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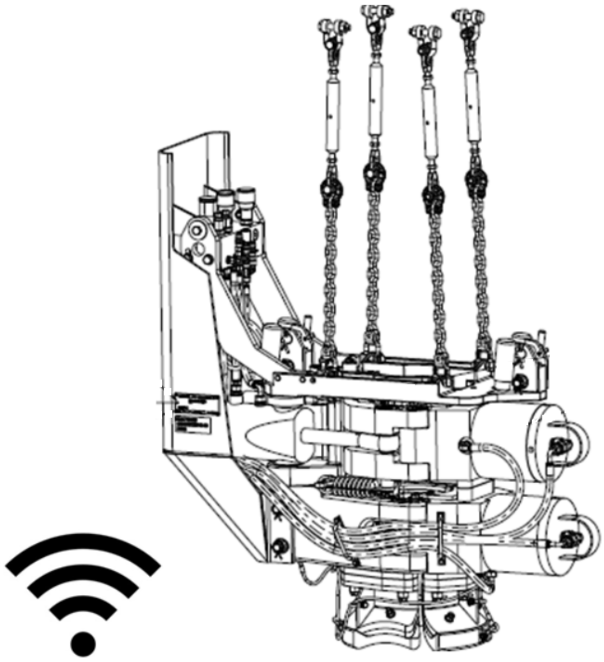
Implementation of Wireless Sensors on Torque Wrench



by

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Abstract

This thesis investigates the possible use of wireless communication of sensor information on drilling equipment. The report both looks at the general requirements for drilling equipment as well as a deeper investigation on how to implement it on a specific equipment module, the Torque Wrench found on Top Drives. The argument for using wireless communication is less cabling, cheaper installation and less weight. The Torque Wrench is of special interest as it is located below a hydraulic swivel and may rotate continuously, making it hard to measure anything with a wired sensor.

An analysis of potential wireless sensor systems is presented and one system is selected based on factors such as how versatile it is and how suitable it is in use for the specific Torque Wrench application. Possible sensing methods for the Torque Wrench is discussed and a solution is chosen and designed, ready to be implemented.

Solutions for integrating the chosen wireless system with Siemens PLCs are described and tested. New auto sequences for the Torque Wrench have been programmed utilizing the new sensor information, testing of software is done with a Torque Wrench simulator programmed on the PLC.

Design changes to the Torque Wrench and Top Drive as a consequence of the new sensors are also evaluated with respect to safety and cost.

Contents

List of Abbreviations

CRC Cyclic Redundancy Check

DB Data Block

DDM Derrick Drilling Machine

EM Electromagnetic

EMI Electromagnetic Inteference

FB Function Block (in TIA)

FBD Function Block Diagram

FC Function (in TIA)

I/O Input/Output

IP Ingress Protection

IR Infrared

NFC Near Field Communication

PT Pressure Transmitter

SHF Super High Frequency

SIL Safety Inegrity Level

SIS Safety Instrumented System

TD Top Drive

TDMA Time-division Multiple Access

TW Torque Wrench

VHF Very High Frequency

WSN Wireless Sensor Network

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Chapter 1

Introduction

The oil industry has always been set high demands for safety, reliability, efficiency, and cost. With the decreasing oil price seen last years, these criteria are ever as important as margins for profit are small and downtime is unacceptable.

MHWirth is a provider of high-end drilling equipment found mainly on drilling ships and offshore installations as well as providing lifecycle services for the oil and gas industry. The product portfolio includes horizontal pipe handling equipment, rotational equipment used in the drilling operations, hoisting systems, mud pumps, derricks etc. In addition to this, the life cycle services provided by MHWirth ranges from concept studies, service and overhauling, personnel training, drilling optimization. etc.

1.1 Background

With the ever-increasing focus on safety, reliability, efficiency, and cost, MHWirth strives to deliver the best solutions on the market through smart product design and use of new technology.

Wireless communication used on drilling equipment has been a growing topic as the technology now is starting to mature. An increasing number of articles are being published related to wireless communication used in the oil and gas industry. MHWirth is as well engaged in investigating the benefits of wireless on their drilling equipment.
In 2016 the thesis Wireless Drilling Equipment [6] was published on wireless transmission of profibus signal to replace drag chains and signal loops. An offshore test was done over a 3 months period yielding promising results and strengthened the belief in wireless transmission.

As this solution is only able to transmit a profibus signal, it requires a remote I/O to collect sensor information. This may be a good solution when looking at making an complete equipment wireless, but is not a preferred method where no power is available or there are only a few sensor signals that may need to be transmitted.

An internal project has taken place in MHWirth in the fall of 2017 with the name "Battery powered wireless sensors". Several product groups have been engaged to discuss their possible use for wireless sensors and several sensor suppliers were evaluated. This thesis will be a continuation of this work with goal to implement the project findings on a Torque Wrench.

1.2 Objective

The Torque Wrench (TW) is a module of the Top Drive (TD) used for connecting drill pipes to the TD drive shaft. The TW contains an upper and lower clamp that can clamp onto two separate pipes. The upper clamp can be rotated approximately 10 degrees either way while the lower clamp is fixed.

The TW is located below the gear box on the TD which means it is on a part of the TD that can rotate continuously, and all connections for controlling and monitoring has to go through a hydraulic swivel. Auto sequences is today driven by position assumptions made on the delta pressure in the cylinders as well as timed functions. There is also a valve in one of the torque cylinders that sends a hydraulic signal when in end position. In both cases the hydraulic signals need to go through the hydraulic swivel to the fixed part of TD and then be sensed by a cabled sensor. The sources of errors are many and troubleshooting can be time consuming and a safety risk.

Several of the TW functions related to monitoring are a result of increased safety after an incident at Stena Spey, when a TW clamped onto a rotating pipe under maintenance, injuring two workers.

By implementing wireless sensors to sense the actual endstop state of both clamp and torque cylinders, it can be possible to increase safety, simplify design and increase efficiency. This report will investigate possibilities of implementing wireless sensors to obtain the mentioned advantages.

The main objectives of this theses are:

1. Engineering related to implementation of wireless sensors on TW clamp- and torque cylinders end-stops.
    - Evaluation of wireless sensor suppliers
    - Concept selection
    - Mechanical implementation
    - Control system implementation
2. Investigate consequences from implementation of end-stop sensors.
    - Safety
    - Reduced make/break sequence times by removing timers in auto sequences
    - Simplify design and remove components that become redundant
    - Cost

Chapter 2

Wireless Communication

Wireless communication is well known to everyone, it is used in our cell phones, credit cards, TVs, computers, cars etc. The type of wireless communication depends on the task to be performed. In credit cards and payment chips, Near Field Communication (NFC) technology is used, while in hand remotes communication is done by Infrared (IR) light. Bluetooth and WiFi are common to most people and are communication protocols transferring data over 2.4 or 5.8 GHz band. This is mostly used for medium range/high data communication. For longer communication links found in wireless door openers or cellphones, signals in the range of 50MHz - 6GHz can be found. All these forms of wireless communication are done by Electromagnetic (EM) waves in different parts of the EM specter as illustrated in figure 2.1.

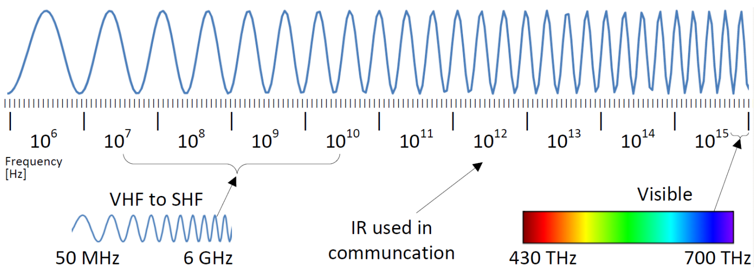


Figure 2.1: Electromagnetic specter

In the industry, systems for wireless transmission of sensor information is often defined as Wireless Sensor Networks (WSN). This systems utilizes the EM specter between 400 MHz to 5.8 GHz to transmit the information. These next sections will look deeper into available wireless systems and the use of these on drilling equipment.

2.1 Wireless Sensor Networks

Wireless Sensor Network (WSN) has been available since the 1980's [7]. At this point the sensors were large and expensive, the technology was not yet ready to be implemented with any practical advantages. In the 1990's micro-electromechanical and computing technologies had advanced, resulting in wireless sensors and sensor networks with reduced cost and size, and improved performance [8]. Today WSN is implemented successfully in several industries with high requirements for security and reliability.

A WSN is a network consisting of a sensor- and receiver/gateway nodes. The sensor nodes collect data from the surroundings and the receiver/gateway node collects information from the sensor network [9]. Several international standards for WSN communication are available as well as proprietary protocols.

WSN is seen as an increasing industrial trend and several standards and protocols have been developed aimed at the industry. These standards ensure high reliability and safety of the wireless communication. There are many reports and articles available today on the subject of most suitable protocols and standards for industrial use. The main concerns often addressed in these reports are attacks from sources that may come within range of the WSN and battery lifetime.

This thesis will be more focused on the feasibility of implementing available wireless technology on drilling equipment. Different standards and protocols will be presented and described, however, a detailed investigation about their underlying technology and philosophy is not within the scope of this thesis.

The evaluation of appropriate wireless equipment will not be based solely on the TW, other parts of the TD as well as other equipment could gain from wireless technology. The possibility for more wireless sensors on the TD and other drilling equipment can be seen in a near future. The wireless system could therefor benefit from being versatile, modular and easily scalable.

2.1.1 Sensor and Gateway

The sensor node is a device composed of several elements. The devices either have an integrated sensor or the possibilities for connecting one or more external sensors. A sensor node may incorporate several of these features:

- Internal sensor or connection for external sensors
- Integrated power source or input for external power
- Memory
- Internal processor for handling events, when to send status, low battery, changes in sensor status etc.

The power source is often a battery in truly wireless devices, however, options for hardwired power is often available and input from energy harvesting modules is often possible. Power options are further described in 2.2.6.

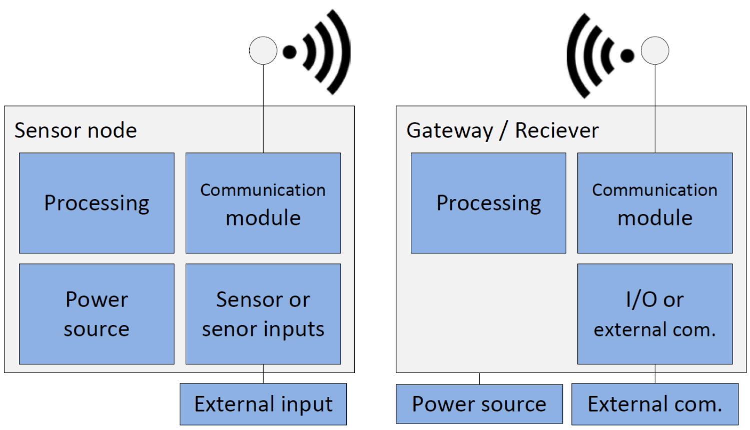


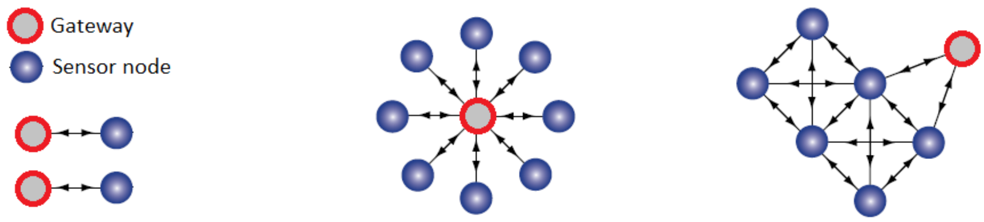
Figure 2.2: Sensor node and gateway

The gateway collects/transfers information from/to the wireless sensors devices. It handles the data and communicates with the outside world in different ways:

- Send data to cloud or email services
- Log data
- Communicate to a host system such as a PLC
- Perform tasks based on defined events and set I/O's as programmed
- Directly controlling a relay output depending on sensor status

2.1.2 Network Topology

How the sensor network is communicating depends on the wireless communication protocol. Some may only communicate sensor node to gateway while other protocols are capable of communicating in advanced topologies[9, 10, 11]. Different WSN topologies can be seen in figure 2.3.



(a) Point-to-point (b) Star (c) Mesh

Figure 2.3: Network topology examples

The WSN protocols that will be further evaluated in this thesis; sWave(Steute), WirelessHART(Emerson) and Surecross(Banner) uses; star, mesh and star topology respectively.

2.2 Considerations

When implementing new technology it is important to take all aspects into consideration [12]. As the signals now are to be transmitted over a new medium, new questions appear. This section will give a general introduction to the most obvious topics that needs to be considered when looking into wireless communication.

2.2.1 Health and Safety

Compared to cell phones that are worn directly on the body, WSN can be assumed to have a low health risk[12]. WSN are devices made for local (short range) communication and with focus on low energy consumption. This means devices with low transmission power (typically 10-150mW [13, 14]), up to 200 times lower then cellphones (up to 2W [15]).
One can also argue that where wireless communication replaces kilometers with wiring and cable trays, the time of installation is reduced and thus the risk for injuries are correspondingly decreased.

However, replacing hardwiring with wireless communication may change the reliability of the functions that are dependent on the communication link. This means that unsafe situations may arise with broken wireless communication links as a cause. This will depend on the functions, operation and environment of where it is implemented, and then thus require independent evaluation in each situation. Having redundant communication links and/or fault finding mechanisms is necessary in such cases.

2.2.2 Standards and Regulations

Drilling equipment delivered to floating vessels is often specified to be in compliance with ABS "Guide for Classification of Drilling System" [16] or DNV GL "Drilling Plant" [17]. None of these standards directly addresses WSN, however, DNV GL's related standard "Automation, safety and telecommunication systems"[18, sec 3.5] has a section regarding wireless communication. Most paragraphs states requirements that are found on well established WSN systems. However there are two statements to be aware of, and that could require further investigation if relevant to the application in question;

> *Wireless technologies may be used in functions that are additional or supplementary to those required by the offshore standard...*[18, sec 3.5.1]

> *Functions that are required to operate continuously to provide essential services dependant on wireless data communication links shall have an alternative means of control that can be brought in action within an acceptable period of time...*[18, sec 3.5.2]

Evaluation of these paragraphs with regards to WSN on TW is found in 3.3.

