UiT
THE ARCTIC
UNIVERSITY
OF NORWAY

Faculty of Engineering Science and Technology

Development of Downhole Control Valve

Hassan Zakaria

Master of Science – Industrial Engineering (SHO6266)

June 2018

Title:

Development of Downhole Control Valve

Date:

01 06 2018

Classification:

Closed

Author(s):

Hassan Zakaria

Number of Pages:

79

Number of Attachments:

1

Subject Name:

Master Thesis – Final Report

Subject Code:

SHO6266

Faculty:

Faculty of Engineering Science and Technology

Master Program:

Industrial Engineering

Supervisor:

Geanette Polanco Pinerez

External Organization's/Company's Liaison:

Qinterra Technologies/ Dag Pedersen

Keywords (max 10):

Downhole Control Valve, CFD, FEA, Well intervention

Abstract (max 150 words):

This master thesis describes the design process of Downhole Control Valve, which is exposed to high concentration of corrosive fluids at high pressure and temperature. The valve is activated and controlled from well surface by increasing the pressure on top of it. The activation pressure allows internal sleeve in the valve to open the inlet flow ports.

Preface

This Master’s Thesis was written during November 2017 and June 2018 as a part of the master’s programme of Industrial Engineering at the Arctic University of Norway, supervised by Prof. Geanette Polanco Pinerez at UiT and Mr. Dag Pedersen at Qinterra Technologies.

Dedication

FOR MY NIECES AND NEPHEWS, THE FUTURE OF SYRIA

AHMAD, NOUR, SALI, AMJAD, MAIS, ABDUL WAHED, YOUSEF and ALISAR
MOHAMED, RAND, LEEN and MAJD
NABEEL, AMINA, AYA, RAMA and AHMAD
AHMAD, AYA, ROA, FIKRI and SARA
AMRO, YOUSEF, LUJAIN and JUNA

أهدي هذا العمل لبنات وابناء أخواتي وإخوتي, مستقبل سوريا

أحمد نور سالي مجد ميس عبد الواحد يوسف أليسار

محمد رند لين مجد

نبيل أمنة آية راما أحمد

أحمد آية رؤى فكري سارا

عمرو يوسف لوجين جنى

Acknowledgment

I wish to express my gratitude to my supervisor Prof. Geanette Polanco Pinerez for her patience, encouragement and concern that have made this project possible.

I would like to thank all professors in the Industrial Engineering department for providing creative and innovative environment.

I would also like to acknowledge the support of Qinterra Technologies and special regards for Dag Pedersen and all my colleagues for tremendous encouragements.

I especially appreciate my good friends for being in my life and give me the limitless inspiration and special regards for Tarek and Marina.

To a large extent, I could not have been able to complete this thesis without the love support and encouragement of my brothers and sisters. Adnan, Kanan, Dalal, Fatema, Ghassan and Abdul Wahed I can't say any better than thank you for encouraging me when I became frustrated with tough life.

Finally, no words describe my thanks to my mother and father for a lifetime of support which has made me who I am today.

Hassan Zakaria

Stavanger, 01.06.2018

Abstract

Designing for downhole environment is a challenging process. High pressure and temperature are the main well conditions that effect the design decisions and the tool geometry. Also, the well fluids can obtain high concentration of corrosive content such H_2S acid that plays major role in material selection.

The intention of this study is to develop Downhole Control Valve that can be connected to plug and packers system, where the valve should be controlled remotely from the wellhead without the use of well intervention methods. Avoiding the use of well intervention will reduce cost and optimize operation time.

Using the design process, the valve evolved from the idea, design requirements, the concepts development, concept selection, hand sketches, 3D CAD modelling, calculation, FEA simulation, CFD simulation, material selection and finally to prepare the model for prototype manufacturing.

This master thesis describes in detail the design process stages of Downhole Control Valve and as result, a unique solution of the valve has been achieved where the valve is designed to be exposed to high concentration of corrosive fluids at high pressure and temperature. The valve is activated and controlled from the wellhead by applying the pressure on top of it. The activation pressure can be adjusted by using calculated number of screws and allows internal sleeve in the valve to open the inlet flow ports. The material selection of the valve was based on traditional material that is commonly used in the industry standard.

The study definitively provides reliable solution of the design considering the harsh environment that will be exposed to.

The calculation used in the study provides the initial understanding of the future development. In the further research on the valve it is recommended to have more in depth CFD simulation for the design optimization.

Table of content

List of figures

List of tables

Abbreviations

API – American Petroleum Institute

BHA – Bottom Hole Assembly

BOP – Blow Out Preventer

CAD – Computer Aided Design

CBL – Cement Bond Log

CCL – Casing Collar Log

CET – Cement Evaluation Tool

CFD – Computational Fluid Dynamics

CT – Coiled Tubing

DCV – Downhole Control Valve

DHSV – Down Hole Safety Valve

FEA– Finite Element Analysis

HPHT – High Pressure and High Temperature

HSE – Health, Safety and Environment

ID – Inner Diameter

IMR – Inspection, Maintenance and Repair

LWI – Light Well Intervention

MD – Measured Depth

MSL – Main Sea Level

NCS – Norwegian Continental Shelf

OD – Outer diameter

P&A – Plug and Abandonment

POOH – Pull Out of Hole

PP&A – Permanent Plug and Abandonment

PSA – Petroleum Safety Authority

RIH – Run In Hole

SL– Slickline

TH – Tubing Hanger

WH – Well Head

WL – Wireline

XMT – Xmas Tree

1. Introduction

The design challenge in the well environment is to overcome the extreme well environment conditions. Well pressure and temperature are the main design constrains to design mechanisms and to select materials that can hold the big variation of these conditions. Also, the downhole tools are continually exposed to the different well mediums that cause material corrosion and finding engineering solutions to sustain the tools in the well is a big challenge.

Understanding the well geometry is one of the main aspect to design appropriate tools, for example studying the well completion type, the completion tools, the surfaces equipment and well intervention methods is very important for designing downhole tools that can adapt to the well structure. In the other hand, increasing awareness of safety requirements and reducing costs become essential of designing modern downhole tools.

This thesis will cover the design Downhole Control Valve (DCV) and the objectives of the work are listed below:

1.1. Objectives

1. Detailed study of the well environment and all relevant completion tools that the proposed downhole control valve needs to be adapted to.
2. Detailed design of Downhole Control Valve by following the design process.

1.2. Project scope

The work is divided into two main parts describing the design process stages.

Part I covers:

1) Problem discussion and clarification by describing the use, the advantages and the need of new DCV.
2) Literature review on the types of products, the well environment, relevant standards and norms, related equipment, etc.
3) Detailed specification description of DCV.

Part II covers:

1) Systematic design process based on design method including functional description, brain storming, solutions proposals, concept evaluation and selection.
2) Geometrical modelling by using Computer Aided Design (CAD) at part level and assembly level.

3) Calculations of mechanical behavior and flow characteristics by combination of Finite Element Analysis (FEA) and Computational Fluid Dynamic (CFD) as well as the design method and failure criteria.
4) Systematic material selection and discussion of material in relation to standards and factors such strength, corrosion and fatigue.
5) Prototype production drawings with geometrical dimensions and tolerances.

2. Background

2.1. Well drilling and well structure

The familiarity with the well design and its completion tools is very important for the downhole tools designer. Understanding the well schematics and well types affects the design and plays major factor on the tool geometry.

After the well site has been carefully prepared to meet environmental health and safety standard, drilling can begin. This is a complex operation requiring a well-planned infrastructure. A variety of processes, and expert well specialists are used to bring the fluids to the surface. Utilizing heavy-duty industrial strength drill bit, a typical well is drilled in several stages starting with large diameter drill bit and then successively smaller drill bits as the drilling advances.

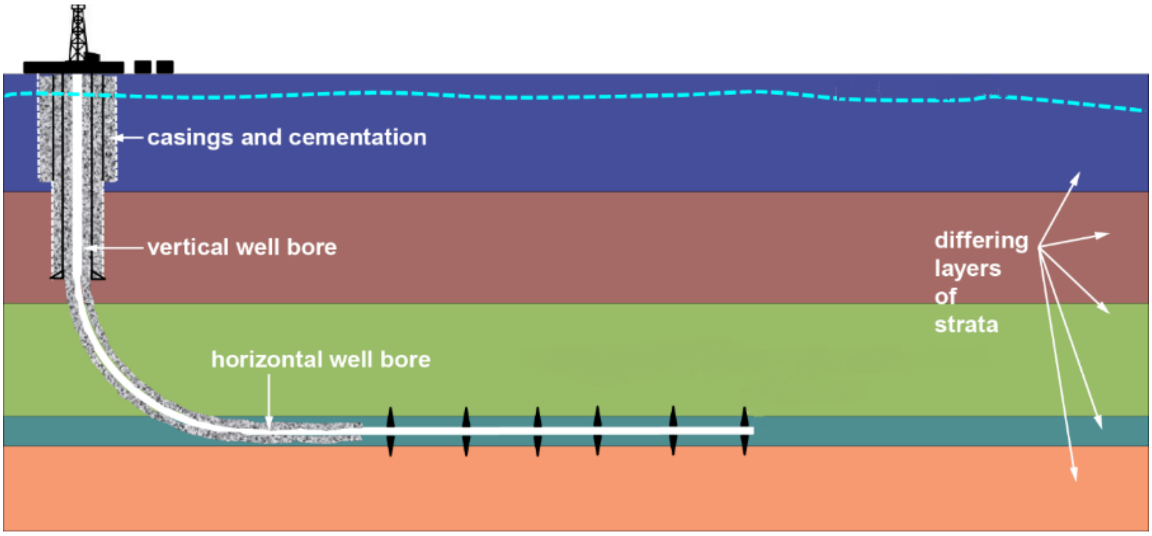


Figure 1: Drilling, casing and perforated wellbore [1]

After drilling each portion of the well, steel protective casing is cemented into place, this will protect ground water and maintain the integrity of the well. Normally a large diameter hole is drilled for the first 15 to 24 meters, where a conductor casing is cemented into place, stabilizing the ground around the drilling rig and the well head and isolating the well from surface water, see Figure 1. During the drilling, a series of compressors and boosters generate the air that is used to lift the rock cutting and fresh water to the surface steel bins. The rock cuttings are then disposed off within the standard guidelines and permits. The drilling equipment is retracted to surface and stored for the second stage of drilling. To protect the integrity of the hole and to protect the surrounding deep freshwater zone a second layer of steel casing called surface casing is installed and cemented inside the newly drilled hole in the conductor casing. Cement is pumped down through the surface casing and up along the sides of the well to provide a proper seal. This completely isolates the well from the deep-water zones. A blowout preventer is installed after the surface casing has been cemented (Figure 1) The blowout preventer is a series of high pressure safety valves and seals attached to the top of the casing to control well pressure and prevent surface releases. Next, a small drilling assembly is passed down through the surface casing. At the bottom of the casing, the bit drills through the cement continuing its journey to the natural gas target area as deep as 2500 m below the surface. The drilling method employed below the surface casing uses drilling mud which is non-hazardous mixture based on bentonite clay or synthetic thickeners. In addition to lifting the rock cutting out the hole, drilling mud also helps to stabilize the hole, cool the drill bit and control downhole pressure. A few hundred meters above the target zone, the drilling assembly comes to a stop. The entire string is pulled out of hole to adjust the drilling assembly and install special drilling tool, this tool allows to turn the drill bit until a horizontal plane is reached. The remainder of the well is drilled in this horizontal plane while in contact with gas producing zone. Drilling continues horizontally through the gas zone at length greater than 1500 m from the point where it entered the formation. Once the drilling is completed the equipment is retracted to the surface, then a smaller diameter casing is called production casing is installed throughout the total length of the well. The production casing is cemented and secured in place by pumping cement down to the end of the casing. Depend on regional geologic conditions, the cement is pumped around the outside casing well to approximately 750 m above the producing zone formation or to the surface. The cement creates the seal to ensure the formation fluids can only be produced via the production casing. After each layer of casing is installed the well is pressure tested to ensure its integrity for continuing drilling. A cross section of the well below surface reveals several protective layers: 1-cement, 2-conductor casing, 3- cement, 4-surface casing, 5- drilling mud, 6- production casing and 7- production tubing, through which the produced gas and water will flow. Seven layers of protection to ensure safe oil and gas production [2].

Horizontal drilling offers many advantages when compared to vertical drilling, since horizontal wells contact more of the gas producing shale. Fewer wells are needed to optimally develop a gas field. Multiple wells can be drilled from the same pad site, for example development of 5 km^2 tract of land using conventional vertical drilling techniques could require as many as 32 vertical wells with each having its own pad site (Figure 2), however one multi pad site with horizontal wells can effectively recover the same natural gas reserves from the 5km^2 tract of land while reducing the overall surface disturbance by 90% [3].

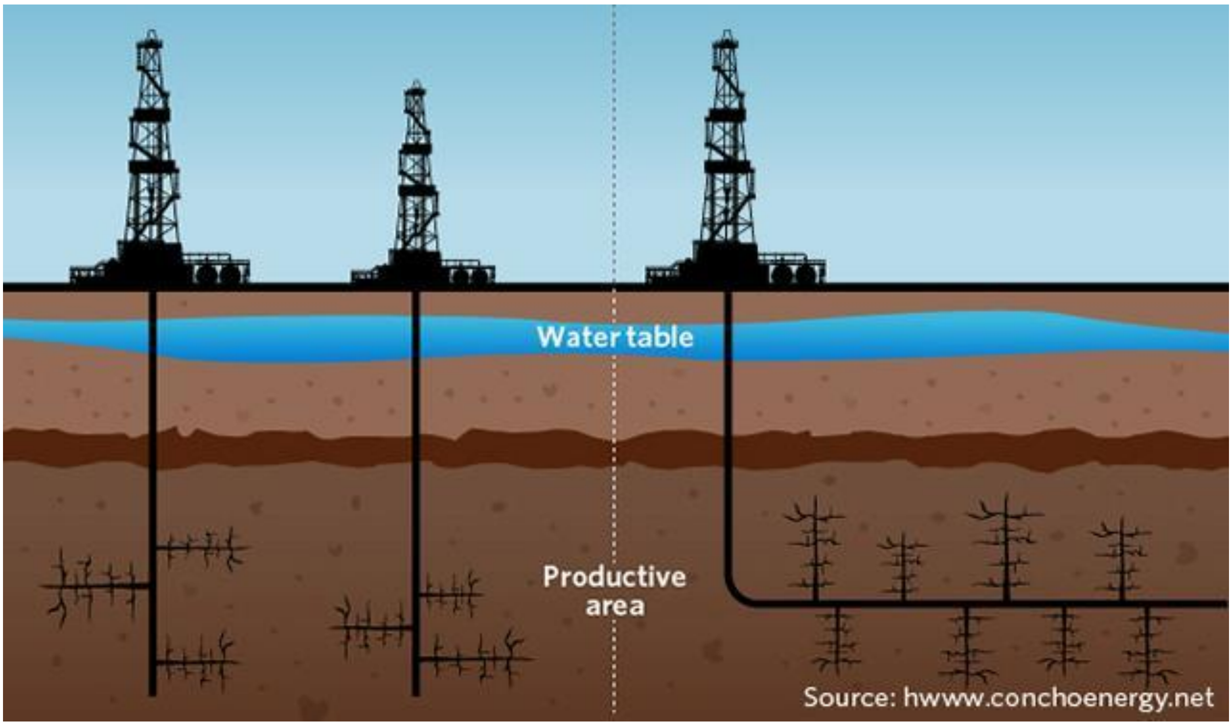


Figure 2: Horizontal wells vs. vertical wells [3]

2.2. Surface equipment

Part of the surface equipment is the Christmas tree, which is combinations of valves connected to the well head. The Christmas tree provides pressure and flow control of the well. There are many types of the trees depend on the well pressure, temperature and the medium see Figure 3.

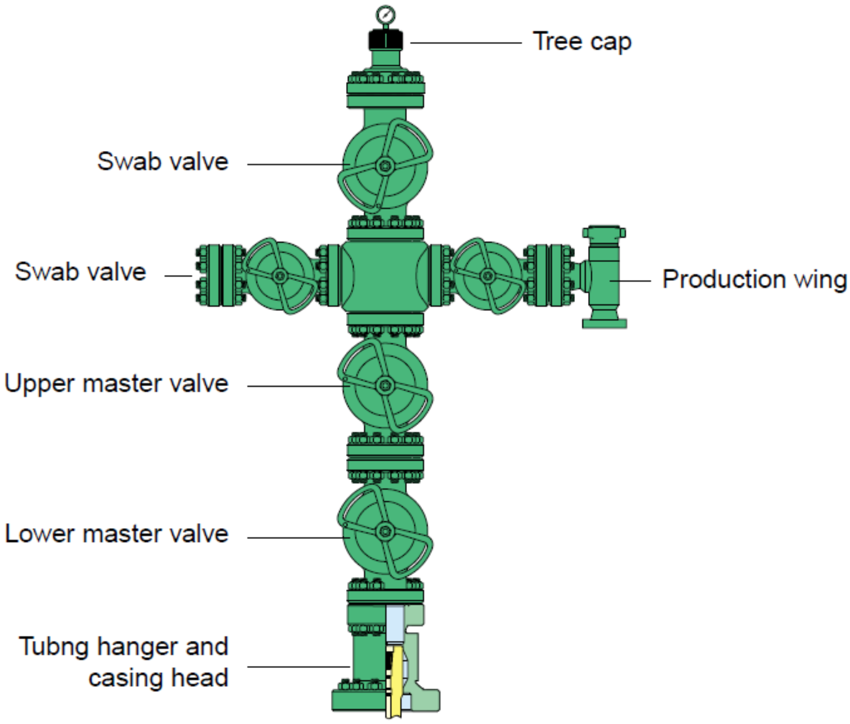
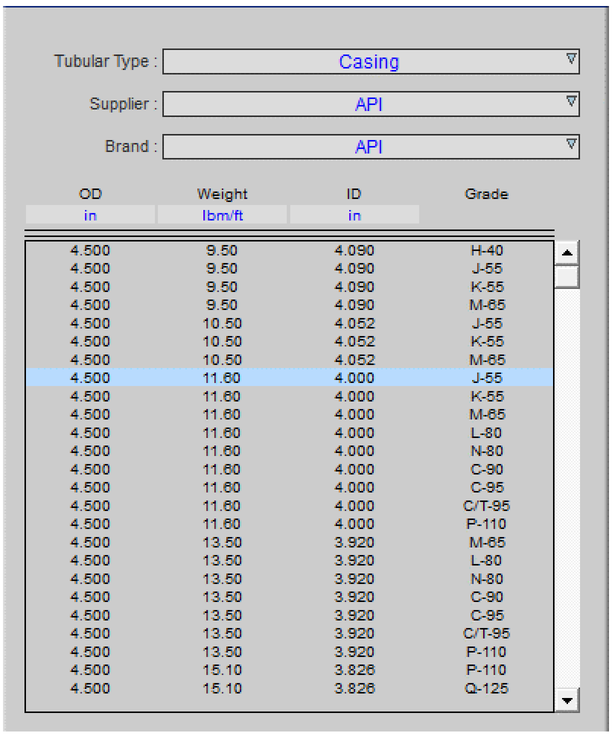


Figure 3: Wellhead Christmas tree [2]

2.3. Tubing and casing specifications

All downhole tools are passed through the well completions casing and tubing. It is necessary for the designer to understand the specifications of the casings and tubing, see Figure 4. There are three main specifications of the casing and tubing should be mentioned [4]:

1) Tubing and Casing nominal size: the size is specified by the outside diameter of the tube, which called the nominal description size.
2) The grade: which referred to the strength of the material that the tube is made of and it is specified by a letter and number as mentioned in the API standard, for example H-40, C-75, N-80 or L-80. The number represents the tensile strength in 1000psi.


Tubular Type : Casing
Supplier : API
Brand : API

OD in	Weight lbm/ft	ID in	Grade
4.500	9.50	4.090	H-40
4.500	9.50	4.090	J-55
4.500	9.50	4.090	K-55
4.500	9.50	4.090	M-65
4.500	10.50	4.052	J-55
4.500	10.50	4.052	K-55
4.500	10.50	4.052	M-65
4.500	11.60	4.000	J-55
4.500	11.60	4.000	K-55
4.500	11.60	4.000	M-65
4.500	11.60	4.000	L-80
4.500	11.60	4.000	N-80
4.500	11.60	4.000	C-90
4.500	11.60	4.000	C-95
4.500	11.60	4.000	C/T-95
4.500	11.60	4.000	P-110
4.500	13.50	3.920	M-65
4.500	13.50	3.920	L-80
4.500	13.50	3.920	N-80
4.500	13.50	3.920	C-90
4.500	13.50	3.920	C-95
4.500	13.50	3.920	C/T-95
4.500	13.50	3.920	P-110
4.500	15.10	3.826	P-110
4.500	15.10	3.826	Q-125

Figure 4: Pipe data table in API standard [4]

3) Weight per length: which specifies the wall thickness of the tubing or casing and since the OD is nominal dimension represent the size, then the thickness of the tube is proportional to the weight per length.

2.4. Well intervention

Well intervention is an operation to access the well safely according to the well control procedures to achieve number of tasks a side of drilling. Well intervention operations started with drilling rigs, and it was the only available method to enter well with the option of well control. In the earlier1980's, innovative technology was developed that allow re-entry into wells with alternatives to the drilling well control systems for offering of non-drilling services. These alternatives such as Coil Tubing, Slickline and Wireline methods are common ways of well intervention and designed to improve the well and reservoir performance. By these technologies many applications include matrix and fracture stimulation, wellbore cleanout, logging, perforating, nitrogen kickoff, sand control, drilling, cementing, well circulation, and mechanical isolation can be achieved at lower cost than drilling rigs [4].

With the growing number of oil and gas wells, there is an increasing demand for the well intervention service. Such a service has been in operation globally for the past two decades and is systematically being improved from year to year. Currently, a long-term commitment has been made by oil companies to improve the technology in order to make the well intervention service more efficient and safe.

However, it is important to keep the well maintained in good working order and adapting completion property to the constantly varying conditions prevailing in the reservoir and around the wellbore. Well servicing covers all of the operations that can be performed on the well to analyze the status of the well and the reservoir, in addition for maintaining or adapting the well to keep the best possible operating status.

The increase of the energy demand in combination with limited resources, have pushed energy companies toward developing more technologies to reach reservoirs that are not only deep but have more harsher characteristics such high pressure and high temperature. In addition, obtaining stable production by providing well service and maintenance to sustain the productivity. These operations are costly and technically demanding, they require special considerations and specially developed tools. As the industry moves towards developing more challenging oil and gas fields, the necessity for using suitable tools to guarantee the safety, efficiency and the productivity of the wells becomes increasingly more important. The industry has responded to this issue by introducing stricter and demanding standard verifications for wide ranges of operational equipment [2].

2.5. Well intervention methods

Currently, there are Slickline, E-line and Coiled Tubing methods of well intervention and the use of each type can be selected due to the type and cost of the well operations, for example Slickline service is quick and low-cost option, it is used in vertical well and it is limited for only this type.
E-line is used for advanced well measurement, where the electric communication is needed. E-line has higher cost an operation time than the Slickline. In the other hand the Coil Tubing commonly used in both vertical and horizontal wells, and it is used in operations where circulation, high force is needed. CT operation takes more time than the other two methods [2].
In the following, more detailed study on the well intervention methods:

2.6. Slickline intervention method

Slickline intervention method is based on using one single wire to access the well, the length of the wire is determined by the depth of the well. Usually the wire is used by the Slickline unit, which control the tension of the wire, RIH and POOH speed. The Slickline operator achieve several actions in the well by controlling the tension of the wire. Many well intervention operations conducted by Slickline such as well maintenance, testing and data gathering during the production.
Variety of downhole tools connect to the Slickline wire and the total weight of the tools allow the tool string to pass in hole [5].
Several accessory tools are used to pressure control the well while the Slickline operations are in progress, these equipment are:

1. Slickline unit: The Slickline unit is hydraulic power unit that provide control of the tension of the wire as well as the speed of the wire spool, see Figure 5.

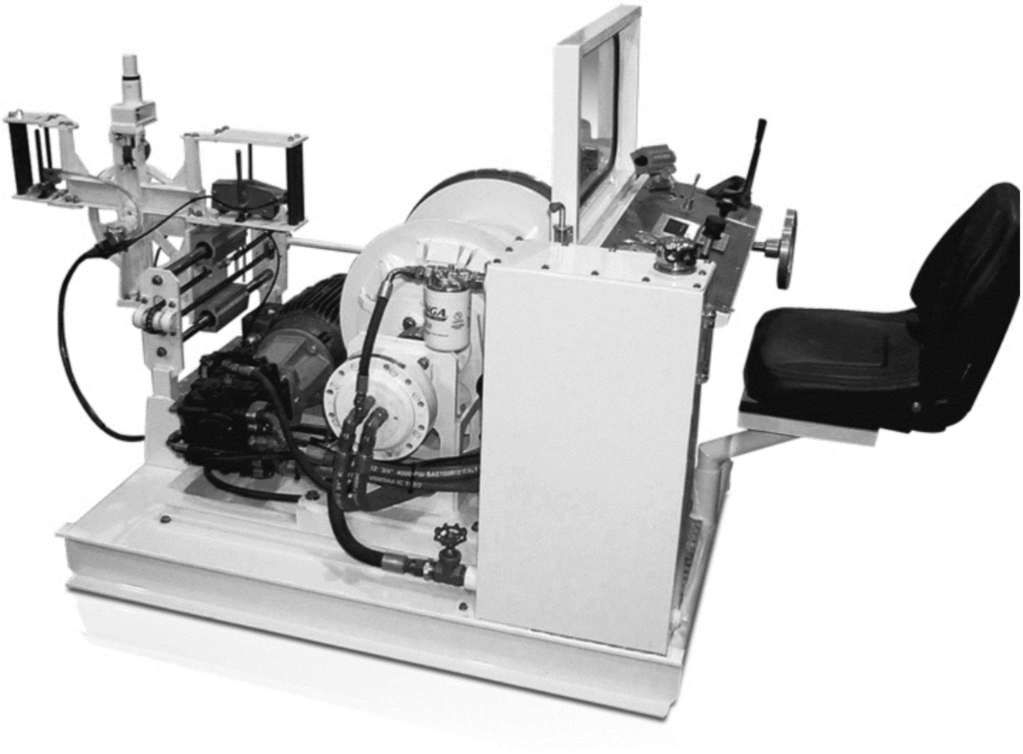


Figure 5: Slickline unit [5]

2. Stuffing box: The stuffing box is used to provide dynamic seal to the wire while it is sliding inside the well also a bully is connected to the top of it to align the wire through the lubricator sections.
3. Lubricator section: The lubricator section is connected to the Stuffing Box from the top side and to the BOP from the lower side. It is used to accommodate the tool string length before accessing the well.
4. Blow out prevent (BOP): The Slickline BOP is always used to provide emergency shut down for the well in case of uncontrolled pressure. It is connected to the Christmas tree and lower section of the lubricator, see Figure 6.

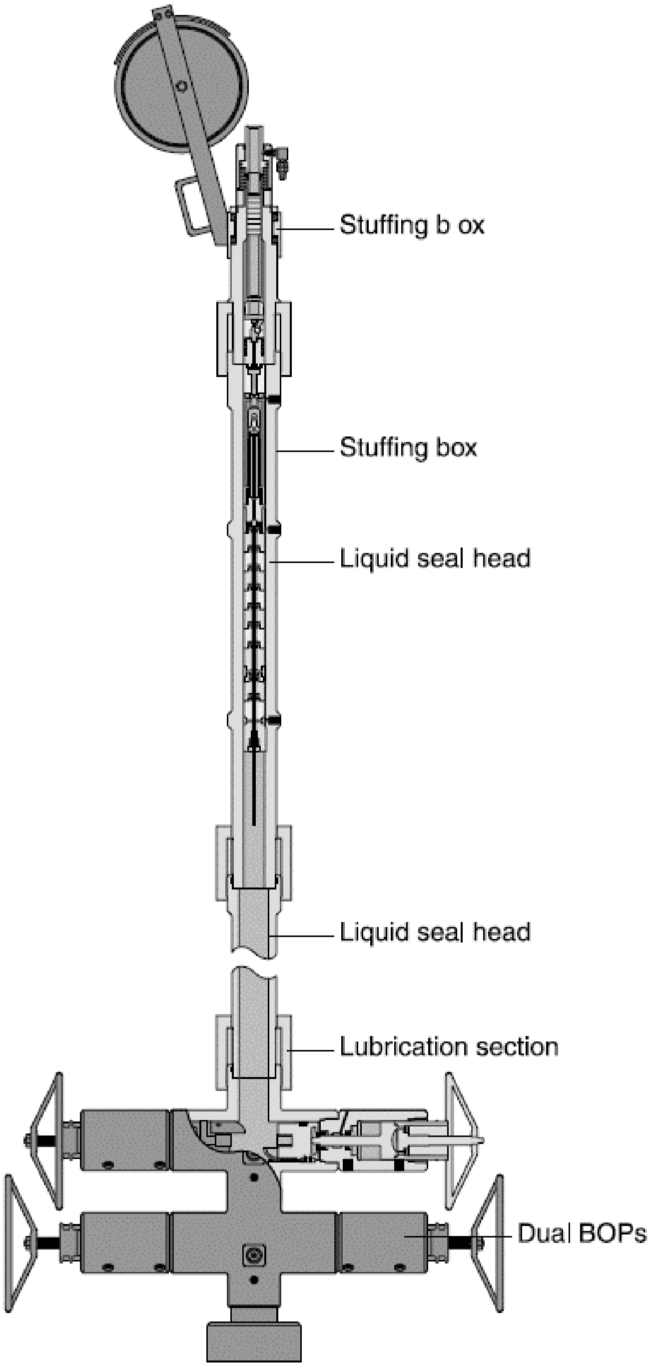


Figure 6: Slickline surface equipment [2]

5. Tool string: the standard tools of the tools string are the rope socket which connect the Slickline to the tools string, swivel joint which provide rotational movement between the Slickline and the tool string, the stem which adds weight to the tools string and overcome the RIH friction and provide mechanical impact to the jarring tool, Finally the mechanical Jar which provide the impact force to achieve downhole activities see Figure 7.

