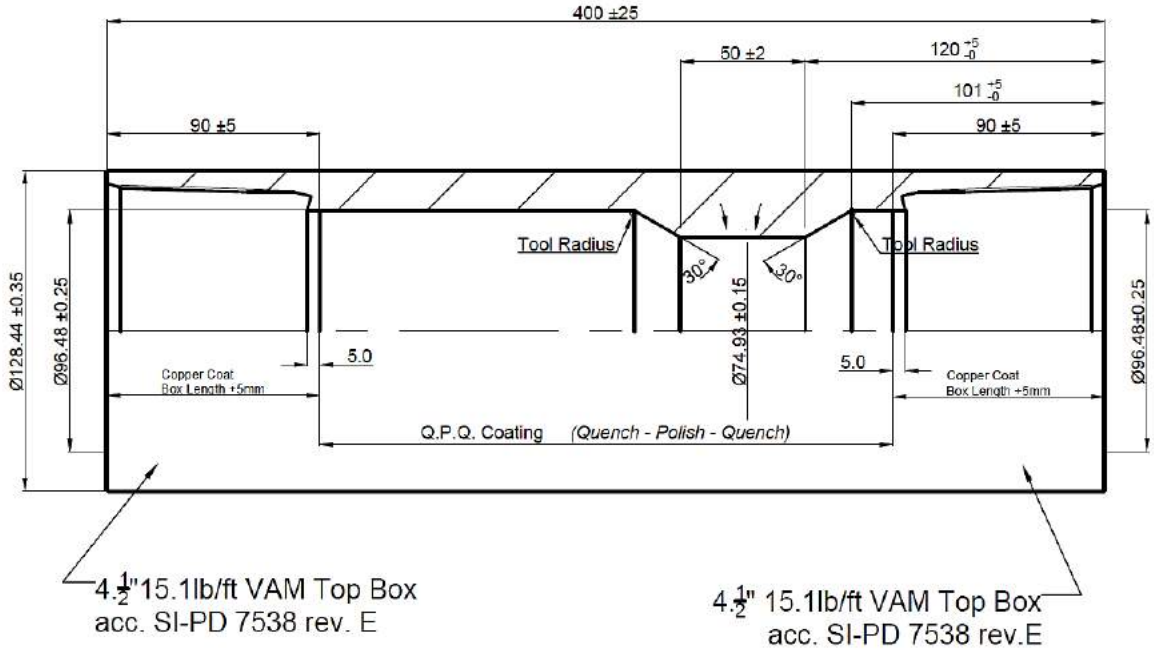
# Ball Seat Milling Yard Test Report

| | |
|---|---|
| Date: | August 09th and 10th 2016 |
| Participants: | Berend Van der Laan (ALS Wellvention) |
| | Timo Hein (Weatherford) (only 9th of August) |
| | Gunnar (Weatherford) (only 9th of August) |
| | Steffen Jurk (Wintershall) |
| Location: | ALS Wellvention, Assen |
| Subject: | Evaluate performance of two different mill designs to mill out ball seat subs on Ravn A-1 to liner drift ID of 3.7". |

## Introduction

Three ball seat subs have been run in the 4-1/2" 15.1 13Cr110 reservoir liner of the development well Ravn A-1. Subject of the yard test was to evaluate the feasibility of milling the ball seats to liner drift of 3.7". The material of the test specimen used for the yard test was identical to the ball seats installed in the well: 13Cr110 with a QPQ coating. The ball seat subs installed in the well have a specific ID of 2.7", 2.95" and 3.2". The ID of the test sub used for the yard test had an ID of 2.7" which equals the ID of the smallest installed ball seat sub in the well. A schematic drawing of the subs is shown below.

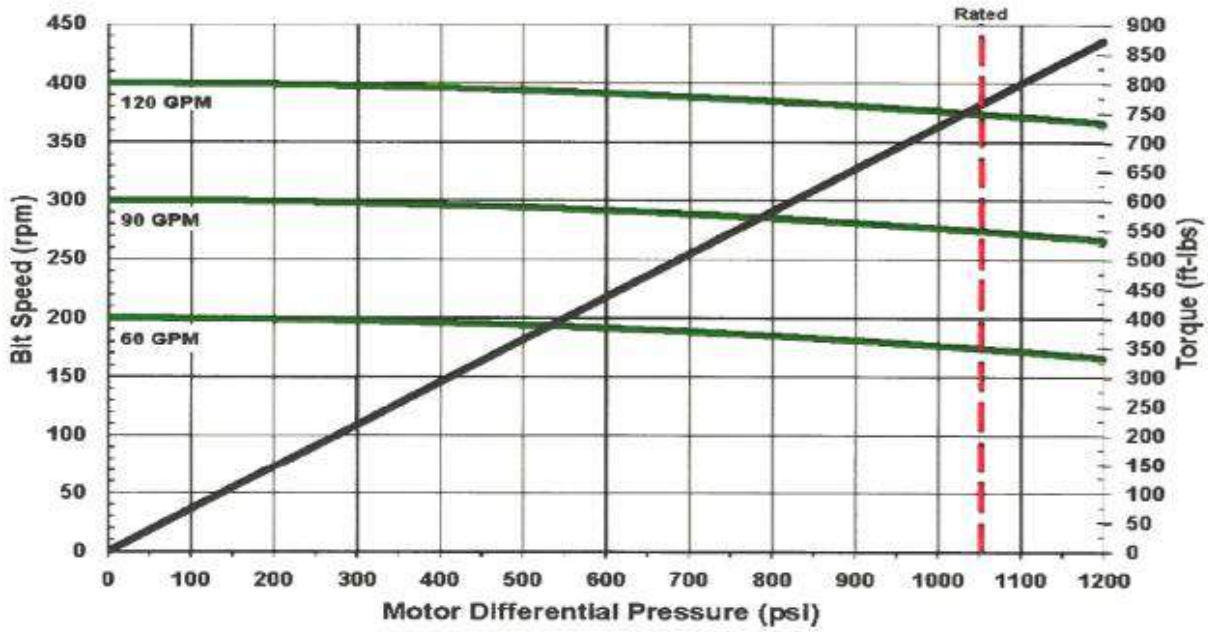



Two different mill types have been evaluated in the test: the Weatherford step mill and the ALS Hexagonal Dragon Back Step Mill.