Wireless communication system is electrical equipment operating in an Control system and standards and directives related to this is obviously applicable for WSN systems. The applicator standards and directives stated in MHWirth "Technical Sales Specification"[19] is:

Standards:	
IEC 60079	Explosive atmospheres - Equipment [20]
IEC 61158	Industrial communication networks - Fieldbus specifications [21]
IEC 61892	Mobile and fixed offshore units - Electrical installations [22]

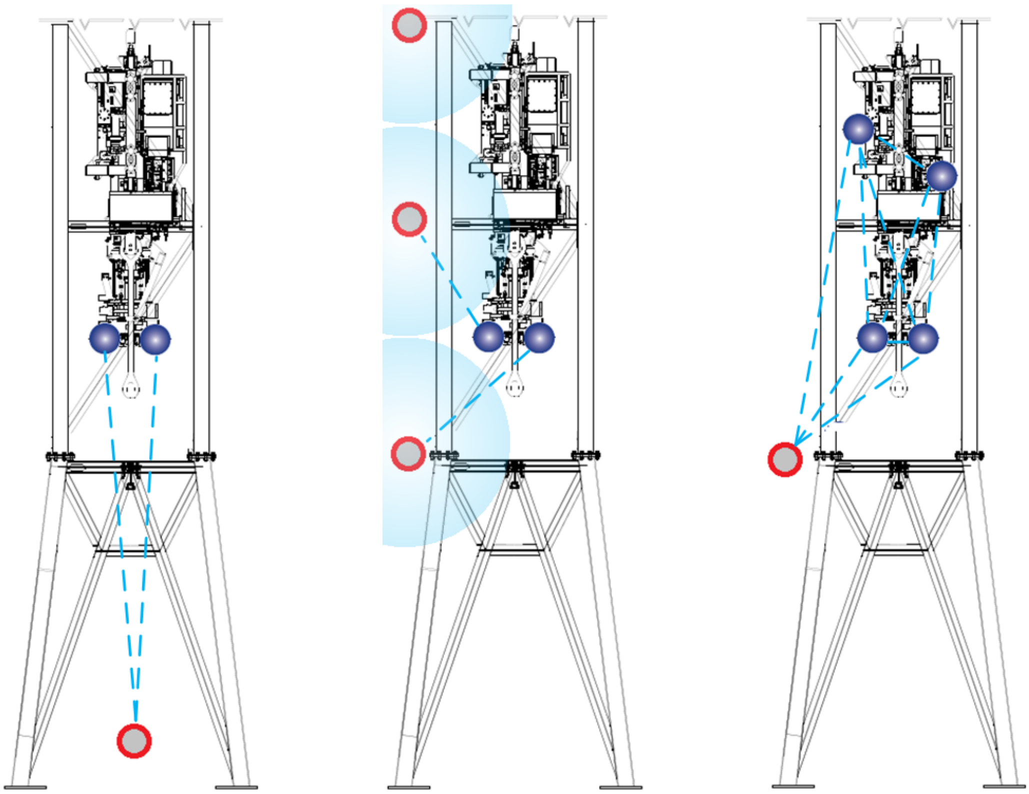
Directives:	
2014/34/EU	ATEX Directive [23]
2004/108/EC	Electromagnetic Compatibility Directive [24]
2006/95/EC	Low Voltage Directive [25]

The standard IEC 62657-1 "Wireless communication requirements and spectrum considerations" [12] has been found highly relevant when working with this thesis. This standard considers many aspects of WSN implementation and is written in a way that is useful for a large audience. The standard is aimed at industrial automation processes, however, most topics are highly relevant for machinery in the offshore industry as well.
Part 2 of the standard IEC 62657-2 "Coexistence Management" [26] describes a process coexistence management where a large number of wireless communication devices are deployed within a short range. This thesis will not go further into this. However, it is an important aspect of WSN when the technology becomes more common in the offshore field and WSN networks with different protocols and principles are to work within the same area.

2.2.3 Component Placement Considerations

As wires are replaced by a new communication medium, electromagnetic waves, the communication link becomes more prone to disturbances and changes in the environment.

When WSN is to be used on drilling and pipe handling equipment offshore, it is essential to plan gateway placement according to the applicable rig layout and machine movement. For the TD, the solution shown in 2.4a can be considered a viable possibility as it only travels vertically inside the derrick. If the gateway is placed above drill floor, other equipment will not move into the line-of-sight. This configuration has been proven with Profibus communication through Bluetooth [6]. Figure 2.4b illustrates a derrick with several gateways spaced out to cover the whole operational area. This layout may be used for equipment operating over a large area or where signal shadow may become a problem. The configuration shown in 2.4c can only be obtained by a WSN with sensor nodes supporting mesh technology. Sensor nodes can communicate with each other and find a way to the gateway without directly communicating with it.



(a) Coverage by line-of-sight (b) Coverage by overlapping gateways (c) Coverage by well established mesh network

Figure 2.4: Ways to ensure coverage. Top drive in derrick used as an example

2.2.4 Frequency Band

The operating frequency of the system is important to define as this both will influence the propensity for Electromagnetic Interference (EMI) and legality to operate different places.

Electromagnetic Interference

The wireless communication needs to keep normal performance under electromagnetic noise that may naturally occur within the operational range. In an offshore environment, powerful interferences from typical arc welding are not likely to happen under normal operation due to strict safety regime and thus the likely hood of disturbances while operating are low. Most communication equipment (radios, etc.) uses lower frequencies in the MHz range and should not be an interference if a 2.4GHz system is chosen. Awareness should be taken when placing sensor nodes, by keeping away from EMI sources under normal operation such as motors and solenoids.

As the use of wireless communication is increasing it becomes important to evaluate the coexistence of the communication systems as described in [26].

Legal Considerations

The Industrial, Scientific and Medical bands (ISM) are frequency bands reserved for such use and WSN categorizes as such. WSN typically uses the frequency bands 868MHz, 915MHz or 2,4GHz where only the latter is allocated as an ISM band internationally. The other frequencies have been allocated to different regions as per Article 5 in ITU Radio Regulations[27] and illustrated in figure 2.5.

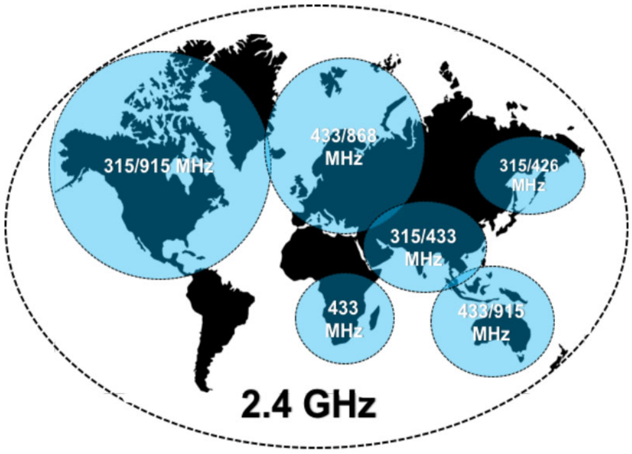


Figure 2.5: Internationally accepted ISM bands [1]

2.2.5 Security

A new risk that arises when going wireless is the increased security risk as the signals now are transmitted "openly". If an unwanted person is to gain access to the network, it may be subjected to eavesdropping, false information, shut down and other unwanted behavior [8].

As most WSN systems are fairly short range and a security breach requires close contact with the system, the security risk on an offshore installation would be fairly low compared to an onshore installation.

The evaluated wireless system is well-established systems that are either compliant with IEE 802 or uses a proprietary transmission protocol with several measures of security [11, 28].

2.2.6 Power Source

The sensor device clearly needs power to operate. A truly wireless device, such as insinuated by "wireless sensor" should be a self-contained unit with the power source included. However, it is important to note that most WSN systems also has input for external power and thus eliminating one of the largest downsides with wireless sensors, battery lifetime, where external power is available.

Battery

Battery powered sensor devices should be thoroughly investigated in regards to its lifetime when used in a specific application. Questions such as increased maintenance and access to sensor node

need to be considered.
Batteries on WSN nodes are often possible to hot swap and is important to keep the maintenance cost down.

(a) Battery used by Emerson nodes

(b) Battery used in Banner nodes, similar type used in Steute nodes

Figure 2.6: Example of batteries used in wireless sensor devices

Battery life is dependent on the sensor type and number, transmitting rate, signal strength and temperature which it operates in. To give an indication of lifetime expectancy some examples from the suppliers are given in table 2.1. All examples are for continuous operation with an update rate of 1 second and an ambient temperature of approx. 21°C.

System	Sensor type	Lifetime [years]
Emerson Rosemount 2051	Pressure Transmitter	0.6
Emerson Rosemount 702	Discrete Transmitter	1.5
Banner DX99	Pressure Transmitter	0.9
Banner DX99	Inductive sensor (NAMUR)	5.2
Banner DX99	Inductive sensor (NPN)	2.4
Steute Ex RF 96 ST SW915	Inductive sensor	1.4

Table 2.1: Battery lifetime examples [3][4][5]

With lower update rates, battery lifetimes can be as long as 10 years.

Due to the limited lifetime, battery solutions should only be considered where power consumption is low enough to keep a long lifetime and/or where external powering are not feasible.

External Power

A selling point for wireless sensors is the removal of cable loops and drag chains which often is a weak point. However, power cables must still be present to run power consuming functions such as solenoids, heaters, lighting, alarms, etc. Where there is available power on the machine this could be utilized also on the wireless devices (if possible). Some wireless sensor devices have the possibility to work on hard-wired power(typically 10V to 30V [4]).

By powering the wireless sensor externally there is no battery lifetime limitation, but the benefits of reduced signal cabling and week points (swivel and moving loops) are eliminated.

Energy Harvesting

Energy harvesting techniques make it possible for devices to be placed in the field in combination with a battery and operate without the need for battery replacement.

Energy harvesting collects energy from the environment by typically solar panels, wind generators, steam generator, thermal energy electromagnetic waves or motion-induced energy. Most methods are fragile, spacious and do not collect enough power to make much difference with high update rates. Thus energy harvesting is not considered of especially interest for drilling equipment applications.

2.2.7 Instrumentation Signals

To get an indication on what signals MHWirth drilling equipment mostly utilizes, a DDM-E 1000 (Drilling machine) has been analyzed with respect to its instrumentation (sensor and actuator) signals (table 2.2).
The purpose of this analysis is to indicate what signals could be beneficial for a WSN system to accommodate. Especially when pursuing a WSN solution that could potentially make a whole machine "wireless" in terms of signal cables.

	Analog				Digital			Bus	
	mV	0-10V	-10-+10V*	2-20mA	Pulse train	NAMUR	24V	Profibus	
Input	2	-	-	14	2	2	1	4	25
Output	-	2	3	1	-	-	18	-	24

* -6-+6V and -10-+10V combined

Table 2.2: Instrumentation signal types found on Top Drive. Input(sensors), Output(actuators)

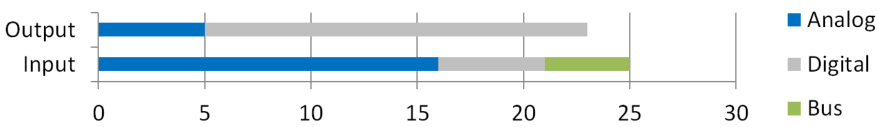


Figure 2.7: Graphical representation of table 2.2

When analyzing the data in table 2.2 and figure 2.7 it is clear that if the goal is a wireless machine only transmitting discreet signals is not enough.

Even though all signals on the TW will be discrete, most of the other sensor readings actually are analog signals of the 4-20mA type often used on pressure transmitters. Some sensors also communicate over Profibus, to accommodate this, either the Bluetooth method for sending profibus [6] or the sensors need to be replaced to some that could be transmitted over a WSN.

Actuator signals are mostly of the discrete type that some WSN are able to output today. However, these systems may only drive applications with a low current draw (<100mA) and a second driving circuit would be necessary to drive the solenoids.

This is a simplified analysis made to indicate the different sensor signals often found on drilling equipment. Even if the WSN system is able to transmit all the signal types, other factors such as update rates, security, battery lifetime and resolution may not be good enough for the functions utilizing the sensor signals.

2.3 Requirements

A list of requirements to help evaluate WSN suppliers have been made based on internal company standards[19][29] for instrumentation and foreseen operational requirements.

Frequency	ISM band 868MHz, 915MHz and 2,4Ghz is possible. Preferably 2,4Ghz.
Range	True range will depend on placement and is hard to foreseen, however free line-of-sight range given by supplier should not be below 50m
Power supply	Possibility for battery is required. Externally powered is highly recommended for a solution to be used across the company. For external power to be applicable it must accept 24V DC.
Update rate	High update rates are required for closed loop regulation (typical 10ms) and is not possible by most WSN systems today. For the application in question slower update rates are tolerated. Update rates of <1 second has been decided as a criteria for the TW functions.
Host protocol	Normal communication on th MH network is done by Profinet and Profibus. Other solutions may be accepted.
Signals	
Discrete	Required
Analog	Not required, but increases the potential area of use
ATEX zone	Zone 1
Ex classification	Ex IIB T3
Operating temperature	-20°C - +45°C
Ingress protection	IP66
Shock and vibration	Shock 10g(IEC 68-2-6), Vibration 1g(IEC 68-2-27)

A similar requirement list will be used to evaluate the suppliers, found in section 2.4.4.

2.4 Suppliers

Based on an internal project in MHWirth done in the fall of 2017, three suppliers of WSN have been found suitable for further evaluation [30].
This section proceeds to investigate each of the qualified suppliers, Steute, Emerson, and Banner. Each supplier has different features incorporated in their devices and a portfolio with different configurations of the devices. I is not possible to cover all devices, but the main intention is to seek out the differences and find the potential in each system.

The following subsections should be read in conjunction with the matrix in 2.4.4.

