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PRIVATE

AN AUGER TO REMOVE DEBRIS WHILE MILLING.

Natasha Stamler

PRIVATE

Research Note

Title **An Auger to Remove Debris While Milling.**

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REPORT ABSTRACT

This report summarizes my internship work for the summer of 2019. The goal of this internship was to design, prototype, and test an auger that could collect and convey wellbore debris; retain wellbore debris without leaking back down; operate within torque, power, size, and cost constraints; and be simple to assemble and maintain. Two prototypes were designed and tested, each with a different method of debris retention: one utilized weight on bit (WOB) and a vertical compression spring with a design similar to an upside-down plunger float valve; a second utilized the direction of rotation of the augers to close or open a gap.

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Introduction

Background

Debris causes loss of time and money by stopping production and damaging hardware. Current debris removal methods, such as coiled tubing and slickline bailers, can be expensive and have limited capabilities. To address this, Schlumberger has designed and tested a wireline debris removal tool that incorporates a downhole pump to separate solid debris from wellbore fluid and store it in bailers (Gourmelon, et al., 2019). However, this tool acts on its own; it cannot serve as an attachment to a milling tool as the suction component is at the bottom of the tool, preventing compatibility with standard bits. This means that when milling, such as through hard scale, a separate run must be performed to remove the residual debris. This results in unnecessary non-productive time (NPT). Mechanical mechanisms serve as the alternative to suction methods for debris removal. Mechanical debris removal methods are exciting because they can be simply integrated into current milling tools.

Purpose

The goal of this project was to design, prototype, and test an auger to remove debris while milling. Overall, the tool must collect and convey wellbore debris; retain wellbore debris without leaking back down; operate within torque, power, size, and cost constraints; and be simple to assemble and maintain. To reach these goals, several factors were considered, as shown in Table 1.

Table 1. Project considerations sorted by priority.

Consideration	Priority
Friction between auger and housing	HIGH
Operational torque	HIGH
Retention of collected debris	HIGH
Disposal of fluid/dehydration	MEDIUM
Bearing solution/supports	MEDIUM
Maintenance and assembly	MEDIUM
Debris cleanout at surface	LOW
Size and cost constraints	LOW

Current Solutions

Altus Intervention PrecisionCollector (Intervention, Altus, 2019)

The PrecisionCollector, produced by Altus Intervention, can remove debris while milling using an auger. It performs mechanical collection for hard, loose, and viscous materials. It can collect unconsolidated (proppants, sand), consolidated (settled barites, hard scale), and viscous (asphaltenes, waxes) debris.

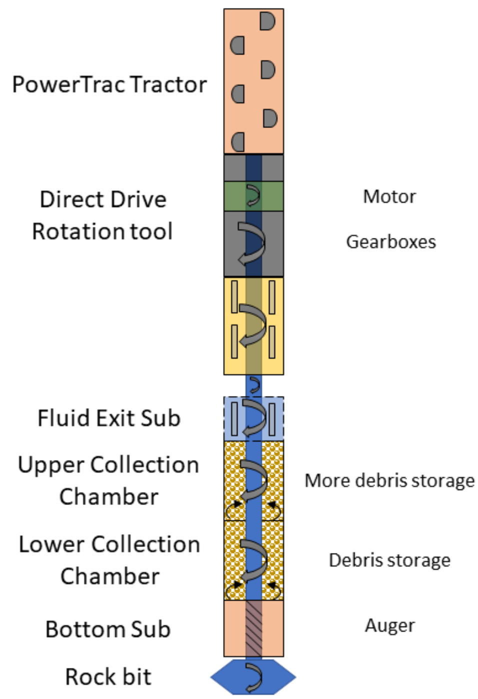


Figure 1. PrecisionCollector components.

Altus and its predecessor, Qinterra Technologies, have written several patents, articles, and case studies on the PrecisionCollector and related technologies. One of these is “System and method for cleaning a production tubing,” which describes a method of cleaning production tubing whereby a collection tool resides downhole while collecting and selectively releasing debris (Patent No. WO2018117854A1, 2017). Overall, these publications describe a tool involving an auger, check valve, several collection chambers (number is variable to accommodate different wellbore depths and amounts of debris), and a fluid exit sub, as shown in Figure 1. PrecisionCollector components.Figure 1. All of these are compatible with standard bits, rotation tools, and tractors (Altus Intervention, 2019). The description of the tool provided by Altus indicated several important areas to pursue. Key questions were formulated based on these areas:

1. Auger specifications – What is the pitch of the auger? What is the length and diameter of the auger relative to the housing?