**TEST SETUP**

Picture below show the test setup of the ALS Wellvention test bay.

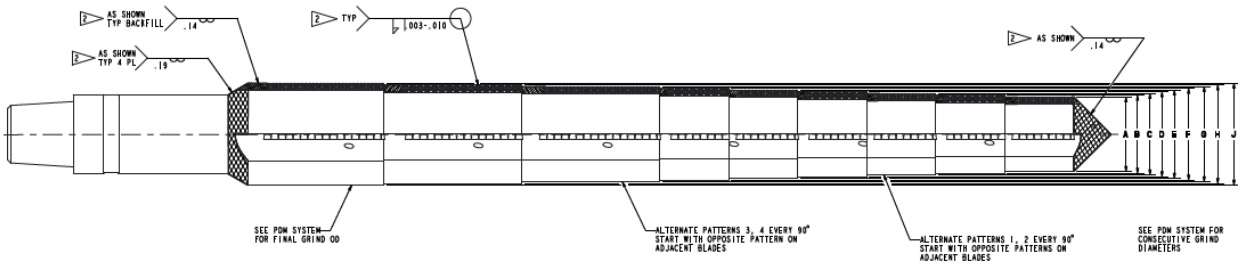

All mill tests have been performed with a 2-7/8” spirostar motor and a flowrate of 350 lpm.



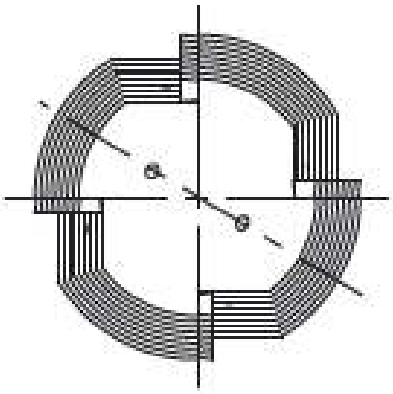
# TEST #1 - Weatherford Step Mill

### Mill Description Pre Test

The Weatherford step mill is divided in nine stages. Each stage is 1/8” larger / smaller than the previous stage. The first stage is 2.7” the last stage 3.7” in OD. Length of the entire mill is 1m. The mill is equipped with octagonal shaped tungsten carbide cutter elements. It provides 24 circulation ports at the sides and 2 circulation ports at the top. It has backreaming features on the shoulder.




| DIM | INCHES | MM |
|---|---|---|
| "A" | 2.700 | 68.58 |
| "B" | 2.825 | 71.76 |
| "C" | 2.950 | 74.93 |
| "D" | 3.075 | 78.11 |
| "E" | 3.200 | 81.28 |
| "F" | 3.325 | 84.46 |
| "G" | 3.450 | 87.63 |
| "H" | 3.575 | 90.81 |
| "J" | 3.700 | 93.98 |



**Test Results:**

#1 – Measured mill, confirmed lengths & diameters – as per drawing.

#2 - 3.7” gauge ring sits tight on the largest stage but is able to move – ok.

#3 – Performed jam test inside 2.7” ball seat sub with 2000 lbs & pulled free with 1,400 lbs – ok.

#4 – Performed jam test inside 2.7” ball seat sub with 3,000 lbs & pulled free with 2,000 lbs - ok.

#5 - Milled 2.7” ball seat with 350 lpm.

- Initially a high WOM was used to check the stall behavior of the mill. This was done due to simulate the uncertain weight transfer in the well. With 1,200 lbs WOM the motor stalled within one minute. Decreasing the WOM decreased the stalling tendency.
- With a constant and steady weight of 600 and 400 lbs the ROP decreased to almost zero, no milling progress was achieved. Best results have been achieved when trying to keep the SPP stable and apply small variations to the WOM (set down, neutral, set down, neutral, etc.) No autodrill should be used for milling!
- The first stages milled through the ball seat sub very easy and quick. The time required for each step to mill through the sub significantly increased with the OD of the steps. Last two stages took most part of the time. It took approximately 15 min (net time milling on seat) for the first +/- 50% of the length of the mill to pass through the ball seat sub. It took another 80 min for the remaining +/- 50% to pass through the ball seat.
- The overpull required to pull the mill free after a stall significantly increased with the OD of the stages. Around 2,500 lbs have been required to pull free after a stall on the first stages, more

than 10,000 lbs overpull have been required to pull free after a stall when milling with the last stages of the mill.

- Efficient net milling time required to mill out ball seat: 95 min (on bottom milling time).
- Number of stalls: 10 (First four stalls have been provoked by the request of the Wintershall representative to apply high WOM in order to determine operational limits of the motor in combination with the mill.)