2.4.1 Steute

Steute is a German company specializing in WSN. Their first portfolio used EnOcean protocol. They have however develop their own series of protocols. s.Wave, s.Wave2.4 and s.Wave.net. For their "extreme" product portfolio certified for zone 1, only s.Wave and s.Wave.net are used ,which utilizes the 868 and 915MHz band. The s.Wave protocol uses a Listen-Before-Talk (LBT) feature that listens to the medium before transmitting, ensuring that the channel is not occupied and that the signal most likely reaches the receiver.

With the s.Wave protocol, the sensor is bound to a specific receiver, a status signal is sent with a given time interval. This contains signal strength, battery lifetime and sensor position. The signal can be used to verify that there is communication between transmitter and receiver. The receivers may be of different types such as simple relays going on and off with respect to sensor status, or rec
eivers that communicate the sensor status to a host system using serial communication.
The s.Wave.net protocol is much the same as the s.Wave. However, the receiver is always a gateway that can communicate with a network of other gateways. The transmitted signal is picked up by the receiver with the strongest signal and in this way obtaining an overlapping gateway network topology, thus making it possible to increase the signal coverage.

In the "extreme" series there is also found a set of self-generating sensors, that generate power and sends a signal when actuated. These have been tested on fingerboards and found unsuitable for the application. This is due to the fact that they only are able to send one package when actuated and not use the LBT feature, this makes the system unreliable for applications that are requires to know the communication link status and sensor value even if no changes has occurred.
The self-generating sensor is not evaluated as an alternative for the Torque Wrench as periodic status from the clamp cylinder is needed without actuating it.

2.4.2 Emerson

Emerson uses WirelesHART as communication protocol which is the only protocol of the three suppliers evaluated that is recognized by IEC [11].

Emerson is well established in the process industry and has a long experience with WSN. Their sensor portfolio covers a large range of sensing devices, most is of a larger size and not always suited for installation on drilling equipment.

There are two WSN nodes that are of interest; Rosemount 648 [13] for analog input and Rosemount 702 [31] for discrete I/O.
An interesting feature of the 702 is the possibility to monitor momentary digital switching down to 10ms (found on puls encoders) to count rotation, fully independent on the communication rate.

Emerson Norway has been asked to find a solution for another function on the TD, the Link tilt system. Emerson then specified that the system could not guarantee an update rate of 1 sec, but rather 1-2 seconds dependent on the network load. Even if the network load in our systems would be low (<100 sensor nodes). Anything above 1 sec updated rate makes the system unlikely to be useful in most feedback control systems on drilling equipment.

2.4.3 Banner

Banner is an American company. They deliver products used in automation systems for many different fields such as material handling, mobile equipment, automotive, oil, and gas etc. They have a product line with WSN products. The products range from sensors and lights communicating wireless to more advanced radios that can transmit several types of signals from external sources. Banner has no all-in-one wireless sensors approved for Zone 1. Communication in hazardous locations is done by the WSN node DX99 that is approved for Zone 0.

DX99 can be delivered with different I/O configurations to accommodate most types of external sensors. The node can be used to transmit serial communication(Modbus), analog or discrete sensor values as well as output discrete signals. Banner use a proprietary protocol SureCross. The information about the protocol is limited, but their wireless technology is used in a wide variety of fields with high demand.

The DX99 node has the possibilities for both battery power and external power source. The communication rate may be adjusted down to 63ms. However, for each sample the sensor node needs to boost up the sensor, some sensors may require a warm-up time that is higher, the possible update rate is then limited by the needed warm-up time.

The SureCross network use star topology meaning each sensor node is assigned to a specific gateway [32, 33]. There are possibilities for extending coverage for a sensor with adding gateways it can communicate with. This will introduce complexity and time delay on the gateway side of the network. Each gateway can have up to 47 sensor nodes connected to it. The SureCross network is based on Time Division Multiple Access (TDMA) which means that the gateway talks to one sensor node at the time. The fastest update rate of 63ms can only be obtained if there is a maximum of 16 nodes connected to a gateway.

(a) Steute Ex RF 96 WH with roller push button

(b) Emerson 702 node

(c) Banner DX99 node

Figure 2.8: Senor nodes

2.4.4 Supplier Matrix

The following matrix is a summary of the evaluated systems specifications for the selected requirements from section 2.3. The sensor/gateway combination most suited for use on TW is selected when finding specification. For some of the suppliers other specifications may yield when other products are selected.

	Steute **Ex RF 96 ST Tx, RF Rx**	**Emerson** **648/702 Tx, 1420 Rx**	**Banner** **DX99 Tx, DXM100 Rx**
Wireless protocol	sWave/ sWave.net	WirelessHART	SureCross
Frequency	868Mhz, 915MHz	2.4GHz	900MHz, 2,4GHz
Range	450 m outside 40m inside	>225m	>3,2km (2,4GHz)
Power supply	Battery	Battery, External power, energy harvesting	Battery, External power, energy harvesting
Update rate	0.3s$\geq$ t	1s$\geq$ t $\geq$ 60min	Analog: 1s$\geq$t$\geq$30min Disc.: 63ms$\geq$t$\geq$16s
Network topology	Star	Mesh	Star
Host protocol	HTTP/XML, Modbus TCP	Modbus RTU, Modbus TCP, OPC, EtherNet/IP	Modbus RTU, Modbus TCP, EtherNet/IP
Signals			
Discrete	Each node can only connect to one proprietary discrete switch	702: Two discrete in or out	Two discrete in or out NAMUR supported
Analog	No	648: Thermocouple, RTD, millivolt, and ohm input	RTD, 4-20mA or 0-10V (12-bit res) Can be delivered with different signal combinations
ATEX zone	Zone 1	Zone 0	Zone 0
Ex classification	II 2G Ex ib IIC T4 Gb	II 1G Ex ia IIC T4	II 2GD Ex ia IIC T4 Ga
Operating conditions	-20°C - +60°C	-40°C - +85°C	-40°C - +65°C
Ingress protection	IP 67	NEMA 4X and IP66/67	IP68
Shock and vibration	Not found specific values. Extreme series should be within req.	Shock? Vibration 2g	Shock: 30g, 11 millisecond half sine wave, 18 shocks Vibration: 0.5 mm p-p, 10 to 60 Hz
Approvals	ATEX, IECEx	ATEX, IECEx, CSA	ATEX, CSA
Features	Listen before talk	- Contineous communication or send on change in status - Channel hopping to avoid interference - Redundant communication paths by mesh topology - Momentary switching measurements(pulse train)	- Sample on demand, Contineous communication or send on change in status

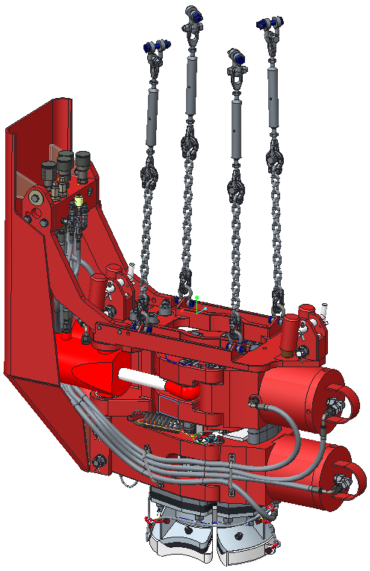
Table 2.3: Specification and features of the evaluated wireless systems

Chapter 3

Torque Wrench

The TW is a module of the TD used for connecting drill pipes to the TD drive shaft. MHWirth delivers three TW's with different torque ratings; 81 kNm, 105 kNm, and 169 kNm. All variants have the same working principle and much the same design. Only the 105kNm will be evaluated from here on, implementation of the final design on other TW variants will be considered the same.

The TW is hung from the Pipe handler which is located below the gearbox of the TD and has 360 degrees continuous rotation. This means that all connections to this part of the machine needs to go through a hydraulic swivel, and no electrical cabling is possible.



(a) 105kNm Tourque Wrench

(b) MHWirth PTD 500

Figure 3.1: Torque Wrench and Top Drive

3.1 Functional Overview

This section serves as a detailed description of today's TW system.

The TW incorporates two clamps which can be clamped on and off (not independent of each other). The lower clamp is fixed while the upper clamp floats and may rotate CW or CCW. This will from here on be referred to as make up or break out.
A circuit diagram of all relevant TW hydraulics is available at page 24. ID numbers for the components are placed in square boxes and are used in the text below when describing the TW functions.

Everything seen below the swivel is mounted on the TW module, everything from the swivel and above is placed on the TD.

Clamp On

PVG segment (22) is set to "on" position, pressure is exerted at port A and proceeds through load holding valve (19). The hydraulic activated isolation valve (18) is in closed position until solenoid (17) is activated. This serves as safety against unintentional clamp on. The pressure is then sent to the Pressure Transmitter (PT) (15) and through the load holding valves (5) and (6) and into the piston side of cylinder (1) and (2). Pressure from piston side of the cylinder is sent back to PT (16) for indication of true clamp pressure.

Clamp Off

PVG segment (22) is set to "off" position, pressure is exerted at the port B and proceeds through load holding valve (19). The pressure is then sent to the PT (14) and to the rod side of cylinder (1) and (2). This pressure is also used to open the load holding valves (5) and (6) to empty the piston side of the cylinders.

Make Up

PVG segment (21) is set to "make" position, the pressure is exerted at port A. This pressure is observed by PT (13) and goes to the piston side of cylinder (4) and rod side on cylinder (3). The pressure (torque) can be regulated by valve (20).
Pressure can be applied to the end stroke sensor (7) by activating clamp on function. If cylinder (3) is in end stroke, the end stroke valve is opened and pressure at PT (15) will drop, indicating end stroke position.

Break Out

PVG segment (21) is set to "break" position, the pressure is exerted at port B. This pressure goes to the piston side of cylinder (3) and rod side on cylinder (4). There is no pressure regulation in break out mode.

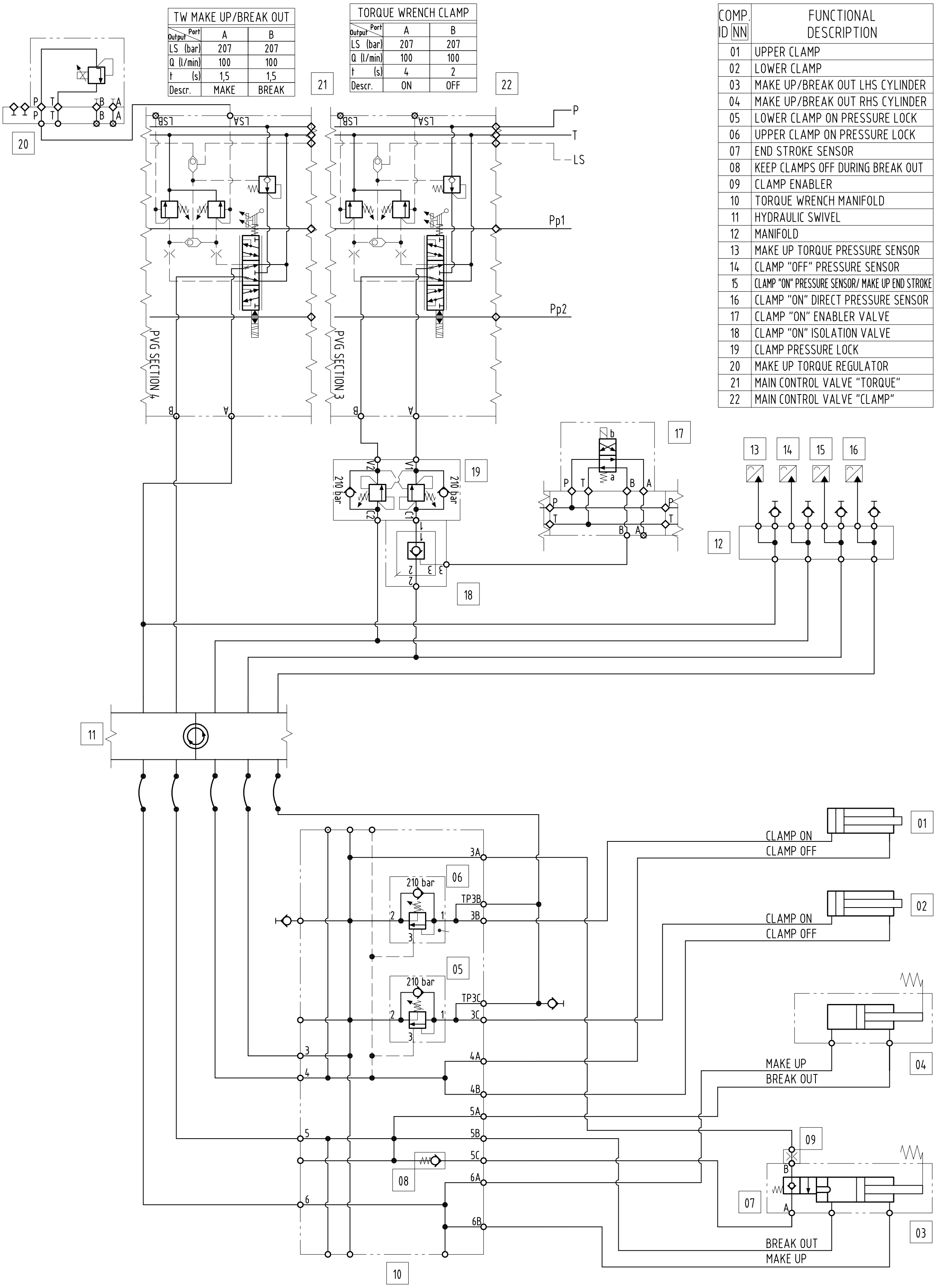


Figure 3.2: Torque Wrench fluid circuit diagram

3.2 Usage

The TW is used in drilling operations to connect and disconnect the drill pipe to the TD shaft.

3.2.1 Utilization Time

The expected time of operation is of special interest when evaluating wireless sensors, as this will be closely connected to the battery life. This is found by internal papers on well-programs, the same data is typically used for FMECA-analysis [34, 35, 36].

Table 3.1 is based on the well-program as well as the sequence times found in figure 3.3.

Assumed operation		
Life time	20	years
Wells per year	5	
Stands per well	159	

Auto Sequences per stand			
Sequence	Cycles	Time[s]	Total time[s]
Make up	2	28	56
Break out	1	20,5	20,5

Table 3.1: Torque Wrench operation data

Numbers from table 3.1 is used to calculate the total utilization time in table 3.2. Total function activations are found by counting the activations in figure 3.3 and multiply it by the number of stands per year.

