is: Tribology, vibration monitoring and NDT testing.

For this tool to function down hole it has to be pressure compensated function optimally, it is critical that no well fluid enters the tool. If minor particles finds a way into the cutter, and settles between two surfaces sliding upon each other the friction could lead to blockage of a moving part. There is not only for this reason I believe tribology analysis should be implemented as a part of the pre job testing but since the tool function is based upon different parts sliding upon each other. This will lead to some degradation on the moving surfaces, and can if not being observed lead to unexpected breakdown of the tool.

Vibration monitoring of this tool between runs are important since the tool is rotating and a change in the vibration parameters could lead to a miss functioning tool. The bearing connection that connects the interface with the cutting tool could be a possible fail source with insufficient maintenance. The bearing connection can also be affected by impact either down hole, during rig up, rig down or during transportation. Misalignments could also occur in other parts of the cutting tool and excessive vibrations can be a possible consequence of this.

NDT testing (Non-destructive testing) will be used to check the surfaces for cracks and irregularities. The parts of the tool that takes the greatest stress during the cutting operation should be prioritized.

7.2.1. Tribology:

Tribology is defined as *"The study of friction, lubrication, and wear between moving surfaces" (T.Markeset,2010 "Wear and oil analysis")*This technology is relatively new and can be divided into 4. Main groups of analysis.

- Lubrication oil analysis
- Wear particle analysis
- Spectrography
- Ferrography *(Markeseth,2010 "Wear and oil analysis")*

Lubrication oil analysis is different methods of analyzing the properties of the lubricant. The properties of both the oil and the contaminants are defined by executing different test. If an abnormal amount of wear particles is found in an oil sample (given that previous oil samples have been taken, and a "baseline" of wear particles is established) this could be an indication of abnormalities in the machine that could lead to a break-down of the machine. If the chemical analysis of the worn metal is of the type that is just to be found in one specific part of the machinery, this part should be inspected and action should be taken depending on its criticality.

If there is sign of contamination in the lubricant oil that is of a kind that is not to be found within the machinery itself. There could be a sign of either particle ingress through bad seals and or reservoir lubrication oil reservoir, or it could be a sign of the maintenance/assembling personnel not being "clean" enough when assembling/overhauling the machinery.
(Davies 1998 p.43)

Wear particle analysis can be useful when finding where in the machinery the wear particles are coming form, and what type of motion that caused it. By examining the size and shape of the particles it is possible to determine what type of wear or fatigue that caused the excessive degradation. It is also important to know that whenever there is moving parts within a machinery there will be some wear no matter how optimal the lubrication or the fittings is, but excessive wear is not wanted. *(Davies A. 1998 p.46*)

Spectrography

Spectrographic analyses are a rapid, accurate measurement of many of the elements present in the lubrication, These metals are generally classified as wear metals, contaminants or additives. There are two methods of spectrographic analysis; emission spectrometry and atomic absorption spectrometry.

Neither of these methods includes particles bigger than ten microns. This limits the analyses and additional techniques are needed to get a review of all particles of the lubrication *oil (Davies A. 1998 p.45*).

Ferrography

Ferrography uses a magnetic field to separate the particles from each other. The lubricant fluid is poured down a slid that is exposed to a magnetic field; the result is that the big particles will settle on one end of the slid and the small ones the other end. This method can take particles up to 100 microns but it is limited to ferrous and magnetic particles. *(Davies A.1998 p.48).*

Spectrography and ferrography are together fast and effective methods of identifying contamination particles in the lubrication oil.

There are two ways of applying tribology analysis to a system, one of them is to have continuous monitoring of the lubricant, and this can be done as in the figure below. Where you have a sampling station you can use to get samples from the machinery while the machine is running. This works best with stationary systems.