| STEP | TIME | PUMP RATE | PRESSURE | Pull Force | Push Force | ORIFICES | COMMENTS |
|---|---|---|---|---|---|---|---|
| | hh:mm | Lpm | bar | Lbs | Lbs | mm | |
| 1 | 10:48 | 0 | 0 | | 2000 | | Set wait on Wheaterford bitt static test |
| 2 | 10:50 | 0 | 0 | | 3000 | | Set wait on Wheaterford bitt static test |
| 3 | 10:57 | 135 | 3 | | | | Funtiontest PDM + Weatherford mill |
| 4 | 11:00 | 200 | 5 | | | | |
| 5 | 11:01 | 300 | 12 | | | | |
| 6 | 11:02 | 350 | 15 | | | | |
| 7 | 11:03 | 400 | 20 | | | | |
| 8 | 11:05 | 350 | 15 | | 624 | | Start test |
| 9 | 11:07 | 350 | 20 | | 624 | | Tag ball seat |
| 10 | 11:09 | 350 | 32 | | 1245 | | Increase weight |
| 11 | 11:10 | 350 | | | 1245 | | Stall #1 |
| 12 | 11:12 | | | 2259 | | | Pull mill free |
| 13 | 11:18 | 350 | 15 | | | | Start pumping #2 |
| 14 | 11:19 | 350 | | | 1245 | | Stall #2 |
| 15 | 11:20 | | | 2464 | | | Pull mill free |
| 16 | 11:21 | 350 | | | | | Start pumping again #3 |
| 17 | 11:22 | 350 | 25 | | 900 | | Tag ball seat |
| 18 | 11:24 | | | | | | Loose connection, stop pumping. O-ring broken. |
| 19 | 11:29 | 350 | 15 | | | | Start pumping #4 |
| 20 | 11:30 | 350 | 34 | | 900 | | Tag ball seat |
| *21* | 11:32 | *350* | 103 | | 900 | | Stall #3 |
| *22* | 11:32 | | | 2672 | | | Pull mill free |
| 23 | 11:34 | 350 | 14 | | 900 | | Start pumping #5 |
| 24 | 11:34 | 350 | 52 | | 900 | | Tag ball seat |
| 25 | 11:37 | 350 | 30 | | 900 | | Pressure decrease |
| 26 | 11:41 | 350 | 98 | | 900 | | Stall #4 |
| 27 | 11:49 | | | 5753 | | | Pull mill free |
| 28 | 11:50 | 350 | 19 | | | | Start pumping #6 |
| 29 | 11:51 | 350 | 105 | | 624 | | Tag ball seat, stall #5 |
| 30 | 11:53 | | | 6985 | | | Pull mill free |
| 31 | 11:53 | 350 | 20 | | | | Start pumping #7 |
| 32 | 11:53 | 350 | 55 | | 624 | | Tag ball seat |
| 33 | 11:57 | | | | | | Stop pumping, PDM at end, change |
| 34 | 12:02 | 350 | 15 | | 624 | | Start pumping #8 |
| 35 | 12:07 | 350 | 38 | | 624 | | Tag ball seat |
| 36 | 12:08 | 350 | 110 | | 624 | | Stall #6 |
| 37 | 12:08 | | | 6985 | | | Pull mill free |
| 38 | 12:11 | 350 | 17 | | 400 | | Start pumping #9 |
| 39 | 12:11 | 350 | 17 | | 400 | | Tag ball seat |
| 40 | 12:37 | 350 | 20 | | 624 | | Set off weight 10 bar |
| 41 | 12:40 | | | | | | Stall#7 |
| 42 | 12:45 | | | 10500 | | | Pull mill free |
| 43 | 12:45 | | | | | | Stop Pumping Lunch |
| 44 | 13:50 | | | | min set weight | | Tag restriction ball seat |
| 45 | 13:56 | 350 | 17 | | 400 | | Start pumping #10 |
| 46 | 13:58 | 350 | 52 | | 640 | | Stall#8 |
| 47 | 14:00 | 350 | | 10250 | | | Pull mill free |
| 48 | 14:01 | | | | 640 | | Start pumping #11 |
| 49 | 14:04 | 0 | | 10750 | | | set down / neutral |
| 50 | 14:05 | 350 | | | | | Stall#9 |
| 51 | 14:07 | 350 | 17 | | 400 | | Start pumping #12 |
| 52 | 14:11 | 350 | 20 | | 640 | | set weight |
| 53 | 14:15 | 350 | 30 | | 640 | | set down / neutral |
| 54 | 14:21 | 350 | 60 | | 640 | | set down / neutral |
| 55 | 14:23 | 350 | 104 | | | | Stall#10 |
| 56 | 14:24 | 0 | | 9344 | | | Pull mill free |
| 57 | 14:25 | 350 | 17 | | 640 | | Start pumping #13 |
| 58 | 14:27 | 350 | 25 | | 640 | | set down / neutral |
| 59 | 14:47 | 350 | 17 | | 640 | | stop RIH |
| 60 | 14:48 | 350 | 17 | | | | POO stop pumping |