TW utilization time		
Time per stand	76,5	seconds
Time per well	3,4	hours
Time per year	17	hours
Life time	338	hours

Yearly function activations		
Function	Activation per stand	Total activations
Clamp on	3	2385
Clamp off	6	4770
Make up rotation	3	2385
Break out rotation	3	2385

Table 3.2: Torque Wrench utilization

As seen in table 3.2 the yearly TW operation is about 17 hours continuous operation. However, the clamp status is needed even when the TW is not running.

This data can be used to interpret the trigger frequency and operational time for the WSN, and in turn be used to estimate battery lifetime.

3.2.2 Sequences

In normal operation, the TW executes auto sequences. The auto sequences activate the functions described in section 3.1. Most functions are timer driven as no position feedback is available [2]. Auto make up sequence is the only sequence utilizing feedback. This is done to verify that all torque has been transferred to the pipe and not by torquing against endstop. This is checked by measuring the end stroke pressure while making up. If it drops below 60bar for more than 0.5s, it is assumed that the TW has reached end stroke and the make up sequence repeats.

3.3 Safety

In 2007, the TW was involved in an accident where two workers were injured at the rig Stena Spey during maintenance work. The TW clamped onto a rotating pipe. As a consequence of this

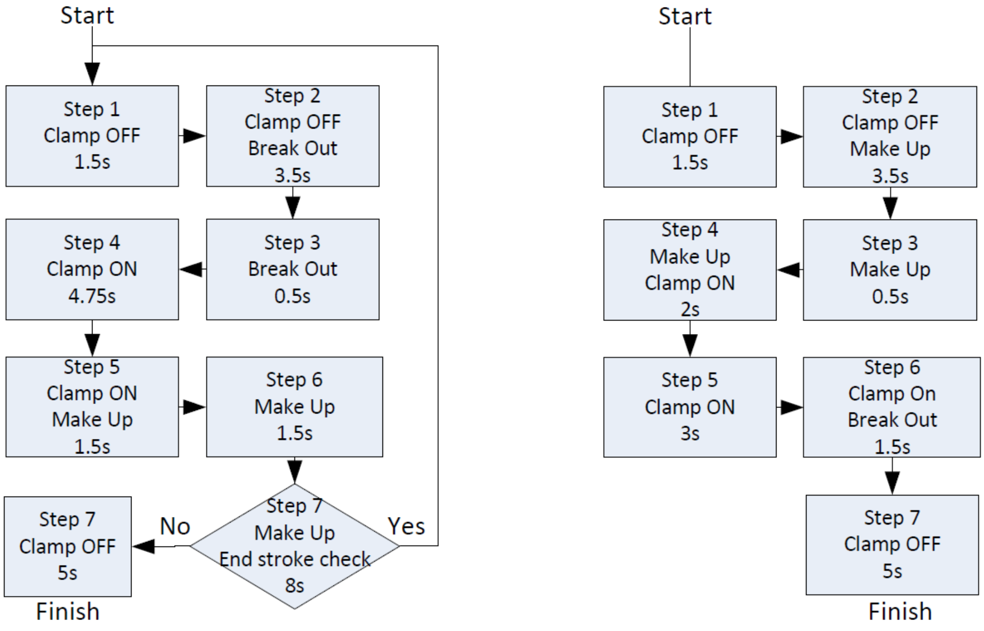


Figure 3.3: Auto sequences [2]

an isolation valve was connected to the clamp on line, which resulted in 2 new electrical signals for clamp on function, increasing safety against component failure causing TW to clamp on. In addition to this, several interlocks are implemented to avoid dangerous clamp on situations.

Self-checks

As per requirements in DNVGL-OS-E101 Drilling plant [17], the system related to the rotation is considered "Important function" and should facilitate self-check. Self-checks is performed for the PTs used in delta pressure monitoring and for the extra isolation valve implemented on the clamp on line. Checks should also be made on the new incorporated sensors. New sensor self-checks are described in section 6.3.

Justifications for using wireless on TW functions

As previously mentioned, DNVGL states the following when it comes to the use of wireless communication:

> *Wireless technologies may be used in functions that are additional or supplementary to those required by the offshore standard...* [18, sec 3.5.1]

> *Functions that are required to operate continuously to provide essential services dependant on wireless data communication links shall have an alternative means of control that can be brought in action within an acceptable period of time.* [18, sec 3.5.2]

The function clamp on/off or make up/break out is an equipment specific function and is not required by any offshore standard, nor is the functions dependent on wireless data communication to be used. Only auto sequences needs to use feedback from the wireless sensors. The system may be operated manually by an operator where the operator is required to verify proper function execution.

Chapter 4

Concept

To select the concept going forward with, a robust concept with regards to sensing method and wireless system should be in place. The evaluation of possible concepts has been evaluated individually, together with engineers familiar with the equipment and together with suppliers of the wireless systems.

4.1 Position Sensing

The optional sensing methods seen as applicable are sensing by an inductive sensor or by triggering a mechanical switch. The sensors may be placed to sense internally in the cylinder or on externally moving parts. This gives four alternatives for measuring cylinder endstop as shown in figure 4.1.

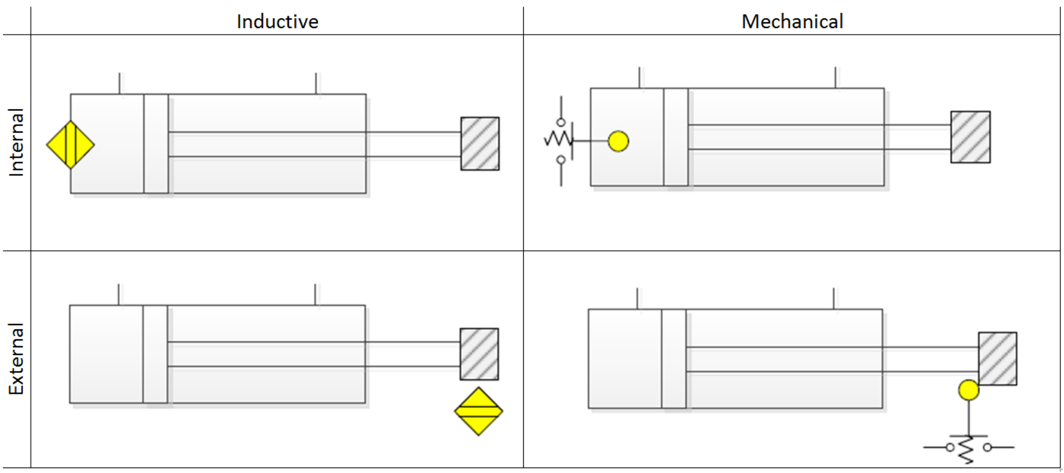


Figure 4.1: Position sensing methods

Inductive Sensing

Inductive proximity sensors may be used to sense metallic objects within close range. It uses a magnetic field to sense and has no moving parts. It is therefore not prone to external contamination such as mud, dirt, ice, etc.
As shown in table 2.1, a sensor using NAMUR signal is the most energy efficient choice for inductive proximity sensors.

Mechanical Sensing

Mechanical switches might be the best choice when looking at power consumption and cost. However, they are more prone to disturbances such as mud, dirt, and ice as they are composed of moving parts and fine mechanics. Stuck mechanical switches can be avoided by using a reciprocal actuation and not rely on a spring to return it to neutral position. However, these solutions requires fine mechanics an are more prone to damage then inductive sensor.

External Placement

Care must be taken when selecting a sensor placement. On the torque wrench, the parts move fairly freely and the sensing should be done as close to the cylinder rods as possible to get a repeatable movement.

Internal Placement

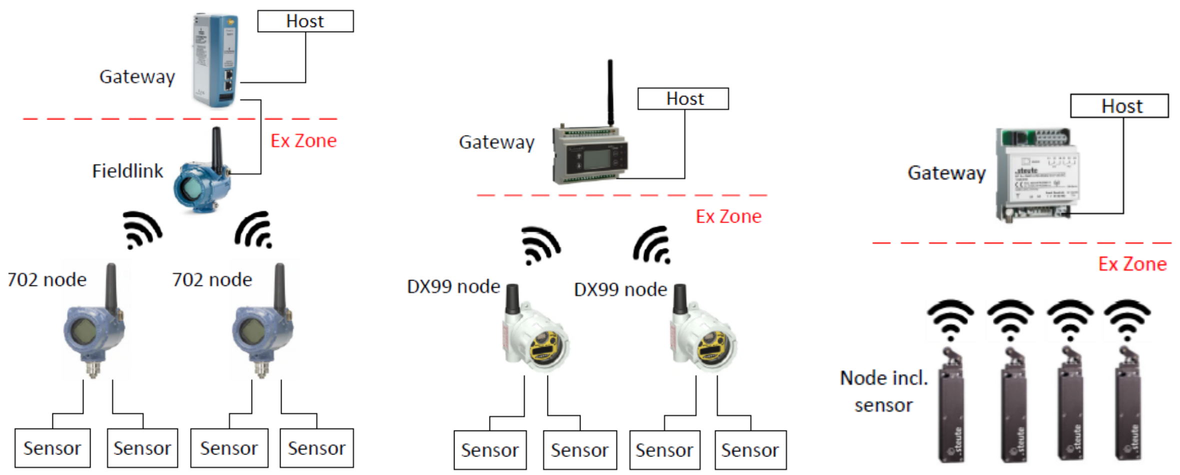
Internal placement requires parts that are made for operating in a pressurized environment. The operational pressure is typically 207bar. It also requires modifications on the cylinder to fit the sensor. For both clamp and torque cylinder, screw-off end cover are available. This makes it possible to only modify the end cover and not altering the complete cylinder. Internal sensing will give a measuring environment with little disturbance.

4.2 Wireless System

The following distributors were contacted for quotation on a wireless system that could communicate four discrete signals;

Elteco AS distributer of Steute
Danyko AS distributor of Banner
Emerson Norway distributor of Emerson wireless

For specifications and features of the different systems, see table 2.3 on page 21. The received offers are illustrated in fig 4.2. The systems cost are available in table 4.1.



(a) Clamp cylinder end (b) Clamp cylinder e (c) Clamp cylinder en

Figure 4.2: Placement of internal proximity sensor

Emerson				Banner				Steute			
Part	Unit price	Qty	Total	Part	Unit price	Qty	Total	Part	Unit price	Qty	Total
Sensor node	13000	2	26000	Sensor node	10412	2	20824	Sensor node	3408	4	13630
Fieldlink	17631	1	17631	Gateway	5634	1	5634	Gateway	3581	1	3581
Gateway	12538	1	12538								
Sum			56169	Sum			26458	Sum			17211

Table 4.1: Cost of wireless system

The different systems were then evaluated and scored based on the four "Selection criteria" listed below. The selection criteria are both based on criteria that apply for implementation on the TW as well as criteria that is applicable when choosing a system for further use on other MHWirth equipment.

Selection criteria	**Related specification**	**Weight**	**Description**
Versatile	Input/output Compatible signals Power supply Update rate	4	Important for further use of the WSN in other applications.
Areas of use	Frequency Certification IP, op. conditions	3	Score depends on areas/locations the node can be used in. 2.4GHz is seen as a considerable advantage. All systems has Zone 1 approvals, other certifications will not influence much.
Reliability	Range Net topology Related features	5	Assumed reliability based on system specifications.
Performance	Update rate Related features	5	It is important that the system does not slow down the operation, higher update speed will also give possibilities for using the system in other operations.
Cost	Price	3	Cost of the wireless systems compared with each other.

Each system has been compared to each other and given a score from 1-6. The results are shown in table 4.2. Justifications for the scores are first presented;

Versatile	Both Banner and Emerson can handle input signals of different types, discrete output signals, has power supply alternatives and selectable update rate. Banner can communicate a lot faster then Emerson and Steute. Steute can only accommodate their own sensors, thus the lowest points.
Areas of use	Emerson uses a wirelessHART protocol which is a recognized standard by IEEE and a communication protocol that is already established in the industrial field, thus highest points. Banner and Steute uses proprietary protocols. Banner and Emerson has the same approvals and environmental limitations. Steute is only available in 868 and 900mHz Ex versions, thus lowest points.
Reliability	Banner has by far the longest range. Emerson support mesh topology which gives redundant pathways. Steute use Listen-before-talk which increases the chance of successful transmittal and decreases energy consumption. All systems have methods for detecting and reporting broken communication links.
Performance	Banner has highest update rate and is highly configurable to suit several applications. Emerson has several smart features but too slow update rate. Steute communicates fast enough for the TW application.

		Emerson		Banner		Steute	
Criteria	Weight %	Points	Score	Points	Score	Points	Score
Versatile	0,20	3	0,60	5	1,00	2	0,40
Areas of use	0,15	5	0,75	4	0,60	3	0,45
Reliability	0,25	4	1,00	4	1,00	4	1,00
Performance	0,25	2	0,50	5	1,25	4	1,00
Cost	0,15	2	0,30	4	0,60	6	0,90
Sum			3,15		4,45		3,75

Table 4.2: Scoring of wireless system

Conclusion

Steute has some shortcomings, especially with regards to further use in other applications. As Steute only supports their own sensors and mainly has mechanically activated switches even the implementation on the TW can be challenging. But for simple sensing applications where it can be used, the Steute system would be the easiest system to install to lowest cost.

Emerson and Banner are similar in the physical design , however, Emerson has a better selection of sensors with an incorporated wireless transmission, but these are mainly designed for process industries. Banner supports more types of input signals and the software and operational parameters are highly configurable. The cost of the Emerson system is approximately doubled compared to Banner without giving the user any benefits to justify the cost.

If inductive sensors are to be used, NAMUR types are one of the most energy efficient solutions. Banner is the only solution that can directly use NAMUR sensors without any extra barrier. The Banner system gives great flexibility in regard to sensing method to be used.
Banner is seen as the most suitable wireless system for the TW as well for further wireless instrumentation on the TD and other MHWirth equipment.

The selected gateway from Banner DXM100 was selected to be able to test different communication protocols with the host system. It has later been confirmed that Modbus RTU can fairly eay be used with Siemens PLCs and thus making it possible to choose the DX80 gateway from banner.