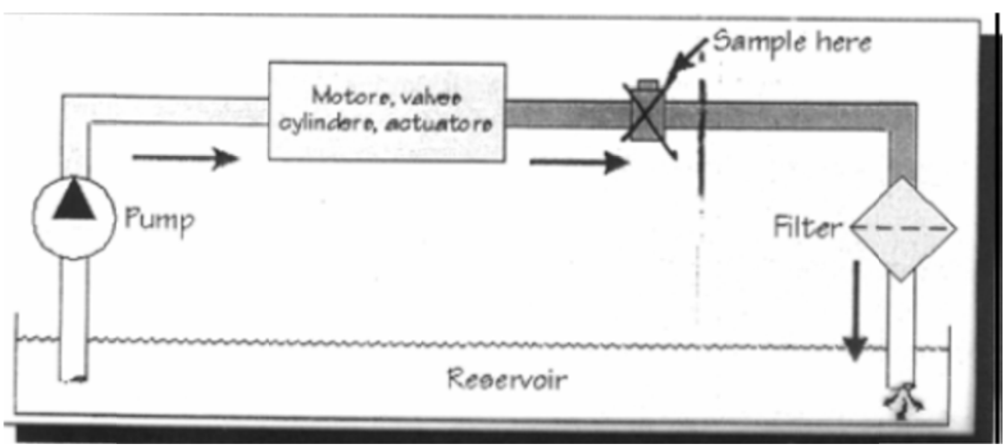

Figure 28 Continious sampling., Markeset. T., 2010 "Wear and oil analysis"

The other method is simply to run the machinery for a certain amount of time and to the inspection after "the job is done". The machinery can then be opened, and a sample of the lubricant can be taken to a laboratory for inspection. With both of these methods cleanliness is extremely important to avoid contamination for the workshop to the lubricant.

7.2.2. Vibration monitoring

The most common and maybe the most effective of the condition monitoring methods are vibration monitoring. Almost all machines or rotary equipment has some sort of a vibrating movement and with different vibration measuring instruments these vibrations are easy to monitor. There are three different instruments that are used when monitoring the vibrations of a machine:

- Displacement sensor
- Velocity sensor
- Acceleration sensor

The human brain is also a good vibration sensor. The human brain can notice changes in vibration and in sound and in some cases this "human sensor" is enough to get a good overview over the machines "vibration condition." In bigger machinery where the baseline vibration is normally high there is a good idea to use one of the sensors listed above. A major benefit of using one of these methods is that the different failure modes within the machinery have a different vibration frequency, If these frequencies is monitored over time and seen in a spectrum analysis it will be possible not to only detect failure modes in an early stadium but also determine what part inside the machine that is causing the excessive vibration. (Rao B.K.N, 1996)

The displacement sensor normally uses an "eddy current principle" to monitor vibration. The sensor works like this: a probe is placed near a vibrating surface; a high frequency field is set up in the gap between the probe and the vibrating surface. When the machine vibrates the gap between the probe and the surface will vary, the probe will sense the change in this gap and measure the relative distance to the surface *(Markeset, T. 2010 "Vibration").*

A velocity sensor is easiest described as a magnet attached between two springs inside a coil. The coil is attached to a vibrating surface, when the machine is started the coil will move up and down while the magnet will stand still. This movement will induce a voltage signal. The signal (volt value) will increase if the velocity of the coil increases. *(Markeset, T. 2010"Vibration")*

A accelometer sensor is a piezoelectric material that is clamped between the vibrating surface (or a material attached directly to the surface) and a seismic mass trough a bolt that runs through the different layers of metal. The piezoelectric metal generates an electric charge when it "feels" a change in force applied.

"The force on the crystal produces an output signal which therefore is proportional to the acceleration of the transducer"(Markeset, T. 2010"Vibration").

The acceleration the piezoelectric material is exposed to is generated by the acceleration in the vibration motion. And we know from Newtons 2. law that: **force = mass* acceleration**

7.2.3. NDT testing

NDT testing consists of several different methods. What's common with all the different techniques is what the name implies not destructive for the material tested. This means that the tested part can be used again after the testing is done, and the material will have the same mechanical properties as before the test was executed. Some NDT testing methods are described shortly below.

Visual inspection is by far the most used NDT method, it is the quickest and probably the cheapest method of checking the condition of a machine or a specific component. A good inspector uses all the different senses to get the best possible picture of the machines condition. Different instruments like mirrors fibrescoops borescoops, magnifying glasses. I.e. makes the inspection more accurate and eases the inspectors' job.