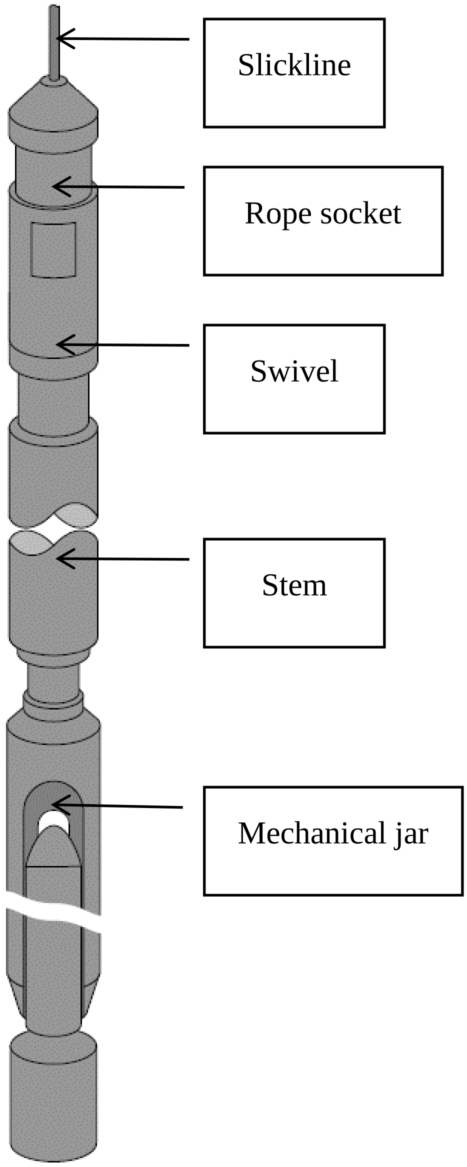


Figure 7: Tool string standard tool [2]

2.7. E-line intervention method

The equipment used in Electric line intervention method is very similar to the one in Slickline, the only difference is that the wire is electric. The E-line method is commonly used in well logging. The E-line unit is always connected to the downhole tools and read all the measurement needed to the well log. There are many types of E-line downhole tools such pressure, temperature, flow, gamma ray, nuclear, resistivity, sonic, ultrasonic, magnetic resonance, casing collar locators and cement bond tools. As well as additional equipment such as the cable head, which is used to connect the electric wire to the bottom hole assembly (BHA) and it provides electric weak point to release the wire in case of emergency. Also, downhole tractors are used to drive the BHA inside the horizontal part of the well [6], see Figure 8.

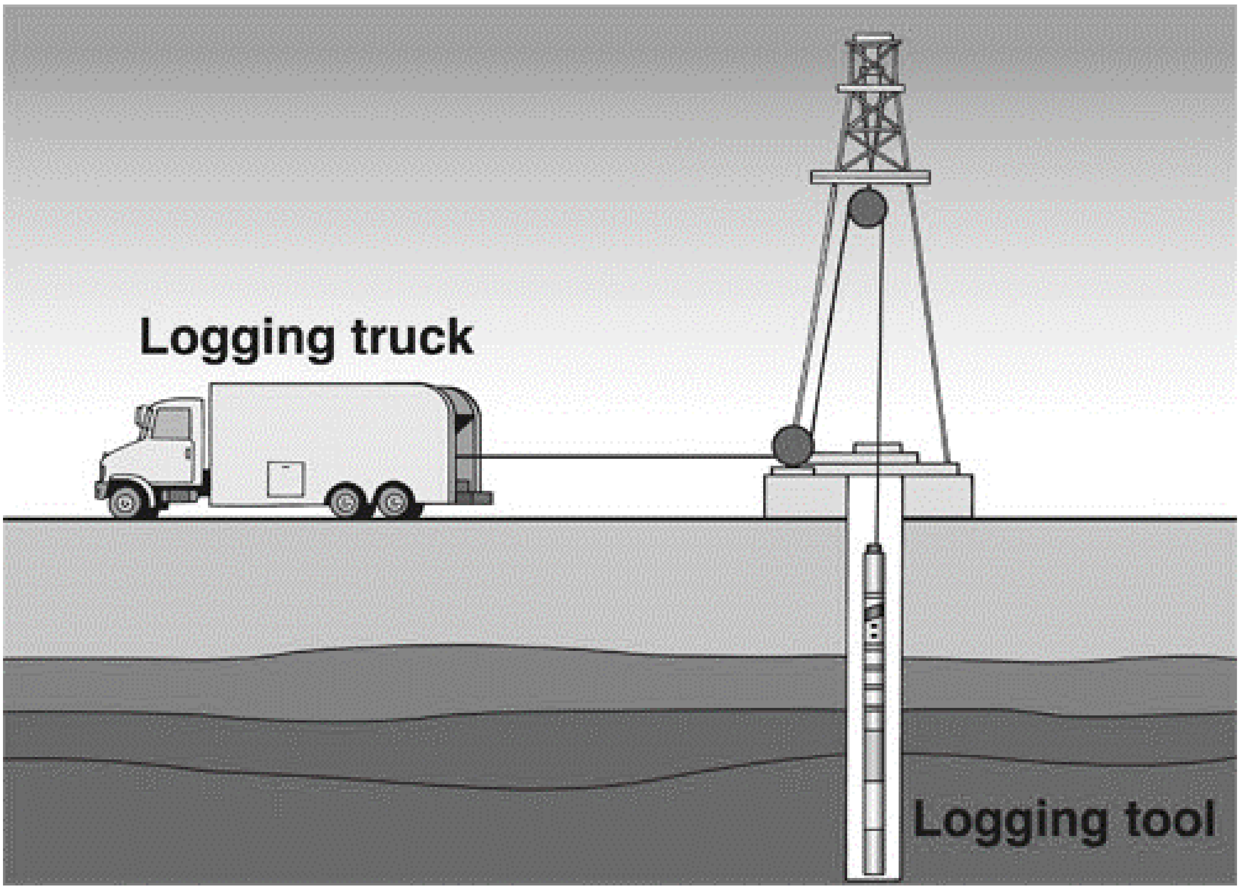


Figure 8: E-Line intervention method [6]

2.8. Coil tubing intervention method

The coil tubing Intervention methods uses (1-3.25 in) diameter and very long metallic tube. Equivalent to the Slickline and E-line methods, the Coil Tubing has similar equipment. The CT unit has very large spool to accommodate the long tube. The tension and the speed are controlled by the unit hydraulically. The CT services are used for well maintenance such circulation, pumping, CT drilling, logging and perforating. CT intervention method is used in vertical, deviated and horizontal wells [7]. The injector head is hydraulic drive tubing injector controlled by the CT unit, which controls the push and pull force of the tube see Figure 9.

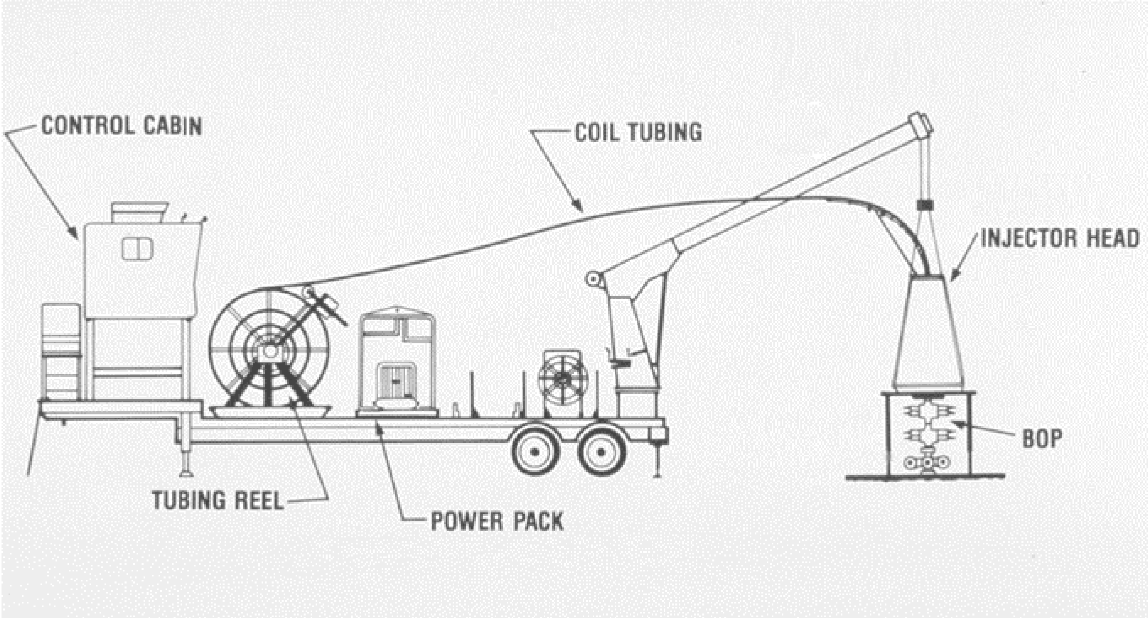


Figure 9: CT intervention method [7]

2.9. Well intervention market

The growth of well intervention according to the report issued by Markets and Markets research center is estimated to USD 8.18 billion in 2017 and it will grow to USD 9.85 billion by 2022. The main factor of this growth is the increasing international demand of the energy, this leads to increasing the production of oil and gas [8].

2.10. Existing downhole control valves and types

The downhole valves can be divided to four categories from the mechanical point of view, where the use of these valves can vary for different downhole applications. And there are many types and they are called according to the variety of operations, but the mechanical functions can be shown in the following:

1. **Hydraulic activated valves**

The downhole subsurface safety valve DSSSV is great example of hydraulic activated valves. Hydraulic pressures signal can be send through hydraulic line to the valve to open and close it. The valve contains a flapper loaded by torsion spring and a sleeve that open and close the flapper. The sleeve position is controlled by hydraulic line. Figure 10 shows the function of these types of valve:

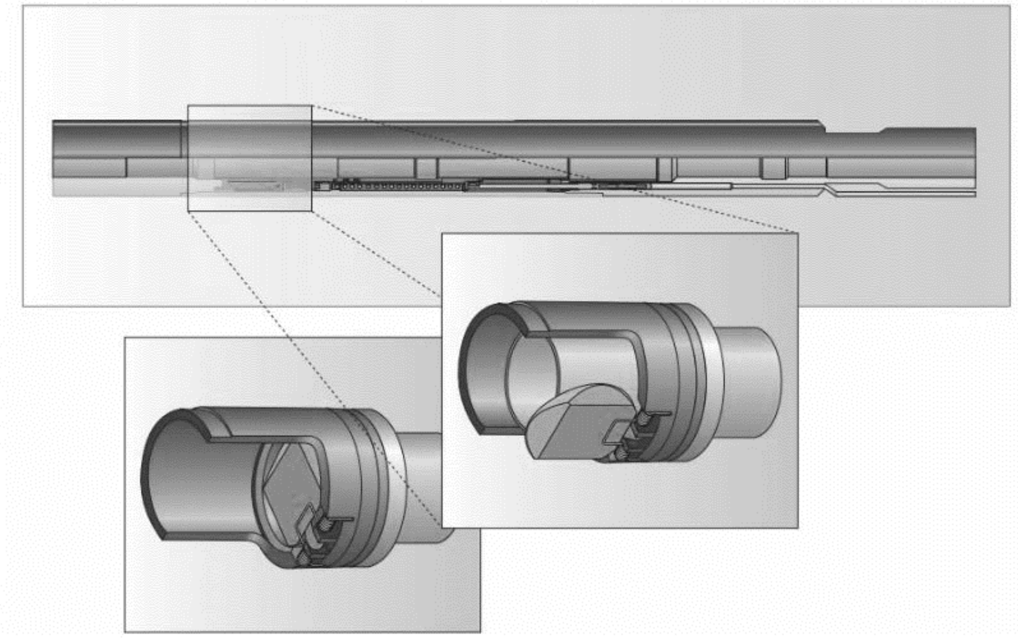


Figure 10: Hydraulic activated valves [3]

2. Ball drop downhole valves

These types of valves can be activated by dropping a ball in the tubing. The ball will land on the valve seat and shift a sleeve, therefor the fluids will be circulated between the tube and the well. An example of such valve is ball activated circulation valve that can be used by coiled tubing to permit the fluid circulation over the coiled tubing tool string, see Figure 11 [9].

Figure 11: Ball drop downhole valve [9]

3. Sliding sleeve valves

A typical sliding sleeve valve consists of double layers of sleeves that contain the flow ports. Mechanical action by slick line or wire line operation bushes or pulls the inner sleeve to allow the flow passes between the production tubing and the annulus, see Figure 12 [10].

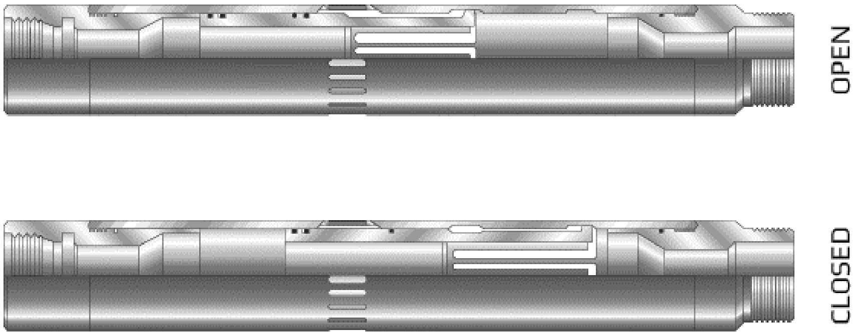


Figure 12: Sliding sleeve valves [10]

4. Electrical actuated valves

This type of valves uses electromechanical actuator to move the flow port sleeve to the correct position to match the external sleeve ports and let the flow access from the well through the valve. This valve is commonly used in well testing, Figure 13 below shows the main function of the tool [11].

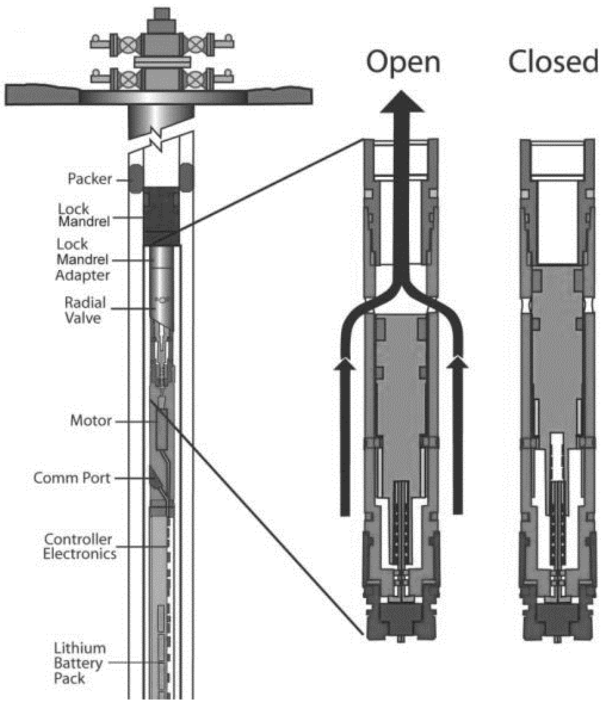


Figure 13: Electrical actuated valve [11]

2.11. Design constraints

Due to thesis scope and limitation of time the following bounders of the project are listed:

1. The DCV flow study will consider the well medium as one phase not multi-phases complex well fluids.
2. Due the complexity of the well fluids, the reservoir science will not be discussed in the thesis.
3. The manufacturing process is not part of the thesis therefore the designer will limit the research for only the design and prepare all materials that can help produce the DCV.
4. The DCV must function with existing Qinterra plug system.

2.12. Standards, norms and guidelines

The design of the DCV will be guided with the following standards:

Norsok standards

1. D-010 Well integrity in drilling and operations
2. M-710 Qualification of non-metallic sealing materials and manufacturers
3. D-SR-007 Well testing system
4. D-002 System requirements well intervention equipment

International standards

1. ISO 10432:2004 Downhole equipment - Subsurface safety valve equipment
2. ISO 14310:2001 Downhole equipment - Packers and bridge plugs
3. ISO 10407:1993 Drilling and production equipment
4. ISO 15156-3 Materials for use in H2S-containing environments
5. An International Code 2013 ASME Boiler & Pressure Vessel Code

2.13. Design requirements

The DCV is meant to be used with the product line of plugs and packers in Qinterra Technologies and it can not be installed as standalone tool without connecting to third party or Qinterra plugs and packers. The main specification of the valve is given by Qinterra and listed in the Table 1. The valve should work with high H2S environment targeting the Middle East market. The tool external diameter should not exceed 68.58 mm (2.7 in), the valve should log the pressure and the temperature of the well fluids. As well as providing instant opening and closing valve. The recommended intervention method is Slickline.

The tool connects to Qinterra plug as shown in Figure 14.

Figure 14: Qinterra prime plug connected to the desired DCV

Table 1: Design requirements list of DCV according to the targeting company

Set of requirements	**Set of performance specifications**
1. Life cycle	10 operations/month for 5 years
2. RIH maximum speed	2 m/sec
3. Maximum OD	68.58 mm
4. Minimum ID	20 mm
5. Maximum weight	20 kg
6. Maximum length	1200 mm
7. Casing/ tubing Size	4.5”-5.5”-7”-9 $^{5}/_{8}$”
8. The allowed maximum temperature	150 ^{0}C
9. Maximum well pressure	68,94 MPa (10000 psi)
10. Axial Force	80000 N
11. H2S	Max. 30%
12. CO2	Max. 10%
13. Well Fluid	Medium crude oil
14. Close/Open cycle time	1 sec
15. Minimum Flow Area	645.16 mm^2
16. Maximum flow rate	0.013 m^3/sec
17. Operation method	From surface with no intervention

2.14. Project management

The project is divided to 8 main milestones:

1. Pre-Study
2. Product specification
3. Concept generation
4. Concept selection
5. Modeling
6. Simulation and calculations
7. Model definition
8. Report delivery.

The time estimation for the project progress is shown in Figure 15.

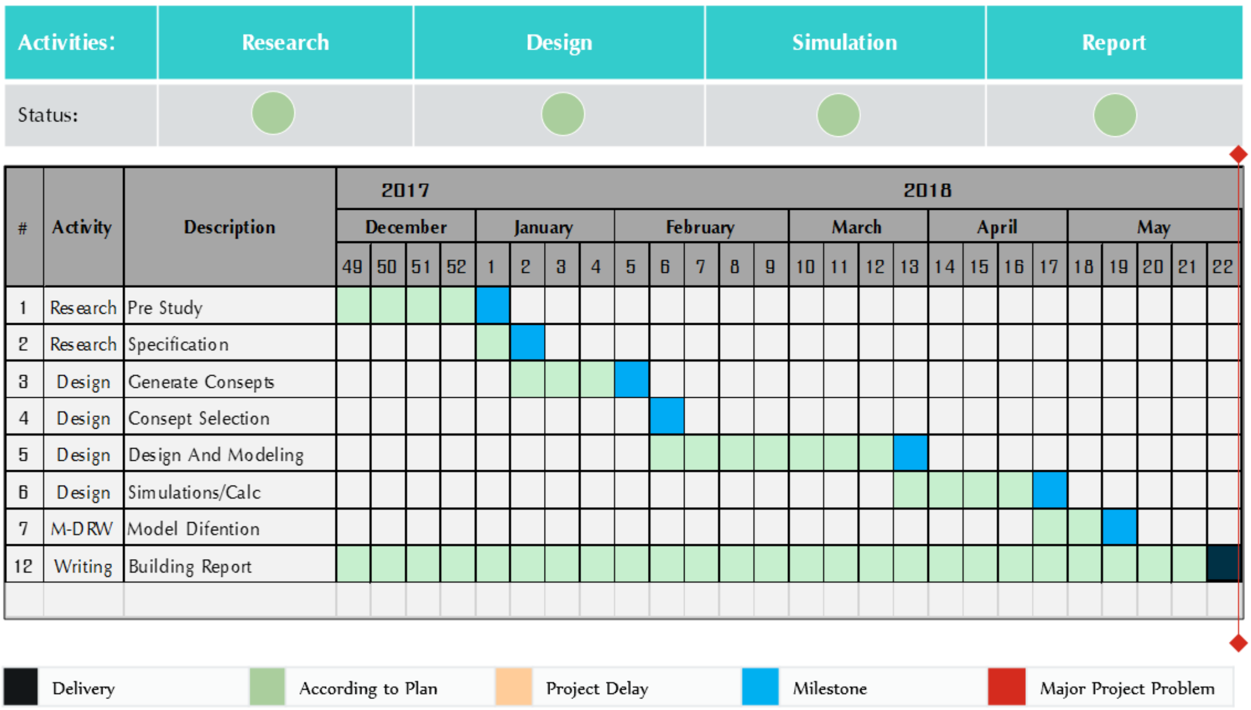


Figure 15: Time schedule and projects milestones

3. Concepts development of the DCV

The previous study describes the list of requirements of the DCV (Table 1) that should be taken into consideration, while generating different concepts for DCV. Moreover, the final product design should be possible to manufacture with well-known processes, be practical to use and easy to operate.

After defining the design requirements in the pre- study, it is essential while generating concepts to keep in mind these requirements. The concepts should be practical and be able to manufacture.

The driving idea of concepts is the way the valve should operate. There are different ways to remote operation of valve:

1. Send pressure pulse from the surface to open or close the valve.

This method is widely used in well control and provide easy way to operate downhole valves, but it requires surface equipment, such as high volume and high-pressure pumps, to send the required pressure pulse.

2. Time delay provided by electronic or mechanical timer.

Building a timer unit inside downhole tool is widely used in well control. And it saves well intervention activities. This method is limited to the time, provided by the operator, and after the delay time is used the downhole tool will start functioning.

3. Send control data to the valve to operate remotely.

The reliability of this method is always a concern and require very complex electronic system and very high level of operation competence.

4. Use smart material in the structure of the valve.

Using smart materials in the structure of the valve may lead to very innovative downhole tools, dissolvable material that has different dissolvable time rate depend on the well medium is good example. As well as temperature activated material can be used in the well environment, the material will react to specific temperature range and activate the tool mechanically. The disadvantage of this method is the uncertainty of the well conditions.

Referring to the design requirements in table it is stated by the targeted company that valve should be operated by pressure pules from surface by using high volume and high-pressure surface pump. This design requirement constrains the main function idea to the first method listed above.

3.1. Design objectives

The translation of the design requirement to project objectives helps to clarify the goals of the project.

The objective tree below shows the important goals that should be achieved when generating concepts.

The main goals of creating any downhole tools can be derived for the following four factors:

1. Reliability: Designing a reliable downhole tool that can handle well environment, can work under hard conditions and provide high performance in every use.
2. Safety: Design should follow safety standard of the industry in terms of reducing human risk and machine damages.
3. Manufacturability: Design should consider exciting and well-known manufacturing processes. Parts and assemblies should be designed in a way that they are easy to produce, fixations and sealing are done with standard fasteners and seals.
4. Efficiency: Design should provide high efficiency in terms of operation time, assembly structure, easy to operate and troubleshooting.

Figure 16 shows the objective tree of the DCV.

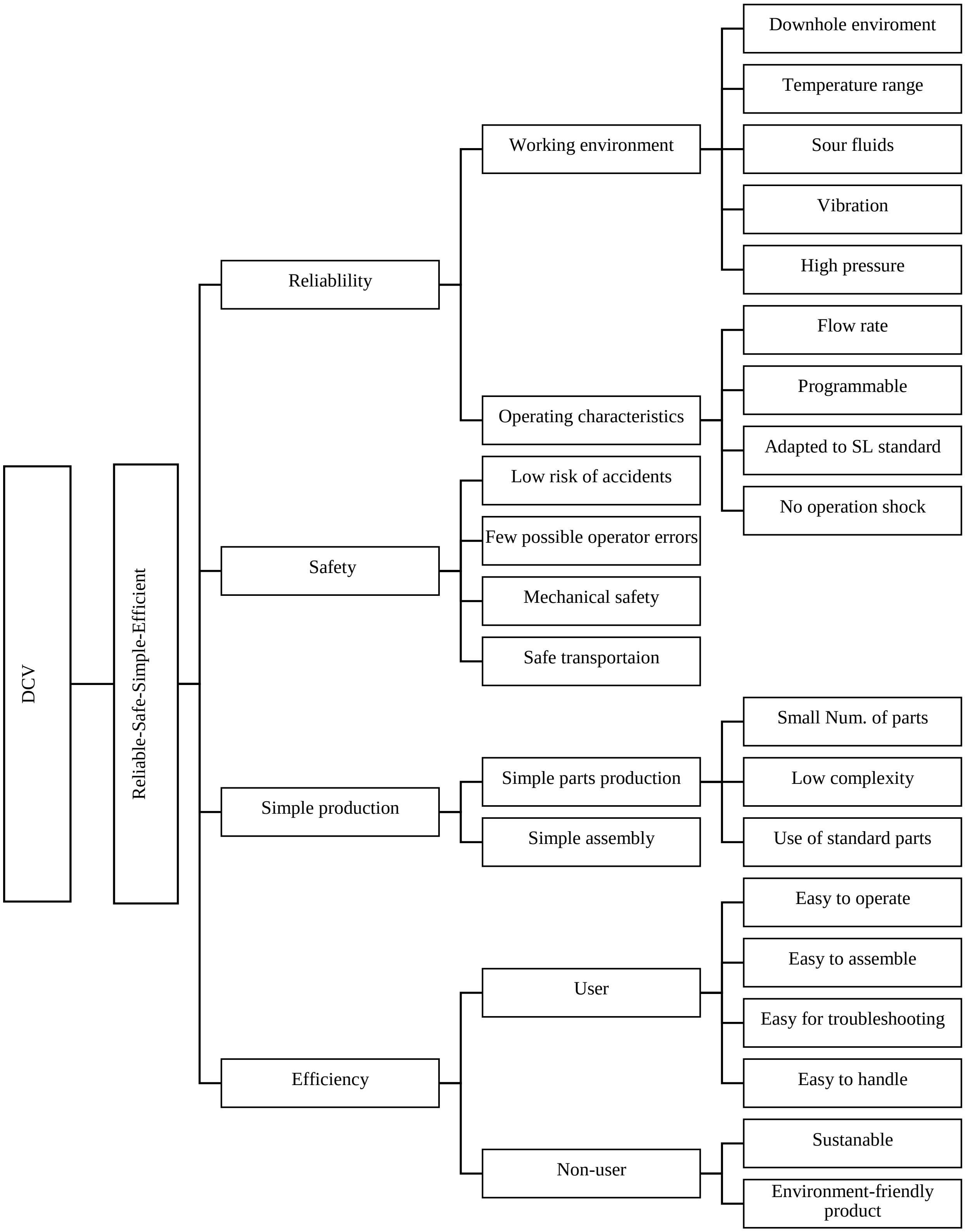


Figure 16: The DCV objectives tree

3.2. Working structure development

Analyzing the objectives tree leads to a design that has many different levels of complexity.
To solve the design problem, it is important to break down the structure to sub functions and provide solutions for each one. The combination of these solutions forms the final design of DCV.
The structure of the DCV should consist of five sub structures, see Figure 17:

1. Body: the body should be pressure and temperature resistance and its material should be suited to the well environment.
2. Control system, which should provide the valve activation method and control the valve flow characteristics as well as speed of the closing cycle.
3. Flow system, which provides the method of opening the flow ports of the valve.
4. Securing system, which provides a confirmed way that the valve will open when it is activated.
5. Measurement system, which will measure and log changes of temperature and pressure.