The DX80 gateway can be placed in zone 2 which also gives Banner an advantage over the other suppliers, a no EXd capsule is needed on the gateway.

4.3 Concepts

Based on the findings in section 4.1 and 4.2, two concepts have been made using the two WSN solution scoring highest, Banner and Steute.
Both concepts use off-the-shelf products from sub-suppliers but, will require some machining of the clamp cylinder end covers.

4.3.1 Concept A

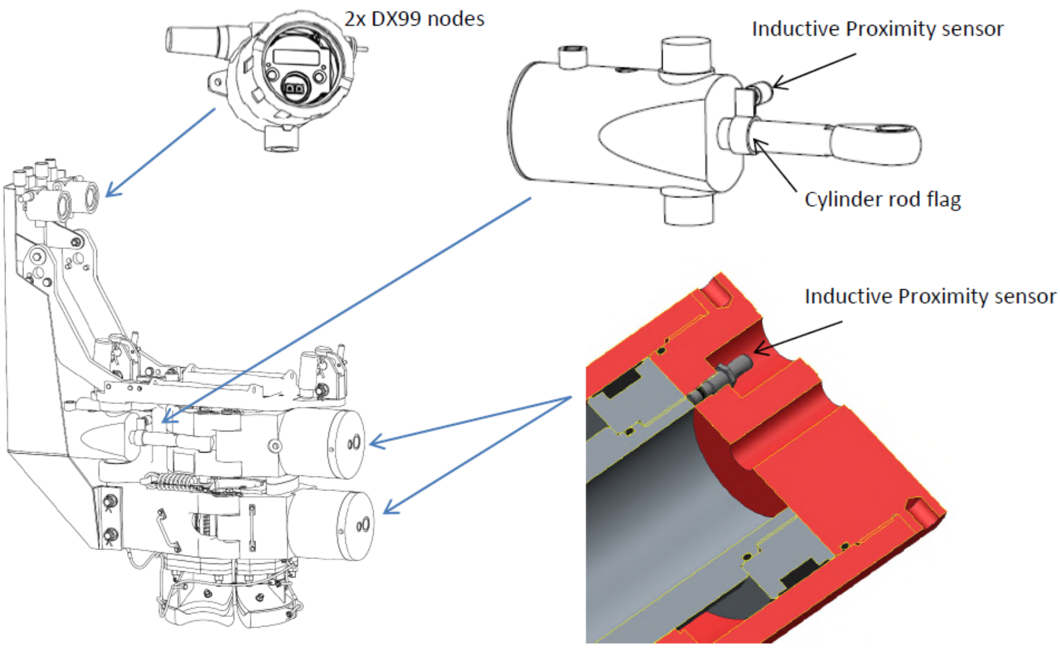


Figure 4.3: Concept illustration using Banner wireless system

Description

This concept uses two Banner DX99 nodes which each has two proximity sensors connected to them, in total four proximity sensors are used.
Clamp cylinder off position will be sensed by a proximity sensor implemented in the end cover. The sensor BES 516-300-S266-S4 is found suitable for this application.
Torque cylinder sensing is done by sensing on a flag mounted on the cylinder rod. For this, several sensors are available, NJ15-30GK are a suitable candidate.
The DX99 nodes are assumed to be mounted in the area which the manifold was mounted before. Antennas are planned to be mounted as illustrated, pointing out to the side of the TW.

Uncertainties

- The sensor BES 516-300-S266-S4 only has 1.5mm operational range. the clamp cylinder piston should retract all the way to the end cover and thus be possible to detect.
- Possible to get repeatable and good measurements when sensing on the cylinder rod flag.
- Does the antenna placement give good enough signal strength.

Required design

- Clamp cylinder end cover needs to be machined for installation of the proximity sensor.
- A cylinder rod flag that is not interfering with the cylinder stroking path and hold its position.

4.3.2 Concept B

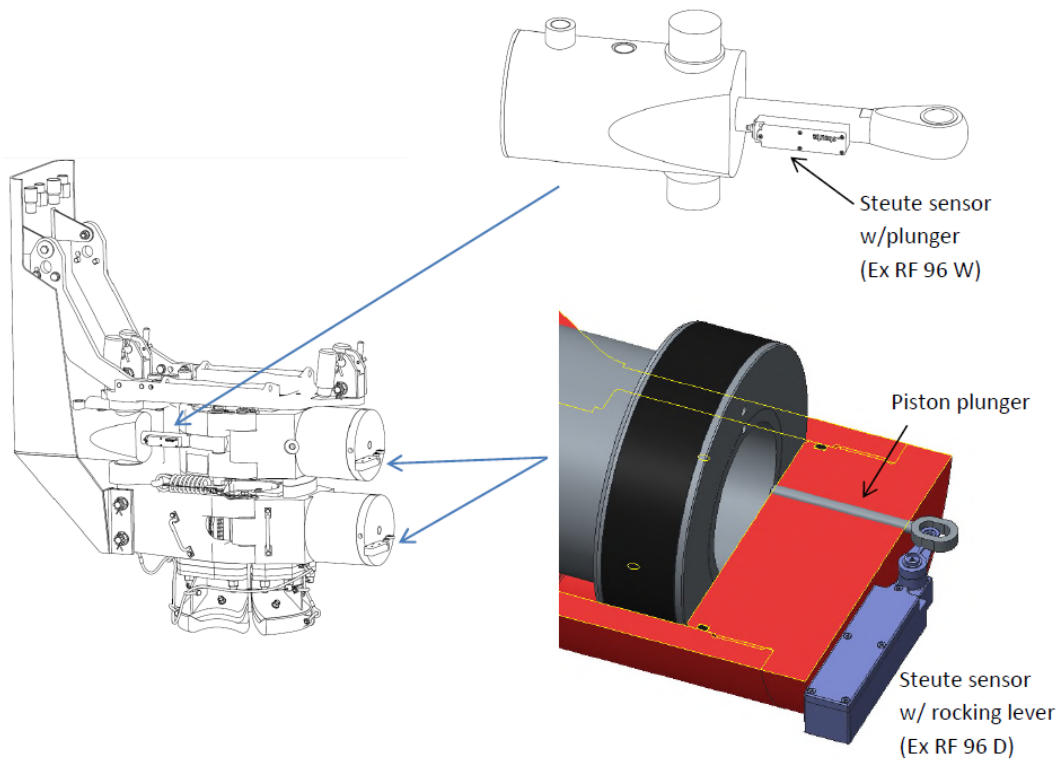


Figure 4.4: Concept illustration using Steute wireless system

Description

This concept uses four Steute sensors with mechanical actuation.
Clamp cylinder piston will hit a plunger when in off position. The plunger will, in turn, actuate a Steute sensor mounted on the outside of the end cover. An EX RF 96 D sensor (sensor with rocking lever) is seen as the most suitable.
Torque cylinder sensing is done by mounting a Steute sensor with plunger actuation on the cylinder rod. The sensor will move with the cylinder rod. When the rod is retracted enough, the sensor plunger will hit the cylinder housing, actuating the sensor.

Uncertainties

- How will the sensor actuators react to mud, dust, and dirt.
- Possible to get repeatable and good measurements when sensing on the cylinder rod.
- The antennas are placed inside the sensor and are not possible to tune further. Does the antenna placement give good enough signal strength.

Required design

- The plunger for clamp cylinder is not found as a finished solution and would need to be designed into the end cover.
- A bracket to mount the sensor to the cylinder rod.

4.4 Conclusion

Concept A has been selected to go forward with. It is preferred to not have too many moving parts. Concept B requires a fairly advanced plunger for the clamp cylinder as well as uncertainties in reliability due to mud and dirt still remains.

The end cover for concept A will be of a much simpler design. The torque cylinder sensing has more possibilities for adjustments if the first solution does not work. Different sensors and flags can be tested. And mechanical sensors can also be implemented afterward if starting out with concept A, however not the other way around.

Chapter 5

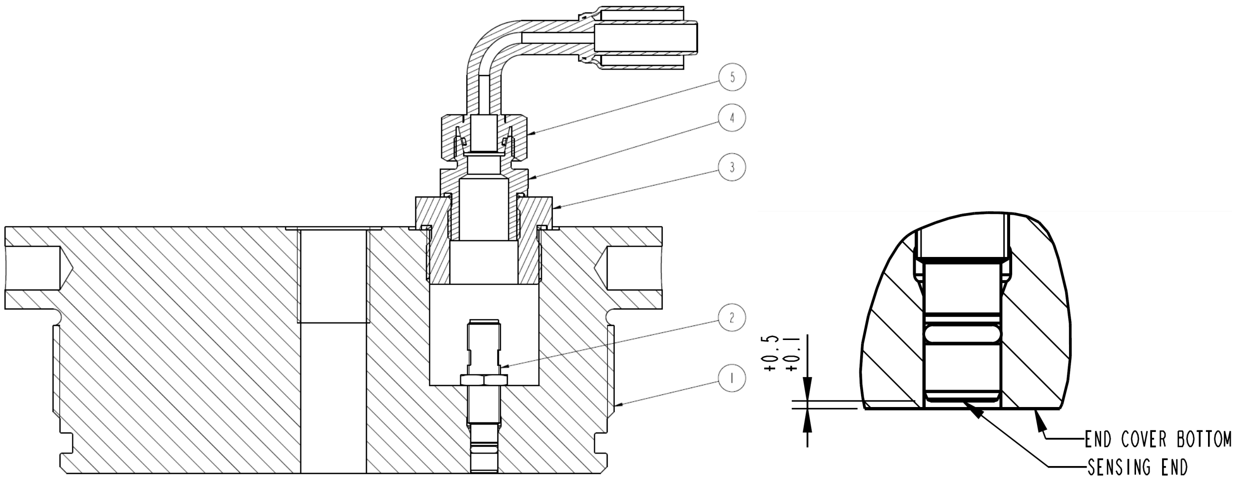
Hardware Implementation

This chapter serves to identify the physical aspects and consequences of implementing the new sensors on the TW as selected in the previous chapter. The working principle and philosophy behind the design is presented in the text, while production drawings for the new items are available in appendix A.

5.1 Sensor Implementation

5.1.1 Clamp Cylinder

A new clamp cylinder end cover has been designed for the purpose of testing the proximity sensor. A 1 1/4" BSP thread is added to the sensor hole. This can either serve as an interface for a plunger if proximity switch is not to be used or used as an interface for a cable protection.



(a) New end cover for clamp cylinder with components

(b) Detail of inductive sensor

Figure 5.1: New clamp cylinder end cover

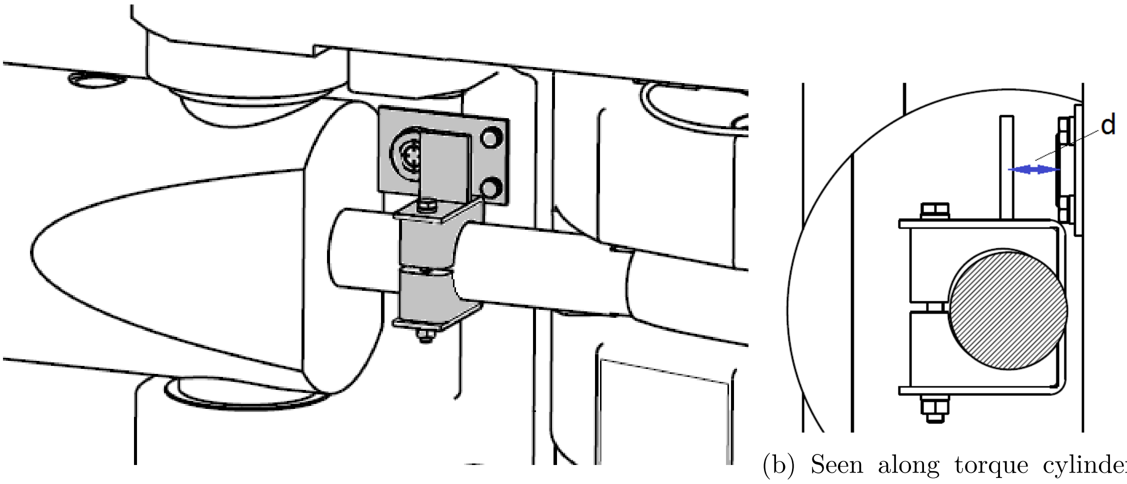
Figure 5.1a shows the new designed end cover (1) with proximity sensor (2) mounted. Adapter (3) and fitting (4) is purposed items for mounting a protection hose (5) for protecting the sensor cable (not shown).

It is beneficial to mount the sensor in the end cover before the end cover is mounted to the cylinder. The sensor can then be mounted as close to the end cover bottom while it is still possible to verify that the sensor is not screwed to far. Figure 5.1b shows the typical mounting tolerance that will be needed. As the sensor only has 1.5mm switching distance it is important to not waste this on mounting it too far inside the cover. If the sensor protrude the end cover bottom surface it will be danged when the piston is retracting.

5.1.2 Torque Cylinder

To sense the torque position, a setup as shown in figure 5.2a is used. A bracket holding the proximity sensor is mounted to the fixed part of the TW while a flag is clamped on to the cylinder rod. The clamp is a custom-made flag that uses a modified rubber pipe clamp to hold onto the cylinder rod.

The flag should be adjusted so that the distance "d" shown in figure 5.2b is not above the switching distance. I addition to this the flag needs to be placed at the correct position along the rod. It is recommended that this adjustment is done on site by driving the cylinder to end stop and fixing the flag so that the sensor is activating. A overlap should be added for safety so that the sensor is triggering a little before hitting end stop. If the cylinder hits end stop without the sensor triggering, the consequences can be that a drill pipe is not fully torqued to the TD shaft.