Radiography is a term for using radiation to get an image of the inspected part. The radiation penetrates the material and it is therefore possible to get an image the internal material as well as the surface areas. The most common Radiographic testing methods are X-ray and Gamma ray. Both X-ray and Gamma ray radiation are electromagnetic waves with very short wave lengths. X-ray radiation is produced by a X-ray machine, and gamma ray radiation comes from a radioactive isotope. Radiographic testing are used to detect internal irregularities. Both of these methods are relatively expensive and time consuming.

Ultrasonic testing is performed by sending high frequency sound waves through a material, when these sound waves hits a border line, they reflects and is sent back. The image from the reflected sound waves is shown in a Oscilloscope. Ultrasonic waves do not have the energy to penetrate solid material. (Mossige, 2009 "NDT")

Liquid penetrant testing is a method for detecting surface cracks and holes. A penetrant liquid with a sharp color are pored over the desired area, the capillary force will draw the material down into the cracks. Whip of the surface, and apply a developer, this can i.e. be chalk or special developer paper. If there is a crack in the material, the developer will now mix with the penetrant liquid that is left in the crack and will be easy to detect.

Magnet particle testing is performed by magnetizing a magnetic material, an applying a powder from a magnetic material. If there are cracks or other irregularities in the material, some of the magnetic power will gather around these, since there are crated local anodes and cathodes around these cracks. A penetrant is often applied to the material in advance, or special light can be used to ease the observation. (Mossige, 2009 "NDT")

Eddy current testing is another method of detecting surface cracks on conductive materials. An inspection probe that basically consists of a coil wrapped around a piece of metal is moved around the surface of the inspected material, a magnetic field is generated by the eddy currents are detected by using the same probe. The signals received are analyzed and shown in an eddyscope. If there is a change in the material, a crack or other irregularities, the eddy currents will be disturbed and the signal received will look different on the eddyscoope. Eddy currents can be used on painted materials, without removing the paint from the inspected surface. *(ndt-ed.org, 2012)*

Strain gauges are attached to the material to easily inspect if the material is exposed to strain. Strain gauges can either be "electrical" or manual. An electrical strain gauge often uses a piezoelectric material to measure strain; the volt value generated by strain on the piezoelectric material can be observed. A manual strain gauge can be inspected visually, if the properties of this strain gauge have changed from its original condition this should be easily recognized. *(Markeset. T. 2010 "NDT").*

7.3. How can condition monitoring be implemented in between run testing

Condition monitoring in between run testing can be applied in many different ways. If used correctly the use of condition monitoring can reduce the downtime, in this case, reduce the possibility for a miss-run.

The between job condition monitoring of this tool should start once the tool is back on deck after a run. The tool should be visually inspected and if any defects on the tool are found, this should be reported immediately. Then the tool should be preserved according to procedures and sent onshore.

In the workshop a sample from the lubricant oil should be taken. This sample should be visually inspected. If there is found debris or contaminants in the oil sample, further tribology analysis should be carried out. Further on the tool should be disassembled; all parts cleaned, and visually inspected. The same principle as with the lubricants applies here, if anything suspicious is found, carry on with NDT testing and find out if the part is suitable for further use.

Figure 29 Handheld vibration monitoring device. fluke.com.2012

If no faults with the existing parts are found, the tool should be re-assembled, and filled with new lubricant oil. The last phase of the between job maintenance is the testing phase. A test rig in the workshop to simulate a cutting operation should be a part of the workshop. The tool should be placed in this rig, anchored to the wall by the driller's anchors, and the cutter should be ran from inner to outer position(without applying pressure on the knife.) In outer position the distance from the tip of the knife to the cutter body should be measured before returning the knife to inner position.

A the cutting tool should be vibration monitored while running from inner to outer position, this could either be done by attaching either a wireless vibration sensor or a vibration sensor with an internal memory somewhere on the rotating parts of the cutter. Another option is to use a hand held vibration monitoring device like the "Fluke 805" *(fluke.com,2012)* and monitor the vibrations just above the bearing connection. The result from this monitoring will not be as accurate as when the transducer is placed on the rotation part.

An in important aspect with all these different measurements and samples taken is to establish a baseline for what's acceptable, and what's not acceptable. It is therefore of extreme importance that all findings, including the workshop technicians and the field engineers impression of the tool condition after the visual inspection, are written down and stored in a database. The first data that comes into this database will provide the foundation for developing the "tool baseline". This means i.e. how much vibration is acceptable, when the tool is running I outer position, or how much debris in the lubrication oil that can be tolerated.