2. Check valve between auger and collection chambers – How does the tool allow wellbore debris to flow up without collected debris flowing down?

3. Exit sub – How are solids and fluids separated? How is debris removed from the tool at the surface?

Prototypes

Material

The prototypes were 3D-printed on a Stratasys PolyJet printer using VeroWhitePlus, a standard form of rigid, opaque acrylic filament produced by Stratasys.

VeroWhitePlus™ (RGD835)

RIGID OPAQUE MATERIAL SIMULATING STANDARD PLASTICS

	ASTM	UNITS	METRIC	UNITS	IMPERIAL
Tensile Strength	D-638-03	MPa	50-65	psi	7250-9450
Elongation at Break	D-638-05	%	10-25	%	10-25
Modulus of Elasticity	D-638-04	MPa	2000-3000	psi	290,000-435,000
Flexural Strength	D-790-03	MPa	75-110	psi	11000-16000
Flexural Modulus	D-790-04	MPa	2200-3200	psi	320,000-465,000
HDT, °C @ 0.45MPa	D-648-06	°C	45-50	°F	113-122
HDT, °C @ 1.82MPa	D-648-07	°C	45-50	°F	113-122
Izod Notched Impact	D-256-06	J/m	20-30	ft lb/inch	0.375-0.562
Water Absorption	D-570-98 24hr	%	1.1-1.5	%	1.1-1.5
Tg	DMA, E»	°C	52-54	°F	126-129
Shore Hardness (D)	Scale D	Scale D	83-86	Scale D	83-86
Rockwell Hardness	Scale M	Scale M	73-76	Scale M	73-76
Polymerized Density	ASTM D792	g/cm3	1.17-1.18		
Ash Content	USP281	%	0.23-0.26	%	0.23-0.26

Figure 2. Stratasys VeroWhitePlus material data sheet. (Stratasys, 2016)

Hand crank

A hank crank was designed and attached to the top of the prototypes to allow for manual testing. Although the crank was designed to be removable from the prototypes due to the hex connection between the crank and the auger shaft, it was super glued to the prototypes for ease of operation during the horizontal tests.

Figure 3. Components of hand crank: (a) shaft, (b) crank, and (c) fully assembled hand crank on tool.

Tolerance

A standard 5% tolerance was used between the augers and the housing. This tolerance was sufficient between the augers and their associated housings as in all trials, the augers did not rub against the housing. A tighter tolerance was used for connections, such as between the augers. This was effective as the augers fit together snugly, preventing them from sliding out of place during gluing.

Prototype 1 – Weight on Bit

Design

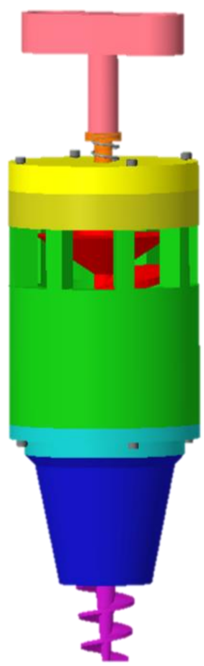


Figure 4. CAD of initial prototype in Creo.

The initial prototype was designed to address the major questions identified from research into past debris removal tools. The main design concept was to utilize weight on bit (WOB) to passively allow debris to flow upwards when debris was being conveyed, but automatically seal once conveyance stops to prevent collected debris from falling back down and out of the tool. The tool included several components, as shown Figure 5, to intake, convey, store, and release debris. The key components, the augers and the check valve, are described in detail below.