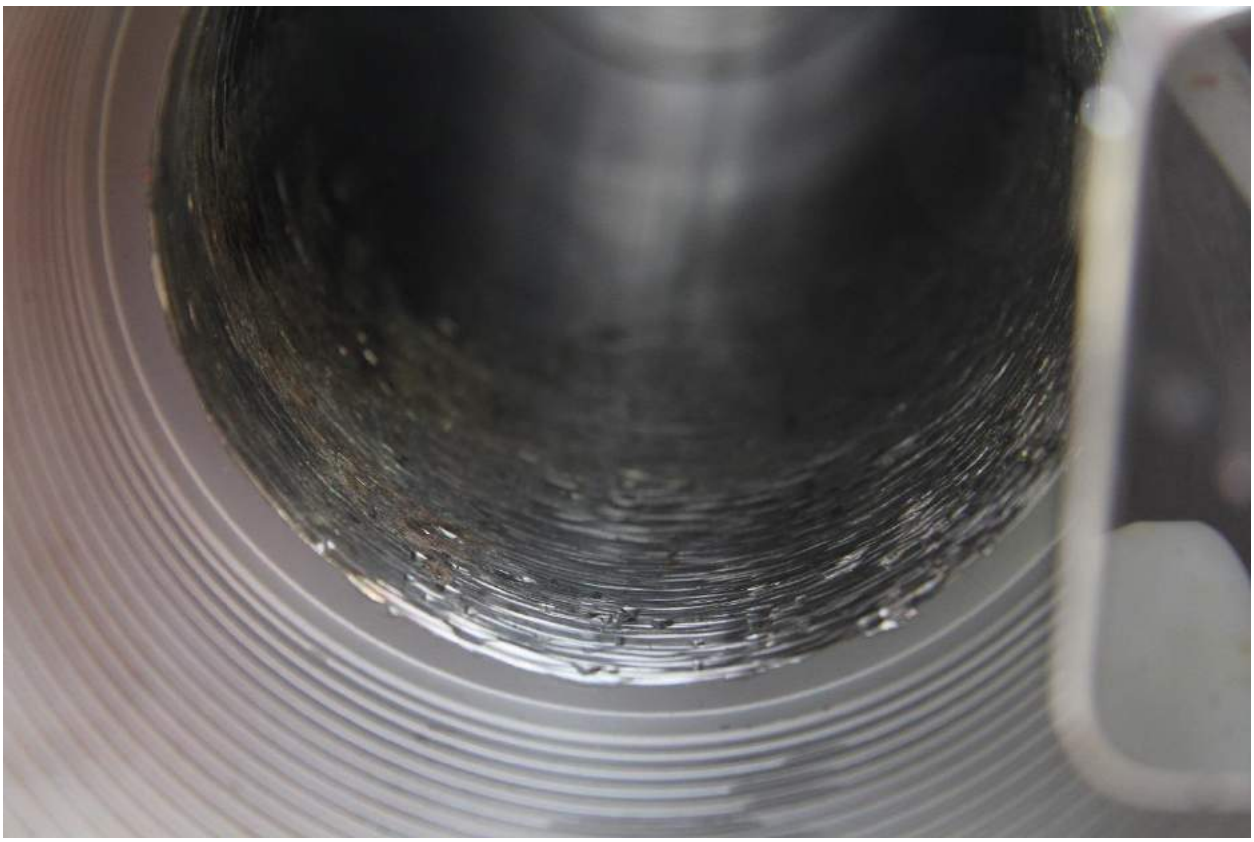
**Post Test Observations**

#1 – Drifted milled out ball seat with 3.7” – drift fits through ball seat sub.

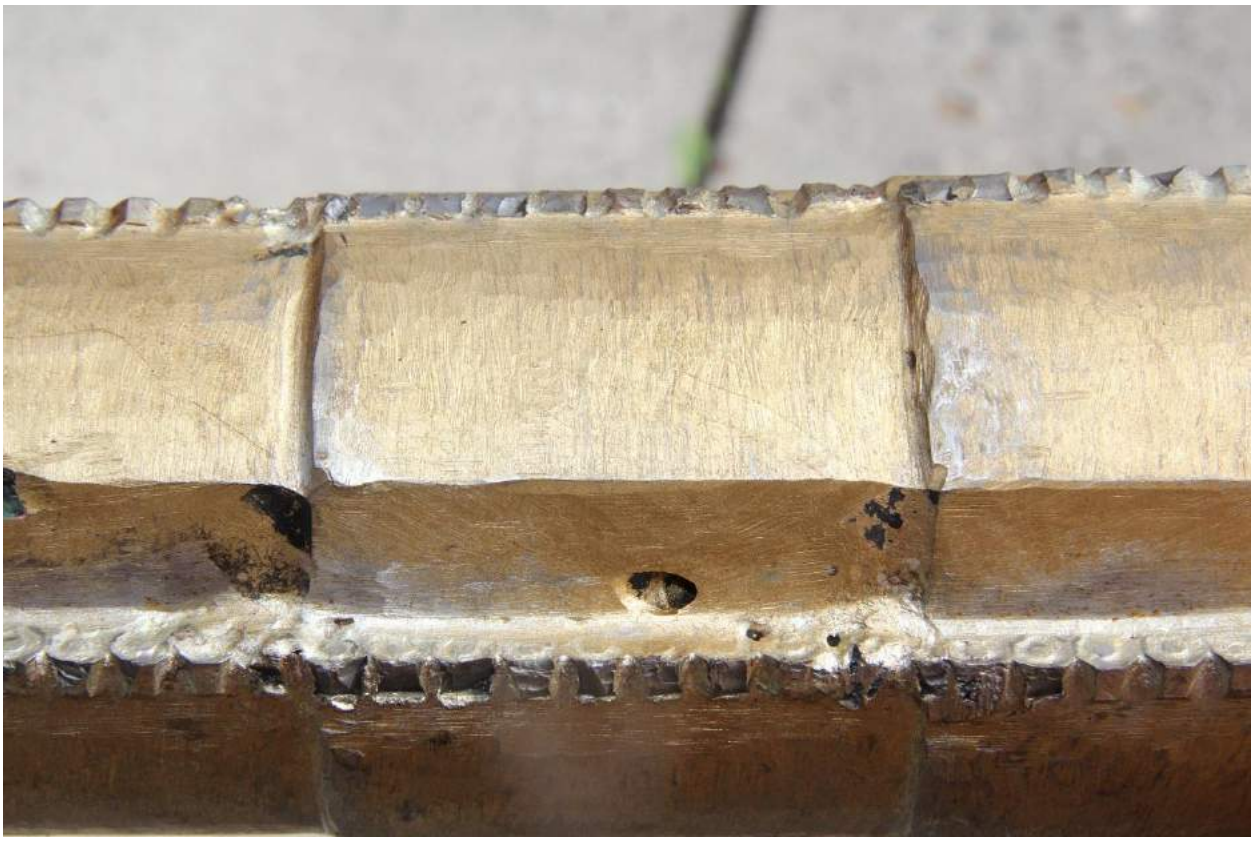
#2 – Checked OD of the mill with 3.7” gauge ring – not undergauged

#3 – For amount and shape of swarf created refer to pictures below.

#4 – Some wear was observed in the 4-1/2” tube.