From this data a maintenance plan will be devolved. With this tool this plan should be based on how many cuts the tool has executed. Since there could go months between each job, there is no point of having a monthly or yearly inspection. There is also possible to get a certain idea of what parts that should be changed between each run, and what parts that can be used during several cuts. When a certain number of jobs are done, and/or testing in similar environments and conditions are executed, it could open for running several cuts with the same tool, without sending the tool to shore for inspection.

This principle can be used with all type of equipment suitable for condition monitoring. The importance lies in the gathering of information, and that this information is gathered in one database. Without a satisfying amount of maintenance data there is impossible to establish a baseline for what's acceptable wear and tear on a component and or the whole system.

8. Concluding remarks

This thesis presents a design concept for how to use the AWS Driller tool can power a downhole cutting tool. The goal was to make the design for this tool as reliable, maintainable and user friendly as possible.

In this thesis, standard cutting tools are presented. Basic well design is explained and what conditions that makes it necessary to cut tubing. An interview with 3 different oil companies has also been conducted. This interview indicates that these three operator companies are positive with running Electro Mechanical cutting tools in the future.

This cutting tool concept is based on the lathe principal, where a part is cut or “turned down”. In a regular lathe the desire part is turned. In this case, the cutting tool itself is turned while a knife is pushed against the tubing wall. This principal is also used by the GE owned company Sondex with their Downhole Electric Cutting Tool (DECT).

For all tools there are positive and negative features. Briefly summarized the positive features with this tool are:

- It is powered by an already existing tool
- The given design makes it easy to maintain

The negative features are:

- Needs a centralization mechanism
- Cutter is not placed in the bottom of the tool

The last chapter in this thesis is dedicated to maintenance of the cutter. This chapter gives a brief introduction in how condition monitoring techniques can be implemented in between-job maintenance of a cutting tool

Based on gathered information I recommend continuing the work with this cutting tool concept. First priority should be to design a centralization mechanism. A good centralization mechanism is critical for this tool concept to function properly. Then advanced strength/material calculations must be conducted prior making a prototype.

If continued development of this cutting tool concept is decided, or another design concept is chosen, I strongly recommend condition monitoring as a part of between-run maintenance of the cutting tool (and any other downhole tools suitable for condition monitoring).

9. Sources

9.1. Text Sources

Bakerhughes.com (2012) “Mechanical piper cutter” Retrieved at: http://www.bakerhughes.com/products-and-services/evaluation/cased-hole-wireline-systems/pipe-recovery/mechanical-pipe-cutter-mpc# (23/3-2012)

Campell S, **Carter B, Amie J.P**, (2009) “ Nonexplosive Tubing Cutter for Safe, Efficient pipe recovery operation” (SPE article) Retrieved at: http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-121574-MS (22/3-2012) 22/3-2012

Chemitryblog.com (2012)”Bromine Trifluoride” Retrived at: http://www.chemistryblog.net/bromine-trifluoride.html 20/2-2012

Davies, A. (1998). Handbook of condition monitoring: techniques and methodology. London, Chapman & Hall.

Fanini O.N., Fuhst, K., Cousin. D., Moeller. M., Ahmed. M.A., Ross. B., Krueger. S, Lowson. P., Cattanach. M.S., (2009) *Baker Hughes Inc Field Test Results of an Electromechanical Precision Pipe Cutting:* (SPE article), retrieved at: http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-124998-MS (23/3-2012)

fluke.com (2012) “Handheld Vibration monitoring device” Retrieved at: http://www.fluke.com/fluke/nono/vibrasjon/fluke-805-vibration-meter.htm?PID=74298# 5/4-2012

Gelgele. H. (2008) Dimensjonering av maskinelementer: University of Stavanger

Ives, D. (1987) [PLAY] *WORDS WORDS WORDS ,* New York, Manhattan Punch Line Theater,

Markeset, T. (2010) MOM 350 – Condition monitoring and management course slides, University of Stavanger. (Slides: Introduction, Wear and oil analysis, Vibration, NDT)