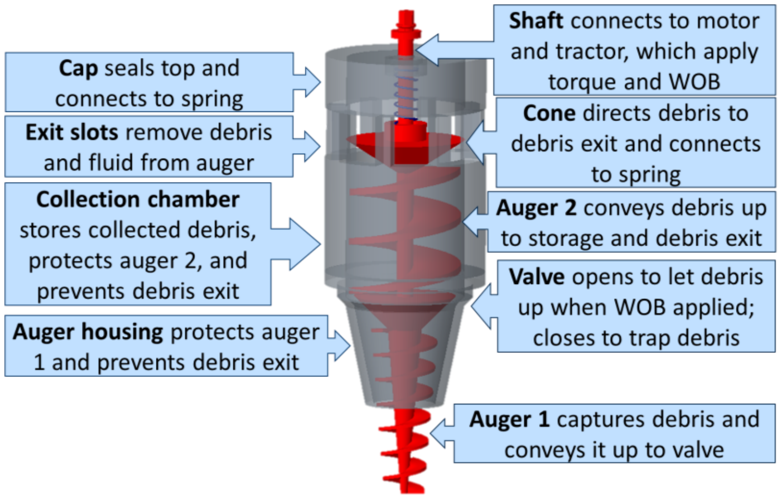


Figure 5. Labeled components of initial prototype.

The tool was 3D-printed to test its capabilities with greasy and dry sand. The tool was printed in 8 pieces for ease of printing and to make the tool modular for improved maintenance and observation and to allow for adjustments for future prototypes.

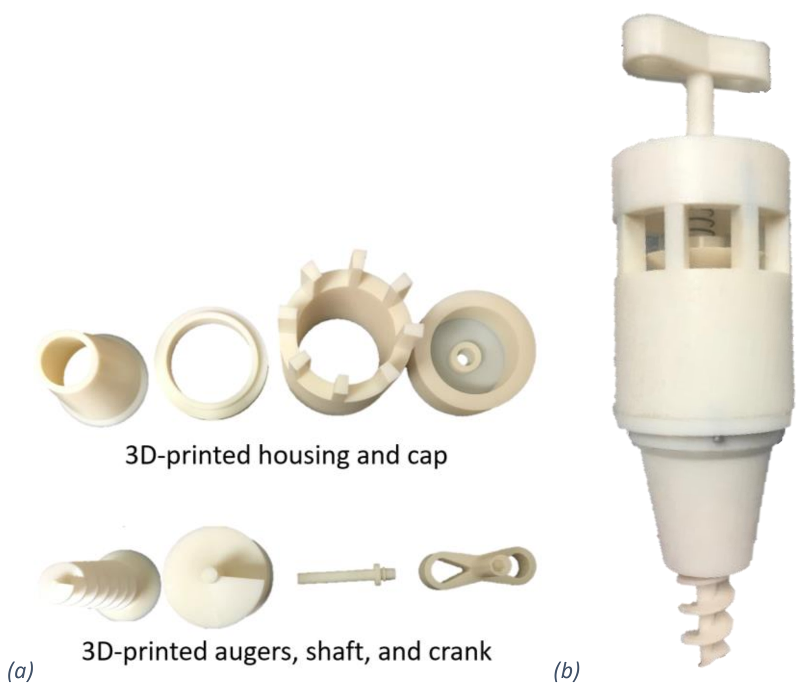


Figure 6. 3D-printed prototype (a) components and (b) assembled.

Attachments and interfaces

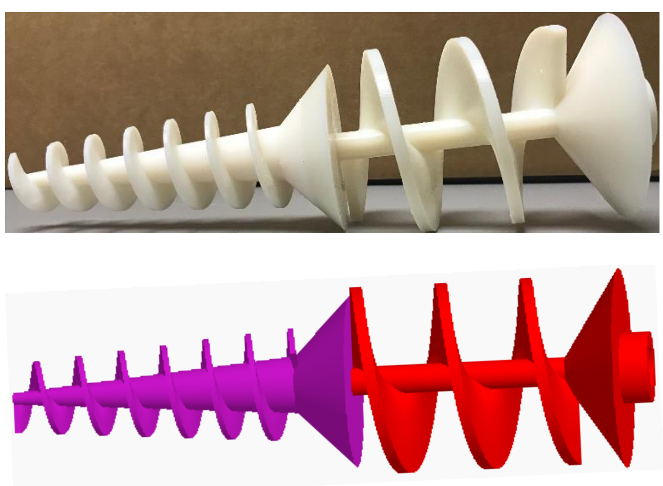
A variety of different attachment methods were used to ensure that the prototype would withstand the rotation and compressive loads of testing, while also allowing modularity for some components to be updated in future testing trials.