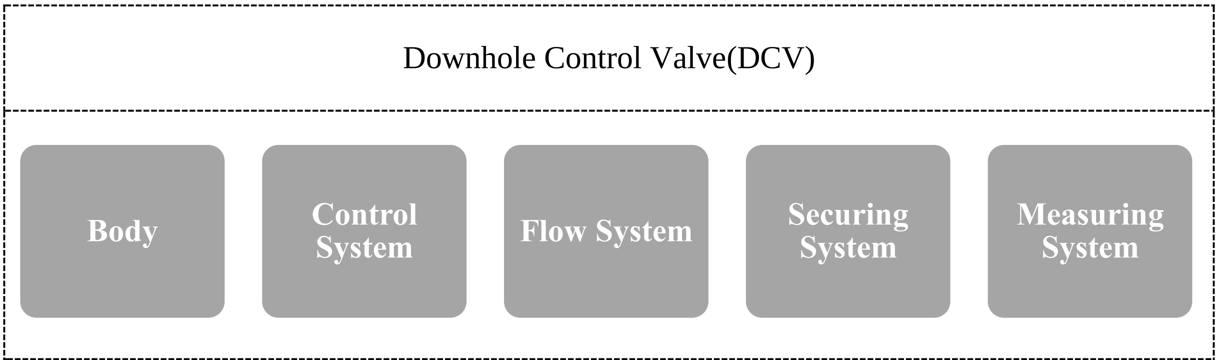
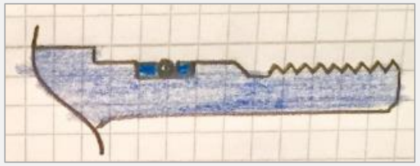
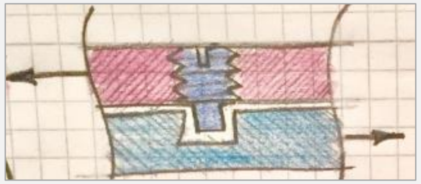
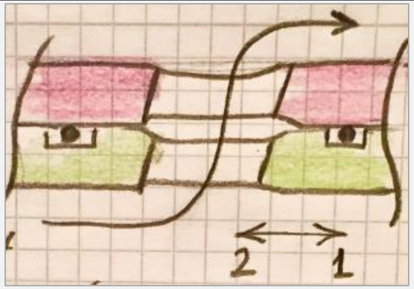
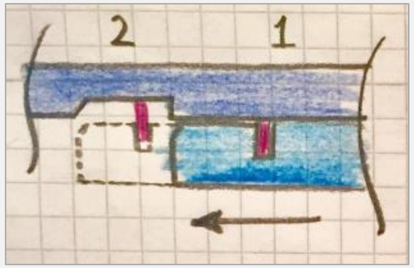
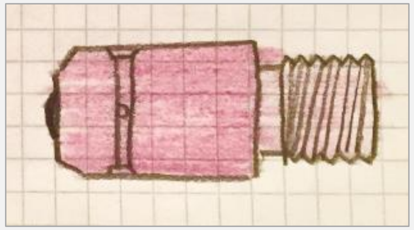
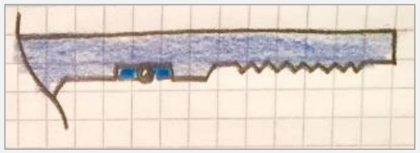
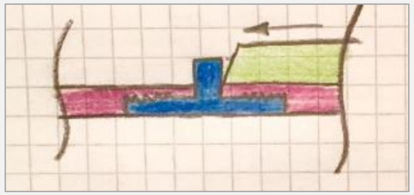
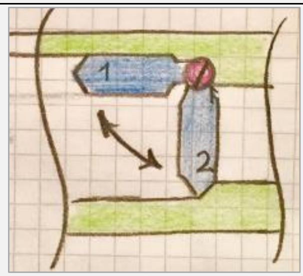
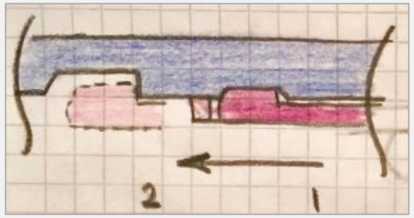
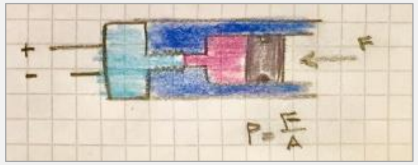


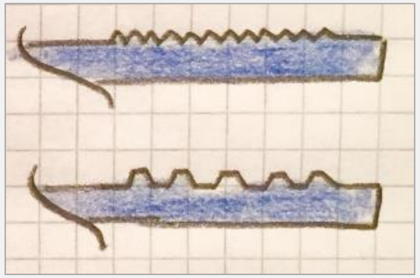
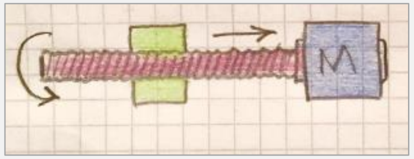
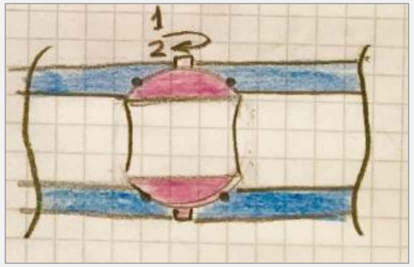
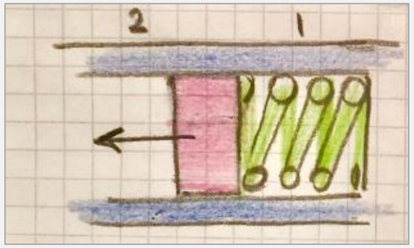
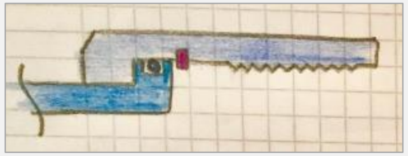
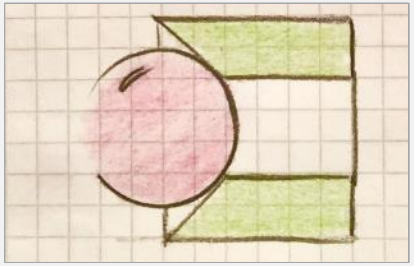
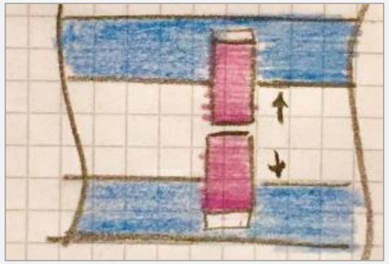
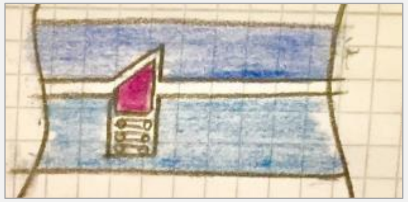
Figure 17: DCV structure

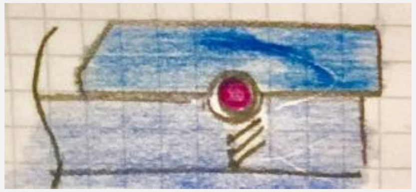
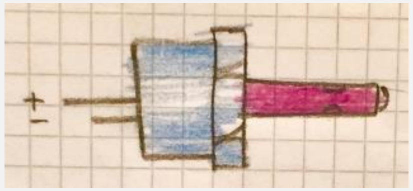
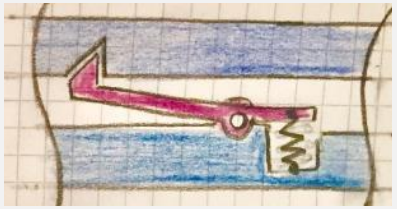
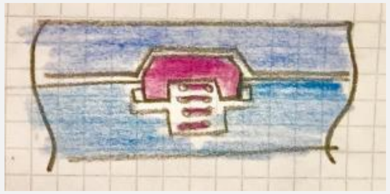
3.3. Concepts

After addressing the sub-functions of the downhole control valve is important to identify the mechanical terms of these functions and providing several concepts for each. The Table 2 is a 6x5 matrix that provides all concepts for the following sub-functions (Connections, Control System, Flow System, Securing System and Measuring System) and they are represented by the columns 1-5. The concepts of each sub-function are represented by rows 1-6. If an alternative concept not found is kept empty, for example concept (5,4) is empty.
Because of the different level of complexity, the Morphological Method is used to generate as many concepts as possible that can provide each sub-function identified in the DCV decomposition.

Table 2: Morphological matrix (6x5) of DCV

1 Connections Concepts (Body)	2 Control System Concepts	3 Flow System Concepts	4 Securing System Concepts	5 Measuring System Concepts
Concept: (1,1)	**Concept: (1,2)**	**Concept: (1,3)**	**Concept: (1,4)**	**Concept: (1,5)**
 External connection with O-ring seal	 Calibrated shear screw	 Sleeve valve	 C lock ring	 Pressure & temperature sensor
Concept: (2,1)	**Concept: (2,2)**	**Concept: (2,3)**	**Concept: (2,4)**	**Concept: (2,5)**
 Internal connection with O-ring seal	 Calibrated shear ring	 Gate valve	 Snapping collet	

Concept: (3,1)	**Concept: (3,2)**	**Concept: (3,3)**	**Concept: (3,4)**	**Concept: (3,5)**
 Metric threads vs Stub Acme threads	 Actuator (Motor-Lead Screw)	 Ball valve	 Compression spring	
Concept: (4,1)	**Concept: (4,2)**	**Concept: (4,3)**	**Concept: (4,4)**	**Concept: (4,5)**
 Swivel connection	 Dissolvable material	 Two gates valve	 Lock key-1	

Concept: (5,1)	Concept: (5,2)	Concept: (5,3)	Concept: (5,4)	Concept: (5,5)
 Quick connection-1	 Solenoid valve		 Lock key-2	
Concept: (6,1)	**Concept: (6,2)**	**Concept: (6,3)**	**Concept: (6,4)**	**Concept: (6,5)**
 Quick connection-1			 Lock key-2	

3.4. Concepts evaluation and selection

After generating many concepts of the sub-functions, it is important to evaluate these concepts. The following criteria are used to evaluate the concepts:

1. **Tool Reliability** [0-80]
   1.1. Working Environment [0-40]
      1.1.1. Downhole Environment [1-10]
      1.1.2. Temperature [0-10]
      1.1.3. Sour Fluids [0-10]
      1.1.4. Pressure [0-10]
   1.2. Operating Characteristics [0-40]
      1.2.1. Flow Rate [0-10]
      1.2.2. Programmable [0-10]
      1.2.3. SL Standard [0-10]
      1.2.4. Operation Shock [0-10]
2. **Tool Safety** [0-40]
   2.1. Low Risk [0-10]
   2.2. Less Human Error [0-10]
   2.3. Safety Factor [0-10]
   2.4. Transportation [0-10]
3. **Production Simplicity** [0-40]
   3.1. Simple parts [0-30]
      3.1.1. Small Number of Parts [0-10]
      3.1.2. Low Complexity [0-10]
      3.1.3. Use of Standard Parts [0-10]
   3.2. Simple Assembly [0-10]
4. **Tool Efficiency** [0-60]
   4.1. User [0-40]
      4.1.1. Easy to Operate [0-10]
      4.1.2. Easy to Assemble [0-10]
      4.1.3. Easy to Handle [0-10]
      4.1.4. Easy for Troubleshooting [0-10]
   4.2. None User [0-20]
      4.2.1. Sustainable [0-10]
      4.2.2. Environment-Friendly [0-10]

The ranking of each criteria and sub criteria is [0-10] the higher the ranking shows that the provided concept is more suited to the selected function. Table 3 provides all the ranking results for each concept in Table 2 and the following wining concepts are:

- Concept (2,1) = 173 (Blue) has the highest ranking of the column 1
- Concept (1,2) = 174 (Blue) has the highest ranking of the column 2
- Concept (1,3) = 168 (Blue) has the highest ranking of the column 3
- Concept (3,4) = 182 (Blue) has the highest ranking of the column 4
- Concept (1,5) = 164 (Blue) has the highest ranking of the column 5

As general result the best concept is the combination of all the wining sub functions concepts, see Figure 18.

Table 3: Concept evaluation matrix of the DCV

DCV	Concept Number	**Reliability** [0-80]								**Safety** [0-40]				**Simple for production** [0-40]				**Efficiency** [0-60]						Total rank [0-220]
		Working environment				**Operating characteristics**								**Simple parts**				**User**				**None user**		
		Downhole environment	**Temprature**	**Sour fluids**	**Pressure**	**Flow rate**	**Programmable**	**SL standard**	**Operation shock**	**Low risk**	**Less human error**	**Safety factor**	**Transportation**	**Small numberof parts**	**Low complexity**	**Use of standard parts**	**Simple assembly**	**Easy to operate**	**Easy to assemble**	**Easy to handle**	**Easy for troubleshooting**	**Sustanable**	**Environment-friendly**	
Connections Concepts	Concept 1,1	9	9	10	10	0	0	10	9	10	10	10	9	8	9	8	5	7	6	9	9	6	6	169
	Concept 2,1	9	9	10	10	0	0	10	9	10	10	10	9	8	9	8	6	7	7	9	9	6	8	173
	Concept 3,1	8	8	5	8	0	0	10	6	8	9	8	9	10	10	8	8	8	7	9	9	6	8	162
	Concept 4,1	7	6	6	5	0	0	0	6	5	8	5	6	6	6	8	10	9	9	9	6	6	6	129
	Concept 5,1	3	6	5	3	0	0	0	6	5	5	5	6	6	5	8	10	9	9	9	6	6	5	117
	Concept 6,1	4	6	5	3	0	0	0	5	5	5	5	6	6	3	8	10	9	9	9	6	6	6	116
Control System Concepts	Concept 1,2	9	10	9	10	10	0	10	8	8	8	8	8	7	8	10	8	8	8	8	9	5	5	174
	Concept 2,2	9	10	9	10	8	0	5	9	8	8	8	6	9	9	6	9	9	9	8	9	9	5	172
	Concept 3,2	6	5	6	6	5	0	5	5	5	6	5	6	5	4	5	5	5	5	5	4	5	5	108
	Concept 4,2	6	5	6	6	7	10	5	8	5	8	5	6	10	10	6	10	10	10	10	5	6	5	159
	Concept 5,2	6	4	5	6	3	10	5	5	3	6	5	6	9	7	6	5	5	5	5	5	6	5	122
Flow System Concepts	Concept 1,3	10	9	10	10	6	0	5	8	8	10	8	8	9	9	6	8	8	9	6	9	6	6	168
	Concept 2,3	8	8	8	6	10	0	5	6	8	8	8	6	7	8	6	6	8	6	6	8	6	6	148
	Concept 3,3	5	7	6	5	10	0	5	6	8	8	6	6	6	6	6	6	6	4	6	7	6	6	131
	Concept 4,3	3	6	7	4	10	0	5	6	6	7	6	5	5	6	6	5	6	6	6	8	6	6	125
Securing System Concepts	Concept 1,4	9	9	8	9	8	0	9	8	8	9	9	8	8	8	10	6	8	6	6	8	6	8	168
	Concept 2,4	9	9	8	9	8	0	9	8	8	9	9	8	9	9	9	8	9	8	6	8	6	7	173
	Concept 3,4	9	9	8	9	8	0	9	8	9	9	9	8	9	10	10	9	10	10	7	9	6	7	182
	Concept 4,4	6	5	5	9	5	0	5	6	5	6	8	6	7	5	6	5	9	5	6	6	5	5	125
	Concept 5,4	5	6	6	9	3	0	5	6	5	8	8	6	7	4	6	5	5	3	6	4	4	6	117
	Concept 6,4	5	6	5	9	5	0	5	5	5	9	8	6	7	5	5	5	5	5	5	5	5	7	122
Measuring System Concepts	Concept 1,5	8	8	5	9	0	8	0	8	9	9	0	9	9	10	10	9	9	9	8	9	9	9	164
	Concept 2,5	6	5	9	5	0	6	0	7	6	6	0	6	4	3	5	6	5	6	6	8	6	7	112
	Concept 3,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Concept 4,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Concept 5,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Concept 6,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

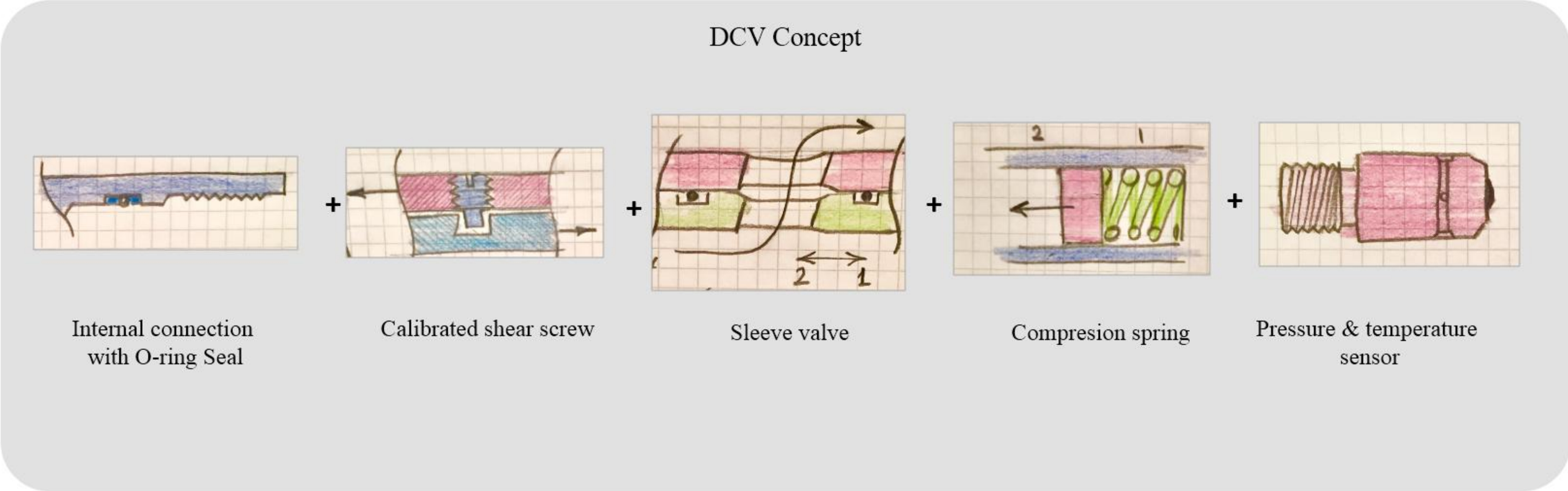


Figure 18:Combination of the winning concepts

3.5. Concept sketches and details

In the previous section the final concept is selected based on concept evaluation method.
Figure 18 shows the combined solution which contains the highest ranked concepts. The DCV final concept contains five sub functions, the adapter connections which provides compatibility with the downhole plug system, depend on the number off shear screws the valve will operates on different pressure. The number and shears strength of the screws should be calibrated and provides different activation pressure. After shearing the specified screws, the pressure will move the internal sleeve that let the external and internal ports to be open to each other and allow the fluid below the valve to access the anti-rotation screws will keep the port alignment before and after the sleeve shifts. The compression spring allows the sleeve to be in the correct open position. The pressure and temperature measuring system is an extra module that can be connected to the bottom side of the valve through the bottom threads. The valve will be assembled with the plug system in closed position where it will not affect the function of the plug. Figure 19-A shows the run-in hole closed position of the valve where the shear screws hold the internal sleeve on place. The shear screws are in contact with shear screws cutter. By increasing the pressure in top of the valve and exceeding the calibrated value of the screws the internal sleeve will be pushed down by the spring very fast and open the valve as shown in Figure 19-B.
The concept consists of the following parts:

1. Interface Connection to the plug system
2. 3x O-Ring Seal
3. Compression Spring
4. Valve Sleeve
5. External Sleeve
6. Valve Body
7. Anti- Rotation Screw
8. Shear Screw
9. Shear Screw Cutter
10. Cutter Bolt
11. Shock Absorber

The number of the parts may increase if there is need to model the valve for disassembly and convenience. The sketches are drawn around symmetrical line since the design is tubular, and they might not contain all the design details. They are made for concept illustration and for further understanding of the design refer to the CAD model in the geometrical modeling section.

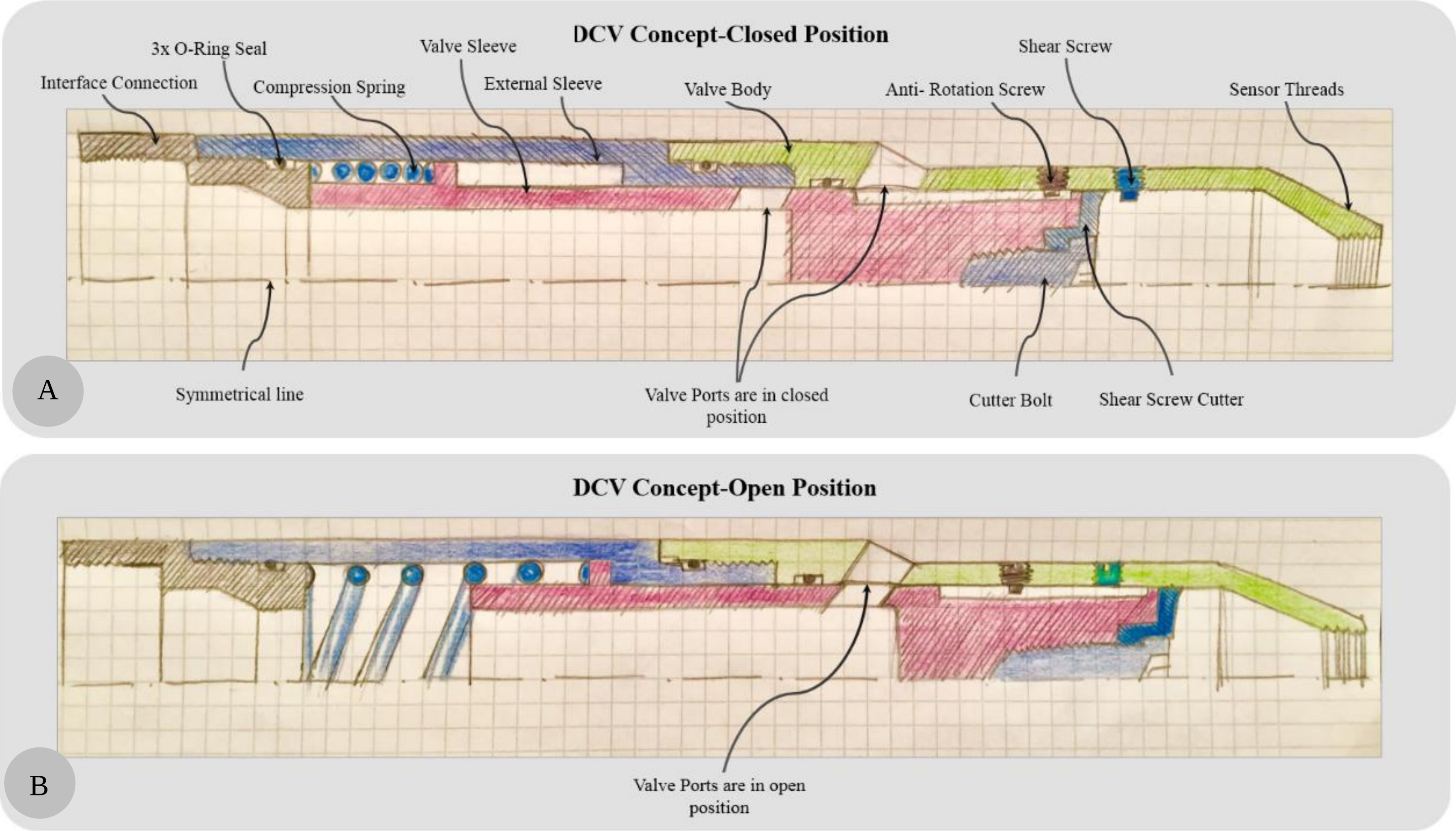


Figure 19: DCV concept in closed (A) and open position (B)

4. Geometrical modelling

Based on the concept sketches in the previous section, 3D model is created using parametric CAD software. The model consists of one assembly that includes 11 unique parts.

The part modelling generally using revolve feature which is represented by sketch revolved about a center axis as shown in Figure 20

The DCV parts and fasteners are represented in the following:

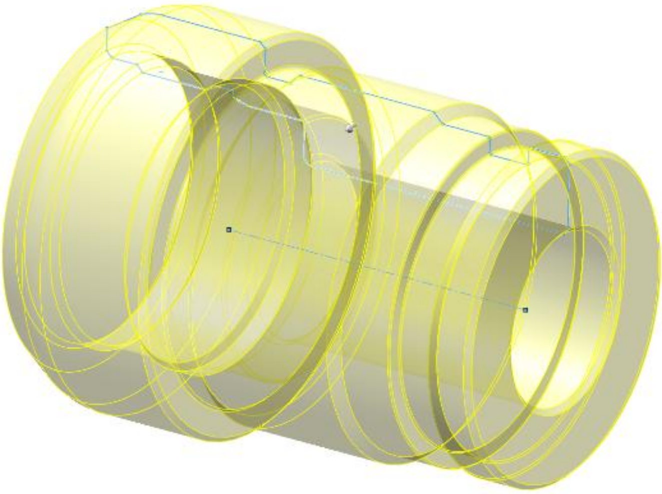


Figure 20: Modeling method -revolve

4.1. The top connector

The top connecter is an important part that provides mechanical connection to Qinterra Plug. It contains the same interface connection threads and provide proper accommodation to the pressure sealing; the part function and features are represented in Figure 21.

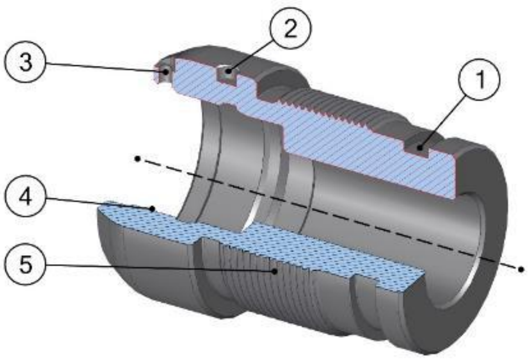


Figure 21: Top connector main features

1. Seal groove is used to prevent the external pressure to enter the valve.
2. Hole is used to aid the assembly and disassembly.
3. Threaded hole is used to place a grab screw to secure the assembly from untightening due to vibration.
4. Stub Acme threads used to interface the plug system.
5. External connection threads.

4.2. The spring housing

The spring housing accommodates the compression spring and connects to the top connector from top and to the valve body from the bottom, the part function and features are represented in the Figure 22.

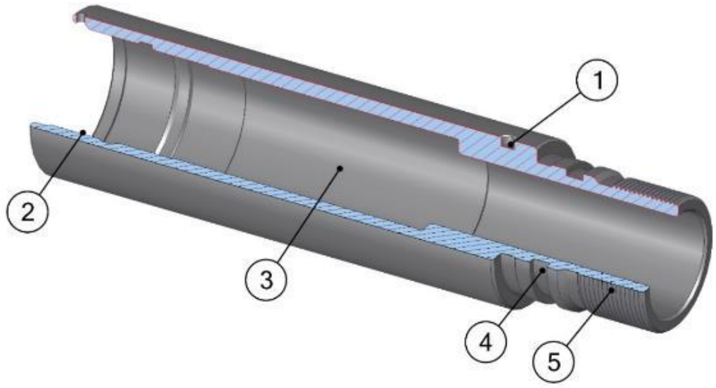


Figure 22: Spring housing main features

1. Assembly hole is used to aid the assembly and disassembly
2. Internal connection threads.
3. Spring chamber.
4. Seal groove to prevent the external pressure to enter the valve.
5. External connection threads.

4.3. The valve body

The valve body contains the inlet ports and accommodates the shear screws in addition to the guide screw which provides the correct orientation of the inlet and outlet ports, the part function and features are represented in Figure 23.

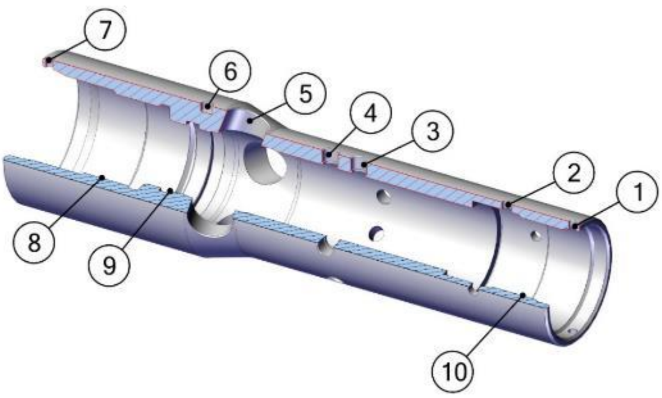


Figure 23: Valve body main features

1. Threaded hole is used to place a grab screw to secure the assembly from untightening due to vibration.

2. Pressure equalizing holes.
3. Shear screws threaded holes are used to accommodate the shear screws.
4. Guide screw hole to accommodate the guiding screw that provide correct orientation of the valve ports.
5. Valve inlet ports provide maximum flow area of the well medium.
6. Hole used to aid the assembly and disassembly.
7. Threaded hole is used to secure the assembly from vibration.
8. Connection threads to the spring housing.
9. Seal groove to prevent the external pressure to enter the valve.
10. Connection threads to the lower connector.

4.4. The bottom connector

The bottom connector connects to the pressure and temperature sensor from bottom and to valve body from top. Internally it connects to the shock absorber from top, the part function and features are represented in the Figure 24.

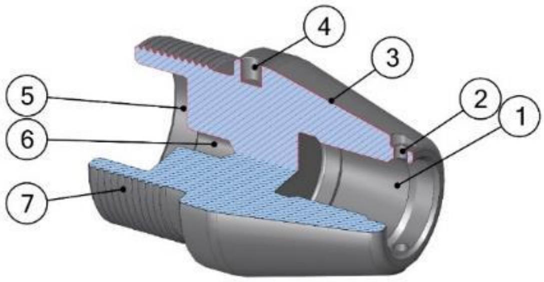


Figure 24: Bottom connector main features

1. Connection threads to the pressure and temperature sensor.
2. Threaded hole is used to secure the assembly from vibration.
3. Taped design to provide less hydraulic drag.
4. Hole is used to aid the assembly and disassembly.
5. Shock absorber chamber.
6. Threaded hole used to fix the shock absorber.
7. Connection threads to the valve body.

4.5. The valve piston

The valve piston is the sliding part in the DCV and it carries the outlet ports. It connects to the shear screws cutter form bottom and to the compression spring seat from top. The guiding groove is place on the top side of the piston, the part function and features are represented in Figure 25.

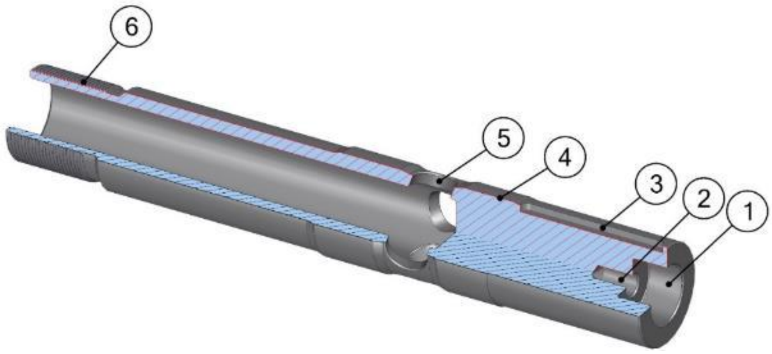


Figure 25: Valve piston main features

1. Shear screw cutter place.
2. Threaded hole is used to fasten the shear screw cutter.
3. Anti-rotation guiding groove.
4. Sealing surface.
5. Outlet ports.
6. Connection threads to the compression spring seat.

4.6. The compression spring

The compression spring provides pushing force to the piston after cutting the shear screws, making the valve ports be aligned to each other, the part function and features are represented in Figure 26.

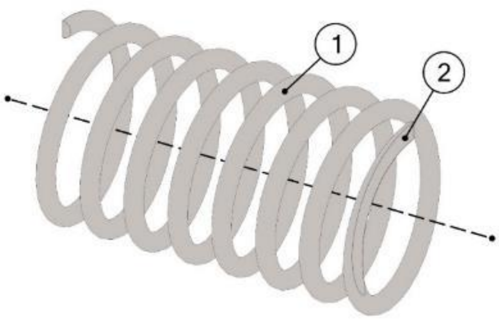


Figure 26: Compression spring main features

1. Grounded compression spring.
2. The spring size is $ID = 45\ mm, L = 100mm, d = 5mm$.

4.7. The spring seat

The spring seat carries the compression spring and connects to the valve piston, the part function and features are represented in Figure 27.