(a) Isometric view

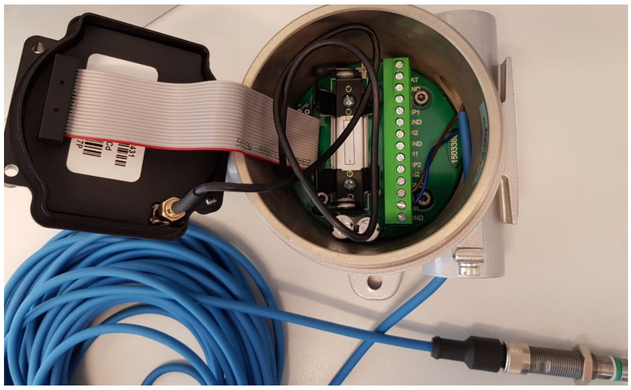
(b) Seen along torque cylinder axis

Figure 5.2: Torque Wrench proximity sensor and flag

5.1.3 Sensor Nodes

The electronics of the sensor node is concealed within a Ex approved enclosure with a window for observing the sensor node status. The barrel end of the sensor node can be screwed off as illustrated in figure 5.3a. In figure 5.3b the electronics inside are shown. On the bottom of the enclosure is a PCB with terminals for connecting the sensors and a slot for the battery. This PCB is connected to the radio module with a gray ribbon cable. The antenna connects directly into the radio module with a SMA connector. Only one sensor is connected in the figure, this is connected to the terminals SP1 (Power soucre 1) and A1 (Analog input 1).

(a) Sensor node, battery and proximity sensor



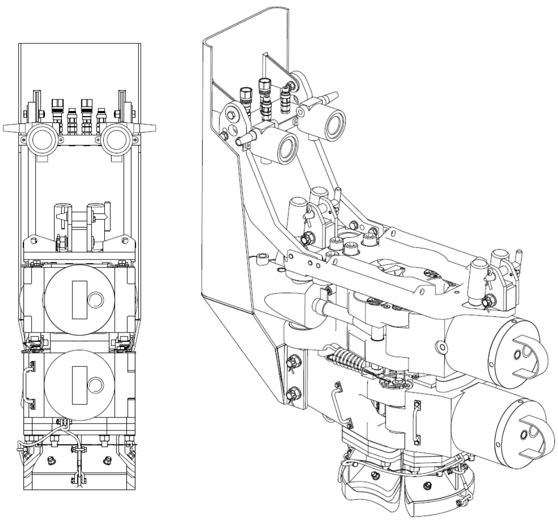
(b) Sensor and batter connection

Figure 5.3: Picture of open DX99 sensor node

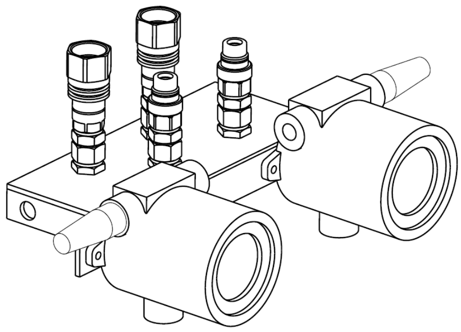
Node placement

As the manifold now becomes redundant and can be removed (ref 5.3.1) a new bracket is purposed for both mounting the quick connectors and the sensor nodes. The bracket may use the same interface as the previous manifold to easily be implemented on rebuilds of old TW.

The sensor cables are routed into the sensor nodes, typically both torque sensors on one node and both torque sensors to another.



(a) TW with senors node mounted



(b) New bracket for mounting quick connectors and sensor nodes

Figure 5.4: New sensor node and quick connector placement

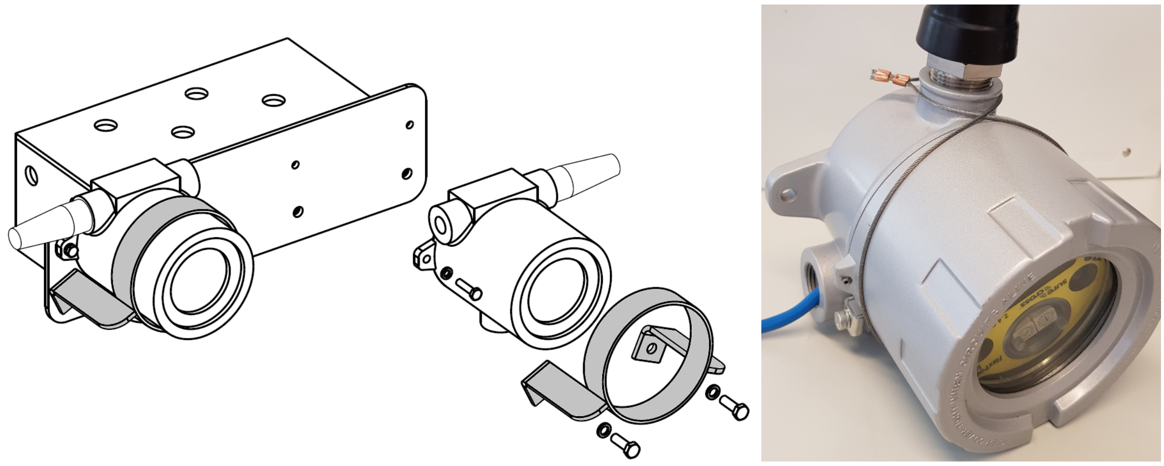
Security against dropped objects

When the sensor nodes were received it was observed that there was not any anchor point for securing the sensor node if the two bolts holding it were to come loose.

The TW is exerted to high accelerations and vibrations when it is operating. The two mounting holes for mounting the sensor node by M6 bolts are not seen as a safe solution by itself. In case of a collision where the bolts are broken off or they come loose due to vibrations, a redundant holding mechanism should be in place. Two solutions are proposed.

In figure 5.5a a retainer that can be bolted on after the sensor node is mounted. This solution requires some more installation time and makes it more time consuming to replace battery. It will also retain the node screw on cover from coming loose as well as giving some added protection.

The wire harness seen in figure 5.5b is a faster way to secure the node, however the harness must be tightened as much as possible when installed to make sure it can not slip off. The geometry of the sensor node is not the best for a wire harness. The wire harness will not keep the screw on cover from coming loose.



(a) Bolt-on retainer

(b) Wire harness

Figure 5.5: Ways to secure the sensor node from falling in case of bolt failure

5.2 Wireless Equipment Placement

To secure reliable communication and good signal strength, considerations should be made when placing the components in the final working environment:

The machine/sensors movement

The sensor is placed on a machine that might move and rotate. If the machine moves too far or reorients the antenna completely, the connection might be lost. If it is not possible to obtain a good link between sensor and gateway in all of the machines positions, an extra gateway may be needed for better coverage. In the case of a TW, the movement is linear along the center of the derrick. The TW may rotate continuously around the same axis. This means that the machine itself will not create any radio shadow down to drill floor.

Fixed or movable obstructions preventing line of sight

If considering the environment such as fixed objects and other equipment, there are few objects that are massive and would completely block a radio signal. Most structures consist of framework, allowing an electromagnetic signal to go through. Some derricks have a fairly open side as seen in figure 5.6b, if the gateway were to be placed outside of the derrick looking in, using this side of the derrick would be preferable. Equipment operating between the TW and drill floor would be Tubular Feeding Machine and Roughneck. Neither of this would completely block line of sight between drill floor and the TW when it is executing its functions and fast response time from the wireless system is required.

EMI sources

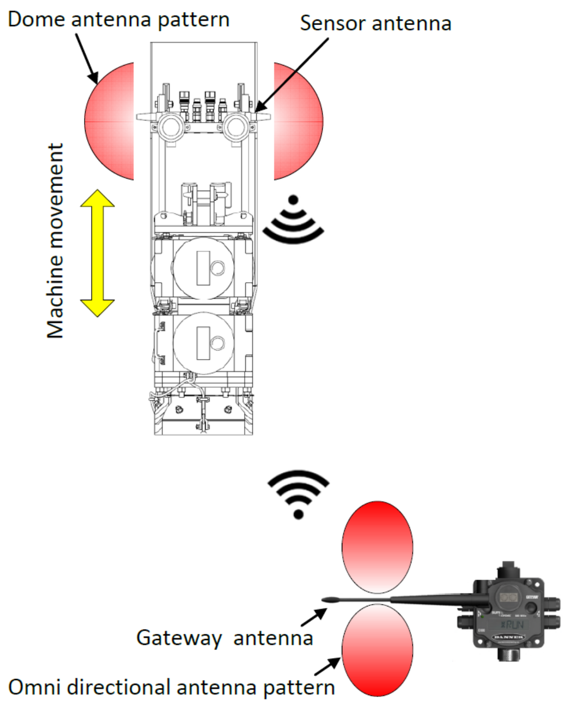
EMI sources locally on the TD is not relevant as the TW is located under the swivel where there is no other electrical equipment. However, interference from other wireless systems may be relevant as the TW will travel over a large area of the derrick. If other wireless equipment is operating close to the TW operational area, co-existence should be tested toughly before the operation is made dependent on the wireless system. The same yields for placement of the gateway. Either it is placed inside the derrick or other places, coexistence with other wireless systems in the area should be verified.

Hazardous zone classification

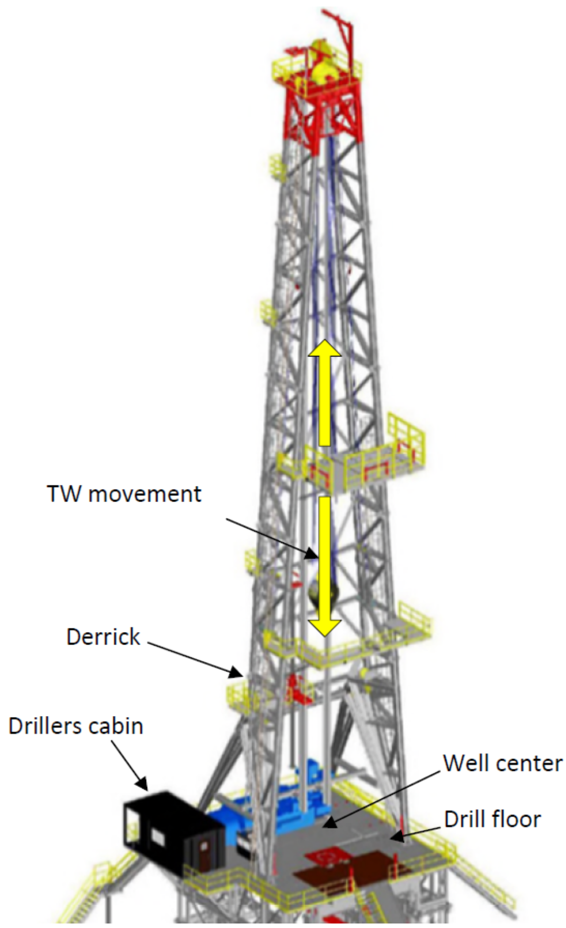
The sensor nodes from banner are designed for operation in Zone 0 and are therefore possible to use at all places on the rig. The gateway, however, is only available in Zone 2. The zone division may change depending on the rig. However, the vicinity of well center is often the only area classified as Zone 1. Meaning most of the derrick anything outside will be possible to use as mounting areas. In special cases where the only possible placement are in Zone 1, Ex D encapsulation of the gateway may be used as an option.

Antenna type and orientation

Antenna selection may help to give the needed coverage. For long-range applications, directional antennas are often used. However, the applicable distances are short considering the given operational distance of 3km. The sensor nodes are delivered with dome-antennas that have a radiation pattern similar to a half sphere. The gateway is delivered with an omnidirectional antenna with a radiation pattern similar to a donut around the antenna axis. The gateway antenna can benefit from being placed horizontally as there is a dead zone in the antenna axis direction and it should not be directed at the point-of-interest. The sensor node antenna is placed horizontally as well. At times one of the sensor nodes will be pointing directly away from the gateway as the TW may rotate continuously,this will result in an unwanted antenna direction. However the antenna will always radiate some in all directions, and for small distances, this will be enough, electromagnetic waves may also be reflected off object and surfaces. Tests from Danyko also shows promising results when testing of the wireless system was done in the test tower facility in Dvergsnes. With 100% signal strengths even if no line of sight between sensor and gateway as long as the distances were short (50m). A test is conducted in chapter 7 to indicate performance with different distances and antenna orientations The test results are inconclusive due to unrealistic test environment. Further testing should be done in the test tower.



(a) Illustration of antenna directions



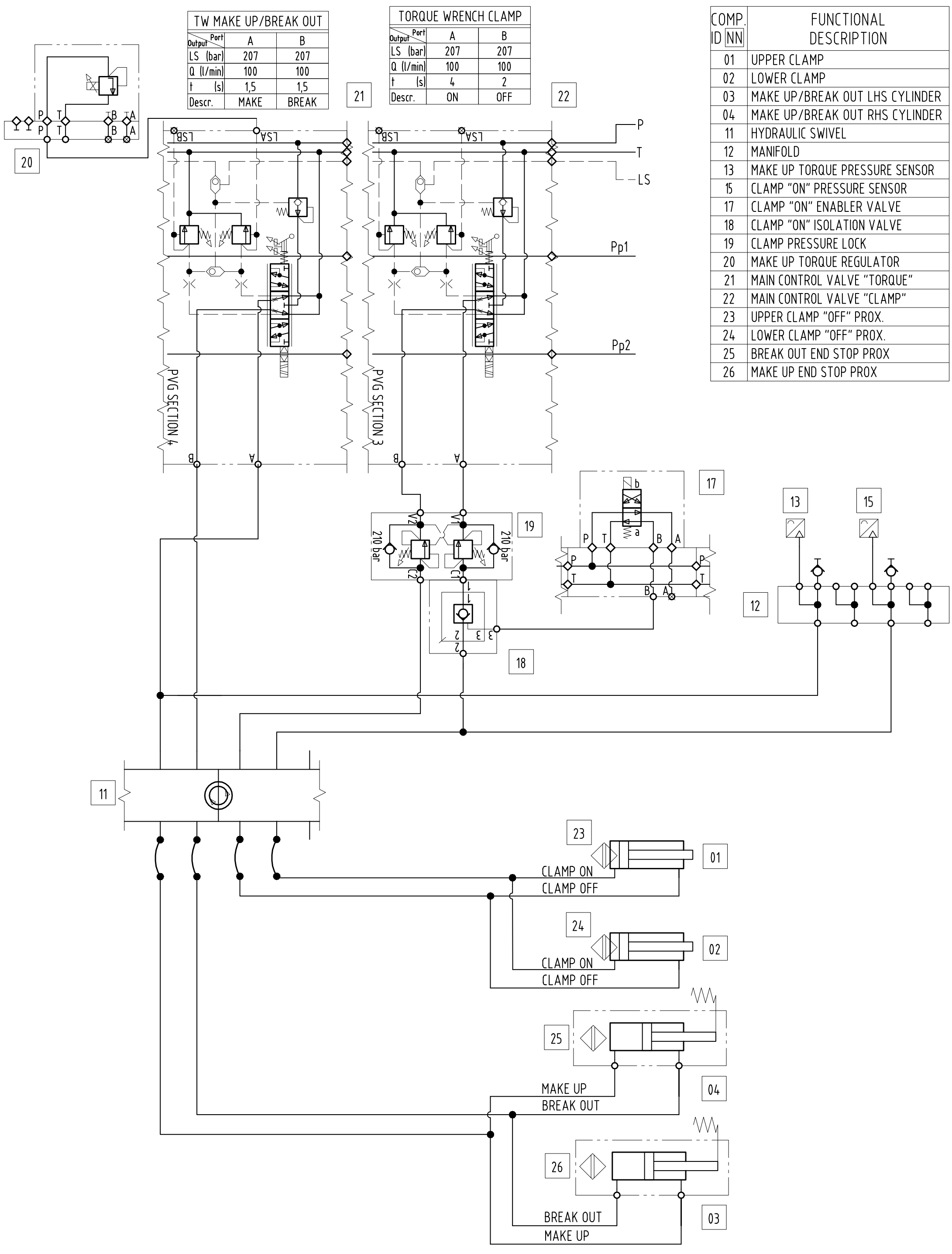
(b) Illustration of typical derrick

Figure 5.6: Wireless placement considerations

With the above considerations in mind, it is seen as a typical component placement will be with gateway either in the lower part of derrick structure (to keep cabling as short as possible) or at the outside looking into the derrick if it has fairly open sides. The TW and neighboring equipment movement does not give any reasons for pursuing a solution with redundant gateways. The absolute positioning of components are dependent on the rig layout and other wireless equipment in the area and would need final consideration when the system is to be placed in the field.