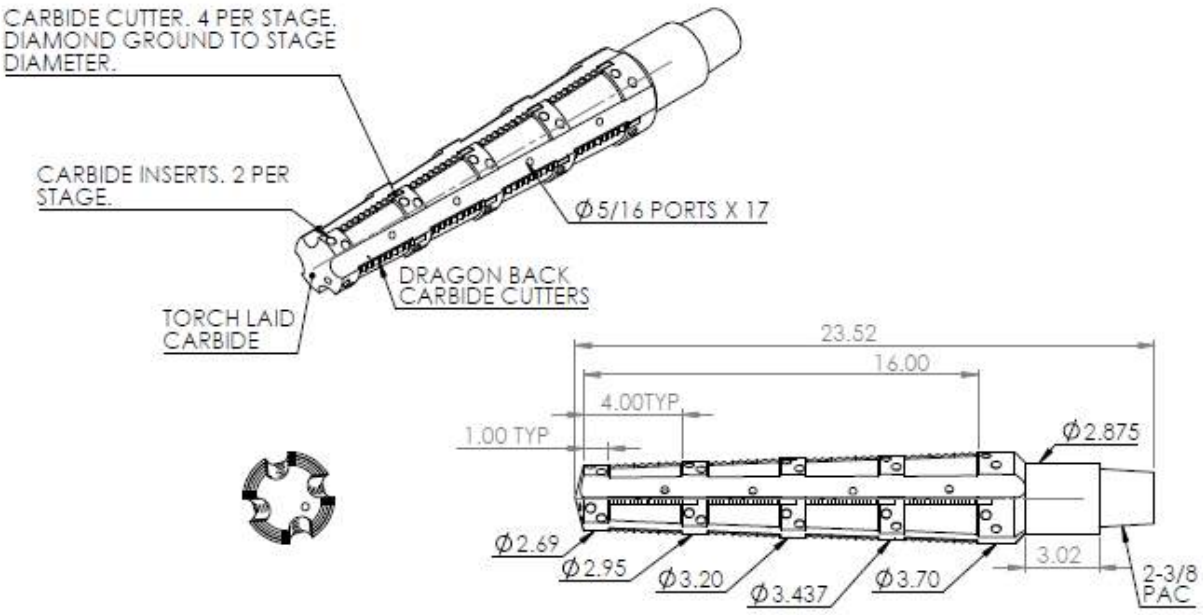
#5 – Mill still functional. Some damage primarily on the first cutter elements of each stage.



# TEST #2 – ALS Hexagonal Dragon Step Back Mill

### Mill Description Pre Test

The ALS step mill is divided in four stages. Different to the Weatherford mill the stages are slightly tapered and not parallel. The stages are separated by guide rings with an OD of 2.7”, 2.95”, 3.2” and 3.45”. Purpose of the guide rings is to support the mill to be in center when milling the ball seats. The mill is equipped with triangular shaped tungsten carbide cutter elements. It provides 16 circulation ports at the sides and 1 off centered circulation port at the nose. Circulation ports are larger than the ports of the Weatherford mill. It has backreaming features on the shoulder and tungsten carbide inserts on shoulder and guide rings for wear protection. On the first glance the mill appears more “aggressive” compared to the Weatherford mill.



**Test Results:**

#1 – Measured mill, confirmed lengths & diameters – as per drawing.

#2 - 3.7” gauge ring sits tight on the largest stage but is able to move – ok.

#3 – Performed jam test inside 2.7” ball seat sub with 2000 lbs & pulled free, no overpull observed - ok.

#4 – Performed jam test inside 2.7” ball seat sub with 3,000 lbs & pulled free with 1,000 lbs - ok.

#5 - Milled 2.7” ball seat with 350 lpm.

- **Milled first 30 cm with 1,200 lbs WOM with no significant resistance, stalls or pressure spikes within 6 minutes(!!)** To test the limits of the system increased the WOM to 1,500 lbs and observed immediate stalls. Stalling tendency continued with 900 and 600 lbs WOM. Stalling tendency significant increased once 3.7” shoulder in the ball seat area. Shoulder has no active cutting structure. Almost no ROP with 3.7” shoulder in ball seat area. Shoulder needs modification!
- Overpulls required to pull mill free after stalls generally between 5000 and 10000 lbs and higher than with Weatherford mill.
- Efficient net milling time required to mill out 2.7” ball seat: 65 min (on bottom milling time).
- Number of stalls: 14

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Test date:*** | 8/9/2016 | ***Job Nr.:*** | | | | ***Customer:*** | Wintershall |
| ***Engineer:*** | LG / BvdL | ***Tool number:*** | | | | | |
| ***Test description:*** | | Ball seat milling Wellvention | | | | | |
| ***Reason for test:*** | | | | | | | |