Table 2. List of attachment method for each component interface in initial prototype.

Lower Component	Upper Component	Attachment Method	Removable?
Lower auger	Upper auger	Tight tolerance, super glue	No
Upper auger	Shaft	Super glue	No
Upper auger	Spring	Slot	Yes
Spring	Cap	Compressive force	Yes
Shaft	Handle	Hex, super glue	No
Lower auger housing	Housing ring	Super glue	No
Housing ring	Debris storage and exit	4 8-32 x 1” screws	Yes
Debris storage and exit	Cap	4 8-32 x 1” screws	Yes

Augers

The initial prototype had two different augers: the upper auger had a pitch of 1.5” and a cylindrical profile with a constant diameter of 3.5”; the lower auger had a pitch of 0.75” and a conical profile with a diameter ranging from 1.2” to 2”.



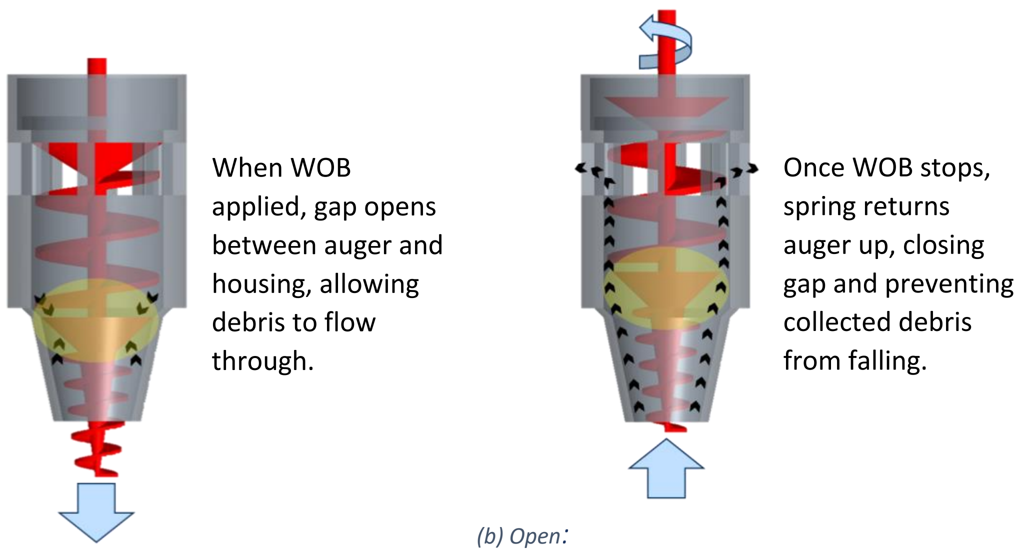
(a)

(b)

Figure 7. Assembled augers for initial prototype (a) 3D-printed and (b) in CAD, with upper auger (red) and lower auger (purple) indicated.

Check valve

A check valve was added between the two augers. By utilizing WOB, the check valve allows debris to flow upwards when the auger is engaged, but seals debris in when WOB is removed. Since the lower housing is conical, increasing in diameter higher up on the tool, the auger by default, because of the force of gravity of the augers and debris and the force of the compression spring on the augers, seals the tool as it sits in the narrower housing, as shown in Figure 8a. Once the auger hits debris, it is pushed up into the wider housing, creating a gap for debris to flow, as shown in Figure 8b.



(a) Closed: *(b) Open:*

Figure 8. Debris flow when valve is (a) closed and (b) open.

Testing

The two major aspects of the tool that had to be tested were the ability of the valve to retain debris and the ability of the augers to convey debris up.

A quick check of the tool dimensions was performed before testing with debris. As shown in Figure 9, a visual inspection shows that there is a tight enough tolerance between the lower auger and its housing to prevent debris from falling, assuming there is nothing obstructing or inhibiting its vertical motion.

Figure 9. Auger valve in closed position.

The auger was then tested in horizontal and vertical configurations, as shown in Figure 10 and Figure 11, with both dry and greasy sand.

Figure 10. Horizonal testing configuration.

Figure 11. Shaking out residual debris in vertical configuration.

Results

Overall, this prototype successfully retained debris but struggled to convey debris.