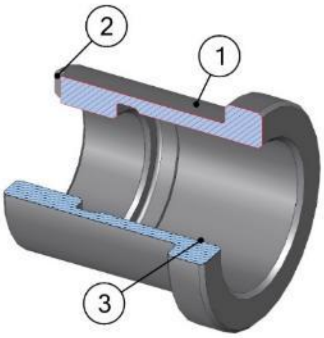


Figure 27: Spring seat main features

1. Compression spring seat.
2. Threaded hole is used to place a grab screw to secure the assembly from untightening due to vibration.
3. Connection threads to the valve piston.

4.8. The pressure and temperature sensor

The pressure and temperature sensor is a memory recording sensor that can be programed, the part function and features are represented in Figure 28.

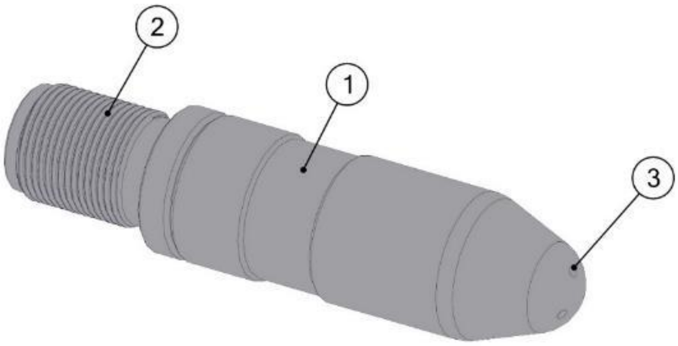


Figure 28: The pressure and temperature sensor main features

1. Sensor body.
2. Connection threads to the valve body.
3. Pressure ports to sense the pressure signal.

4.9. The shear screws cutter

The shear screws cutter is made of hard seal to insure ideal cutting of the shear screws, the part function and features are represented in Figure 29.

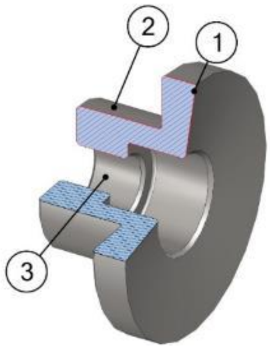


Figure 29: Shear screws cutter main features

1. Sharp edge to cut the shear screws.
2. Adapter place to the valve piston.
3. Fastener place for assembly.

4.10. The shear screw

The shear screw is the part that controls the movement of the valve piston after reaching the required pressure signal. The screw is calibrated to specific shear force, the number of the screws is adjusted to the required activation pressure see Equation (1), the part function and features are represented in Figure 30.

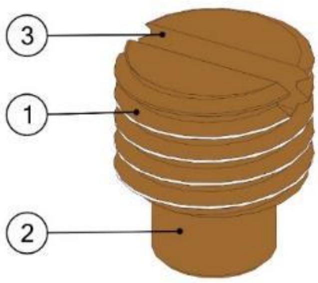


Figure 30: Shear screw main features

1. Connection threads to the valve body.
2. Calibrated cross shear section.
3. Slot for aiding the assembly.

4.11. The shock absorber

The shock absorber is the part that take the impact of valve piston after shearing the screws, see Figure 31.

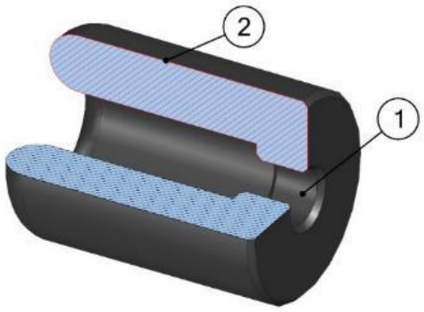


Figure 31: Shock absorber main features

1. Fastener hole for the assembly.
2. The shock absorber body

4.12. Fasteners

The DCV uses DIN standard fasteners for assembly see Figure 32.

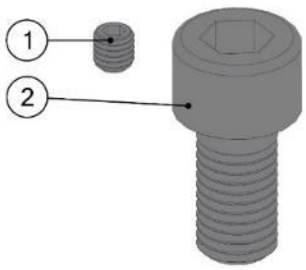


Figure 32: DIN fastener used in the DCV

1. DIN 913 M5x5 Set screw used as grab screw to secure the assembly from untightening due to vibration.
2. DIN 912 M10x20 Hex Socket Head used to assemble the shear screw cutter and the shock absorber.

4.13. Seals

The Seals used in the DCV is AS568 standard O-Rings and double backup rings. The sizes selected in the tool is marked in Appendix B.

The backup rings used to support the O-Ring due to the external and internal pressure and minimize the extrusion of the seal rubber, the seal material used in the DCV is FFKM material which ISO15156-3 approved for acid environment such H2S contents, see Figure 33.

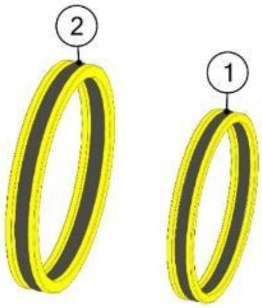


Figure 33: AS568 Seals used in the DCV

1. O-RING (2-132) 44.12x2.62/BACK-UP 47.5x43x1.5mm.
2. O-RING (2-226) 57x3.53/ BACK-UP 57x50.8x1.5mm.

4.14. Full assembly and layout

By connecting the parts shown in the previous section the DCV assembly will be completed as shown Figure 34.

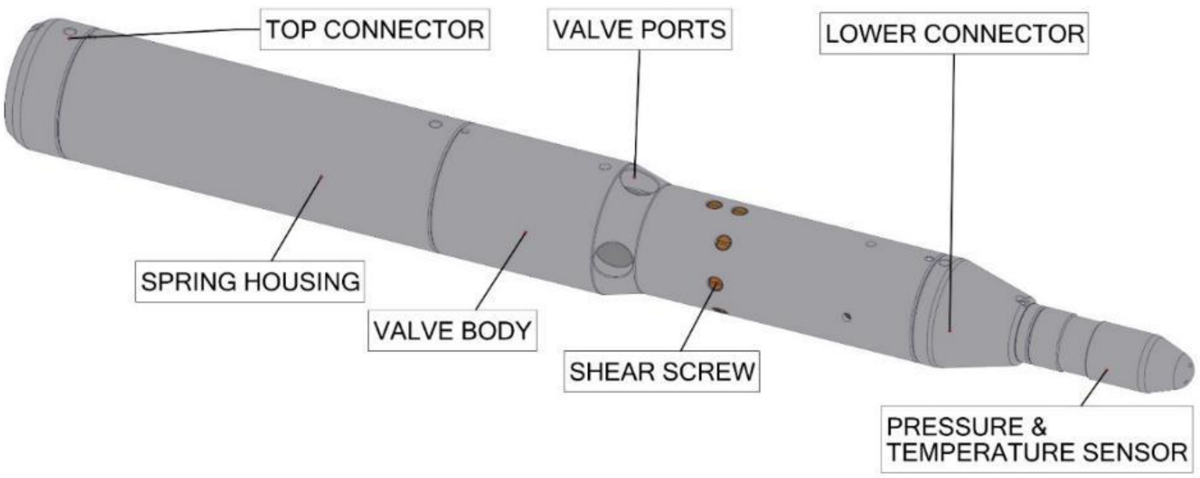


Figure 34: DCV full assembly

4.15. DCV function

The DCV function is determined by to positions closed and open. The valve will be used in closed position were the user select the number of shear screws depends on the required activation pressure.

1. **Closed position**

   The closed position of the DCV is the running in hole position where the valve piston will not allow the well fluids to enter the internal section of the valve. The spring is in compression stage applying a continuous force on the internal piston which is fixed in place by the shear screws.

The number of the shear screws determine the maximum pressure allowed to activate the valve from surface. The Pressure and Temperature Sensor is in the logging mode and recording all the changes of the well environment.

Figure 35 shows a section view of the DCV in the closed position.

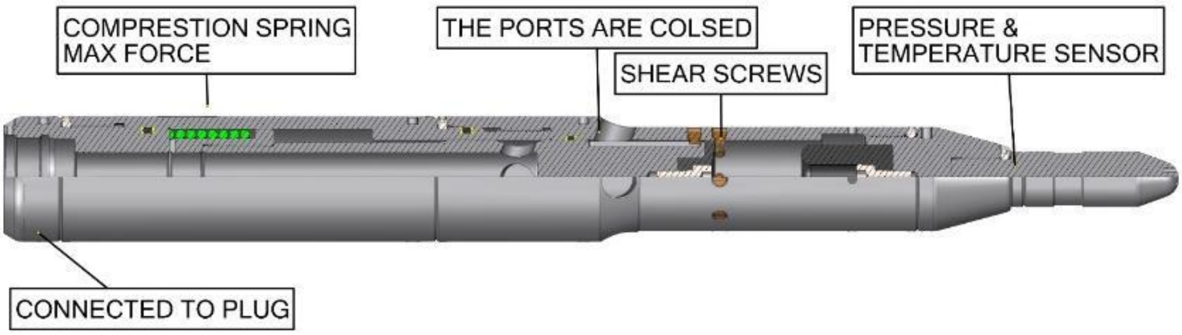


Figure 35: DCV section view in closed position

2. **Open position**

   By increasing the downhole pressure over the valve to the activation pressure, the valve will open the ports to let the well pressure below the valve to enter the valve. The activation pressure will overcome the reaction force provided by the shear screws and cut them. The spring will provide the force to open the piston to the inlet ports, see Figure 36. Due to the sudden movement of the piston the shock absorber will damp the kinetic energy.

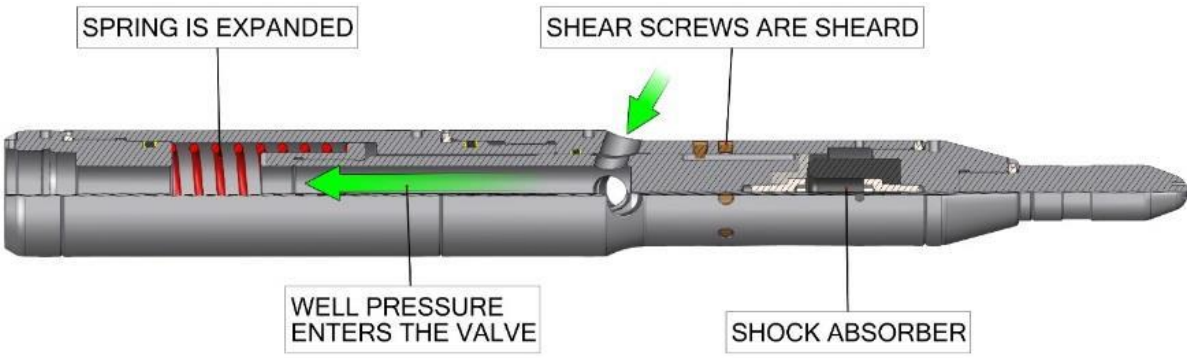


Figure 36: DCV section view in open position

5. Design and calculations

The studies in this section are selected to be the most important in order to the DCV to function properly. The studies cover the following calculations:

1. Thick wall pressure cylinder
2. Shear screw calculation
3. Flow area calculation

4. Pressure drop calculation
5. FEA simulation
6. CFD simulation

5.1. DCV sleeve design

All the sleeves of the valve are subjected to the well deferential pressure. The design of the DCV based on Lamé Burst and collapse maximum pressure [12] , see equations (2) and (3).

$$P_B = \frac{S.(D^2 - d^2)}{(D^2 - d^2).SF} \tag{2}$$

$$P_C = \frac{2.S.((D/t) - 1)}{(D/t)^2.SF} \tag{3}$$

Where; P_B *: Maximum burst pressure, MPa*
P_C : Maximum collapse pressure, MPa
S: Material yield strength, MPa
D: Outer diameter of the sleeve, mm
D: Inner diameter of the sleeve, mm
SF=1.2: Standard safety factor
t=(D-d)/2 : Wall thickness, mm

This study focusses on critical design scenario of the valve sleeve. According to the design specification the valve should stand high percentage of H2S and 10 000 psi maximum operation pressure. The selected material for the sleeve is INCOLOY 925 see Appendix A for more information.

The shear modulus of the material between 150-200 °C is 724 MPa. The geometry of the critical section has the following conditions:

D = 50.8 mm
d =42.926 mm
SF=1.2
t=3.937 mm

substituting in equation (2) the sleeve maximum allowed burst pressure will be:

$$P_B = \frac{724 * (50.8^2 - 42.926^2)}{(50.8^2 - 42.926^2) * 1.2} = 101\ MPa = 14566\ psi \ > 10000\ psi \tag{4}$$

substituting in equation (3) the sleeve maximum allowed collapse pressure will be at:

$$P_C = \frac{2 * 724.((50.8/3.937) - 1)}{(50.8/3.937)^2 * 1.2} = 86\ MPa = 12511\ Psi > 10000\ psi \tag{5}$$

Comparing the collapse and burst maximum pressure to the pressure rating design specification, the critical section (the smallest wall thickness) of the DCV sleeve is considered to be safe see Figure 20 .

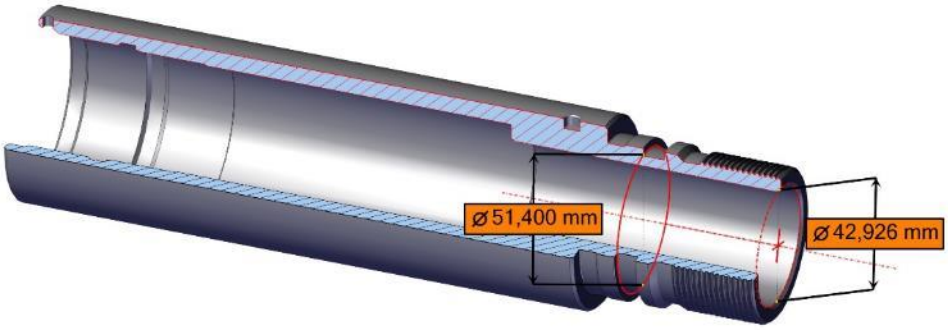


Figure 37: DCV critical sleeve section

5.2. Shear screw calculations

The design of the shear screws based on the ultimate shear strength. The section area is designed to be sheared at the 5000 N and if more well pressure is needed to activate the valve, calculated number of screws can be assembled.

1. Valve Piston Area calculations:

   The area is calculated according to (6) to provide accurate pressure steps in the valve for example 500, 1000, 1500, 2000 psi etc. as well as the force such: 5000, 10000, 15000N, etc.

$$A_v = \frac{F}{P} \tag{6}$$

Where; A_v *: Valve piston area mm²*
F *: Activation Force N*
P *: Activation Pressure MPa , the values are converted to (psi)*

The calculated valve piston area if the activation pressure is 500 psi (3,4MPa) and the activation force is 5000 N is

$$A_v = \frac{5000N}{3{,}4\ \mathrm{MPa}} = 1450{,}5\ mm^2 \tag{7}$$

The calculated diameter of the valve piston is:

$$D_v = \sqrt{\frac{4A_v}{\pi}} = \sqrt{\frac{4 * \ 1450{,}5}{\pi}} = 43\ mm \tag{8}$$

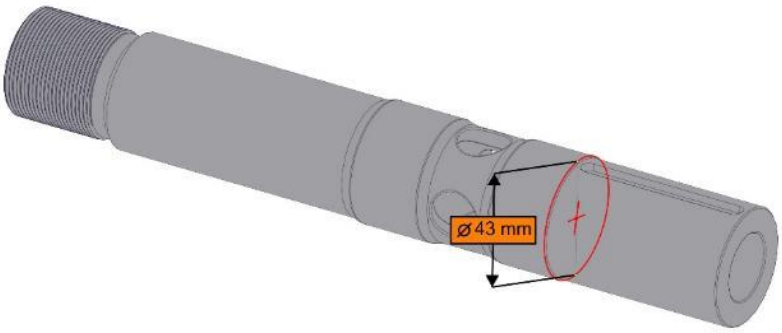


Figure 38: Valve piston effective diameter

To the cross section of the shear screw is calculated by the equation (9).

The unit force of each screw is determined as 5000 N and the shear strength is $\sigma_S = \sigma_y/\sqrt{3}$ and the yield strength σ_y of the material is determined, see Appendix C for the material properties

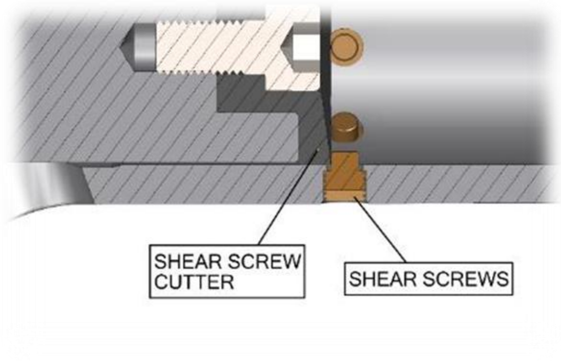


Figure 39: DCV critical sleeve section

$$A_S = \frac{F}{\sigma_S} \quad \textbf{(9)}$$

Where; *A_S : Shear Screw section area (mm^2)*
F : Activation Force (N)
σ_S: Material shear strength $\sigma_S = \sigma_y/\sqrt{3}$

The cross section of the shear screw is:

$$A_S = \frac{5000}{420/\sqrt{3}} = 20{,}6\ mm^2$$

The diameter of the section area is calculated by

$$D_s = \sqrt{\frac{4A_s}{\pi}} = \sqrt{\frac{4 * 20{,}6}{\pi}} = 5{,}125\ mm \quad \textbf{(10)}$$

The number of screws needed to have different activation pressure can be calculated by the equation (11).

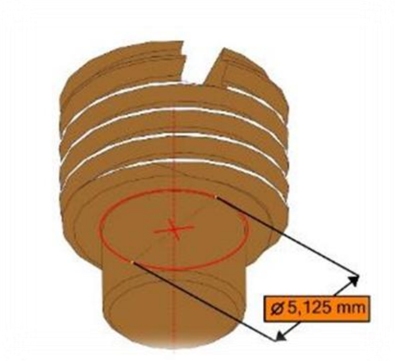


Figure 40: Shear screw shearing diameter

$$n = \frac{P_a}{P_S} \quad \textbf{(11)}$$

Where; P_S *: Pressure needed to activate one shear screw (psi)*
P_a *: Activation pressure*

See Table 4 for the number of screws for different activation pressure:

Table 4: Shear screw quantity for different activation pressure

Activation Pressure	(Psi)	500	1000	1500	2000	2500	3000	3500	4000
Force on Valve Piston	(Ton)	0,5	1,0	1,5	2,0	2,6	3,1	3,6	4,1
Number of Screws	(Qty)	1	2	3	4	5	6	7	8

5.3. Flow area calculations

The specification sheet (Table 1) shows that the required minimum flow area needed for the valve is $A_R = 645{,}16\ mm^2$ and this flow area should be obtained in any section of the of the valve. the diameter D_V of this area can be calculated by equation (12).

$$D_V = \sqrt{\frac{4A_R}{\pi}} = \sqrt{\frac{4 * 645{,}16}{\pi}} = 28{,}6\ mm \quad \textbf{(12)}$$

$D_V = 28{,}6\ mm$ will be the minimum inner diameter of the valve.

The area of inlet ports should be the same of the required flow area and to have symmetric flow through the valve tis area van be divided to 4 inlets and the diameter of each inlet can be calculated by equation (13).

$$D_{inlet} = \sqrt{\frac{4 \cdot \frac{A_R}{4}}{\pi}} = \sqrt{\frac{645{,}16}{\pi}} = 14{,}3\ mm \quad \textbf{(13)}$$

5.4. Pressure drop calculation

By installing the DCV in the well, the minimum flow area of the valve will be internal section of the valve and it is calculate to be 28,66 mm. The valve will be installed in 3.5 in N 80 tubing with 10,2 lb/ft which has 74.16 mm internal diameter with maximum flow rate 5 BPM (0.013 m^3/s) as referred in Table 1. The minimum diameter of the valve is determined by equation (12).

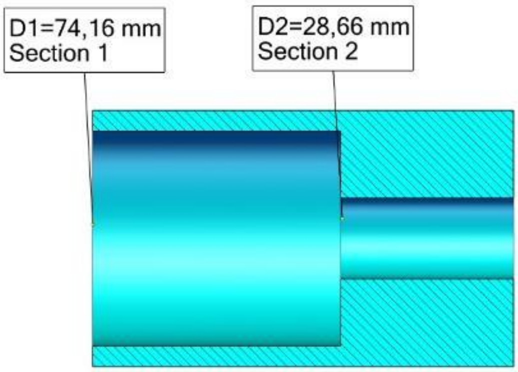


Figure 41: Flow across the DCV

Calculating the total pressure loss across the DCV between the two cross section areas A_1 (tubing) and A_2 (DCV), with inlet speed V_1 and out let sped V_2, it is assumed that the flow will not lose any mechanical energy between 1 and 2.

By Appling Bernoulli equation [13] between 1 and 2.

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

$$\rightarrow P_1 - P_2 = \frac{1}{2}\rho V_1^2 \left(\frac{V_2^2}{V_1^2} - 1\right) \quad \textbf{(14)}$$

Where; P_1 *: Pressure at section 1 (N/m²)*
P_2 *: Pressure at section 2(N/m²)*
V_1 *: Velocity at section 1 (m/sec)*
V_2 *: Velocity at section 2 (m/sec)*
ρ *: Fluid density (kg/m³)*

A_1 and A_2 are given in Figure 41 and by applying conservation of mass law between 1 and 2

$$Q = V_1 A_1 = V_2 A_2$$

$$A_1/A_2 = V_2/V_1 \quad \textbf{(15)}$$

Where; Q *: Flow Rate (m³/sec)*

By substituting (15) in (14)

$$P_1 - P_2 = \frac{1}{2}\rho V_1^2 \left(\left(\frac{A_1}{A_2}\right)^2 - 1\right) \quad \textbf{(16)}$$

$$\rightarrow \Delta P = \frac{1}{2}\rho\, V_1^2\left(\left(\frac{D_1}{D_2}\right)^4 - 1\right)$$

$$Where, Q = V_1 A_1$$

$$\Delta P = 8.\rho\,\left(\frac{Q}{\pi}\right)^2\left(\frac{1}{D_2^4} - \frac{1}{D_1^4}\right) \quad \textbf{(17)}$$

$$\rightarrow \Delta P = 8 * 920\,\left(\frac{0,0132}{\pi}\right)^2 * \left(\frac{1}{28,66^4} - \frac{1}{74,16^4}\right) = 284531\ \mathrm{N/m^2}$$

Where the density for medium crude oil is approximately $\rho = 920\ \mathrm{kg/m^3}$.

5.5. FEA simulations

The selection of the FEA studies in this section was selected in order the DCV function properly and safe to be used. The connection between parts is very relevant case where understanding how the connection threads behave under force. As well as the valve body which is an important part in the valve where the flow go throw it and it has relatively complex geometry analyses in hand calculations.

1. Threads Connection FEA simulation

The threads connections simulation is based on the Finite Element Method using SolidWorks nonlinear stress analysis. It simulates how the parts will react in reality rather than applying static force, the nonlinear simulation will introduce the load not at once but gradually with time. The model is threaded connection that is simplified to be used only for this study.

The model is an assembly of pin and box parts (Figure 42-A) that are connected with M55x2 threads, see Appendix E. Due to the axisymmetric model the simulation study is achieved by using the 2D simplified version of the 3D model, which can reduce the analysis time. For axisymmetric models, a 2D projection of the model is sufficient to fully represent the 3D model. The axisymmetric is used when the geometry, load and restraints are symmetric (360 degrees) about the center axis, see Figure 42-B. After the simplification the model will be presented in Figure 42-C. The material selection of the parts is INCOLOY 925 that has 724MPa yield strength, see Appendix A. The simulation model type of the material is selected for the nonlinear static simulation as Plasticity-von Mises. And the nonlinear study is defined as large strain where pseudo time steps are used to apply loads/fixtures in small increments. Where the time increment was outstepping with initial increment 0.01 by using direct sparse solver [14]. Hence that the model is an assembly it is essential to define contact set between the parts and it is selected to be No Penetration surface to surface contact. The fixture (green arrows) is used in the

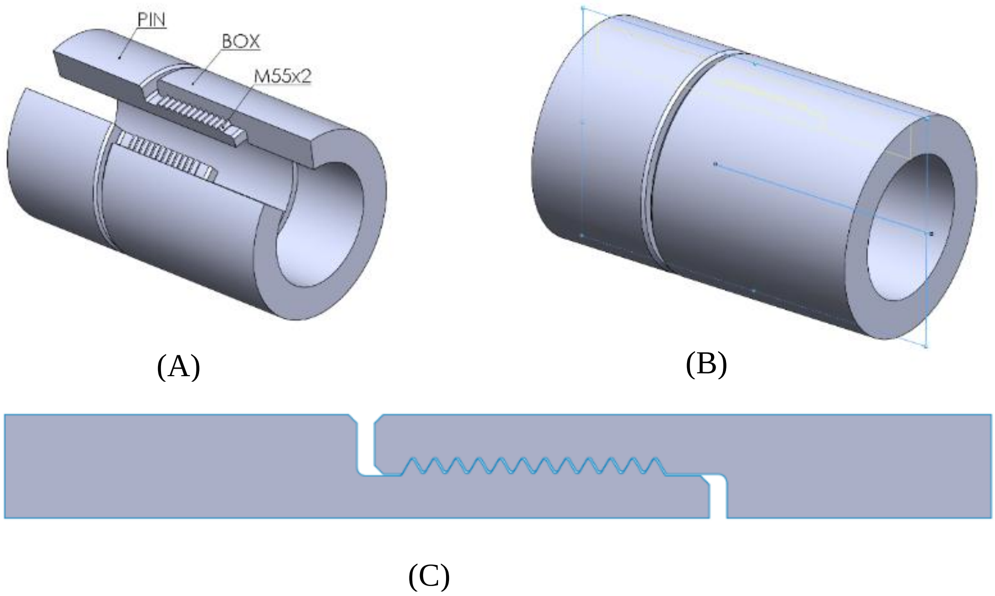


Figure 42: Pin-Box threaded connection (Simulation model)

. model is Roller /Slider and by selecting the horizontal edge of the pin and vertical edge of the Box, that will prevent the box from moving along the horizontal direction when the force is applied on the pin, see Figure 43.

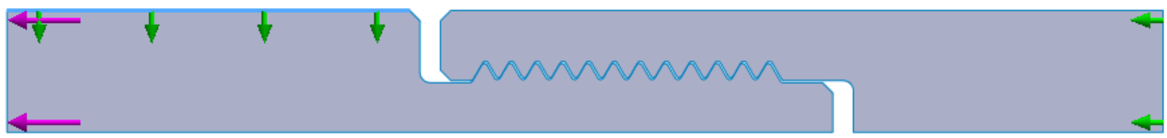


Figure 43: Model fixture and external force

An external force (80000 N) (Table 1) is applied on the vertical edge of the box (pink arrows) which is pulling the model to the left see Figure 43. The study properties are listed in the Table 5:

Table 5: FEA threads connection study properties

Study name	Pin-Box thread connection
Analysis type	Nonlinear - static 2D simplification
Mesh type	Planar 2D mesh
Start time	0 sec
End time	1 sec
Time increment	Auto stepping

Solver type	Direct sparse solver
Incompatible bonding options	Simplified
Iterative technique:	NR (Newton-Raphson)
Integration Method	Newmark

The mesh type is selected to Planer 2D Mesh with curvature based mesh and the maximum element size is 0.12 mm and the minimum element size is 0.028 mm and the total nodes is 371912 and the total elements is 184584 the shows the meshed view of the study in starting iteration and the final iteration.

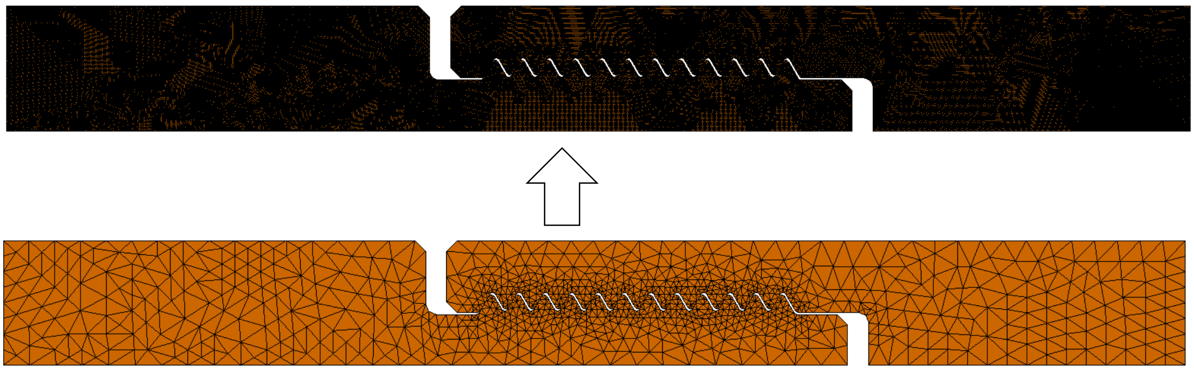


Figure 44: FEA Meshing model

The study results

The maximum Von-Mises stress located in the root of the threads with value 234.2 MPa see Figure 45. The maximum displacement is located at the end with applied force and it has the value of 0.04 mm see Figure 46.