| ***STEP*** | ***TIME*** | ***PUMP RATE*** | ***PRESSURE*** | ***Pull Force*** | ***Push Force*** | ***ORIFICES*** | ***COMMENTS*** |
|---|---|---|---|---|---|---|---|
| | hh:mm | Lpm | bar | Lbs | Lbs | mm | |
| 1 | 8:43 | 0 | 0 | NA | 2000 | | Set wait on Wellvention mill static test |
| 2 | 8:47 | 0 | 0 | 1000 | 3000 | | Set wait on Wellvention mill static test |
| 3 | 8:48 | 135 | 2 | | | | Funtiontest PDM + Wellvention mill |
| 4 | | 200 | 5 | | | | |
| 5 | | 300 | 10 | | | | |
| 6 | | 350 | 14 | | | | |
| 7 | | 400 | 18 | | | | |
| 8 | 8:52 | 350 | 14 | | 624 | | Start test |
| 9 | 8:54 | 350 | 21 | | 624 | | Tag ball seat |
| 10 | 8:55 | 350 | 26 | | 1245 | | Increase weight |
| 11 | 9:01 | 350 | 104 | | 1500 | | Stall #1 |
| 12 | 9:03 | | | 10000 | | | Pull mill free |
| 13 | 9:05 | 350 | 15 | | | | Start pumping #2 |
| 14 | 9:07 | 350 | 104 | | 1500 | | Stall #2 |
| 15 | 9:08 | | | 8000 | | | Pull mill free |
| 16 | 9:09 | 350 | 14 | | | | Start pumping again #3 |
| 17 | 9:10 | 350 | 104 | | 900 | | Stall #3 |
| 18 | 9:11 | | | 9000 | | | Pull mill free |
| 19 | 9:13 | 350 | | | | | Start pumping #4 |
| 20 | 9:14 | 350 | 34 | 6200 | 900 | | Stall #4 |
| 21 | 9:17 | *350* | 14 | | 624 | | Start pumping #5 |
| *22* | 9:19 | *350* | 104 | 2672 | 900 | | Stall#5 |
| 23 | 9:20 | | | 7200 | | | Pull mill free |
| 24 | 9:21 | 350 | 14 | | 900 | | Start pumping #6 |
| 25 | 9:22 | 350 | 23 | | 624 | | Tag ball seat |
| 26 | 9:24 | 350 | 104 | | 624 | | Stall#6 |
| 27 | 9:25 | | | 6000 | | | Pull mill free |
| 28 | 9:26 | | | | | | Welding test tubing |
| 29 | 9:31 | | | | | | Start pumping #7 |
| 30 | 9:32 | 350 | 23 | | 624 | | Tag ball seat |
| 31 | 9:36 | | | 8000 | | | Stall#7 |
| 32 | 9:38 | 350 | 15 | | | | Start pumping #8 |
| 33 | 9:39 | 350 | 25 | | 624 | | Tag ball seat |
| 35 | 10:09 | 350 | 103 | 3100 | | | Stall#8 |
| 36 | 10:10 | | | 3100 | | | Pull mill free |
| 37 | 10:15 | | | | | | Inspection at Mill |
| 38 | 10:50 | 350 | 22 | | 624 | | Start pumping #9 |
| 39 | 10:55 | | | | | | Stop pumping Wlding test pipe |
| 40 | 11:06 | 350 | 15 | | 624 | | Start pumping #10 |
| 41 | 11:07 | | | 5500 | | | Stall#9 |
| 42 | 11:08 | 350 | 15 | | 624 | | Start pumping #11 |
| 43 | 11:09 | | | 6200 | | | Stall#10 |
| 44 | 11:10 | 350 | 15 | | 624 | | Start pumping #12 |
| 45 | 11:11 | | | 5900 | | | Stall#11 |
| 46 | 11:10 | 350 | 15 | | 624 | | Start pumping #13 |
| 47 | 11:13 | | | 5900 | | | Stall#12 |
| 48 | 11:14 | 350 | 15 | | 624 | | Start pumping #14 |
| 49 | 11:18 | | | 6000 | | | Stall#12 |
| 50 | 11:22 | 350 | 15 | | 624 | | Start pumping #15 |
| 51 | 11:25 | | | 9500 | | | Stall#14 |
| 52 | 11:26 | 350 | 15 | | 624 | | Start pumping #16 |
| 53 | 11:27 | 350 | 14 | | 0 | | Through ball seat |

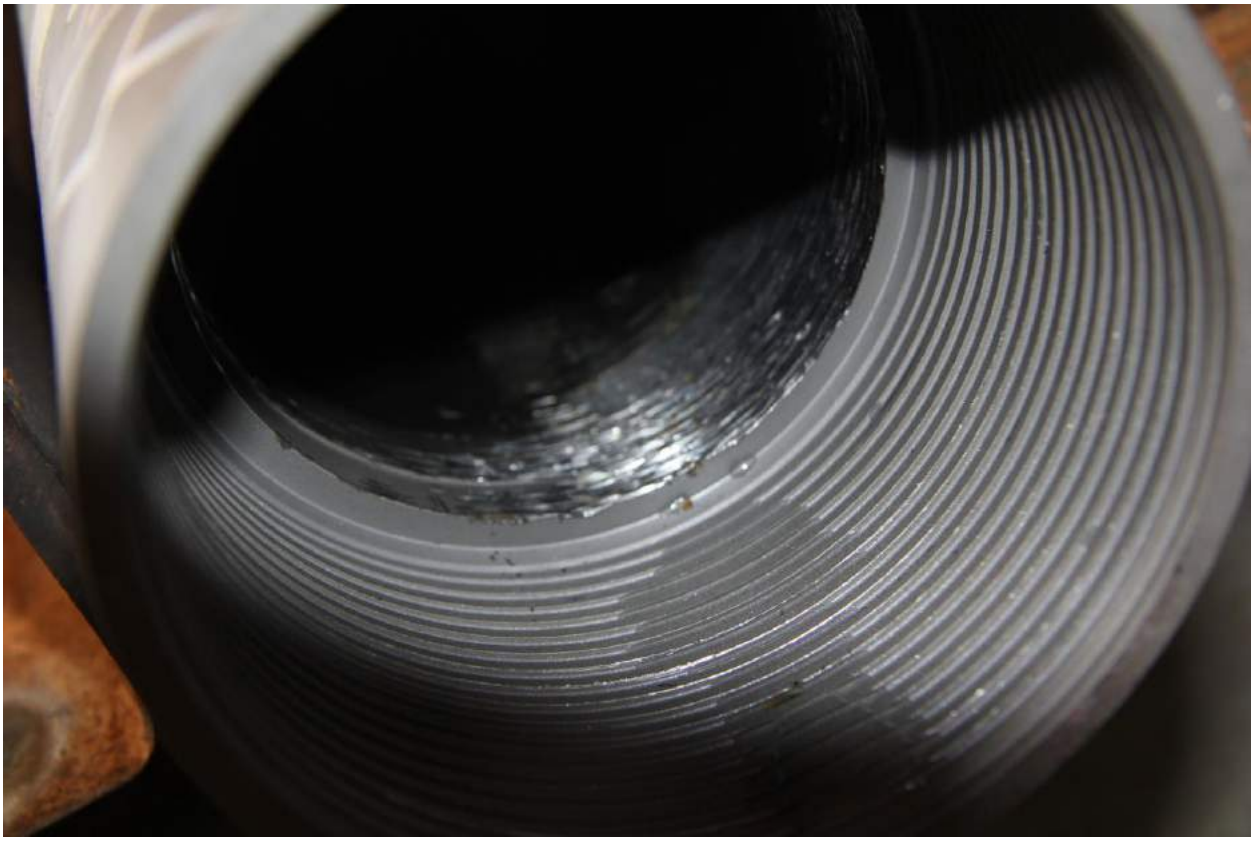
**Post Test Observations**

#1 – Drifted milled out ball seat with 3.7” – drift fits through ball seat sub.