Table 3. Summary of success of mitigation methods for initial prototype.

		Horizontal		Vertical	
Consideration	**Mitigation**	**Dry**	**Greasy**	**Dry**	**Greasy**
Friction between auger and housing	5% tolerance.	3	3	3	3
Operational torque	Sufficient testing torque applied manually with hand crank.	3	3	3	3
Retention of collected debris	Valve traps debris when closed. Housing sealed.	3	3	2	3
Disposal of fluid	Exit slots.	-	-	-	-
Supports	Adequate vertical support but needed more radial support	2	2	2	2
Maintenance and assembly	2 sets of 4 screws for housing. Augers glued together, making prototype only partially modular.	2	2	2	2
Debris cleanout at surface	Exit slots.	3	2	2	1
Size and cost	Used only 3D-printed and off-the-shelf components. Prototype larger than actual tool to better see issues.	2	2	2	2

Ability to convey debris

The first prototype struggled to convey debris. This was due to several factors:

1. The spring was too stiff and constant WOB had to be applied – A significant downwards force had to be applied to keep the valve open. Initially, this was attributed to the high stiffness of the spring. However, after repeated trials, it became apparent that this was also the result of the inability to maintain constant WOB, especially for the less dense dry sand. Since there was no hard surface for the auger to press up against, there was not enough resulting upwards force to compress the spring.

2. The gap between the augers was too large – The valve itself created a 1” gap between the augers. Because of this, debris could not be conveyed efficiently until there was enough debris build up in the lower auger to push the debris past this gap.

3. Lower auger was too narrow relative to housing to intake debris efficiently – The width of the auger limits the amount of the debris the can be fed into the tool. Since the lower auger of this prototype had a conical shape, the width of the end of the lower auger

sticking out of the housing was a quite narrow 1.2”. This meant that debris was fed in at a low rate.

4. Greasy sand stuck to auger and housing – This is difficult to avoid due to the nature of the debris but could be reduced for the housing by putting bristles along the outer edge of the upper auger. Different materials may also cause greasy debris to adhere less.

Ability of exit slots to dispose of solid and fluid debris

Exit slots were initially included in the prototype to determine the appropriate size to drain fluid out of the tool. Solid debris was planned to be removed by reversing the rotation of the augers. However, for simplicity, and to better determine the functioning of other components of the tool, the slots were used to dispose of both fluid and solid debris for testing. The exit slots successfully debris once the debris reached the top of the storage chamber.

Length and diameter of lower auger

The length of the lower auger had to be determined to ensure that it was long enough to extend past the housing when the maximum upward force is applied so that debris could be taken up. However, it should not too long so as to unnecessarily increase material and time during manufacturing. Initially, the diameter of the lower auger was less than the housing so that the auger could recess inside of the housing to open the valve. However, as shown in red in Figure 12, this made horizontal milling inefficient as it created “blind spots”, areas within the housing where debris could not be conveyed.

Figure 12. Conical auger with "blind spots" highlighted in red.

Length and stiffness of spring

The length of the spring, in addition to other tool dimensions, such as the length of the lower auger, determines the amount of the lower auger exposed below the opening in the housing. The stiffness of the spring determines the upward force required to compress the spring and let debris into the tool.

The tool was tested with 2.5” long, 9.9 lbs./in. rate compression spring from McMaster-Carr (9657K506).

(a) 

(b)

Length	2.5"
OD	0.72"
ID	0.594"
Wire Diameter	0.063"
Compressed Length @ Maximum Load	0.7"
Maximum Load	17 lbs.
Rate	9.9 lbs./in.
Material	Music-Wire Steel
End Type	Closed and Ground

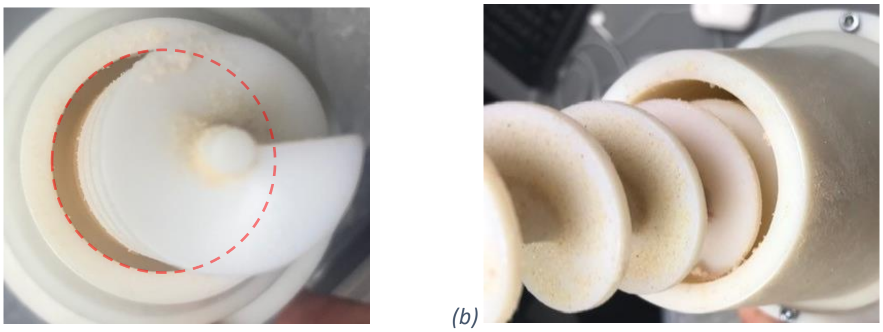
(McMaster-Carr, 2019a)

Figure 13. (a) Compression spring used for initial prototype testing and (b) spring details.