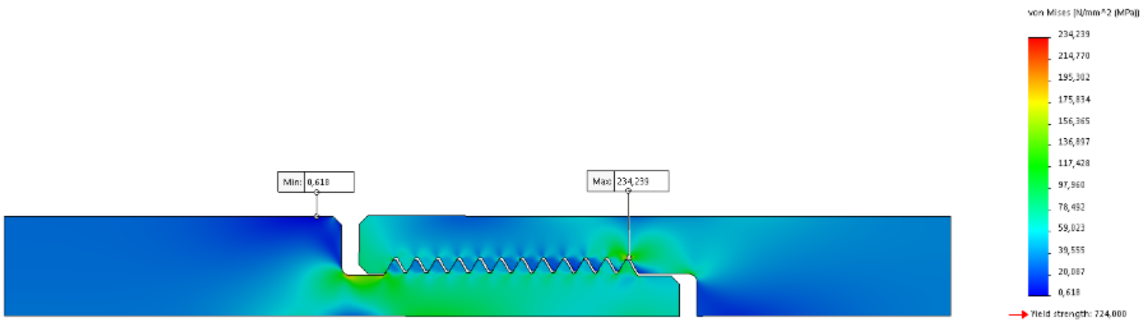


Figure 45: Von-Mises stress results on the threads connection

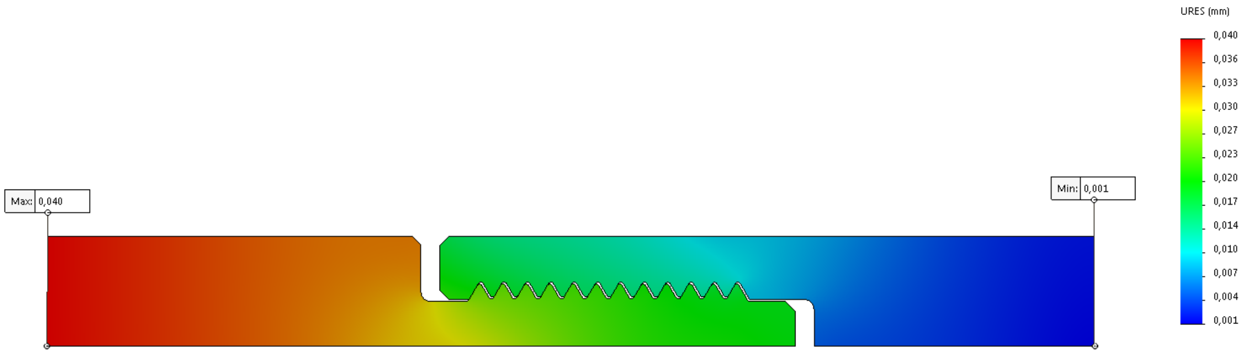


Figure 46: The displacement results on the threads connection

These results were found after mesh refinement which is summarized in Table 6 where the different simulation is used at different mesh size and the result were accepted after when the result error is less than 1%. Table 6 shows 4 different FEA studies that has different mesh for each and by increasing the mesh the error percentage decreases.

Table 6: FEA threads connection FEA study convergent

Study number	Mesh information		Von-Mises stress (MPa)	Error percentage %	Time (min)
	Total nodes	Total elements			
1	3518	6376	225.1	-	10
2	40537	19769	229.6	1.99	19
3	47095	22943	233.3	1.61	40
4	371912	184584	234.2	0.386	120

2. Valve body FEA simulation

The valve body simulation is based on the FEA using SolidWorks static stress analysis. The valve body part is simplified to be used only for this study. The model has 4 inlet circular ports and 8 shear screws holes (Figure 47).

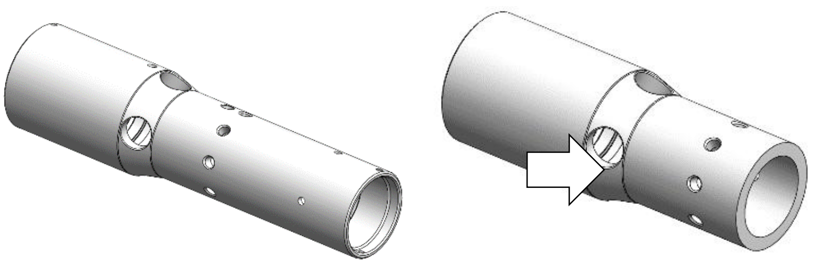


Figure 47: Valve body (Simulation model)

The material selection of the study is INCOLOY 925 that has 724MPa yield strength, see Appendix A. simulation model type of the material is selected for static simulation as Liner Elastic Isotropic. The fixture (green arrows) is used in the model is fixed geometry applied on the entire surface of the threads and this will prevent the model of moving in three directions, see Figure 48. An external force 80000 N (Table 1) is applied on the other side of the valve body (pink arrows) which is pulling the model to the right see Figure 48

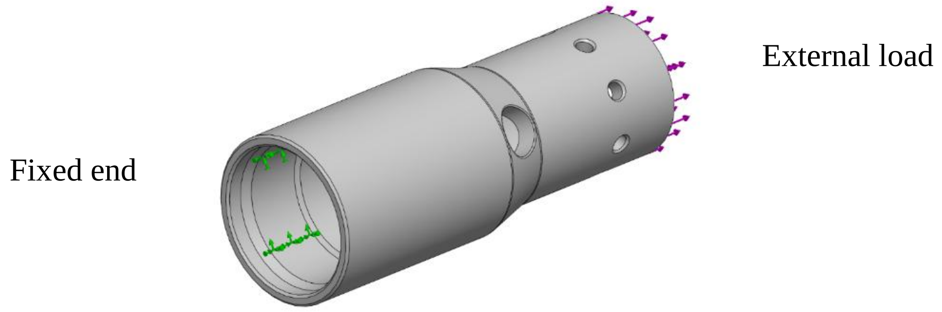


Figure 48: Model fixture and external force

The study properties are listed in the Table 5:

Table 7: FEA valve body study properties

Study name	Static-Valve Body
Analysis type	Static
Mesh type	Solid Mesh
Solver type	FFEPlus

The mesh type is selected to Solid Mesh with curvature-based mesh and the Jacobian points are 16 points. Maximum element size is 2.1 mm and the minimum element size is 0.4 mm and total number of nodes is 355963 and the total elements is 238263. Figure 49 shows the meshed view of the study in starting iteration and the final iteration.

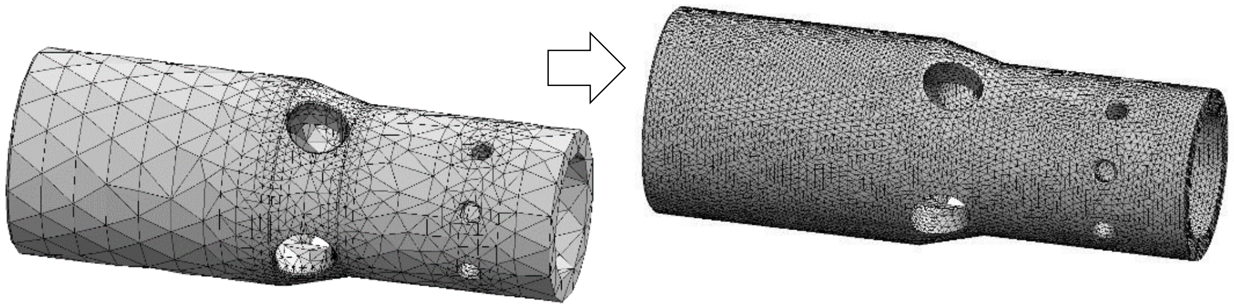


Figure 49: FEA Meshing model

3. The study results

The maximum Von-Mises stress located in the share screws holes area with value (227.2 MPa) see the Figure 50. The maximum displacement is located at the end with applied force and it has the value of 0.06 mm see the Figure 51. These results were found after mesh refinement which is summarized in Table 8 where the different simulation is used at different mesh size and the result were accepted when the result error is less than 1%. Table 8 shows 4 different FEA studies that has different mesh for each and by increasing the mesh the error percentage decreases

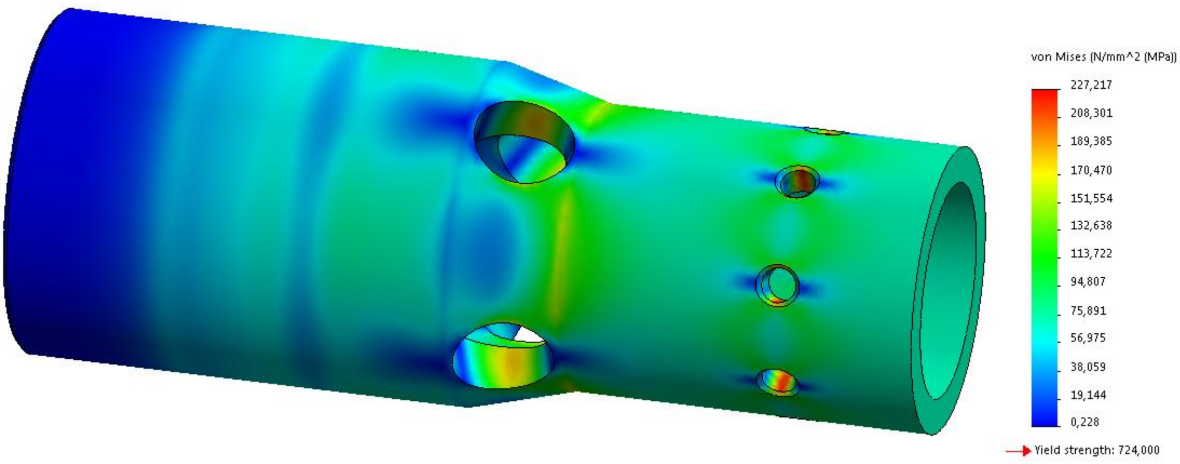


Figure 50: Von-Mises stress results on the Valve Body

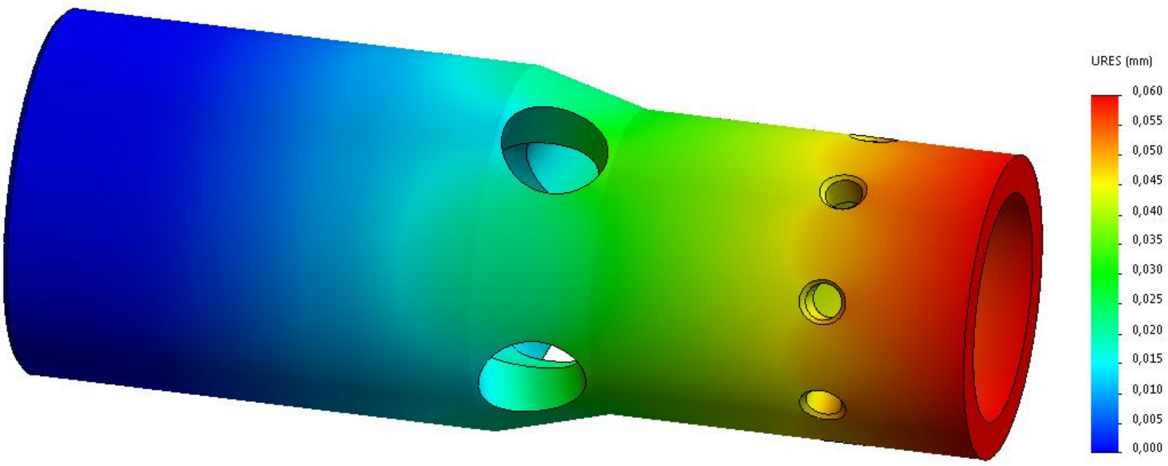


Figure 51: The displacement results on the Valve Body

Factor of safety in the valve body is presented in Figure 52 which shows that the critical area in the model is where the shear screws holes are and that creates the minimum cross section of the model.

Table 8: Valve body FEA study convergent

Study number	Mesh information		Von-Mises stress MPa	Error percentage	Time (min)
	Total nodes	Total elements			
1	22286	12756	220.367	-	1
2	31111	18311	223.674	1.501%	5
3	67826	41921	226.596	1.306%	12
4	371912	184584	227.217	0.274	30

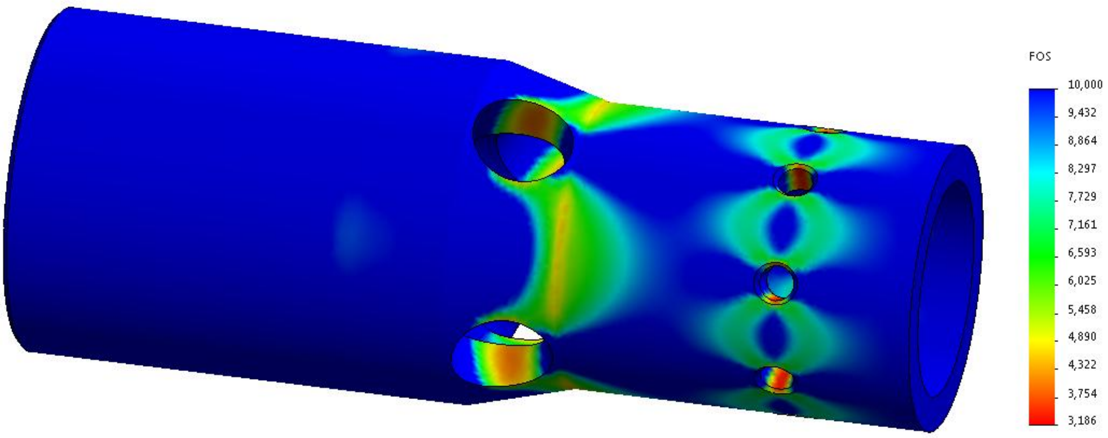


Figure 52: Factor of safety on the valve body

5.6. CFD simulations

1. Flow simulation mathematical background

The flow simulation used in SolidWorks solves Navier-Stokes equations that deals with mass, momentum and energy conservation low of the fluids [14] see equations (18),(19) and (20) .as well as the simulation determine whether the flow is laminar, turbulent or both based on Reynolds number.

$$\frac{\delta\rho}{\delta t} + \frac{\delta}{\delta x_i}(\rho u_i) = 0 \quad \textbf{(18)}$$

(mass conversation equation)

$$\frac{\delta \rho u_i}{\delta t} + \frac{\delta}{\delta x_i}(\rho u_i u_j) + \frac{\delta P}{\delta x_i} = \frac{\delta}{\delta x_i}(\tau_{ij} + \tau_{ij}{}^R) + S_i\,; i = 1,2,3 \quad \textbf{(19)}$$

(N-S equation)

$$\frac{\delta \rho H}{\delta t}+\frac{\rho u_i H}{\delta x_i}=\frac{\delta}{\delta x_i}\left(u_j\left(\tau_{ij}+\tau_{ij}{}^{R}\right)+q_i\right)+\frac{\delta P}{\delta t}-\ \tau_{ij}{}^{R}\frac{\delta u_i}{\delta x_j}+\rho\varepsilon+S_i u_i+Q_H \quad \textbf{(20)}$$

(energy balance equation)

$$;H=h+\frac{u^2}{2}$$

Where; u *: Fluid velocity*

ρ *: Fluid density*

S_i*: Mass -distributed external force per unit mass due to a porous media resistance*

Q_H*: Heat source per unit volume*

q_i*: Diffusive heat flux*

τ_{ij} *=Viscous shear stress tensor*

The equations are used in 3 directions x y z

2. Model Simplification

Due to the complication of the DCV assembly the model was prepared and simplified for CFD simulation. All internal parts that are not related to the flow was removed and created as one solid body which simulate the inlet ports and the external shape of the DCV. Figure 53 shows the simplification process.

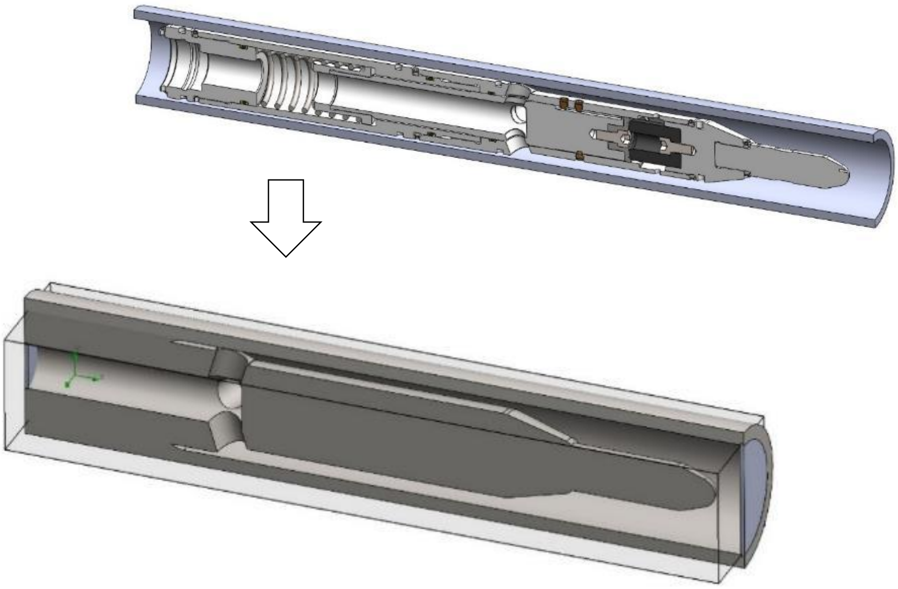


Figure 53: CFD simplified model

3. The computational domain

The computation domain is calculated by SolidWorks flow simulation after creating two lids in both sides of the flow. And it is calculated to be as cuboid with size $37x37x425\ mm$, see Figure 54

4. Boundary conditions

1. Inlet volume flow: the inlet of the flow is determined to be volume flow with rate 0.013 $\frac{m^3}{s}$ and it is applied on the lid in front of the DCV.
2. Outlet pressure: the outlet of the flow is determined to be unit pressure to determine the pressure drop between the inlet and the outlet.

5. Meshing Model

The flow simulation was conducted in two mesh sizes where the total number of elements in the first study is 1224 elements and 24064 elements in the second one. The increasing quality of the mesh size is calculated to be 19,6 times larger than first study, see Figure 54.

6. Simulation goals

The simulation goals were set as the average velocity and the pressure drop across the computational domain.

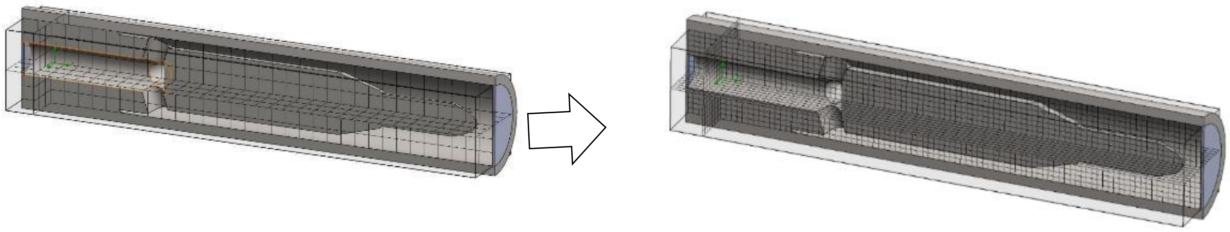


Figure 54: CFD mesh and compactional domain

7. Results

Figure 55 shows the fluid velocity behavior around the DCV and trough the inlet ports. The maximum velocity at the minimum flow area reaches 26 m/s in the centre of the outlet the average velocity is 6.5 m/s see the graph in Figure 57.

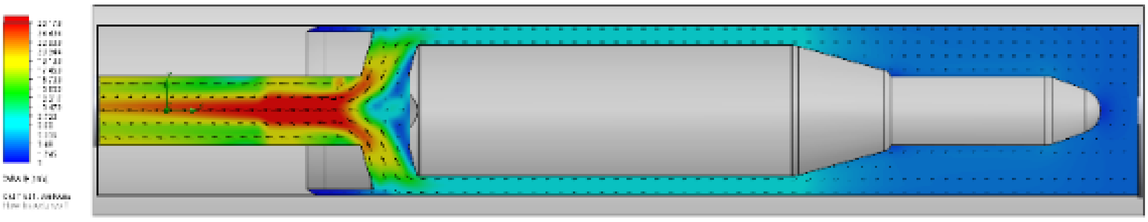


Figure 55: The CFD velocity result in the DCV

The shows the pressure drop across the DCV and it has the maximum value of 455931 Pa
And the pressure drop is calculated as by the differences between the inlet pressure and outlet pressure 183789 Pa see the pressure drop diagram in Figure 57

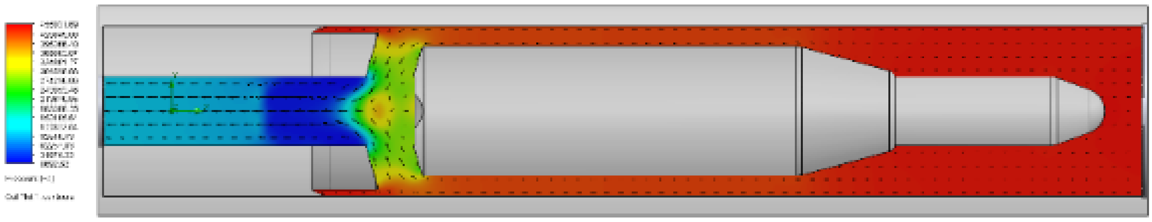


Figure 56: The CFD pressure result in the DCV

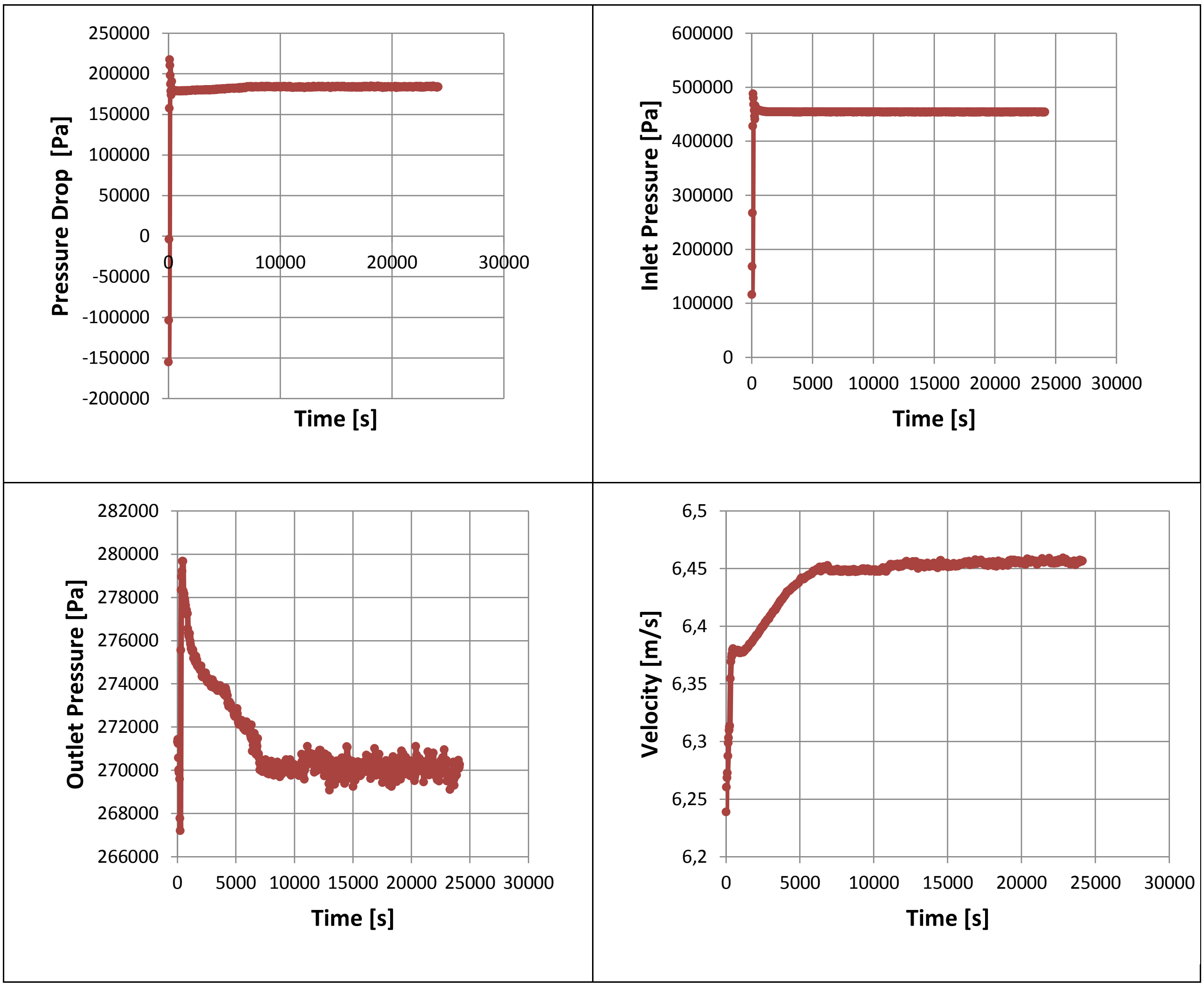


Figure 57: The CFD results

6. Material selection

Considering the NORSOK-M-01 [15] and ISO15156-3 [16] standards as guidance for material selection of the DCV. The standards provide the engineering guidance of the material to perform in the most reliable way in the environment conditions. The standards recommend set of material that can works in corrosive, high pressure and temperature fluids. The material such Nickle alloy family which includes INCOLOY 925, INCONEL 718-725-X750, MONEL K-500 are materials typically used in pressure vessels applications that exposed to H2S and CO_2 fluids. The seals material that works in high H2S and CO2 is considered very rare and the standard recommend FFKM rubber material that is very good in high temperature and in application that has high corrosive fluids.

6.1. DCV material selection and Bill of Material (BOM)

The material selection of the valve is based on ISO15156-3 [16]and NORSOK-M-01 [15] standard. Materials for use in H2S-containing environment. The **Figure 58** shows the exploded view of the DCV with balloon for each item number. The Table 9 shows the BOM of the DCV including the quantity and material selection.

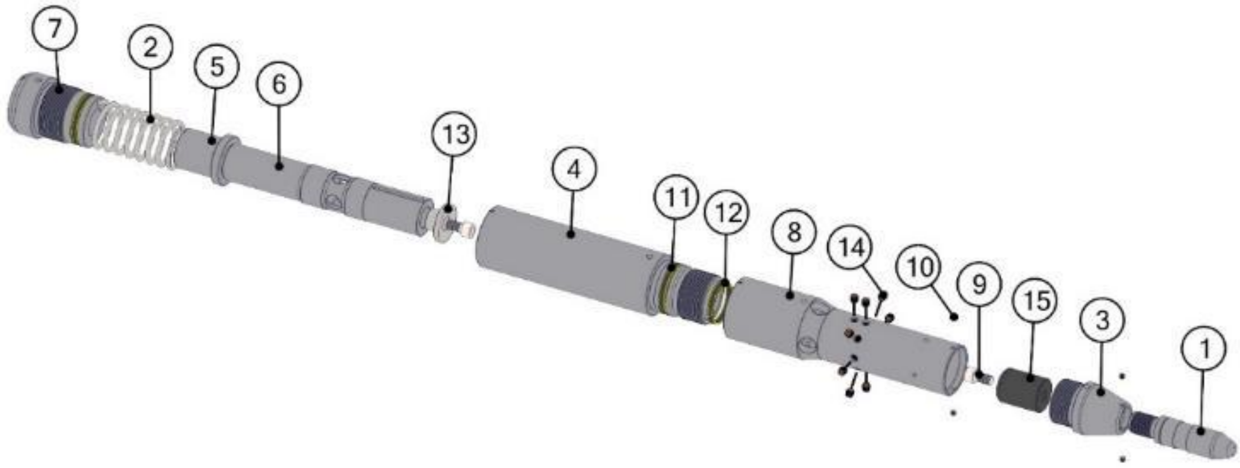


Figure 58: DCV exploded view

Table 9: DCV material selection based on ISO15156-3 and NORSOK-M-01

NO.	QTY.	PART NUMBER	DESCRIPTION	MATERIA SELECTION
1	1	270 DCV 113	PRESSURE &TEMPERATURE SENSOR	INCOLOY 925
2	1	270 DCV 114	COMPRESTION SPRING	INCOLOY 925
3	1	270 DCV 105	LOWER CONNECTOR	INCOLOY 925
4	1	270 DCV 103	SPRING HOUSING	INCOLOY 925
5	1	270 DCV 102	SPRENG SEAT	INCOLOY 925
6	1	270 DCV 107	PISTON	INCOLOY 925
7	1	270 DCV 106	TOP CONNECTOR	INCOLOY 925
8	1	270 DCV 104	VALVE BODY	INCOLOY 925

9	2	DIN 912 M10 x 20	BOLT	INCOLOY 925
10	10	DIN 913 – M4 x 5	SET SCREW	INCOLOY 925
11	2	270 DCV 109	O-RING 57x3.53/ BACK-UP 57x50.8x1.5	FFKM/PEEK
12	1	270 DCV 110	O-RING 47.5x2.62/ BACK-UP 47.5x43x1.5	FFKM/PEEK
13	1	270 DCV 111	CUTTER	INCOLOY 925
14	8 Max	270 DCV 108	SHEAR SCREW	BRASS HPB59-1
15	1	270 DCV 112	SHOCK ABSORBER	FFKM

7. Product manufacturing information

The DCV manufacturing information is obtained by using SolidWorks 2D drawings. The 3D CAD model is used to describe the manufacturing details of the DCV parts. The drafting of the parts is guided by:

1. NS-ISO 2768-1-fine for general dimensions and tolerances [17]
2. NS-EN ISO 1302: 2002 for surface finish [18]
3. NS 1874-ISO R965/1 for threads tolerances [19]

Unless otherwise specified all sharp have fillet radius $0{,}5mm$ and broken edges with chamfer $0{,}1 - 0{,}5mm\ at\ 45°$.

All the details drawing of the DCV are attached in the Appendix F.

7.1. DCV Assembly steps

The design is made for easy assembly and disassembly, the assembly steps is illustrated in Appendix G in the Solid Composer files.

7.2. Naming, serial numbers and engraving

The serial numbers used to name the parts in SolidWorks follows the system:

1. **Assembly Numbering**

270	DCV	X00	01

Outer Diameter of the valve

Abbreviation: Product Name

Assembly Staring Number

Revision Number

2. **Part Numbering**

270	DCV	1XX	925	01

Outer Diameter of the valve

Abbreviation: Downhole Control Valve

Assembly Staring Number

Material Abbreviation

Revision Number

8. Conclusion and future work

8.1. Conclusion

The purpose of the thesis is to design Downhole Control Valve that can handle high pressure and temperature in addition to high percentage of H2S. the valve is designed to be connected to plug and packer system. The study covers the design process stages of the DCV and details all the steps to create, reliable, safe, simple and efficient valve by creating a unique design concept that satisfy all the design requirement.

The conclusion of this project is that the DCV can function properly with the selection of the materials. Hand Calculation FEA simulation and CFD flow simulation was performed to ensure that the valve will perform as per the design requirement. Factors of safety was used as per the industry standard to ensure safe and reliable use of the valve.

8.2. Future work and development

It is necessary for further development to consider the following points:

1. Nonlinear FEA simulation on the shock absorber material.
2. Further calculations and design optimization of the CFD study.
3. Creating G -Cods for manufacturing process.
4. Prototype testing, including pressure, temperature and flow testing.