5.3 Resulting Torque Wrench System

Figure 5.7 shows TW fluid diagram after the new concept is implemented. Compared with the original fluid diagram on page 24, most of the hydraulic components placed on the TW (below the swivel) has been removed. In addition to this two PT from above the swivel is also removed as a consequence of adding the four endstop sensors.



Output \ Port	A	B
LS (bar)	207	207
Q (l/min)	100	100
t (s)	1,5	1,5
Descr.	MAKE	BREAK

Output \ Port	A	B
LS (bar)	207	207
Q (l/min)	100	100
t (s)	4	2
Descr.	ON	OFF

Figure 5.7: Torque Wrench fluid circuit diagram with new component layout

5.3.1 Components and Functions

This section will serve to justify the removal of parts (ID 05-10, 14, 16) by adding items (ID 23-26) and explain how the new system may achieve improved functionality over the old design.

End stroke detection

Hydraulic end stop valve (ID 07, 09) becomes redundant due to a proximity sensor (ID26) doing the same task. As a result, the Hydraulic circuity placed locally on the TW can be simplified significantly.

The pressure locks (ID 05, 06) Were needed to lock the clamp cylinders as the clamp line pressure were dumped if end stop valve were triggered. The clamp main control valve may be kept active throughout the whole clamping sequences and the pressure in clamp line will no longer be dumped when hitting end stop. Thus, ID 05 and 06 becomes redundant.

As a consequence of adding end stop sensors (ID 23-26) the hydraulic manifold and end stop trigger can be removed (ID 05-10).

Clamp off pressure sensor

The clamp off pressure sensor was before used for delta pressure monitoring in the clamp cylinders to assume clamp position when clamped off. The clamp off state can now be verified by the new sensors (ID 23, 24) and the clamp off pressure sensor can be removed.

Clamp on direct pressure sensor

As the pressure lock valves (ID 05,06) are removed, the same pressure is available throughout the whole clamp on line and pressure sensor ID 13 and 16, therefore, will be measuring the same pressure. Clamp on direct pressure sensor (ID 16) has been removed.

Clamp enable valve

The clamp enable system (ID 17, 18) has been kept for machine safety. If these valves were removed, there is no redundant safety barrier if unintentional or faulty activation of clamp valve(ID 22) in clamp on direction.

The end stop sensors on clamp valves should be able to detect such happenings, however, the wireless system is not approved for use in safety instrumented systems (SIS) and cannot be used to obtain a safety integrity level (SIL). In addition to this there would be a practical challenge as the sample rate would need to be high (<100ms) and the system on for long time intervals. The resulting battery lifetime would not be acceptable[1].

[1]According to Banner battery lifetime calculation sheet, a DX99 node with two NAMUR sensors and 63ms update/report rate would be approx. 4 months continuously operation

5.3.2 Cost

Changes influencing the product cost are presented in table 5.1. All cost is in NOK.

Material cost			
Removed cost	**Qty**	**Cost**	**tot. Cost**
Manifold related parts			
Overcentre valve	2	1 412	2 824
Custom manifold	1	4 707	4 707
Check valve	1	113	113
Clamp pressure line	1	1 000	1 000 [1]
Removed fittings, hose...	1	3 000	3 000 [2]
Endstop related parts			
Endstop cost	1	8 152	8 152 [3]
End stop throttle adapter	1	387	387
Top drive related parts			
Pressure transmitter	2	4 400	8 800
Cabeling and piping	1	5 000	5 000 [4]
Added cost			
Wireless system			
Sensor node DX99	2	10 412	20 824
Gateway	1	5 634	5 634
TW related cost			
Inductive Sensor	4	3 500	14 000
Torque cylinder	2	1 500	3 000 [5]
Clamp cylinder	2	1 000	2 000 [5]
Results			
Removed material cost			-33 983
Added material cost			45 458
Cost difference			**11 475**

(a) Cost impact of all parts in the TW system

Material cost			
Removed cost	**Qty**	**Cost**	**tot. Cost**
Manifold related parts			
Overcentre valve	2	1 412	2 824
Custom manifold	1	4 707	4 707
Check valve	1	113	113
Clamp pressure line	1	1 000	1 000 [1]
Removed fittings, hose...	1	3 000	3 000 [2]
Endstop related parts			
Endstop cost	1	8 152	8 152 [3]
End stop throttle adapter	1	387	387
Added cost			
Wireless system			
Sensor node DX99	2	10 412	20 824
TW related cost			
Inductive Sensor	4	3 500	14 000
Torque cylinder	2	1 500	3 000 [5]
Clamp cylinder	2	1 000	2 000 [5]
Results			
Removed material cost			-20 183
Added material cost			39 824
Cost difference			**19 641**

(b) Cost impact of parts on TW module only

Table 5.1: Cost calculation for new Torque Wrench system

Table 5.1a represents the cost associated with a complete TD delivery. As several parts of the TW system that can be removed are mounted on the TD, this results in a lower cost increase then if only looking at the TW as a module, as table 5.1b represents.

When looking at the TW as a stand-alone module the component and production cost is about 470 000 NOK. The this means that the 19 641 NOK will increase the cost by approximately 4.2%. Component and production cost of a total TD system can be typically 10 million NOK (depending on TD). If assuming 10 million, the increased cost of 11 475 NOK only makes up 0.111% of the total cots. In both cases the cost increase is marginally and indirect cost saving such as less electrical drawings or installation time could weigh up for it.

1. Includes removal of hose with quick connectors
2. Lump sum for removed miscellaneous mounting material
3. Estimated from the difference between cylinder with and without hydraulic endstop
4. The cost consequences of a removed sensor can be hard to estimate as this depends heavily on the instrument loop length and complexity, it will both give reduced material and installation cost as well as reduced drawings and machine complexity. A cost of 5000 NOK can be considered conservative.
5. Added machining cost for proximity sensor mounting hole. Estimated as 10% of plain cylinder cost

5.3.3 Efficiency

A TW without end stop positions uses timed sequences to run as seen on flow charts on page 26. These timed sequences are tuned on each delivered machine, requiring time-consuming test time on the actual equipment. In addition, the final times used in the sequences must have a safety margin to compensate for unknown factors such as cold hydraulic fluid and friction.

Table 5.2 shows a calculation of the potential time decrease in auto sequences when using feedback from endstop sensors. The times used in the column "Times from old auto sequence" is based on the functional description of the TW [2]. The "Max theoretical function time" is based on information from the fluid diagram of the TW. If assuming no function overlapping on the new sequences and just run the functions in order, the savings for both make up and break out auto sequence can be approximately 30%.

This will depend on the fluid temperature and other factors, but the bottom line is that the TW may work more effectively with less tuning time by use of the new sensor signals.

Make up		
Function	Times from old auto sequence [s]	Max theoretical function time[s]
Clamp OFF	1,5	2
Clamp OFF Break out	3,5	0
Break out	0,5	3
Clamp ON	4,75	4
Clamp ON Make up	1,25	0
Make up	3	8
Make up check	8	0
Pause	0,5	0,5
Clamp OFF	5	2
Sum time	28	19,5
Saved %		30,4

(a) Make up sequence

Break out		
Function	Times from old auto sequence	Max theoretical function time
Clamp OFF	1,5	2
Clamp OFF Make up	3,5	0
Make up	0,5	3
Make up Clamp ON	2	0
Clamp ON	3	4
Clamp ON Break out	5	3
Clamp OFF	5	2
Sum time	20,5	14
Saved %		31,7

(b) Break out sequence

Table 5.2: Auto sequence time savings

Chapter 6

Control System Implementation

This part of the thesis has two objectives. One is to set up the wireless system and acquire data from it, the other is to develop a PLC program that can run the TW auto sequences with the new sensor setup.
The control system is restricted to the TW only with its operational sequences. Operation and interlocks together with the rest of the TD are neglected to limit the scope of programming. HMI will only be developed for illustrating the created sequences and will not necessarily reflect the HMI when the TW is incorporated in the complete equipment.

The TW sequences and the host system communication will be tested separately as hardware to test both at the same time is not available.

The tested system is composed of a PLC (Siemens S-1500), a gateway for the wireless system (Banner DXM100) and a PC set up as HMI.

First Modbus communication protocol is presented as this is vital for the communication between PLC and the host system (gateway).

6.1 Modbus

Modbus is an open communication protocol first developed in 1979 for transmitting information used by PLCs [37]. Modbus was first developed for communication over serial lines (Modbus RTU) but a protocol for Ethernet communication has also been developed (Modbus TCP). A Modbus network consists of master/client that can request information and slaves/servers that responds to the master. Each slave has an address from 1 to 247, making it possible to have a network with one master and up to 247 slaves.

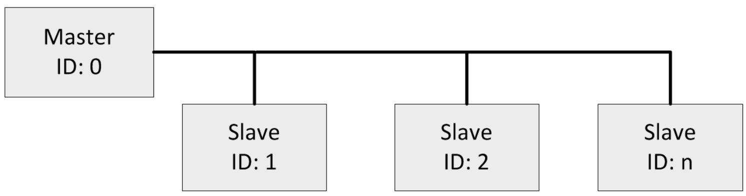


Figure 6.1: Modbus network

Data is stored in different registers in Modbus. An overview of address locations named coils, contacts and register can be seen in 6.1.

Address	Table Name	Access	Size
00001-09999	Coils	Read, Write	1-bit
10001-19999	Contacts	Read	1-bit
30001-39999	Input Register	Read	16-bits
40001-49999	Holding Register	Read, Write	16-bits

Table 6.1: Modbus registers

When data is requested or transmitted, a function code is used. The function tells if it is a read or write command as well as what table that is applicable. For example, when code 3 is used, it is known that holding registers (40001-49999) are to be read. As the table are given by the function code only the four last digits (xNNNN) are needed to know what address to look at. The first digit (Nxxxx) in the register address can therefore just be seen as location name, and are not used in the data transmission.

Code	Function
1	Read Coils
2	Read Contacts
3	Read Holding Register
4	Read Input Register

Code	Function
5	Write Single Coil
6	Write Single Register
15	Write Multiple Coils
16	Write Multiple Holding Registers

Table 6.2: Modbus functions

A complete Modbus message is built up as the following:

8-bits	8-bits	n-bits	16-bits
Slave ID	Function Code	Data	CRC

Where the data length depends on the function used and tables accessed.

A Modbus master sends a message in the format seen above out to the slave devices, the applicable slave device will act upon the function and data given. If a read function is requested, the salve device returns the Modbus message but the data placeholder is now filled with the requested information. If the message is a write function the slave device will return the same message as an acknowledgment message to the master when the write operation is completed. The cyclic Redundancy check (CRC) that follows is a number calculated based on the occurring bits in the message. Both the slave and master calculates and compares the CRC when receiving a message. If one bit of the message is lost, the CRC will not be correct and indicates an error.

Modbus Master Request Example

The following message calls Slave ID 02 with function code 03 (Read Holding Registers). The data holder first specifies the starting register to read from (000A hex = 10 dec) then continuous to specie how many registers to read (4).

02	03	000A 0004	E43A

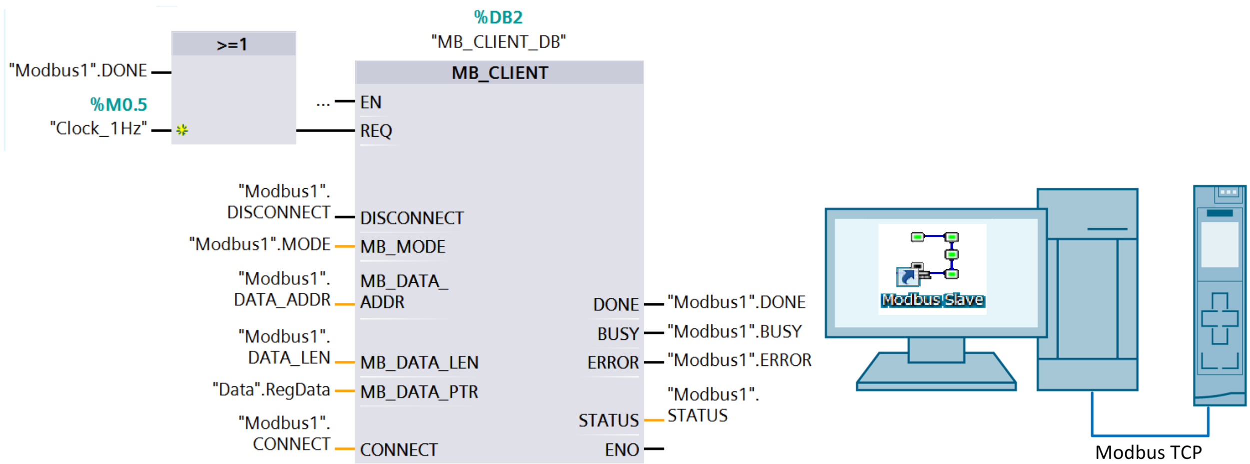
Modbus Slave Response Example

When the slave receives the message it will return the value of the four registers requested. The returned message contains the same slave ID and function code, but the data field now contains the value of the four registers. As an example 0201, A002, B102 and 0050 would be the value of register 40011, 40012, 40013 and 40014 respectively.