In order to minimize the downwards force opposing the upwards motion of the auger, the spring could be replaced by a coupling, such as the McMaster High-Speed Vibration-Damping Flexible Shaft Coupling (part numbers 6507K142 and 6507K690). However, in minimizing the downwards force, this means that the auger no longer automatically seals itself. Without a spring, besides for the relatively insignificant gravitational force due to the debris, there is no downwards force pushing the valve back down into the sealed position.

Auger supports

Although it did not seem to affect testing, the auger did not have sufficient radial support. This meant that the auger was off-center relative to the housing, as shown in Figure 14. For further testing, a bushing should be used to stabilize the auger radially. Vertically, the auger was sufficiently supported by the shaft.

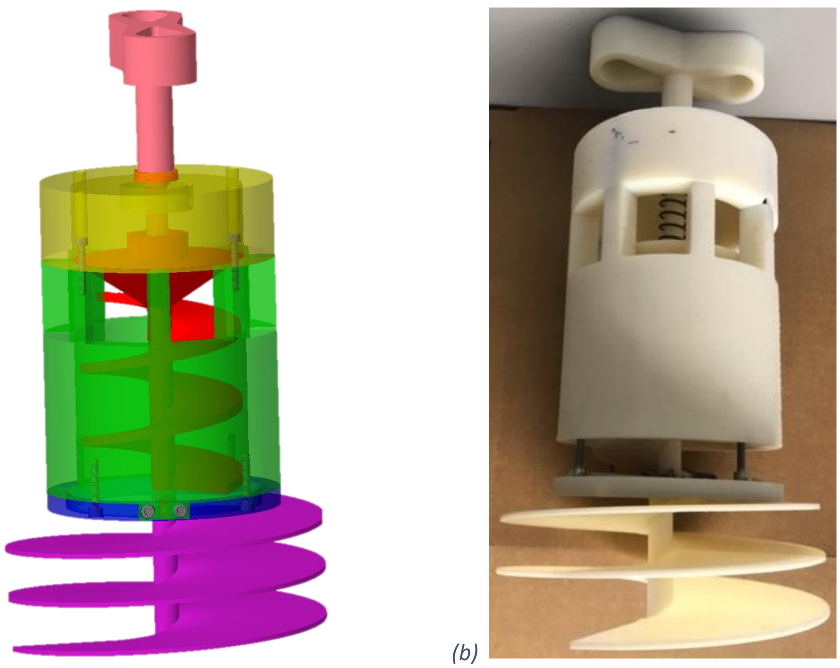


(a) *(b)*

Figure 14. (a) Bottom and (b) side view of lower auger indicating need for radial supports.

Prototype 2 – Ratchet

Design



(a) *(b)*

Figure 15. (a) CAD of secondary prototype in Creo and (b) 3D-printed prototype.

Ratchet

The ratchet takes advantage of the rotation and direction of rotation of the auger shaft. As shown in Figure 16, the auger shaft rotates a disc (teal) that either opens or closes a slot by aligning with a platform attached to the housing.

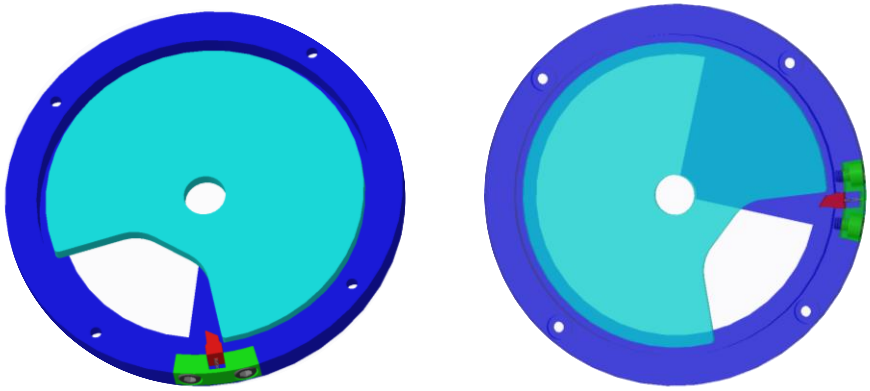


Figure 16. Ratchet valve, including disc (teal), housing (blue), and stopper assembly.