8.3. Summary

The project objective was to develop Downhole Control Valve that works in highly corrosive environment such H2S. The DCV handles internal and external pressure up to 10 000 psi and temperature up to 150c and all the material selected in the project are recommended from the commonly used standard in the industry. The design process method is followed in all stages from the hand sketches to the 3D modelling and creating manufacturing drawings. The thesis covers eight chapters as follows:

The Chapter-1 is an introduction of the project and it contains the project objectives and scope. Chapter-2 is a research study about the well drilling and structure, surface equipment, tubing and casing specifications, well intervention methods, well intervention market and existing products, also it covers the design constrains, industry standards, design requirement and project management. Chapter-3 is focused on generating and evaluating concepts, where hand sketches were created, and the selected concept is explained. Chapter-4 includes the geometrical molding, where SolidWorks was used to generate 3D models of all parts and assembly of the valve. Chapter-5 consist of theoretical and numerical analyses of critical parts in the valve. SolidWorks FEA simulation and CFD flow simulation were used to solve the problems numerically. Chapter-6 covers the material selection which has been achieved by following the industry standards. Chapter-7 includes the product manufacturing information where SolidWorks 2D drawing was used to generate manufacturing information of the valve assembly and parts. The conclusion and the future works are covered in Chapter-8.

References

[1] "https://www.pistonheads.com/gassing/topic.asp?t=1410012," [Online].

[2] Schlumberger, Slickline Training Manual, 2nd ed., SophiaPublish-SRC-General, 2002, pp. 10-100.

[3] K. M. D. M. D. M. James Garner, "Oilfield Review," *At the Ready: Subsurface Safety Valve,* 2002.

[4] API, Specification for Casing and Tubing, Washington,DC: American Petroleum Institute, 2011, pp. 90-100.

[5] "NOV," [Online]. Available: https://www.nov.com/Segments/Completion_and_Production_Solutions/Intervention_and_Stimulation_Equipment/Elmar/K-WINCH_Winches_and_Masts/DynaWinch_Product_Line/Wireline_Skid_Equipment/Slickline_Skid_Units/SS1_220_Series/DynaWinch_SS1-220_Series.aspx. [Accessed 28 12 2017].

[6] "Hamamatsu," [Online]. Available: http://www.hamamatsu.com/us/en/community/oil_well_logging/application.html. [Accessed 27 12 2017].

[7] "CT," [Online]. Available: http://www.octgproducts.com/what-is-coiled-tubing.html. [Accessed 27 12 2017].

[8] "M&M," [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/well-intervention-market-1099.html?gclid=CjwKCAiA7JfSBRBrEiwA1DWSG5bygCd7z0Bm3rc13-6W0jrkQOyB5HHLlPdlXQYVLEiIRhtwhdv9zRoCiQ0QAvD_BwE. [Accessed 12 29 2017].

[9] [Online]. Available: https://www.nov.com/Segments/Wellbore_Technologies/Downhole/Thru_Tubing/Coiled_Tubing_Tools_2/Primary_Tools/CT_Circulation_Subs/Ball_Activated_Circulation_Valve.aspx. [Accessed 17 December 2017].

[10] "http://peakcompletions.com," [Online]. Available: http://peakcompletions.com/index.php/menu-products-and-services/menu-ps-p-service-tools/menu-ps-p-ch-flow-control/menu-ps-p-ch-fc-model-el-sliding-sleeve. [Accessed 17 December 2017].

[11] [Online]. Available: http://www.sparteksystems.com/siteimages/Brochures/Flyer_Multi-Cycle_Shut-in_Tool_20080729.pdf. [Accessed 17 December 2017].

[12] SPE, "http://petrowiki.org/Strength_of_casing_and_tubing," [Online]. Available: http://petrowiki.org/Strength_of_casing_and_tubing.

[13] T. H. O. W. W. H. A. P. R. Bruce R. Munson, Fluid Mechanics, 7th Edition SI Version, Wiley, Jan 2013.

[14] SolidWorks, THEORETICAL MANUAL SOLIDWORKS Simulation, Dassault System, 2018.

[15] "NORSOK-M-001, Materials selection, Standard Norge, 2004.".

[16] ISO15156-3, "Materials for use in H2S-containing environments," 2010.

[17] "NS-ISO 2768-1-fine Genral ISO Geomerical Tolerances".

[18] "Geometrical Product Specifications (GPS) - Indication of surface texture in technical product documentation (ISO 1302:2002)".

[19] "ISO 965-1:1998, ISO general purpose metric screw threads — Tolerances — Part 1: Principles and basic data.".

[20] ISO10407, "Drilling and production equipment - Drill stem design and operating limits," 1993.

[21] ISO10432, "Downhole equipment - Subsurface safety valve equipment," 2004.

[22] ISO14310, "Downhole equipment - Packers and bridge plugs," 2001.

[23] ASME, An International Code of Boiler & Pressure Vessel Code, vol. ASME VIII, ASME, 2013.

[24] NORSOK-D-002, "System requirements well intervention equipment (Rev. 1, Oct. 2000)".

[25] NORSOK-D-SR-007, "Well testing system," 1996.

[26] NORSOK-D-010, "Well integrity in drilling and operations," 2013.

[27] NOROSK-M-710, “Qualification of non-metallic sealing materials and manufacturers (Rev. 2, October 2011)”.

[28] S. Pugh, Total Design Integrated Methods for Successful, Addison Wesley, 1991.

[29] D. Annaratone, Pressure Vessel Design, Milano: Springer Berlin, 2012.

[30] Qinterra, “Qinterra Technologies,” 2015. [Online]. Available: http://www.qinterra.com/products. [Accessed 11 March 2015].

[31] “ISO15156-3, “Materials for use in H2S-containing environments,” 2010.”.

Appendix A : Incoloy alloy 925

SPECIAL METALS

www.specialmetals.com

INCOLOY® alloy 925 (UNS N09925) is an age-hardenable nickel-iron-chromium alloy with additions of molybdenum, copper, titanium and aluminum. The alloy's chemical composition, listed in Table 1, is designed to provide a combination of high strength and excellent corrosion resistance. The nickel content is sufficient for protection against chloride-ion stress-corrosion cracking. The nickel, in conjunction with the molybdenum and copper, also gives outstanding resistance to reducing chemicals. The molybdenum aids resistance to pitting and crevice corrosion. The alloy's chromium content provides resistance to oxidizing environments. The titanium and aluminum additions cause a strengthening reaction during heat treatment.

INCOLOY alloy 925 is used in various applications requiring a combination of high strength and corrosion resistance. Because of the alloy's resistance to sulfide stress cracking and stress-corrosion cracking in "sour" (H_2S containing) crude oil and natural gas, it is used for down-hole and surface gas-well components including tubular products, valves, hangers, landing nipples, tool joints and packers. The alloy is also useful for fasteners, marine and pump shafting and high-strength piping systems.

Table 1 - Limiting Chemical Composition (UNS N09925) of INCOLOY alloy 925, %

Nickel	42.0-46.0
Chromium	19.5-22.5
Iron	22 min
Molybdenum	2.5-3.5
Copper	1.5-3.0
Titanium	1.9-2.4
Aluminum	0.1-0.5
Manganese	1.0 max.
Silicon	0.5 max.
Niobium	0.5 max.
Carbon	0.03 max.
Sulfur	0.03 max.

Physical Properties

Some physical constants of INCOLOY alloy 925 are given in Table 2. They are room-temperature values except for the melting range. Table 3 provides physical property data for INCOLOY alloy 925 at elevated temperatures. Coefficient of expansion and specific heat data over a range of temperatures are in Table 4. Elevated temperature thermophysical properties are given in Table 5.

Table 2 - Physical Properties of INCOLOY alloy 925

Density, lb/in³	0.292
g/cm³	8.08
Melting Range, F	2392-2490
C	1311-1366
Electrical Resistivity, ohm circ mil/ft	701
µΩ m	1.17
Permeability at 200 oersteds (15.9 kA/m)	1.001

Table 3 - Elevated Temperature Dynamic Young s Modulus and Shear Modulus Values for INCOLOY alloy 925 (hot rolled round, solution-annealed and aged)

Temperature		Young s Modulus		Shear Modulus		Poisson s Ratio
F	C	10³ ksi	GPa	10³ ksi	GPa	
70	21	28.9	199	11.2	77	0.293
100	38	28.8	199	11.1	76	0.299
200	93	28.3	195	10.8	75	0.308
300	149	27.8	192	10.6	73	0.316
400	204	27.3	188	10.4	72	0.315
500	260	26.8	185	10.2	70	0.317
600	316	26.3	182	10.0	69	0.319
700	371	25.9	178	9.8	68	0.319
800	427	25.4	175	9.6	66	0.323
900	482	24.9	172	9.4	65	0.323
1000	538	24.4	168	9.2	64	0.324
1100	593	23.8	164	9.0	62	0.326
1200	649	23.2	160	8.7	60	0.330
1300	704	22.5	155	8.4	58	0.334
1400	760	21.8	150	8.2	56	0.338
1500	816	21.0	145	7.9	54	0.335
1600	871	20.1	139	7.6	52	0.330
1700	927	19.2	132	7.2	50	0.326

INCOLOY® alloy 925

INCOLOY® alloy 925

Table 4 - Thermal Properties of INCOLOY alloy 925

Temperature	Coefficient of Expansion[a]	Specific Heat
F	10^6 in/in F	Btu/lb F
70	-	0.104
200	7.8	0.109
400	8.1	0.116
600	8.4	0.122
800	8.5	0.129
1000	8.7	0.136
1200	9.0	0.143
1400	9.5	0.150
1600	-	0.157
Temperature	**Coefficient of Expansion[a]**	**Specific Heat**
C	µm/m C	J/kg C
20	-	435
100	13.2	456
200	14.2	486
300	14.7	507
400	15.0	532
500	15.3	561
600	15.7	586
700	16.3	611
800	17.2	641
900	-	666

[a]Expansion testing in accordance with ASTM E228.
Reference temperature = 77 F (25 C).

Table 5 - Elevated Temperature Thermophysical Properties of INCOLOY alloy 925 (hot rolled round, solution-annealed and aged)

Temperature		Thermal Conductivity	
C	F	W/m C	BTU in/ft² h F
23	73	12.0	83.1
100	212	12.9	89.2
200	392	14.3	99.2
300	572	15.9	110.0
400	752	17.4	120.9
500	932	19.3	133.8
600	1112	22.2	153.7
700	1292	24.0	166.7
800	1472	28.2	195.8
900	1652	27.7	192.3
1000	1832	24.6	170.7
1100	2012	26.0	180.2
1150	2102	26.9	186.8

Mechanical Properties

Mechanical properties at room temperature of solution-annealed and solution-annealed plus aged products are given in Table 6. Mechanical properties limits for specification purposes are shown in Table 7 (Special Metals Corporation internal specification HA 46).

As shown in Figure 1, INCOLOY alloy 925 retains a substantial portion of its strength at temperatures up to about 1200°F (650°C).

Figure 2 shows rotating beam fatigue data for INCOLOY alloy 925 and MONEL alloy K-500.

Figure 3 shows mean axial stress vs. cycles of fatigue in the 1365°F (740°C) dual aged condition. The compression test result, at room temperature, for a solution-annealed and aged bar was 122.7 ksi (846 MPa) and the yield strength tension test result was 123.5 ksi (851 MPa)

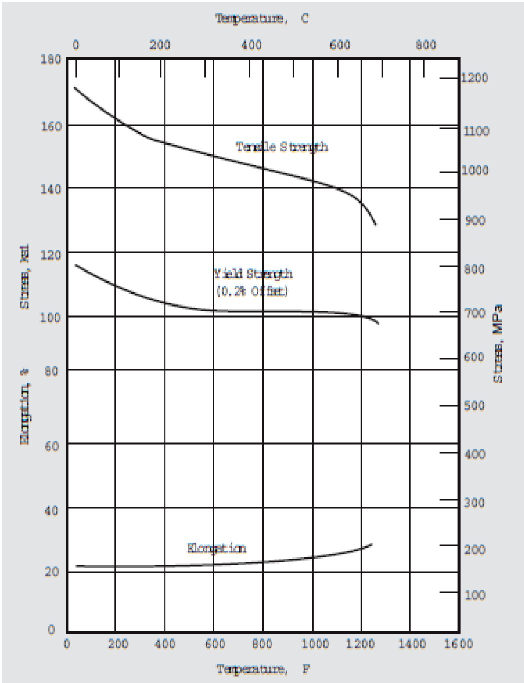


Figure 1. Tensile properties at high temperatures of solution-annealed and aged INCOLOY alloy 925.

Appendix B : Seals size

ORD 5712
O-Ring Material Offering Guide

2-xxx Sizes, Cross-Section: .103 ± .003 in (2,62 ± 0,08mm)					2-xxx Sizes, Cross-Section: .103 ± .003 in (2,62 ± 0,08mm)				
Parker No.	Inside Dia. in.	Tol. ± in.	Inside Dia. mm	Tol. ± mm	Parker No.	Inside Dia. in.	Tol. ± in.	Inside Dia. mm	Tol. ± mm
2-102	.049	.005	1,24	0,13	2-141	2.300	.020	58,42	0,51
2-103	.081	.005	2,06	0,13	2-142	2.362	.020	59,99	0,51
2-104	.112	.005	2,84	0,13	2-143	2.425	.020	61,60	0,51
2-105	.143	.005	2,84	0,13	2-144	2.487	.020	63,17	0,51
2-106	.174	.005	4,42	0,13	2-145	2.550	.020	64,77	0,51
2-107	.206	.005	5,23	0,13	2-146	2.612	.020	66,34	0,51
2-108	.237	.005	6,02	0,13	2-147	2.675	.022	67,95	0,56
2-109	.299	.005	7,59	0,13	2-148	2.737	.022	69,52	0,56
2-110	.362	.005	9,19	0,13	2-149	2.800	.022	71,12	0,56
2-111	.424	.005	10,77	0,13	2-150	2.862	.022	72,69	0,56
2-112	.487	.005	12,37	0,13	2-151	2.987	0.24	75,87	0,61
2-113	.549	.007	13,94	0,18	2-152	3.237	.024	82,22	0,61
2-114	.612	.009	15,54	0,23	2-153	3.487	.024	88,57	0,61
2-115	.674	.009	17,12	0,23	2-154	3.737	.028	94,92	0,71
2-116	.737	.009	18,72	0,23	2-155	3.987	.028	101,27	0,71
2-117	.799	.010	20,30	0,25	2-156	4.237	.030	107,62	0,76
2-118	.862	.010	21,89	0,25	2-157	4.487	.030	113,97	0,76
2-119	.924	.010	23,47	0,25	2-158	4.737	.030	120,32	0,76
2-120	.987	.010	25,07	0,25	2-159	4.987	.035	126,67	0,89
2-121	1.049	.010	26,64	0,25	2-160	5.237	.035	133,02	0,89
2-122	1.112	.010	28,24	0,25	2-161	5.487	.035	139,37	0,89
2-123	1.174	.012	29,82	0,30	2-162	5.737	.035	145,72	0,89
2-124	1.237	.012	31,42	0,30	2-163	5.987	.035	152,07	0,89
2-125	1.299	.012	32,99	0,30	2-164	6.237	.040	158,42	1,02
2-126	1.362	.012	34,59	0,30	2-165	6.487	.040	167,77	1,02
2-127	1.424	.012	36,17	0,30	2-166	6.737	.040	171,12	1,02
2-128	1.487	.012	37,77	0,30	2-167	6.987	.040	177,47	1,02
2-129	1.549	.015	39,34	0,38	2-168	7.237	.045	183,82	1,14
2-130	1.612	.015	40,94	0,38	2-169	7.487	.045	190,17	1,14
2-131	1.674	.015	42,52	0,38	2-170	7.737	.045	196,52	1,14
2-132	1.737	.015	44,12	0,38	2-171	7.987	.045	202,87	1,14
2-133	1.799	.015	45,69	0,38	2-172	8.237	.050	209,22	1,27
2-134	1.862	.015	47,29	0,38	2-173	8.487	.050	215,57	1,27
2-135	1.925	.017	48,90	0,43	2-174	8.737	.050	221,92	1,27
2-136	1.987	.017	50,47	0,43	2-175	8.987	.050	228,27	1,27
2-137	2.050	.017	52,07	0,43	2-176	9.237	.055	234,62	1,40
2-138	2.112	.017	53,64	0,43	2-177	9.487	.055	240,97	1,40
2-139	2.175	.017	55,25	0,43	2-178	9.737	.055	247,32	1,40
2-140	2.237	.017	56,82	0,43					

Parker Hannifin Corporation • O-Ring Division
2360 Palumbo Drive, Lexington, KY 40509
Phone: (859) 269-2351 • Fax: (859) 335-5128
www.parkerorings.com

ORD 5712
O-Ring Material Offering Guide

2-xxx Sizes, Cross-Section: .139 ± .004 in (3,53 ± 0,10mm)					2-xxx Sizes, Cross-Section: .139 ± .004 in (3,53 ± 0,10mm)				
Parker No.	Inside Dia. in.	Tol. ± in.	Inside Dia. mm	Tol. ± mm	Parker No.	Inside Dia. in.	Tol. ± in.	Inside Dia. mm	Tol. ± mm
2-201	.171	.055	4,34	0,13	2-243	4.109	.028	104,37	0,71
2-202	.234	.005	5,94	0,13	2-244	4.234	.030	107,54	0,76
2-203	.296	.005	7,52	0,13	2-245	4.359	.030	110,72	0,76
2-204	.359	.005	9,12	0,13	2-246	4.484	.030	113,89	0,76
2-205	.421	.005	10,69	0,13	2-247	4.609	.030	117,07	0,76
2-206	.484	.005	12,29	0,13	2-248	4.734	.030	120,24	0,76
2-207	.546	.007	13,87	0,18	2-249	4.859	.035	23,42	0,89
2-208	.609	.009	15,47	0,23	2-250	4.984	.035	126,59	0,89
2-209	.671	.009	17,04	0,23	2-251	5.109	.035	129,77	0,89
2-210	.734	.010	18,64	0,25	2-252	5.234	.035	132,94	0,89
2-211	.796	.010	20,22	0,25	2-253	5.359	.035	136,12	0,89
2-212	.859	.010	21,82	0,25	2-254	5.484	.035	139,29	0,89
2-213	.921	.010	23,39	0,25	2-255	5.609	.035	142,47	0,89
2-214	.984	.010	24,99	0,25	2-256	5.734	.035	145,64	0,89
2-215	1.046	.010	26,50	0,25	2-257	5.859	.035	148,82	0,89
2-216	1.109	.012	28,17	0,30	2-258	5.984	.035	151,99	0,89
2-217	1.171	.012	29,74	0,30	2-259	6.234	.040	158,34	1,02
2-218	1.234	.012	31,34	0,30	2-260	6.484	.040	164,69	1,02
2-219	1.296	.012	32,92	0,30	2-261	6.734	.040	171,04	1,02
2-220	1.359	.012	34,52	0,30	2-262	6.984	.040	177,39	1,02
2-221	1.421	.012	36,09	0,30	2-263	7.234	.045	183,74	1,14
2-222	1.484	.015	37,69	0,38	2-264	7.484	.045	190,09	1,14
2-223	1.609	.015	40,87	0,38	2-265	7.734	.045	196,44	1,14
2-224	1.734	.015	44,04	0,38	2-266	7.984	.045	202,79	1,14
2-225	1.859	.018	47,22	0,38	2-267	8.234	.050	209,14	1,27
2-226	1.984	.018	50,39	0,46	2-268	8.484	.050	215,49	1,27
2-227	2.109	.018	53,57	0,46	2-269	8.734	.050	221,84	1,27
2-228	2.234	.020	56,74	0,51	2-270	8.984	.050	228,19	1,27
2-229	2.359	.020	59,92	0,51	2-271	9.234	.055	234,54	1,40
2-230	2.484	.020	63,09	0,51	2-272	9.484	.055	240,89	1,40
2-231	2.609	.020	66,27	0,51	2-273	9.734	.055	247,24	1,40
2-232	2.734	.024	69,44	0,60	2-274	9.984	.055	253,59	1,40
2-233	2.859	.024	72,62	0,61	2-275	10.484	.055	266,29	1,40
2-234	2.984	.024	75,79	0,61	2-276	10.984	.065	278,99	1,65
2-235	3.109	.024	78,97	0,61	2-277	11.484	.065	291,69	1,65
2-236	3.234	.024	82,14	0,61	2-278	11.984	.065	304,39	1,65
2.237	3.359	.024	85,32	0,61	2-279	12.984	.065	32,79	1,65
2-238	3.484	.024	88,49	0,61	2-280	13.984	.065	355,19	1,65
2-239	3.609	.028	91,67	0,71	2-281	14.984	.065	380,59	1,65
2-240	3.734	.028	94,84	0,71	2-282	15.955	.075	405,26	1,91
2-241	3.859	.028	98,02	0,71	2-283	16.955	.080	430,66	2,03
2-242	3.984	.028	101,19	0,71	2-284	17.955	.085	456,06	2,16

Parker Hannifin Corporation • O-Ring Division
2360 Palumbo Drive, Lexington, KY 40509
Phone: (859) 269-2351 • Fax: (859) 335-5128
www.parkerorings.com

Appendix C : Brass material

TECHNICAL DATASHEET

Aurubis

CuZn39Pb3

Revision 13 03 EU

Comparable standards: EN CW614N • UNS C38500 • BS CZ121
Aurubis designations: PNA253

Description

CuZn39Pb3 is mainly used where machinable or machining forming is required. The material is particularly suitable for the treatment on machines. It has an excellent hot working property.
In Germany CuZn39Pb3 is the benchmark material for the assessment of the machinability (index 100%).

Composition

Cu [%]	Pb [%]	Zn [%]
57,0 – 59,0	2,5 – 3,5	rem.

Physical properties

Melting point [°C]	Density [g/cm³]	Specific heat cap. at 20 °C [kJ/kgK]	Electrical cond. [MS/m]	Thermal cond. at 20 °C [W/mK]	Mod. of elasticity [GPa]	Coef. of therm exp. at 20 °C [10^{-6}/K]
888	8,47	0,377	14,6	113	96	21,4

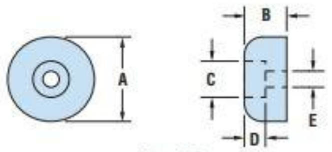
The specified conductivity applies to the soft condition only

Mechanical properties

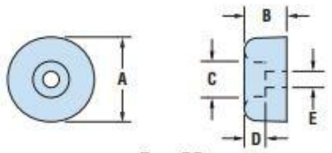
	Diameter [mm]	Tensile strength R_m [MPa]	Yield strength $Rp_{0.2}$ [MPa]	Elon-gation $A_{11.3}$ min [%]	Hardness HV [-]	Hardness HB [-]
R450	0,5 – 1,5	> 450	(200)			
R430 H130	1,5 – 4,0	> 430	(200)		130-165	
R420 H120	4,0 – 8,0	> 420	(200)	8	120-155	
R410	8,0 – 14,0	> 410	(200)			
R520	0,5 – 1,5	> 520	(400)			
R510 H155	1,5 – 4,0	> 510	(400)		155-185	
R500	4,0 – 8,0	> 500	(390)	6		
R490 H145	8,0 – 14,0	> 490	(390)		145-175	
R570 H170	1,5 – 4,0	> 570	(520)		> 170	

Appendix D : Shock absorber

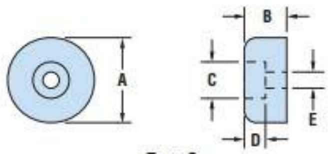
- **Bumpers can be used as mounting feet** to prevent equipment from sliding or moving.
- Designed for through hole installation.
- 60-70 Durometer Range.
- 29 sizes available that will accommodate various mounting holes and panel thicknesses.
- Provide vibration dampening.



Type RS



Type RR



Type S

Heyco® Screw-In Rubber Pocket Bumpers

A Outside Diameter in.	A mm.	B Overall Height in.	B mm.	C Recess Diameter in.	C mm.	D Recess Depth in.	D mm.	Black Part No. No Washer	Black Part No. With Steel Washer	E Fastner Hole Dia.* in.	E mm.
Type RS											
.50	12,7	.25	6,4	.25	6,4	.16	4,0	-	G2201	.13	3,2
.63	15,9	.38	9,5	.25	6,4	.19	4,7	-	G2205		
.75	19,1	.38	9,5	.32	7,9	.19	4,7	-	G2209	.16	4,0
.81	20,6	.72	18,3	.38	9,5	.28	7,1	-	G2213	.22	5,5
1.00	25,4	.81	20,6	.25	6,4	.44	11,1	-	G2217	.13	3,2
		1.00	25,4	.31	7,9	.63	15,9	G2220	G2221	.16	4,0
1.09	27,7	.63	15,9	.44	11,1	.41	10,3	-	G2225	.19	4,7
Type RR											
.50	12,7	.25	6,4	.25	6,4	.16	4,0	-	G2229	.09	2,4
.75	19,1	.56	14,3	.38	9,5	.25	6,4	-	G2233	.19	4,7
		.75	19,1	.31	7,9	.25	6,4	-	G2237	.13	3,2
.81	20,6	.81	20,6	.47	11,9	.44	11,1	-	G2241	.25	6,4
.94	23,8	.35	8,9	.38	9,5	.18	4,6	-	G2245	.19	4,7
		.38	9,5	.38	9,5	.22	5,5	G2244	-		
.97	24,6	.34	8,7	.38	9,5	.19	4,7	-	G2249		
1.00	25,4	.44	11,1	.38	9,5	.19	4,7	-	G2253		
		.50	12,7	.50	12,7	.25	6,4	-	G2257	.22	5,5
		.56	14,3	.53	13,5	.31	7,9	-	G2261	.28	7,1
1.25	31,8	1.25	31,8	.38	9,5	.75	19,1	-	G2267	.25	6,4
		1.88	47,6	.38	9,5	.75	19,1	-	G2271		
1.50	38,1	.63	15,9	.50	12,7	.34	8,7	-	G2275	.19	4,7
				.75	19,1	.34	8,7	G2278	G2279	.31	7,9
		.75	19,1	.47	11,9	.50	12,7	-	G2283	.25	6,4
1.70	43,2	1.12	28,4	.60	15,2	.72	18,3	G2286	-	.38	9,6
1.71	44,5	1.66	44,5	.62	15,9	.50	12,7	G2290			
2.50	63,5	1.00	25,4	1.13	28,6	.50	12,7	G2294 G2296† G2298†			
		2.00	50,8	1.13	28,6	1.25	28,6	G2302			
Type S											
1.00	25,4	.50	12,7	.36 / .43	9.0 / 10,9	.20 / .16	5,0 / 4,1	-	G2307	.19	4,7
1.50	38,1	.75	19,1	.75	19,1	.38	9,5	-	G2311	.25	6,4

Standard color black. Standard material SBR (Styrene Butadiene Rubber), 60-70 durometer.
***Fastener not included.**
†**Part Nos. G2296** and **G2298** are made from **White** SBR, 60-70 durometer.