Mossige, A. (2009) PP. presentation of NDT testing, Aker Kværner. UIS

Mcroiltools.com (2012) “RCT” Retrieved at: http://www.mcroiltools.com/LinkClick.aspx?fileticket=ndH5YKlxH20%3d&tabid=115&mid=792 2/3-2012

Na24.no (2012) ”Statoil presser riggratene” Retrieved at: http://www.na24.no/article2754101.ece (24/3-2012)

ndt-ed.org (2012) “Eddy current testing” Retrieved at: http://www.ndt-ed.org/EducationResources/HighSchool/ Electricity /eddycurrenttesting.htm 4/5-2012

Rao B.K.N (1996) Handbook of Condition Monitoring. Oxford, Elsevier Advanced Technology

Schiaci V., Tjoonk R., Mahammed H., Waheed A., (2009) *Non explosive soutions for high performance and operational efficiencies.* (SPE article): Retrieved at http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-121574-MS

Statoil.com (2012) “ Plug and Abandonment” Retrieved at: http://innovate.statoil.com/challenges/Pages/PlugAndAbandonment.aspx 1/2-2012

9.2. Picture Sources:

1 **EXPLOSIVE CUT**, George E. King Engineering, (2009), Retrieved at: http://gekengineering.com/Downloads/Free_Downloads/Pipe_Cutoff.pdf 6/2-2012

2 **CHEMICAL CUT**, George E. King Engineering, (2009), Retrieved at: http://gekengineering.com/Downloads/Free_Downloads/Pipe_Cutoff.pdf 6/2-2012

3 **RCT CUT,** MCR-OIL TOOLS (2011) Retrieved at: http://www.mcroiltools.com/ 4/3-2012

4 **SPLIT SHOT & HWT,** George E. King Engineering, (2009) Retrieved at: http://gekengineering.com/Downloads/Free_Downloads/Pipe_Cutoff.pdf 6/2-2012

5 **SONDEX DECT:** General electrics 2010 Retrieved at: http://www.ge-energy.com/content/multimedia/_files/downloads/GEA18626C%20HT%20Downhole%20Electric%20Cutting%20Tool%20(DECT200).pdf28/2/2012 2/3-2012

6 **Weatherford "Pizza wheel"** Campell S, Carter B, Amie J.P, Weatherford (2009) Nonexplosive Tubing Cutter for Safe, Efficient pipe recovery operations Retrieved at: http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-121574-MS (22/3-2012) 22/3-2012

7 **MPCT Cutting Head** Fanini O.N., SPE, K. Fuhst, D. Cousin, M. Moeller, M.A. Ahmed, SPE, B. Ross, S. Krueger, P. Lowson, and S. M. Cattanach, SPE, Baker Hughes Inc, Field Test Results of an Electromechanical Precision Pipe Cutting Tool (2009) Retrieved at:: http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-124998-MS (23/3-2012)

8 **OIL WELL,** AWS, 2010, powerpoint presentation, Basic completion for field engineers. (internal company presentation)

9 **DHSV**, AWS, 2010, powerpoint presentation, Basic completion for field engineers. (internal company presentation)

10 **SPM,** Americancompletiontools inc. 2010 Retrieved at: http://americancompletiontools.com/gasliftequipment/images/sidepocketmandrel1.jpg 2/2-2012

11 **COMPLETION**, AWS, 2010, powerpoint presentation, Basic completion for field engineers. (internal company presentation)

12 – 25 Own drawings

26 -> 28 Markeset, T. (2010). MOM 350 – Condition monitoring and management, University of Stavanger. (Slides: Intoduction and Wear and oil analysis"

29 fluke.com (2012) "Handheld vibration monitoring device" Retrieved at: http://www.fluke.com/fluke/nono/vibrasjon/fluke-805-vibration-meter.htm?PID=74298# 5/4-2012

10. Appendix

1. **Når dere må kutte en tubing som skal trekkes enten for rekompletering eller permanent plugging hvilket wireline deployed kuttetool er foretrukket/mest brukt ?**

BP: Jeg personlig foretrekker DECT (gitt at tubing er satt i tension), men det brukes også en del eksplosiver og litt kjemikalier, Vi kan knekke kniven på decten om denne skulle bli sittende fast etter kutting i kompreson, men vi ønsker nødvendigvis ikke å komme i den situasjonen. Det betyr ikke at vi ikke vil vurdere DECT uansett.