When the shaft is rotated counterclockwise, the disc is blocked by the flat left side of the stopper, as shown in Figure 17, preventing the gap from opening, sealing in the debris. In a log, the disc hitting the stopper would be indicated by a spike in torque detected by ReSOLVE sensors, a clear message to a tool operator in the field that the tool is sealed. When operating manually with the hand crank, the disc hitting the stopper should be felt by the operator as a significant increase in effort to rotate the tool. However, when the shaft is rotated clockwise, the disc pushes the stopper in, compressing the spring, and allowing the auger to spin and convey degree. As this prototype uses two right-hand augers, this means a gap can only be opened when debris can be conveyed. The stopper can be flipped to accommodate a left-hand auger.

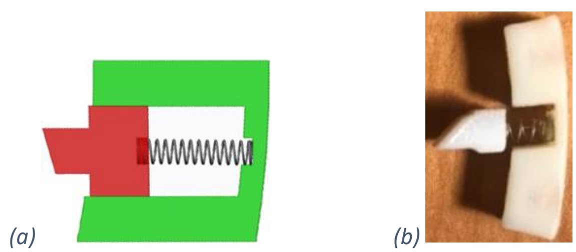


Figure 17. (a) Stopper assembly, including stopper (red), cap (green), and spring and (b) prototype stopper assembly.

Augers

Like the initial prototype, the secondary prototype had two different augers: the upper auger was the same as in the initial prototype, having a pitch of 1.5” and a cylindrical profile with a constant diameter of 3.5”; the lower auger had a pitch of 1” and a cylindrical profile with a constant diameter of 6.5”. The lower auger diameter was widened to larger than the housing diameter to be able to intake more debris than the initial prototype. This would prevent “blind spot” issues in the horizontal configuration.

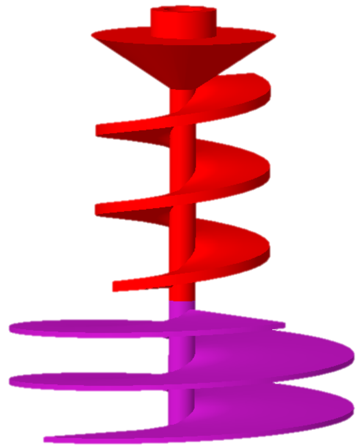


Figure 18. CAD of assembled augers for secondary prototype in Creo with upper auger (red) and lower auger (purple).

Attachments and interfaces

A variety of different attachment methods were used to ensure that the prototype would withstand the rotation and compressive loads of testing, while also allowing modularity for some components to be updated in future testing trials. When testing, there were issues with the strength of connection between the shafts, so super glue was switched to epoxy. In reality, this connection should be replaced with a pin or collar.

Table 4. List of attachment method for each component interface in second prototype.

Component 1	Component 2	Attachment Method	Removable?
Lower auger	Upper auger	Tight tolerance, epoxy	No
Upper auger	Shaft	Super glue	No
Shaft	Cap	Slot, super glue	No
Shaft	Handle	Hex, super glue	No
Disc	Shaft	Tight tolerance, super glue	No
Housing ring	Debris storage and exit	4 8-32 x 1” screws	Yes
Debris storage and exit	Cap	4 8-32 x 1” screws	Yes
Stopper cap	Housing ring	4 8-32 x 3/16” screws	Yes
Stopper cap	Spring	Super glue	No
Spring	Stopper	Super glue	No

Length and stiffness of spring

The length of the spring, in addition to other tool dimensions, such as the length of the stopper and the diameter of the disc, determines how much the disc interfaces with the stopper. This amount should be large enough the stop the rotation of the disc when spinning counterclockwise, but not too large so as to block the rotation of the disc when spinning clockwise. The stiffness of the spring determines the amount of torque that needs to be applied to the shaft for the disc to spin past the stopper. This amount should be as low as possible while maintaining a high enough maximum load to ensure that the spring is pushed in instead of bent side to side with the applied torque.