Quick Specs

Material	SBR
Temperature Range	-40°F (-40°C) to 221°F (105°C)

Appendix E : Metric threads sizes

BASIC DIMENSIONS

Dimensions in millimeters - Ref: ISO/R 724-1968

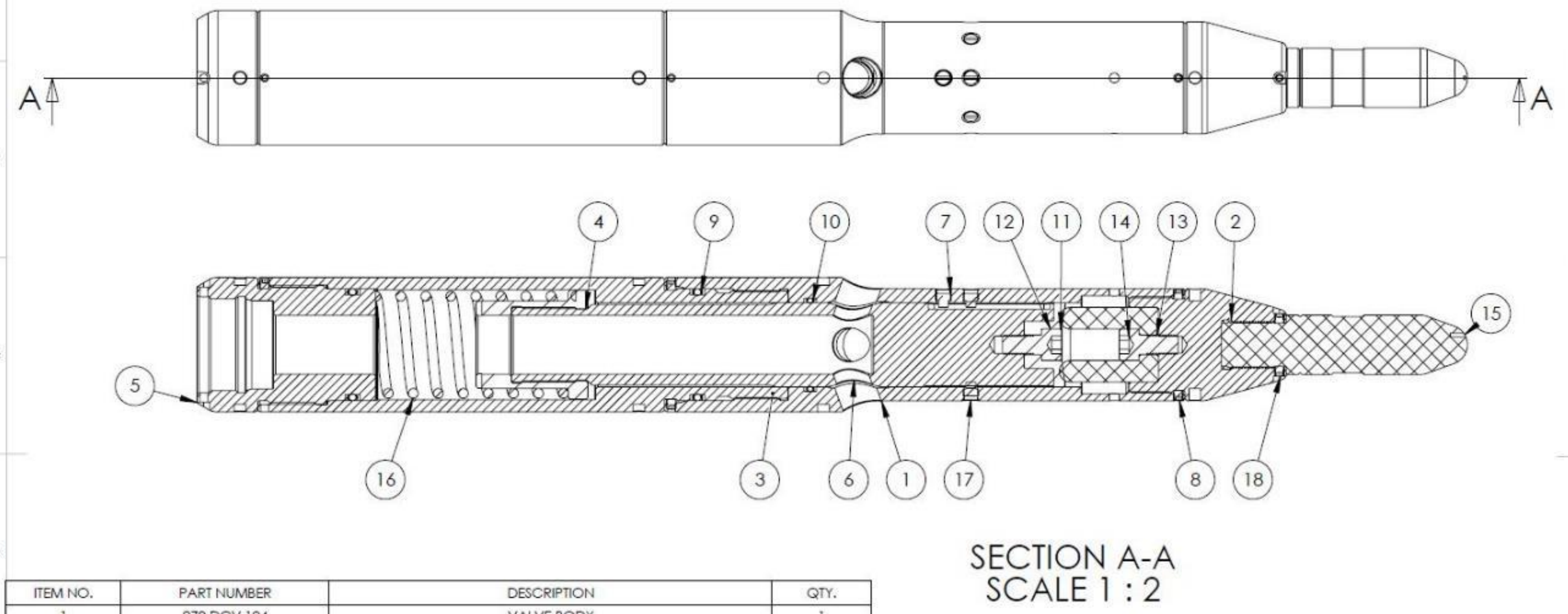
NOM. THREAD DIA.	PITCH P	MAJOR DIA. D d	PITCH DIA. D2 d2	MINOR DIA. D1 d1
M 0.3	0.08	0.300	0.248038	0.213397
M 0.35	0.09	0.350	0.291543	0.252572
M 0.4	0.1	0.400	0.335048	0.291747
M 0.45	0.1	0.450	0.385048	0.341747
M 0.5	0.125	0.500	0.418810	0.364684
M 0.55	0.125	0.550	0.468810	0.414684
M 0.6	0.15	0.600	0.502572	0.437620
M 0.7	0.175	0.700	0.586334	0.510557
M 0.8	0.2	0.800	0.670096	0.583494
M 0.9	0.225	0.900	0.753858	0.656430
M 1	0.25	1.000	0.837620	0.729367
	0.2		0.870096	0.783494
M 1.1	0.25	1.100	0.937620	0.829367
	0.2		0.970096	0.883494
M 1.2	0.25	1.200	1.037620	0.929367
	0.2		1.070096	0.983494
M 1.4	0.3	1.400	1.205144	1.075241
	0.2		1.270096	1.182494
M 1.6	0.35	1.600	1.372668	1.221114
	0.2		1.470096	1.383494
M 1.8	0.35	1.800	1.572668	1.421114
	0.2		1.670096	1.583494
M 2	0.4	2.000	1.740192	1.566987
	0.25		1.837620	1.729367
M 2.2	0.45	2.200	1.907716	1.712861
	0.25		2.037620	1.929367
M 2.5	0.45	2.500	2.207716	2.012861
	0.35		2.272668	2.121114
M 3	0.5	3.000	2.675240	2.458734
	0.35		2.772668	2.621114
M 3.5	0.6	3.500	3.110289	2.850481
	0.35		3.272668	3.121114
M 4	0.7	4.000	3.545337	3.242228
	0.5		3.675240	3.458734
M 4.5	0.75	4.500	4.012861	3.668101
	0.5		4.175240	3.958734
M 5	0.8	5.000	4.480385	4.133975
	0.5		4.675240	4.458734
M 5.5	0.5	5.500	5.175240	4.958734
M 6	1	6.000	5.350481	4.917468
	0.75		5.512861	5.188101
M 7	1	7.000	6.350481	5.917468
	0.75		6.512861	6.188101
M 8	1.25	8.000	7.188101	6.646835
	1		7.350481	6.917468
	0.75		7.512861	7.188101
M 9	1.25	9.000	8.188101	7.646835
	1		8.350481	7.917468
	0.75		8.512861	8.188101
M 10	1.5	10.000	9.025721	8.376202
	1.25		9.188101	8.646835
	1		9.350481	8.917468
	0.75		9.512861	9.188101
M 11	1.5	11.000	10.025721	9.376202
	1		10.350481	9.917468
	0.75		10.512861	10.188101
M 12	1.75	12.000	10.863342	10105569
	1.5		11.025721	10.376202
	1.25		11.188101	10.646835
	1		11.350481	10.917468
M 14	2	14.000	12.700962	11.834936
	1.5		13.025721	12.376202
	1.25		13.188101	12.646835
	1		13.350481	12.917468
M 15	1.5	15.000	14.025721	13.376202
	1		14.350481	13.917468
M 16	2	16.000	14.700962	13.834936
	1.5		15.025721	14.376202
	1		15.350481	14.917468

NOM. THREAD DIA.	PITCH P	MAJOR DIA. D d	PITCH DIA. D2 d2	MINOR DIA. D1 d1
M 17	1.5	17.000	16.025721	15.376202
	1		16.350481	15.917468
M18	2.5	18.000	16.376202	15.293671
	2		16.700962	15.834936
	1.5		17.025721	16.376202
	1		17.350481	16.917468
M 20	2.5	20.000	18.376202	17.293671
	2		18.700962	17.834936
	1.5		19.025721	18.376202
	1		19.350481	18.917468
M 22	2.5	22.000	20.376202	19.293671
	2		20.700962	19.834936
	1.5		21.025721	20.376202
	1		21.350481	20.917468
M 24	3	24.000	22.051443	20.752405
	2		22.700962	21.834936
	1.5		23.025721	22.376202
	1		23.350481	22.917468
M 25	2	25.000	23.700962	22.834936
	1.5		24.025721	23.376202
	1		24.350481	23.917468
M 26	1.5	26.000	25.025721	24.376202
M 27	3	27.000	25.051443	23.752405
	2		25.700962	24.834936
	1.5		26.025721	25.376202
	1		26.350481	25.917468
M 28	2	28.000	26.700962	25.834936
	1.5		27.025721	26.376202
	1		27.350481	26.917468
M 30	3.5	30.000	27.726683	26.211139
	3		28.051443	26.752405
	2		28.700962	27.834936
	1.5		29.025721	28.379202
	1		29.350481	28.917468
M 32	2	32.000	30.700962	29.834936
	1.5		31.025721	30.376202
M 33	3.5	33.000	30.726683	29.211139
	3		31.051443	29.752405
	2		31.700962	30.834936
M 35	1.5	35.000	34.025721	33.376202
M 36	4	36.000	22.401924	31.669873
	3		34.051443	32.752405
	2		24.700962	33.834936
	1.5		35.025721	34.376202
M 38	1.5	38.000	37.025721	36.376202
M 39	4	39.000	36.401924	34.669873
	3		37.051443	35.752405
	2		37.700962	36.834936
	1.5		38.025721	37.376202
M 40	3	40.000	38.051443	36.752405
	2		38.700962	37.834936
	1.5		39.025721	38.376202
M 42	4.5	42.000	39.077164	37.128607
	4		39.401924	37.669873
	3		40.051443	38.752405
	2		40.700962	39.834936
	1.5		41.025721	40.376202
M 45	4.5	45.000	42.077164	40.128607
	4		42.401924	40.669873
	3		43.051443	41.752405
	2		43.700962	42.834936
	1.5		44.025721	43.376202
M 48	5	48.000	44.752405	42.587341
	4		45.401924	43.669873
	3		46.051443	44.752405
	2		46.700962	45.834936
	1.5		47.025721	46.376202
M 50	3	50.000	48.051443	46.752405
	2		48.700962	47.834936
	1.5		49.025721	48.376202

NOM. THREAD DIA.	PITCH P	MAJOR DIA. D d	PITCH DIA. D2 d2	MINOR DIA. D1 d1
M 52	5	52.000	48.752405	46.587341
	4		49.401924	47.669873
	3		50.051443	48.752405
	2		50.700962	49.834936
	1.5		51.025721	50.376202
M 55	4	55.000	52.401924	50.669873
	3		53.051443	51.752405
	2		53.700962	52.834936
	1.5		54.025721	53.376202
M 56	5.5	56.000	52.427645	50.046075
	4		53.401924	51.669873
	3		54.051443	52.752405
	2		54.700962	53.834936
	1.5		55.025721	54.376202
M 58	4	58.000	55.401924	53.669873
	1.5		57.025721	56.367202
M 60	5.5	60.000	56.427645	54.046075
	1.5		59025721	58.376202
M 62	4	62.000	59.401924	57.669873
	1.5		61.025721	60.376202
M 64	6	64.000	60.102886	57.504809
	4		61.401924	59.669873
	3		62.051443	60.752405
	2		62.700962	61.834936
	1.5		62.025721	62.376202
M 65	4	65.000	62.401924	60.669873
	1.5		64.025721	63.376202
M 68	6	68.000	64.102886	61.504809
	1.5		67.025721	66.376202
M 70	6	70.000	66.102886	63.504809
	1.5		69.025721	68.376202
M 72	6	72.000	68.102886	65.504809
	4		69.401924	67.669873
	3		70.051443	68.752405
	2		70.700962	69.834936
	1.5		71.025721	70.376202
M 75	4	75.000	72.401924	70.669873
	1.5		74.025721	73.376202
M 76	6	76.000	72.102886	69.504809
	1.5		75.025721	74.376202
M 78	2	78.000	76.700962	75.834936
M 80	6	80.000	76.102886	73.504809
	4		77.401924	75.669873
	3		78.051443	76.752405
	2		78.700962	77.834936
	1.5		79.025721	78.376202
M 82	2	82.000	80.700962	79.834936
M 85	6	85.000	81.102886	78.504809
	2		83.700962	82.834936
M 90	6	90.000	86.102886	83.504809
	4		87.401924	85.669873
	3		88.051443	86.752405
	2		88.700962	87.834936
M 95	6	95.000	91.102886	88.504.809
M 100	6	100.000	96.102886	93.504809
	4		97.401924	95.669873
	3		98.051443	96.752405
	2		98.700962	97.834936
M 105	6	105.000	101.102886	98.504809
M 110	6	110.000	106.102886	103.504.809
	4		107.401924	105.669.873
	3		108.051443	106.752405
	2		108.700962	107.834936
M 115	6	115.000	111.102886	108.504809
M 120	6	120.000	116.102886	113.504809

10-1004

Appendix F : DCV 2D drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	270 DCV 104	VALVE BODY	1
2	270 DCV 105	LOWER CONNECTOR	1
3	270 DCV 103	SPRING HOUSING	1
4	270 DCV 102	SPRENG HOLDER	1
5	270 DCV 106	TOP CONNECTOR	1
6	270 DCV 107	PISTON	1
7	270 DCV 108	SHEAR SCREW	9
9	270 DCV 109	O-RING 57x3.53/ BACK-UP 57x50.8x1.5	2
10	270 DCV 110	O-RING 47.5x2.62/ BACK-UP 47.5x43x1.5	1
11	270 DCV 111	CUTTER	1
13	270 DCV 112	SHOCK ABSORBER	1
14	DIN 912 M10 x 20	BOLT	2
15	270 DCV 113	PRESSURE &TEMPERATURE SENSOR	1
16	270 DCV 114	COMPRESSION SPRING	1
17	270 DCV 108	SHEAR SCREW	8
18	DIN 913 - M4 x 5	SET SCREW	10

THIS DOCUMENT AND ALL INFORMATION AND DATA DISCLOSED HEREIN OR HEREWITH ARE THE CONFIDENTIAL AND PROPRIETARY PROPERTY OF UIT AND ARE NOT TO BE USED, REPRODUCED OR DISCLOSED IN WHOLE OR IN PART BY OR TO ANYONE WITHOUT THE WRITTEN PERMISSION OF UIT.

	NAME	DATE
DESIGNED	H.Zakaria	21.05.2018
CHECKED	H.Zakaria	21.05.2018
APPROVED	H.Zakaria	21.05.2018

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS

SURFACE FINISH: Ra 3.2 NS-EN ISO 1302:2002

DIM.TOL.: NS-ISO 2768-1-f

THREAD TOL.: 6g/6H (NS 1874 - ISO 8965/1)

BROKEN EDGES: (R, ALT 45) 0,1-0,5

FILLET RAD.: 0,5

FIRST ANGLE PROJECTION

UiT/ NORGES ARKTISKE UNIVERSITET

PROJECT: DOWNHOLE CONTROL VALVE

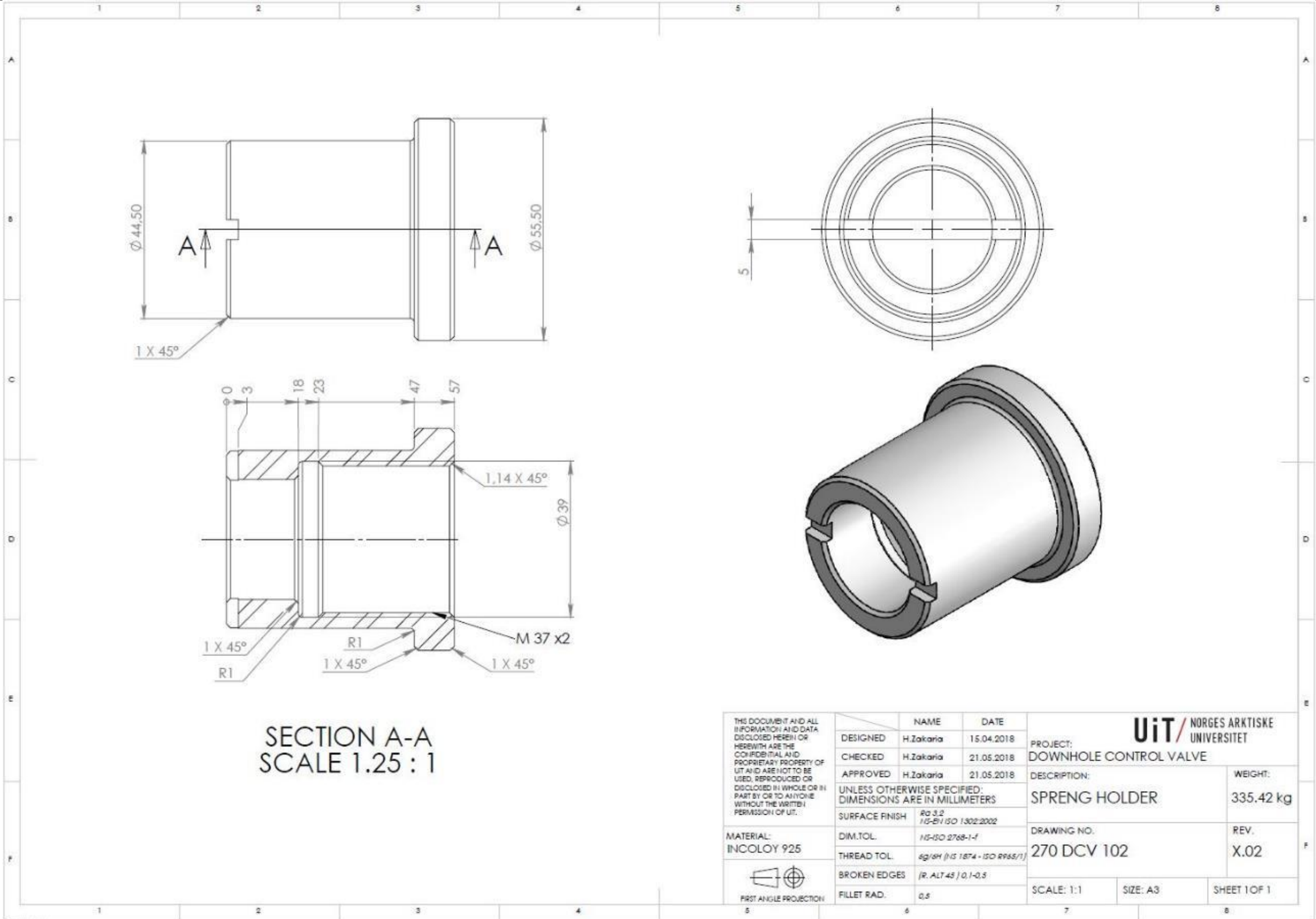
DESCRIPTION: DCV BOM

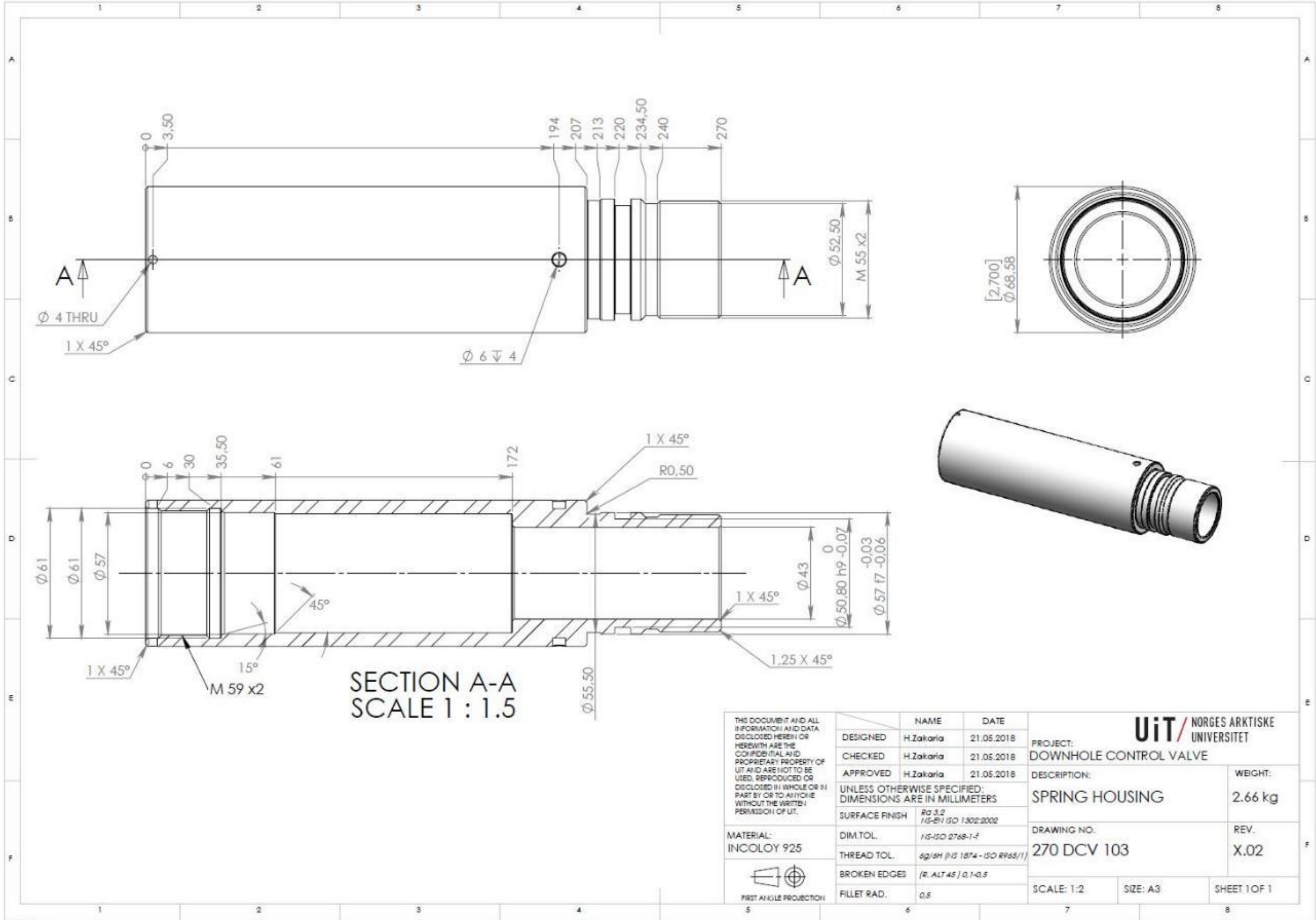
WEIGHT: 20 kg

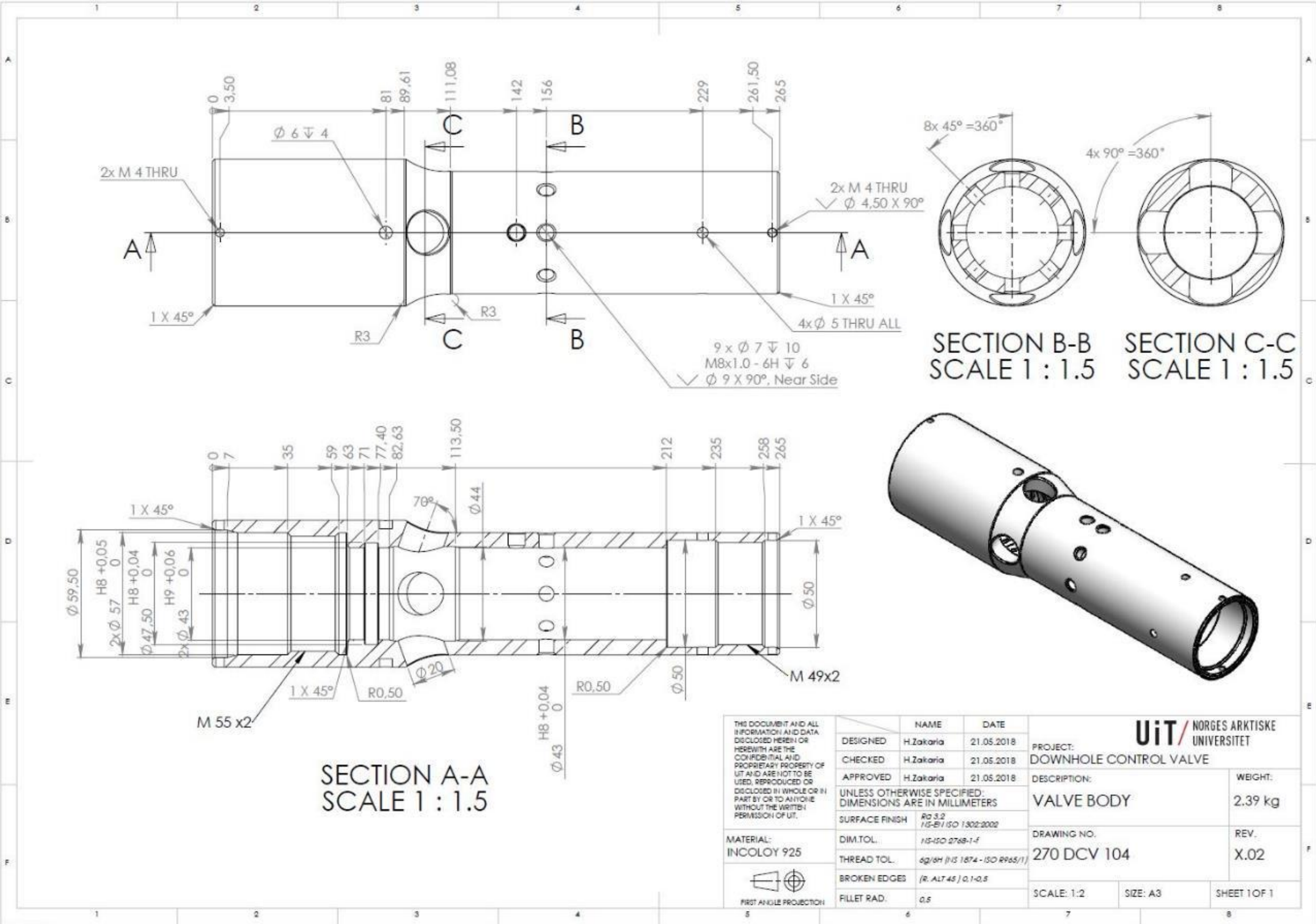
DRAWING NO.: 270 DCV 100.SLDPRT

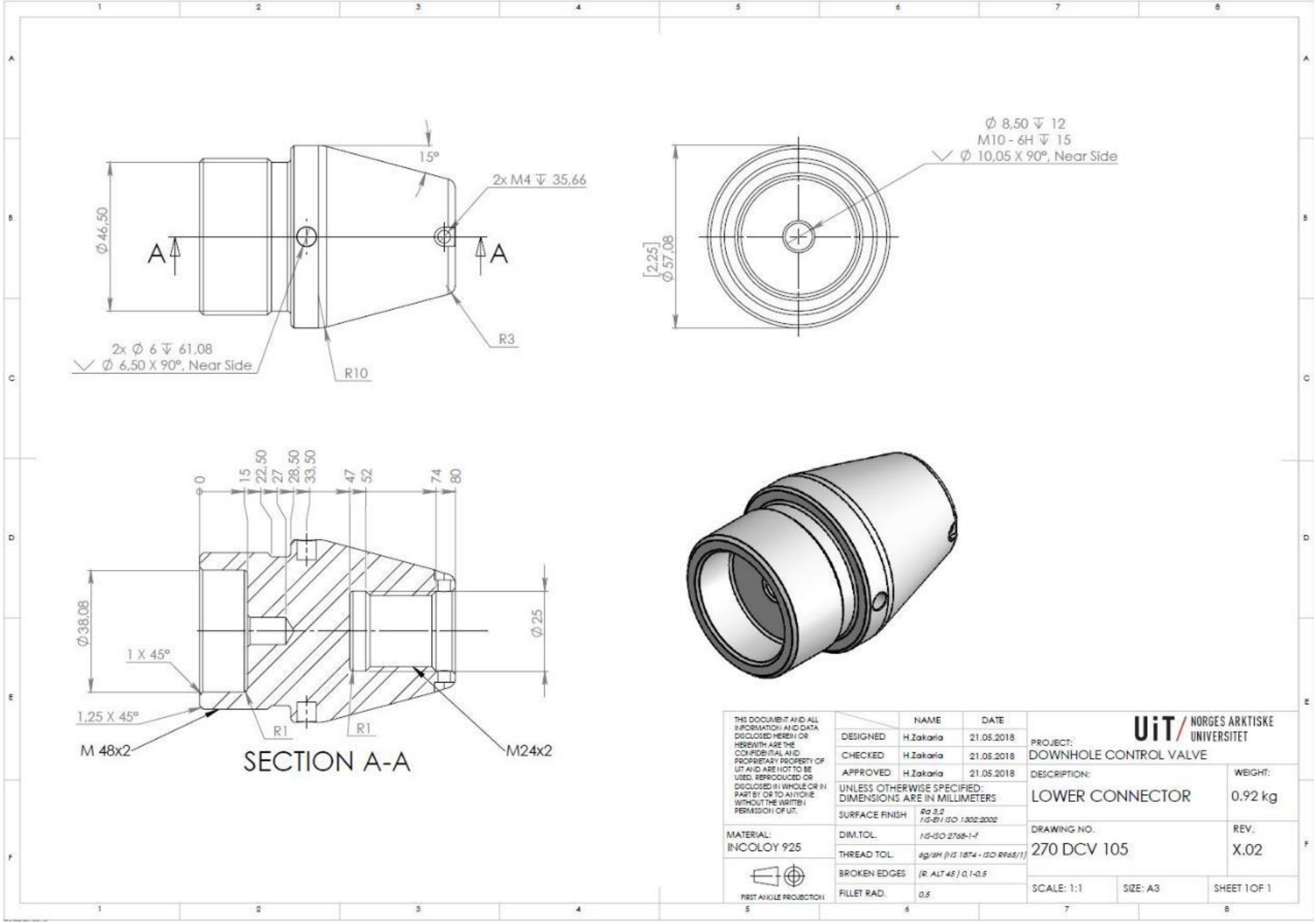
REV.: X.02

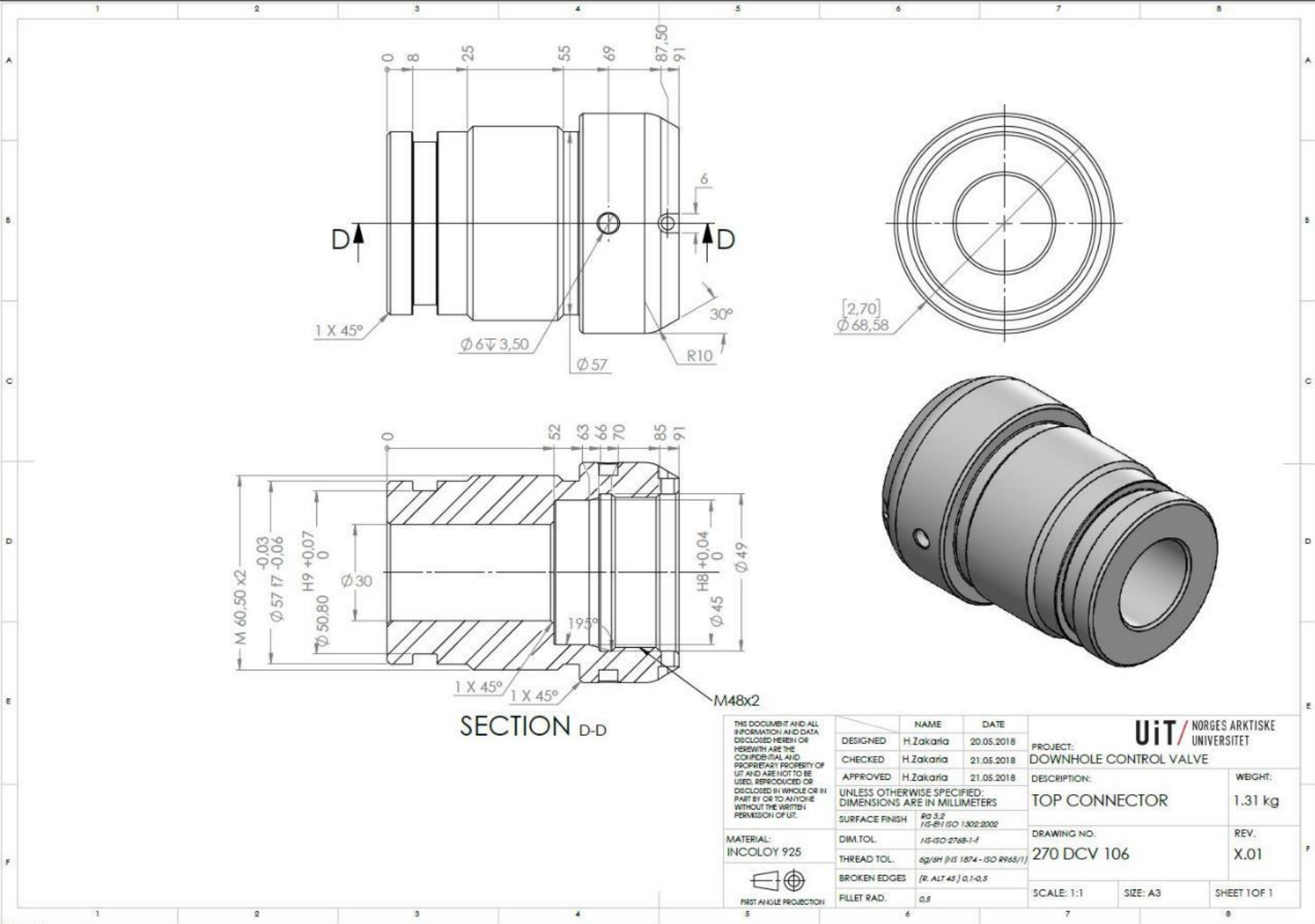
SCALE: 1:5 SIZE: A3 SHEET 1OF 1

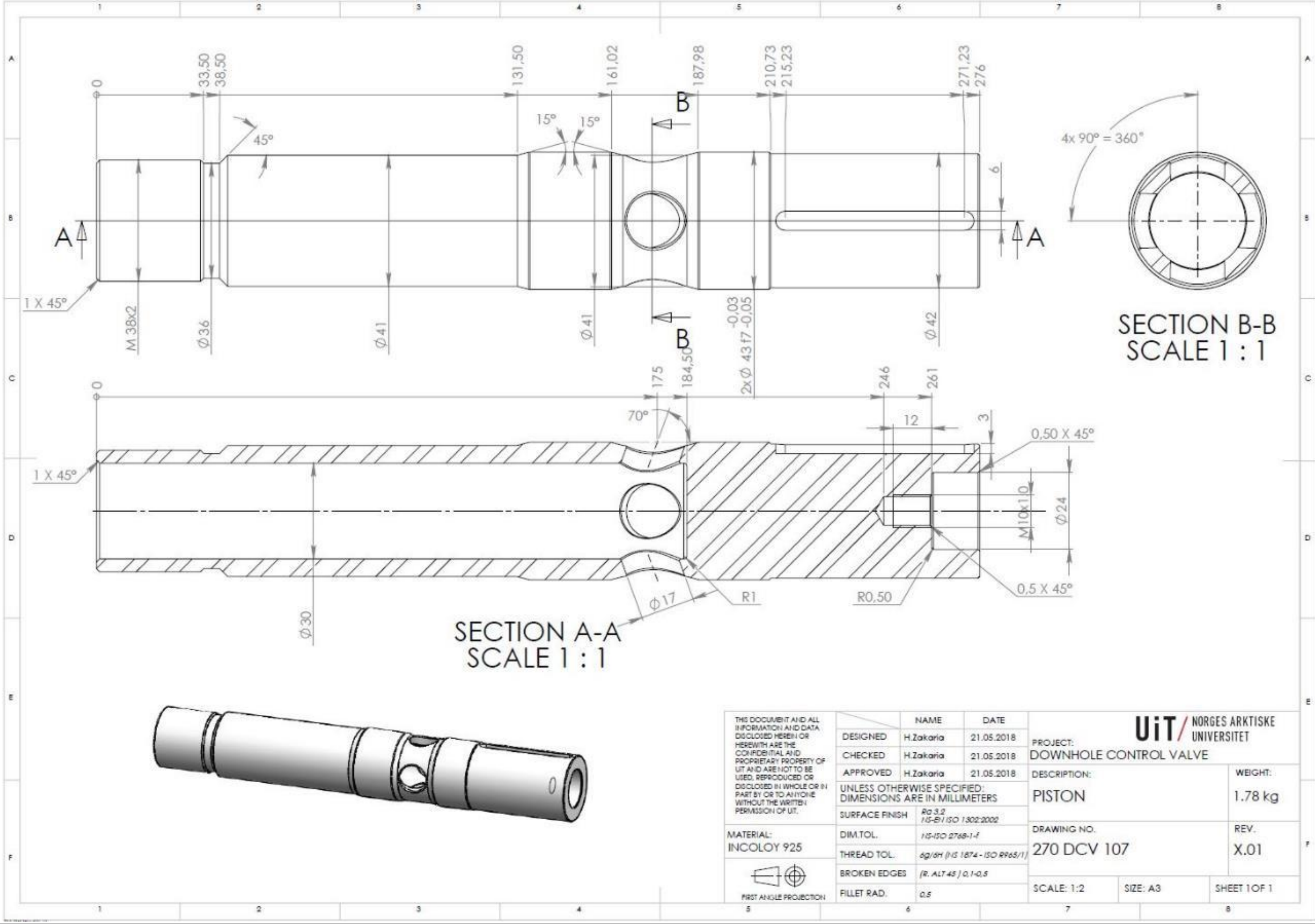

Ø 44,50
A
A
Ø 55,50
1 X 45°
5
0
3
18
23
47
57
1,14 X 45°
Ø 39
M 37 x2
1 X 45°
R1
1 X 45°
R1
1 X 45°
1 X 45°
SECTION A-A
SCALE 1.25 : 1
NAME
DATE
DESIGNED
H.Zakaria
15.04.2018
CHECKED
H.Zakaria
21.05.2018
APPROVED
H.Zakaria
21.05.2018
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH
DIM.TOL.
THREAD TOL.
BROKEN EDGES
FILLET RAD.
MATERIAL:
INCOLOY 925
FIRST ANGLE PROJECTION
UiT NORGES ARKTISKE UNIVERSITET
PROJECT:
DOWNHOLE CONTROL VALVE
DESCRIPTION:
SPRENG HOLDER
WEIGHT:
335.42 kg
DRAWING NO.
270 DCV 102
REV.
X.02
SCALE: 1:1
SIZE: A3
SHEET 1OF 1