Statoil: Power Cutter fra SLB, DECT elektro mekanisk kutte tool fra Aker Well Service, RCT Radial Cutting Torch fra MCR Oil Tools (HES og AWS)

Talisman: RCT kuttetool. Kunne ikke kutte i kompresjon med DECT før, men skal vist nok være noe nytt på gang.

2. **Hvilke risikovurderinger tas om det skal brukes et eksplosiv/kjemisk kuttetool? Er dette noe man forsøker å unngå for å slippe å ha eksplosiver/kjemikaler på riggen?**

BP: Det må alltid tas en risikovurdering når vi tar ombord eksplosiver. Vi forsøker å unngå å ha dette ombord, gitt at det finnes alternative tool som er like bra eller bedre

Statoil: Vi har lang erfaring i bruk av eksplosive kuttere. Hver leverandør følger strenge prosedyrer for håndtering av utstyret på overflaten, og så vidt jeg kjenner til har det ikke forekommet ulykker på Norsk sektor de siste 30 år. Kjemikaliekuttere har ikke vært i bruk de siste 3 år på grunn av for høg risiko hvis noe går galt. Vi fra hovedkontoret anbefaler elektromekaniske kuttere hvor det er mulig, men den enkelte lisens avgjør selv hvilket kutte redskap de bruker.

Talisman: Regner det som såpass sikkert at det er om det funker som er avgjørende. Aldri hørt om noen ulykker her i Norge, Men man ønsker jo selvfølgelig minst mulig eksplosiver om bord.

3. Når man skal velge hvilket kuttetool som skal brukes, hva er det som er avgjørende faktor når det kommer til utvelgelsen. Sikkerhet, pålitelighet, pris?

BP: Sikkerhet - pålitelighet - pris. I den rekkefølge

Statoil: Alle kuttere vi bruker er kvalifisert sikkerhetsmessig. Det er pålitelighet og pris som er avgjørende, og i noen tilfeller hvilke selskap som har wireline arbeidet om bord.

Tasiman: Pålitelighet. Vi gjør ofte dette of-line før riggen kommer inn. Hvis vi visste at tubing var kuttet slapp vi mye mob. Kostnadder for back-up utstyr. Ikke minst går det tid og penger hvis man må kutte på ny gjennom rig. Alle kuttere vi bruker er kvalifiserte.

4. Av de elektro mekaniske kuttetoolene som finnes på markedet er det Sondex sin Dect som virker som har slått best igjennom. Har dere noe erfaring med andre elektro mekaniske kuttetools? f.eks Weatherfords MCT, eller Baker Hughes sitt kuttetool?

BP: DECT'en har vi brukt. Jeg kjenner ikke til de andre tool'ene

Statoil: DECT er det eneste elektromekaniske kutte toolet som er kvalifisert for Statoil. Weatherford sin MCT kutter bare små størrelser tbg, og er lite aktuell for oss. Baker sin MPC er et interessant redskap som foreløpig ikke finnes tilgjengelig i Norge, men vi har nær kontakt med BH om et kvalifiseringsløp for å ta dette i bruk.

Talisman: De jeg spurte har kun erfaring med Sondex.

5. Hva er deres erfaring med å kjøre elektro mekaniske kuttetools fremfor eksplosive/kjemiske og RCT?

BP: Jeg er veldig for dette og vi har hatt veldig god erfaring med elektro mekaniske kuttetool

Statoil: Elektromekaniske tools er foretrukket av oss på grunn av rene kutt uten å skade casing på utsiden av tubing, samt at minimalt med debris blir igjen i brønnen. Vi opplevde en del problemer med DECT i starten, men ser at toolet fungerer bedre nå etter noen modifiseringer.

Talisman: Når strengen ikke er i kompresjon er mekanisk mer pålitelig. Har også mer kontroll med et mekanisk tool når det gjelder presisjon, og når nøyaktighet er viktig. Har også opplevd at RCTen kan lage såkalte "sveiseperler" og bli hengende fast i tubing/casing.