The tool was tested with a 0.25” long, 2.66 lbs./in. rate, 0.5 lbs. maximum load compression spring from McMaster-Carr (8969T112).

(a)

(b)

Length	0.25"
OD	0.12"
ID	0.1"
Wire Diameter	0.01"
Compressed Length @ Maximum Load	0.07"
Maximum Load	0.5 lbs.
Rate	2.66 lbs./in.
Material	316 Stainless Steel
End Type	Closed
Rate Tolerance	-0.27 to 0.27 lbs./in.
OD Tolerance	-0.005" to 0.003"

Figure 19. (a) Compression spring used for secondary prototype testing and (b) spring details. (McMaster-Carr, 2019b)

Results

Overall, the stopper allowed for only clockwise rotation, which should imply ability to convey debris. The flap blocked the gap when in the closed position, which should imply retention. However, this prototype was not tested with debris so there may be issues with debris falling out during counterclockwise rotation to close the gap. Debris may also black the stopper, although this is unlikely. Overall, design adjustments include widening the stopper and its slot to ease manufacturing and smooth rotation, angling the slot to be in line with the tilt of the stopper head, thickening the ring base, and printing the upper auger and disc as one piece for easier assembly in future prototypes.

Conclusion

The results of the prototypes of these designs indicate a preliminary proof of concept for the use of an auger to remove debris while milling. Further work must be done to ensure compatibility with the Schlumberger Active Debris Removal Module (ADRM), including existing milling bits and bailers. Calculations should be done referencing CEMA Standard 550 to determine the ideal auger pitch for relevant debris types and to determine the use cases for this tool. Optimization should also be done to reduce mass and cost and improve manufacturability and assembly of the tool.

Acknowledgements

Thank you to my manager, Gabriel Isaicu, and the rest of the Slim team, including Alan Sprain, Sherrie Chen, and Fayyaz Mehmood. Further thanks to Kyle Wiesenborn for design feedback. Special thanks to Rene Leal for 3D printing the prototype and Albert Dionisio, Joseph Casassa, and Mark Hinton for help acquiring parts and manufacturing adjustments to the prototype.

References

Gourmelon, P., Wiesenborn, K. & Chochua, G. (2019). "A Novel Approach to Wireline Debris Removal." SPE-194279-MS.

Haugen, I., Dossland, L., Brankovic, M., Osaland, E., Osugo, L., Grodem, M. & Gronnerod, A. (2017). "Electric-Line Deployed Lightweight Intervention Technology for The Effective Removal of Barium Sulphate Scale Obstructions from Small Diameter Wellbores." SPE-184758-MS.

Intervention, Altus. (2019). PrecisionCollector Spec Sheet. Retrieved from Altus Intervention: https://www.altusintervention.com/resources/spec-sheets/precisioncollector

Kleppam, T., Dahle, K. O., Tinnen, B., Brankovic, M., Osugo, L. & Danielsen, R. (2016). "Removing Settled Barites From a Wellbore Using an Electrically Powered Well Cleanout System." SPE-179102-MS.

Kulinowski, P. & Kasza, P. (2012). "Belt Conveyors for Belt Materials Calculations by CEMA 5th Edition." AGH University, Dept. of Mining, Dressing and Transport Machines.

McMaster-Carr. (2019a). Compression Spring. Retrieved from McMaster-Carr: https://www.mcmaster.com/9657k506

McMaster-Carr. (2019b). 316 Stainless Steel Corrosion-Resistant Compression Springs. Retrieved from McMaster-Carr: https://www.mcmaster.com/8969t112

Schwanitz, B. & McKay, A. (2007). "An E-Line Solution to Sand and Scale Remediation in High-Angle Wells." SPE 107243.

Shigley, J. E. & Mischke, C. R. 2004. *Mechanical Engineering Design* (7th ed.). New York, NY: McGraw-Hill.

Stratasys. (2016). The Complete Guide to 3D Printing Plastic Parts with PolyJet. Retrieved from Stratasys: https://www.stratasysdirect.com/technologies/polyjet#pj-materials