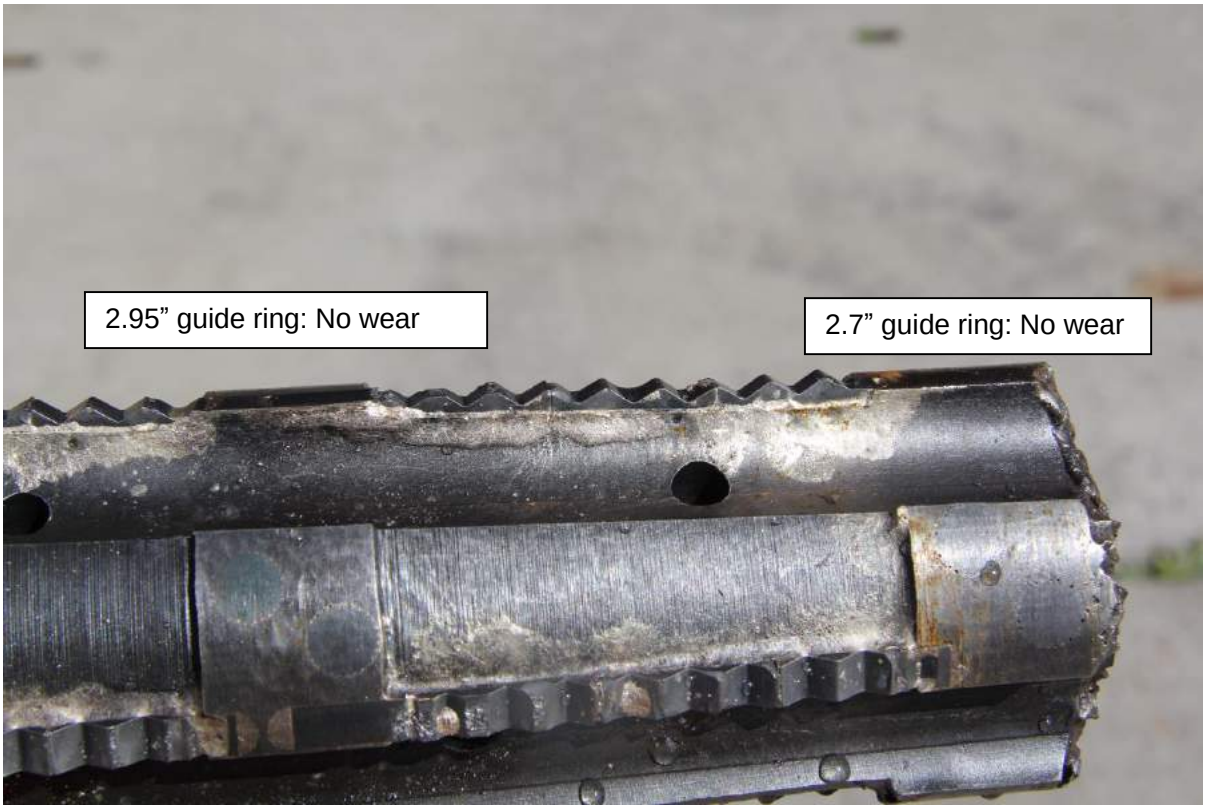
#2 – Checked OD of the mill with 3.7” gauge ring – not undergauged in area with tungsten carbide buttons of the shoulder, slightly undergauged (3.69 – 3.695”) in area with no tungsten carbide buttons on shoulder)

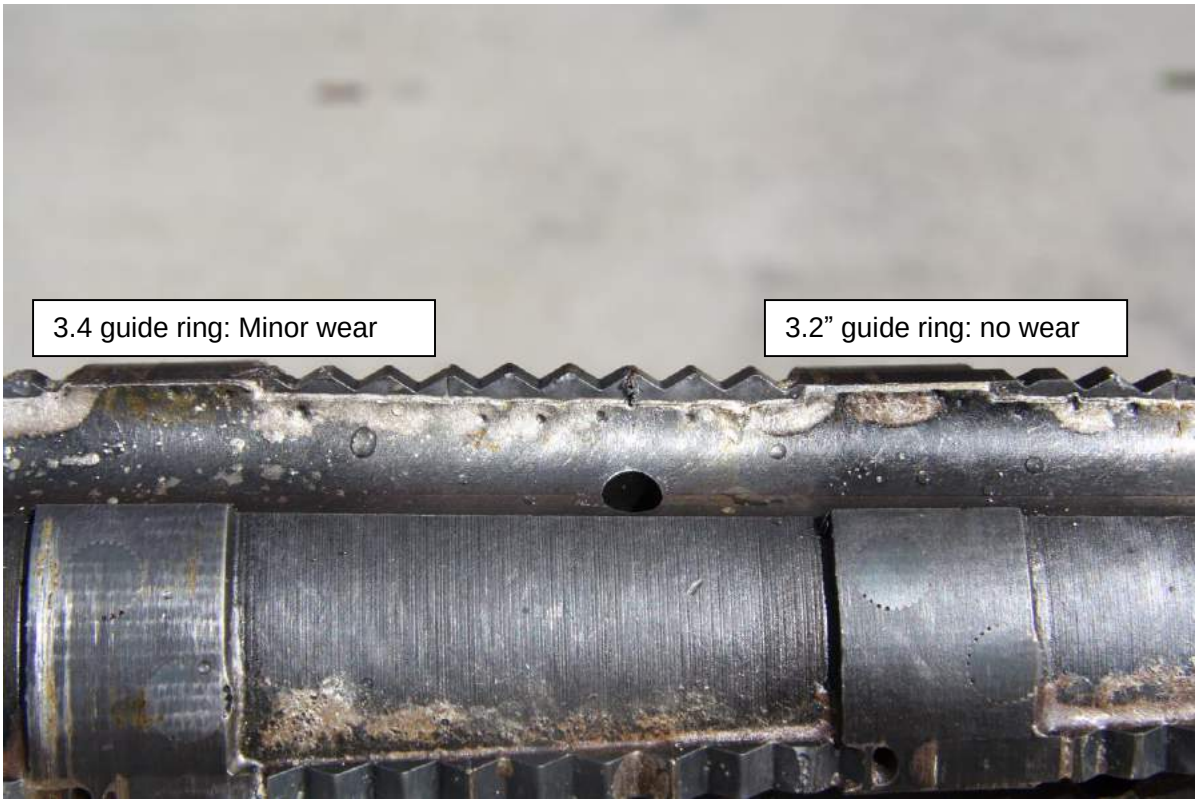
#3 – The ALS mill produced approx. three times more swarf compared to the ALS mill when milling ball seats of identical sizes. Looking at the size and shape distribution of the swarf, the swarf produced by the ALS mill is more homogeneous compared to swarf produced by the Weatherford mill. Suspect the Weatherford mill to produce more fines that bypassed the screens of the test bay.