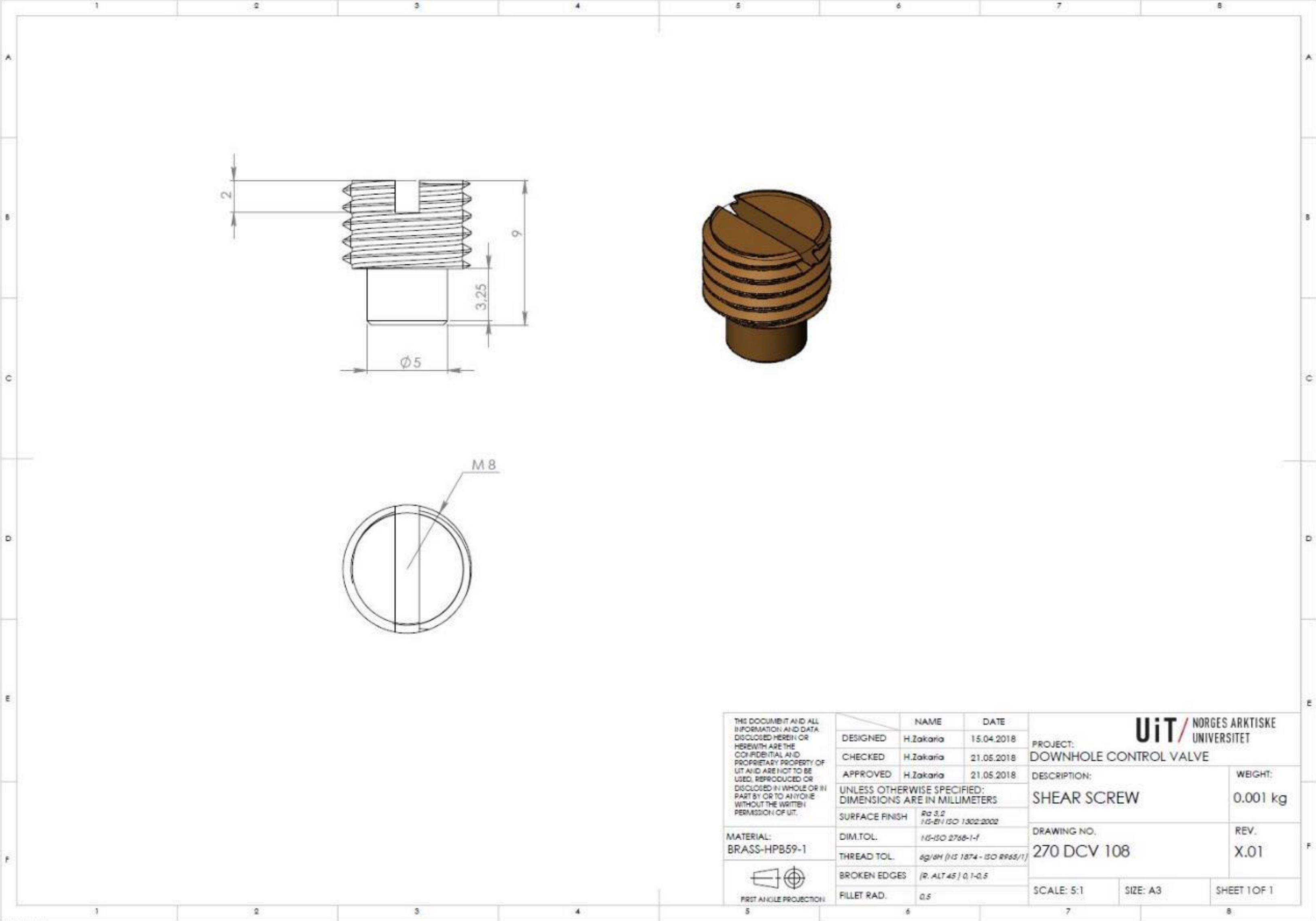

SECTION A-A
SCALE 1 : 1.5
M 59 x2
Ø 4 THRU
1 X 45°
Ø 6 ↧ 4
Ø 52,50
M 55 x2
Ø 68,58
R0,50
1,25 X 45°
Ø 43
Ø 50,80 h9
Ø 57 f7
Ø 55,50
NAME
DATE
DESIGNED H.Zakaria 21.05.2018
CHECKED H.Zakaria 21.05.2018
APPROVED H.Zakaria 21.05.2018
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
MATERIAL: INCOLOY 925
PROJECT: DOWNHOLE CONTROL VALVE
DESCRIPTION: SPRING HOUSING
WEIGHT: 2.66 kg
DRAWING NO. 270 DCV 103
REV. X.02
SCALE: 1:2
SIZE: A3
SHEET 1 OF 1
UiT NORGES ARKTISKE UNIVERSITET

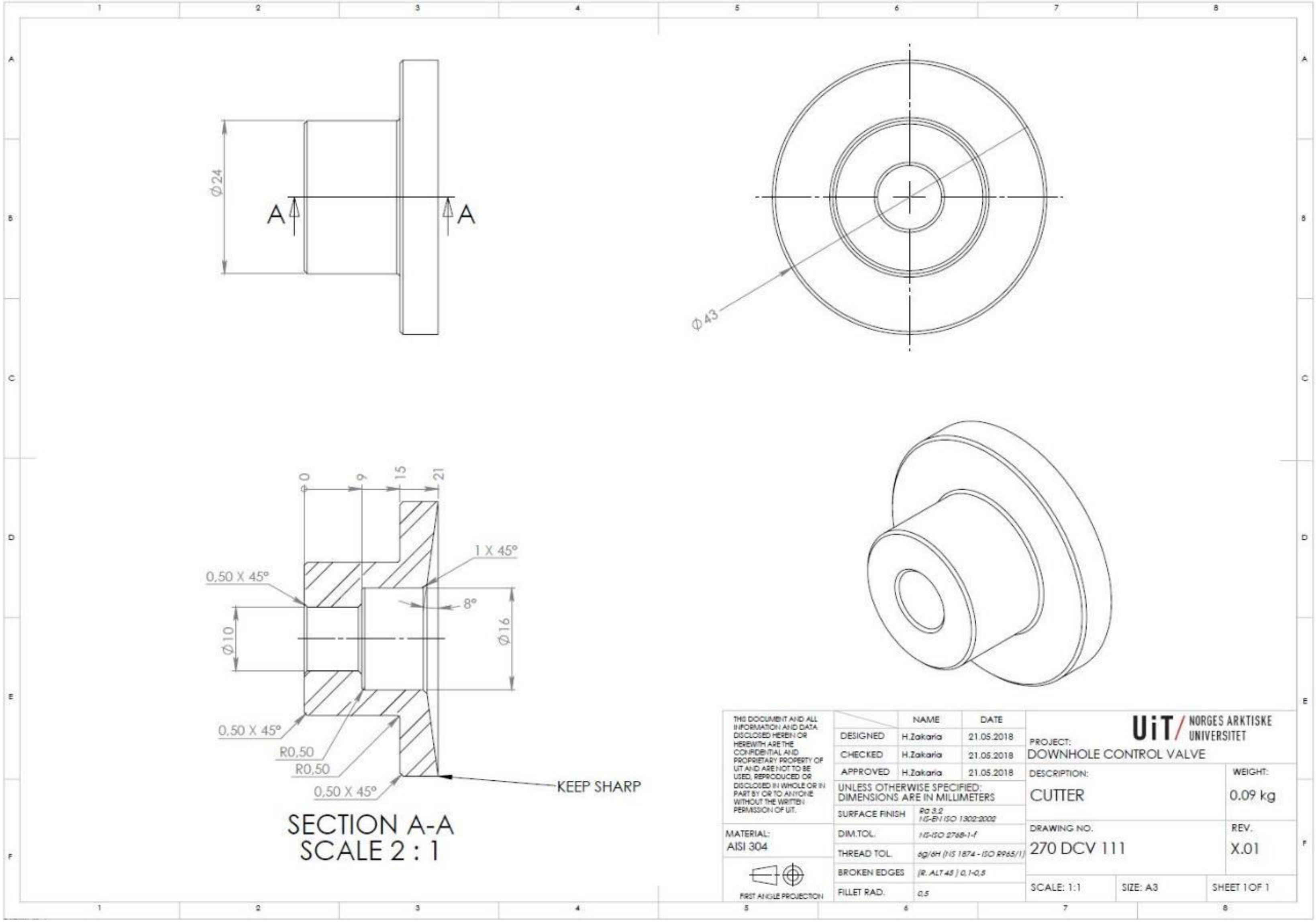

SECTION B-B
SCALE 1 : 1.5
SECTION C-C
SCALE 1 : 1.5
SECTION A-A
SCALE 1 : 1.5
8x 45° =360°
4x 90° =360°
2x M 4 THRU
2x M 4 THRU
Ø 4,50 X 90°
Ø 6 ↧ 4
1 X 45°
R3
R3
4x Ø 5 THRU ALL
9 x Ø 7 ↧ 10
M8x1.0 - 6H ↧ 6
Ø 9 X 90°, Near Side
70°
Ø 44
Ø 20
Ø 50
Ø 43
R0,50
M 55 x2
M 49x2
THIS DOCUMENT AND ALL INFORMATION AND DATA DISCLOSED HEREIN OR HEREWITH ARE THE CONFIDENTIAL AND PROPRIETARY PROPERTY OF UIT AND ARE NOT TO BE USED, REPRODUCED OR DISCLOSED IN WHOLE OR IN PART BY OR TO ANYONE WITHOUT THE WRITTEN PERMISSION OF UIT.
NAME DATE
DESIGNED H.Zakaria 21.05.2018
CHECKED H.Zakaria 21.05.2018
APPROVED H.Zakaria 21.05.2018
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
UiT NORGES ARKTISKE UNIVERSITET
PROJECT: DOWNHOLE CONTROL VALVE
DESCRIPTION: VALVE BODY
WEIGHT: 2.39 kg
MATERIAL: INCOLOY 925
DRAWING NO. 270 DCV 104
REV. X.02
SCALE: 1:2
SIZE: A3
SHEET 1 OF 1
FIRST ANGLE PROJECTION

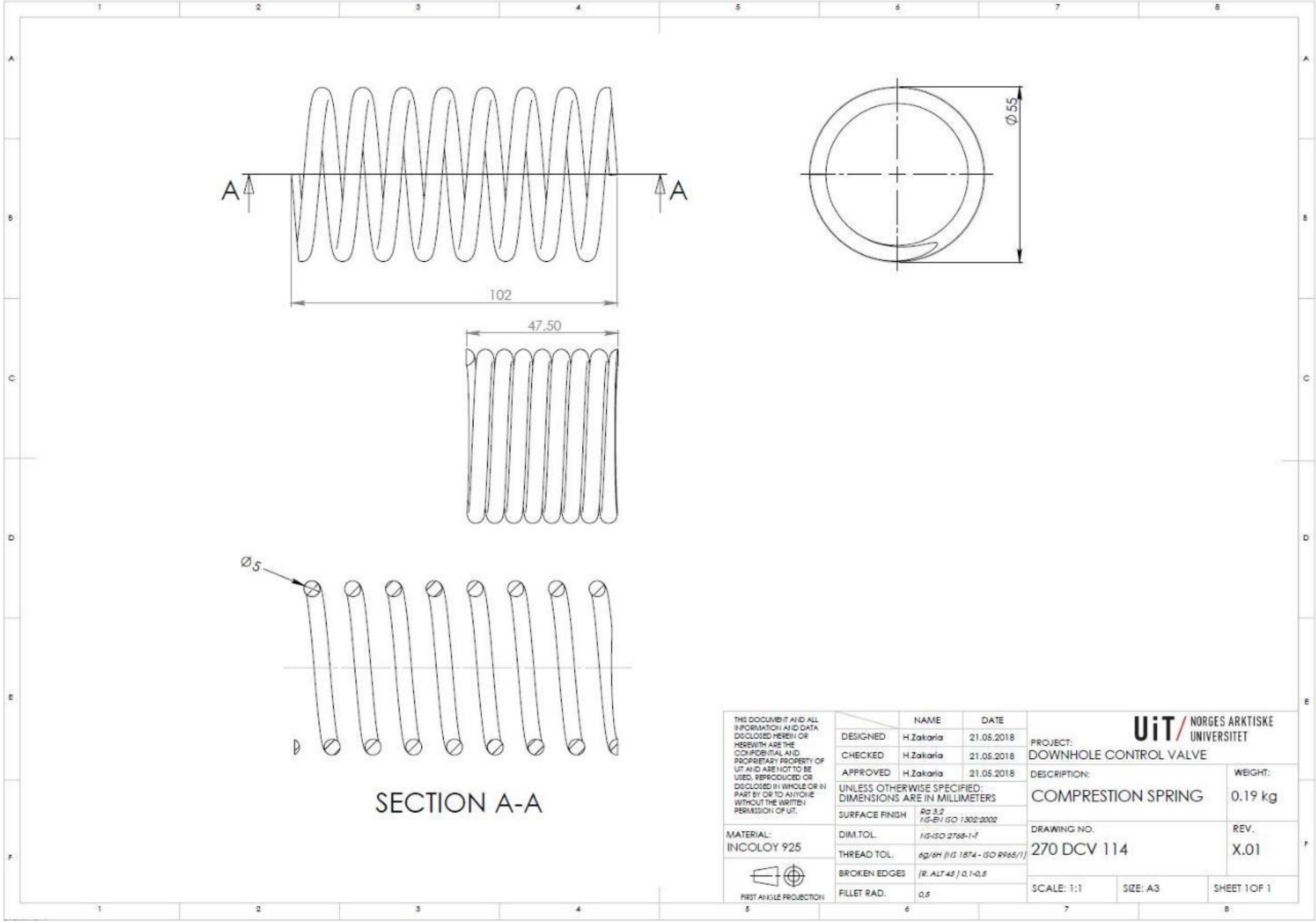

Ø 8,50 ↧ 12
M10 - 6H ↧ 15
Ø 10,05 X 90°, Near Side
15°
2x M4 ↧ 35,66
Ø46,50
A
A
R3
2x Ø 6 ↧ 61,08
Ø 6,50 X 90°, Near Side
R10
[2,25]
Ø57,08
0
15
22,50
27
28,50
33,50
47
52
74
80
Ø38,08
1 X 45°
1,25 X 45°
M 48x2
R1
R1
SECTION A-A
M24x2
Ø25
THIS DOCUMENT AND ALL INFORMATION AND DATA DISCLOSED HEREIN OR HEREWITH ARE THE CONFIDENTIAL AND PROPRIETARY PROPERTY OF UiT AND ARE NOT TO BE USED, REPRODUCED OR DISCLOSED IN WHOLE OR IN PART BY OR TO ANYONE WITHOUT THE WRITTEN PERMISSION OF UiT.
NAME
DATE
DESIGNED
H.Zakaria
21.05.2018
CHECKED
H.Zakaria
21.05.2018
APPROVED
H.Zakaria
21.05.2018
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH
Ra 3,2
DIM.TOL.
THREAD TOL.
BROKEN EDGES
FILLET RAD.
0,5
MATERIAL:
INCOLOY 925
FIRST ANGLE PROJECTION
UiT NORGES ARKTISKE UNIVERSITET
PROJECT:
DOWNHOLE CONTROL VALVE
DESCRIPTION:
LOWER CONNECTOR
WEIGHT:
0.92 kg
DRAWING NO.
270 DCV 105
REV.
X.02
SCALE: 1:1
SIZE: A3
SHEET 1OF 1

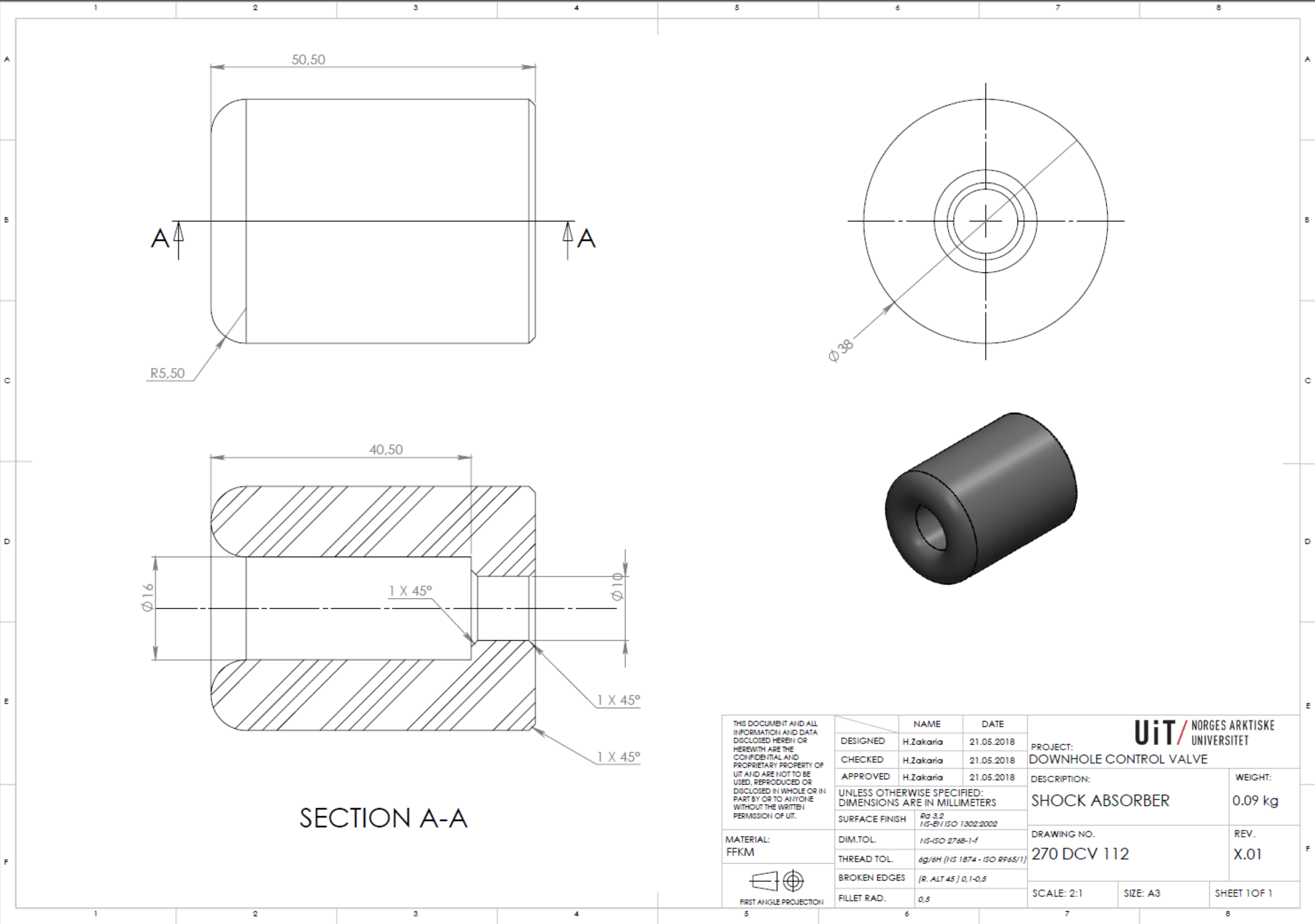

SECTION D-D
M48x2
1 X 45°
Ø 57
R10
30°
Ø 6 ↧ 3,50
[2,70]
Ø 68,58
M 60,50 x2
Ø 57 f7 -0,03 -0,06
Ø 50,80 H9 +0,07 0
Ø 30
Ø 45 H8 +0,04 0
Ø 49
195°
THIS DOCUMENT AND ALL INFORMATION AND DATA DISCLOSED HEREIN OR HEREWITH ARE THE CONFIDENTIAL AND PROPRIETARY PROPERTY OF UiT AND ARE NOT TO BE USED, REPRODUCED OR DISCLOSED IN WHOLE OR IN PART BY OR TO ANYONE WITHOUT THE WRITTEN PERMISSION OF UiT.
NAME
DATE
DESIGNED H.Zakaria 20.05.2018
CHECKED H.Zakaria 21.05.2018
APPROVED H.Zakaria 21.05.2018
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH Ra 3,2 NS-EN ISO 1302:2002
DIM.TOL. NS-ISO 2768-1-f
THREAD TOL. 6g/6H (NS 1874 - ISO 8965/1)
BROKEN EDGES (R. ALT 45) 0,1-0,5
FILLET RAD. 0,5
MATERIAL: INCOLOY 925
FIRST ANGLE PROJECTION
UiT NORGES ARKTISKE UNIVERSITET
PROJECT: DOWNHOLE CONTROL VALVE
DESCRIPTION: TOP CONNECTOR
WEIGHT: 1.31 kg
DRAWING NO. 270 DCV 106
REV. X.01
SCALE: 1:1
SIZE: A3
SHEET 1OF 1


SECTION B-B
SCALE 1 : 1
SECTION A-A
SCALE 1 : 1
4x 90° = 360°
M 38x2
Ø36
Ø41
Ø42
Ø30
Ø17
Ø24
M10x1.0
1 X 45°
0,50 X 45°
0,5 X 45°
R1
R0,50
2x Ø 4317 -0.03 -0.05
PROJECT:
DOWNHOLE CONTROL VALVE
DESCRIPTION:
PISTON
WEIGHT:
1.78 kg
DESIGNED H.Zakaria 21.05.2018
CHECKED H.Zakaria 21.05.2018
APPROVED H.Zakaria 21.05.2018
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
MATERIAL:
INCOLOY 925
DRAWING NO.
270 DCV 107
REV.
X.01
SCALE: 1:2
SIZE: A3
SHEET 1 OF 1
FIRST ANGLE PROJECTION
UiT NORGES ARKTISKE UNIVERSITET


2
9
3,25
Ø5
M8
THIS DOCUMENT AND ALL INFORMATION AND DATA DISCLOSED HEREIN OR HEREWITH ARE THE CONFIDENTIAL AND PROPRIETARY PROPERTY OF UIT AND ARE NOT TO BE USED, REPRODUCED OR DISCLOSED IN WHOLE OR IN PART BY OR TO ANYONE WITHOUT THE WRITTEN PERMISSION OF UIT.
NAME
DATE
DESIGNED H.Zakaria 15.04.2018
CHECKED H.Zakaria 21.05.2018
APPROVED H.Zakaria 21.05.2018
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH Ra 3,2 NS-EN ISO 1302:2002
DIM.TOL. NS-ISO 2768-1-f
THREAD TOL. 6g/6H (NS 1874 - ISO R965/1)
BROKEN EDGES (R. ALT 45) 0,1-0,5
FILLET RAD. 0,5
MATERIAL: BRASS-HPB59-1
FIRST ANGLE PROJECTION
UiT / NORGES ARKTISKE UNIVERSITET
PROJECT: DOWNHOLE CONTROL VALVE
DESCRIPTION: SHEAR SCREW
WEIGHT: 0.001 kg
DRAWING NO. 270 DCV 108
REV. X.01
SCALE: 5:1
SIZE: A3
SHEET 1 OF 1


Ø24
A
A
Ø43
Ø0
9
15
21
1 X 45°
0,50 X 45°
8°
Ø10
Ø16
0,50 X 45°
R0,50
R0,50
0,50 X 45°
KEEP SHARP
SECTION A-A
SCALE 2 : 1
THIS DOCUMENT AND ALL INFORMATION AND DATA DISCLOSED HEREIN OR HEREWITH ARE THE CONFIDENTIAL AND PROPRIETARY PROPERTY OF UIT AND ARE NOT TO BE USED, REPRODUCED OR DISCLOSED IN WHOLE OR IN PART BY OR TO ANYONE WITHOUT THE WRITTEN PERMISSION OF UIT.
NAME
DATE
DESIGNED
H.Zakaria
21.05.2018
CHECKED
H.Zakaria
21.05.2018
APPROVED
H.Zakaria
21.05.2018
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH
Ra 3,2
NS-EN ISO 1302:2002
MATERIAL:
AISI 304
DIM.TOL.
NS-ISO 2768-1-f
THREAD TOL.
6g/6H (NS 1874 - ISO R965/1)
BROKEN EDGES
(R. ALT 45) 0,1-0,5
FILLET RAD.
0,5
FIRST ANGLE PROJECTION
UiT/ NORGES ARKTISKE UNIVERSITET
PROJECT:
DOWNHOLE CONTROL VALVE
DESCRIPTION:
CUTTER
WEIGHT:
0.09 kg
DRAWING NO.
270 DCV 111
REV.
X.01
SCALE: 1:1
SIZE: A3
SHEET 1 OF 1


A
A
Ø55
102
47,50
Ø5
SECTION A-A
NAME
DATE
DESIGNED
H.Zakaria
21.05.2018
CHECKED
H.Zakaria
21.05.2018
APPROVED
H.Zakaria
21.05.2018
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH
DIM.TOL.
THREAD TOL.
BROKEN EDGES
FILLET RAD.
MATERIAL:
INCOLOY 925
FIRST ANGLE PROJECTION
UiT NORGES ARKTISKE UNIVERSITET
PROJECT:
DOWNHOLE CONTROL VALVE
DESCRIPTION:
COMPRESTION SPRING
WEIGHT:
0.19 kg
DRAWING NO.
270 DCV 114
REV.
X.01
SCALE: 1:1
SIZE: A3
SHEET 1 OF 1


50,50
A
A
R5,50
Ø 38
40,50
Ø16
1 X 45°
Ø 10
1 X 45°
1 X 45°
SECTION A-A
NAME
DATE
DESIGNED
H.Zakaria
21.05.2018
CHECKED
H.Zakaria
21.05.2018
APPROVED
H.Zakaria
21.05.2018
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH
DIM.TOL.
THREAD TOL.
BROKEN EDGES
FILLET RAD.
MATERIAL:
FFKM
FIRST ANGLE PROJECTION
UiT NORGES ARKTISKE UNIVERSITET
PROJECT:
DOWNHOLE CONTROL VALVE
DESCRIPTION:
SHOCK ABSORBER
WEIGHT:
0.09 kg
DRAWING NO.
270 DCV 112
REV.
X.01
SCALE: 2:1
SIZE: A3
SHEET 1OF 1

Appendix G 1-3: CAD-Simulations files

Appendix G is electronic folder that has all related project files:

1. CAD files
2. Simulation files
3. Animation of CFD
4. Composer file
5. Drawings PDFs