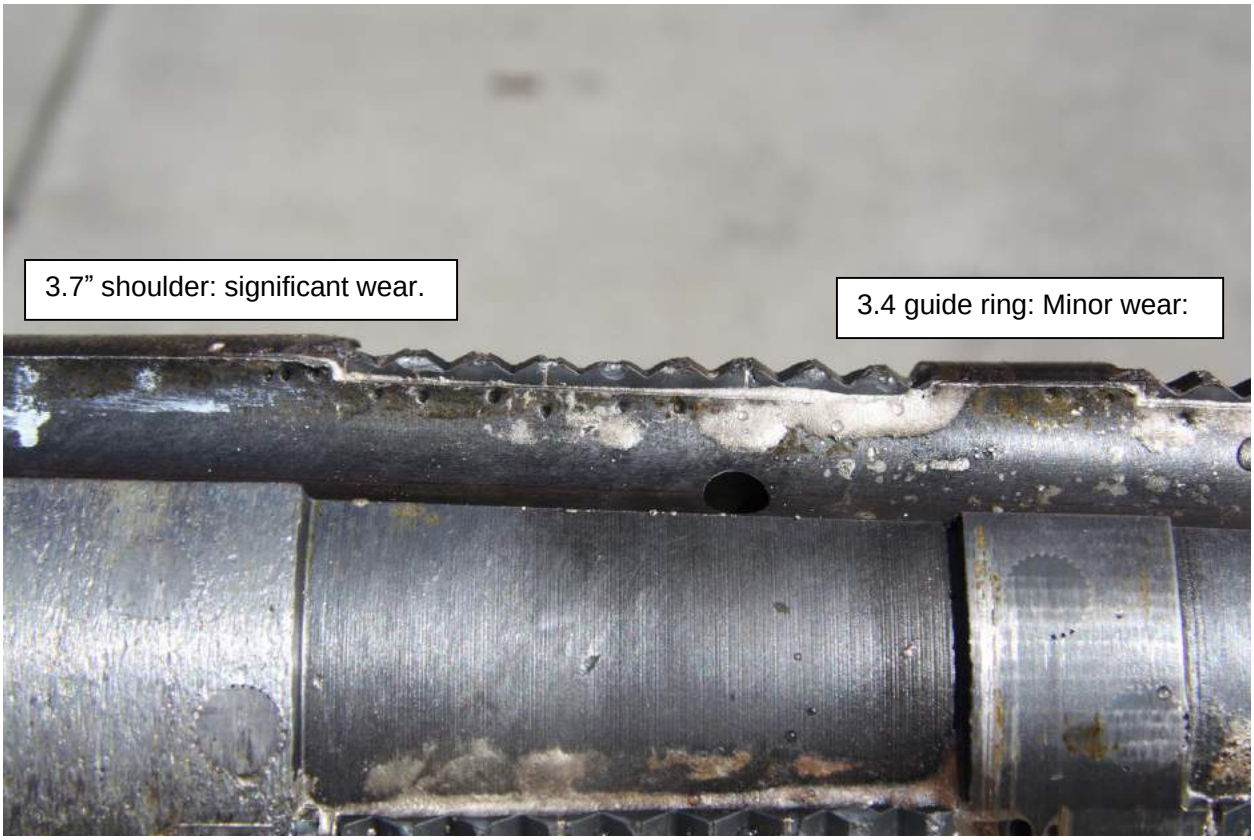
#4 – Some wear was observed in the 4-1/2” tube. Wear is less compared to wear caused by Weatherford mill.



#5 – Mill still functional. Minor damage on the cutting structure. Wear on the 3.7” shoulder. Minor wear on the 3.4” guide ring. No wear on 2.95”, 3.2” and 2.7” guide ring.




3.7” shoulder: significant wear.
3.4 guide ring: Minor wear:

# CONCLUSIONS, SUMMARY & PLAN AHEAD

The Weatherford step mill demonstrated an acceptable overall performance and proofed to be able to fulfill the scope of work. However it is sensitive to fluctuations in the WOM and caused several motor stalls that could significantly decreases motor lifetime in the HPHT environment of Ravn A-1.

Impressive performance of the ALS mill until the 3.7” shoulder reached the ball seat. 3.7” shoulder provides no active cutting action and needs modification. Plan ahead is to modify the mill with a half active cutting structure on the shoulder consisting of one row of tungsten carbide cutter elements. (similar to the Weatherford step mill - see pictures below). This modification should increase the performance of the mill in this area. If successful it is a clear favorite for the planned ball seat milling operations on Ravn A-1.

Next yard test with modified ALS mill is planned in one week time after the first test and release of this report.