02	03	0201 A002 B102 0050	B384

6.1.1 Modbus TCP with Siemens S-1500

Siemens S-1500 and S-1200 support Modbus TCP communication via the onboard Ethernet connections (PROFINET interfaces)[38]. The TIA portal has pre-built blocks that make it easy to set up the PLC to work as a client (master in TCP) or server (slave in TCP). In this case, the PLC will always be the client and the host system act as the server, therefore only setting up PLC as a client is described.



(a) TIA program (b) Test setup

Figure 6.2: Siemens Modbus TCP Client communication test

To get the Modbus TCP communication tested before receiving the Gateway, a Modbus simulator was used. A Modbus slave was set up on the computer using the software "Modbus Slave"[39]. Both Modbus TCP between PLC and simulator and the communication between PLC ant TIA portal for on-line diagnostics were able to work over the same Ethernet connection at the same time. As seen in figure 6.2a, the MB_CLIENT block was set up to send a request each time the previous connection was done or each second.

6.2 Host System

The host system (Banner gateway) is consisting of one gateway and two nodes. The nodes may be set up to read different types of sensor signals, as well as outputting a signal if it is configured for it. The system can be set up to work as a simple stand-alone system where different input states of one node may trigger an output of another node or on the gateway. In this application, the system will be used as a host system to the PLC, meaning the PLC will poll and write values to the system. In the Banner system, the gateway and each node have 16 I/O points each, that has a separate Modbus address a client can access.

All Modbus addresses for the Banner system is located in the holding register (4xxxx)[33, 40]. The gateway 16 I/O points are the first 1-16 (40001 - 40016) while the 16 I/O points for each node continuous after this. The first I/O point of a node is given by 1+1x(Node #). The following table displays the address of all gateway, node 1 and node 2 I/O points.

	I/O point															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gateway	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Node 1	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Node 2	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

Table 6.3: Host system modbus register addresses

I/O point 1-8 is defined as input (information that can be read), while 9-16 is output (registers that can be written to). 1-6 and 9-14 are inputs/outputs on the DX80 node. Register 7, 8 is used for status messages, the messages on available on register 7 depends on the commando sent to the node, while register 8 is the status of the node/gateway. Register 15 and 16 is used to send commandos and changing parameters on the node/gateway.

6.2.1 System Configuration

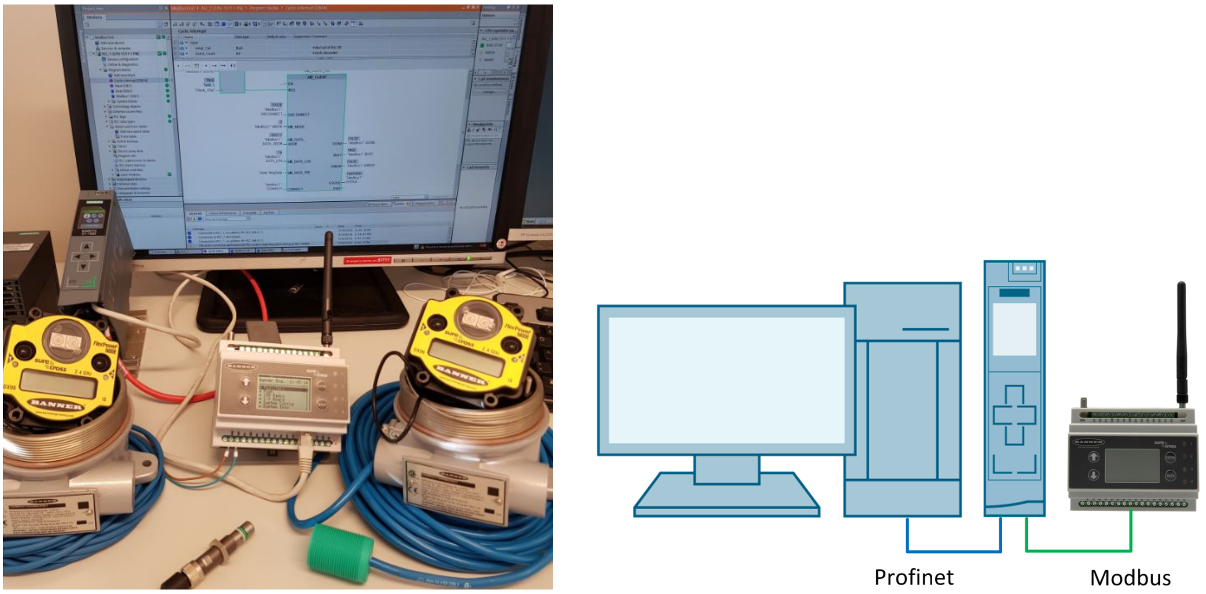
Configuration tools for easily setting up the sensor nodes are available from Banner engineering homepage. There is one software called "Sure Cross User Configuration Tool (2nd Gen)" used for DX80 and another "DXM Controller Configuration Tool (V3)" used for DXM100. The DX80 configuration tool is used with both DX80 and DXM100 gateways to configure the sensor nodes, while the DXM100 configuration tool can be used to access the extra features of the DXM100 gateway and set up simple rules and messaging services. The DXM100 tool was only used to set up a static IP address for the gateway. For configuring the sensor nodes, the DX80 tool was used. The setup will not be shown in the report but a step by step guide has been made with an example of setting up a sensor node with one inductive sensor. The guide can be found in appendix C.

For the current test setup, node 1 and 2 has been set up with a sensor input on I/O point 3. Meaning the sensor value can be read from register address 3 on each node.

All node configurations available in the DX80 configuration tool can also be set using Modbus commands.

6.2.2 PLC and Gateway Communication

A user program for the PLC has been written to enable communication with the host system, see appendix D. The PLC communicates with the host system over Modbus TCP same way as described in section 6.1.1. The client block is now set to communicate with the IP address of the gateway.
The PLC always polls the first 48 register from the host system (I/O point 1-16 for gateway and node 1 and 2). And can write Modbus commands to the host system to perform parameter changes or start "Site Survey" (signal strength test).



(a) PLC connected with computer and gateway (b) Connection topology

Figure 6.3: Gateway, sensor nodes, PLC and PC setup

To make it possible to connect, disconnect, change parameters and read host system values from PLC, a simple HMI has been developed (figure 6.4).

In the node 1 and 2 fields, the current sensor value (I/O point 3) and node status (I/O point 8) are displayed. The value is displayed in hexadecimal and an explanation is also displayed depending on the register value. The status messages are made using text list in TIA.

A field for writing register values to the host system is available. The number of registers to write needs to be specified, as well as the starting register and the value for the register. When pressing write, the code in figure 6.5 is executed. In the current display, if pressing write, value 0x2000 is written to register 40015 (I/O point 15 for gateway) this will exit "Site Survey" mode if it is ruining. To start "Site Survey" for node one, value 0x2001 needs to be written.

The field in the lower right corner shows the signal strength if "Site Survey" mode is active. In the bottom of the screen, a trend shows the historical sensor values.

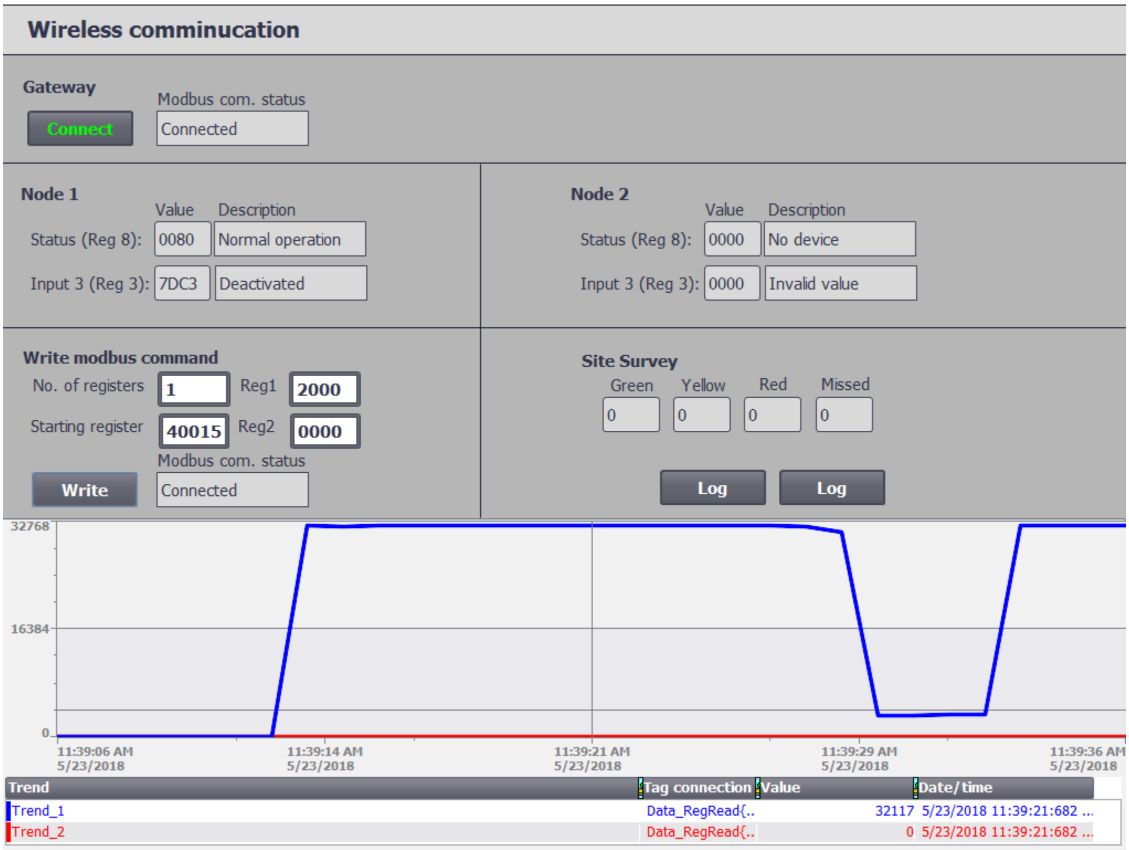


Figure 6.4: HMI screen for modbus communication

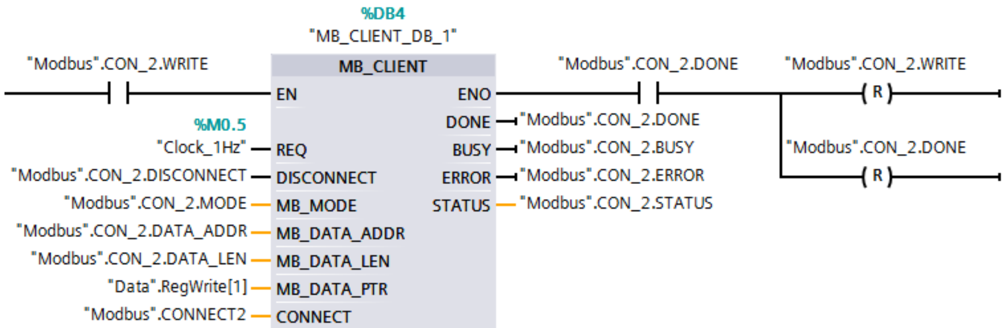


Figure 6.5: Code for writing modbus register to host system

6.3 Torque Wrench Control System

This section explains how the control system for the TW module has been programmed. In figure 6.6 the data flow between the FB (Function Blocks) and the DB (Data Blocks) is shown. The part of the system that is only applicable for the testing is framed in a gray box. Rest of the system may be used further when implementing the wireless solution on the TD.

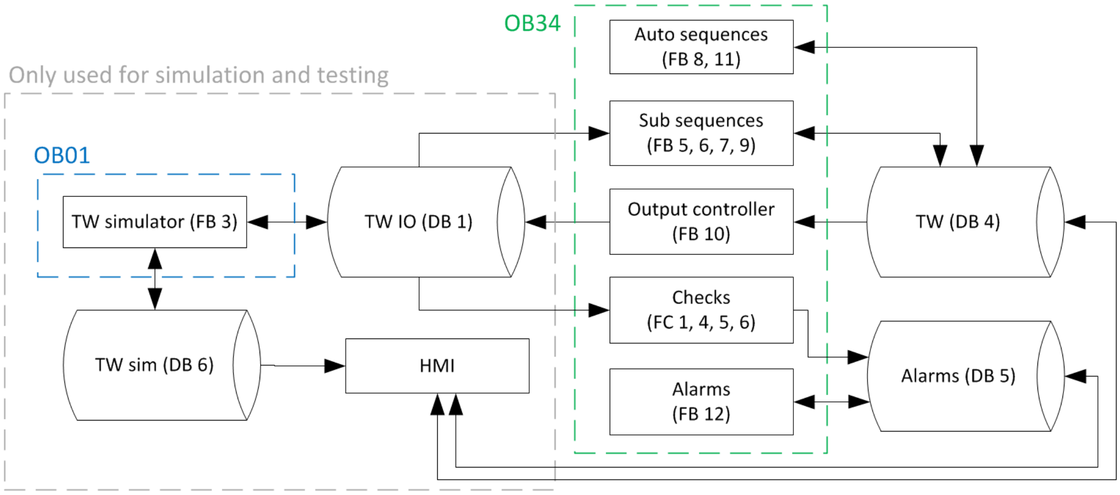


Figure 6.6: Control system flow

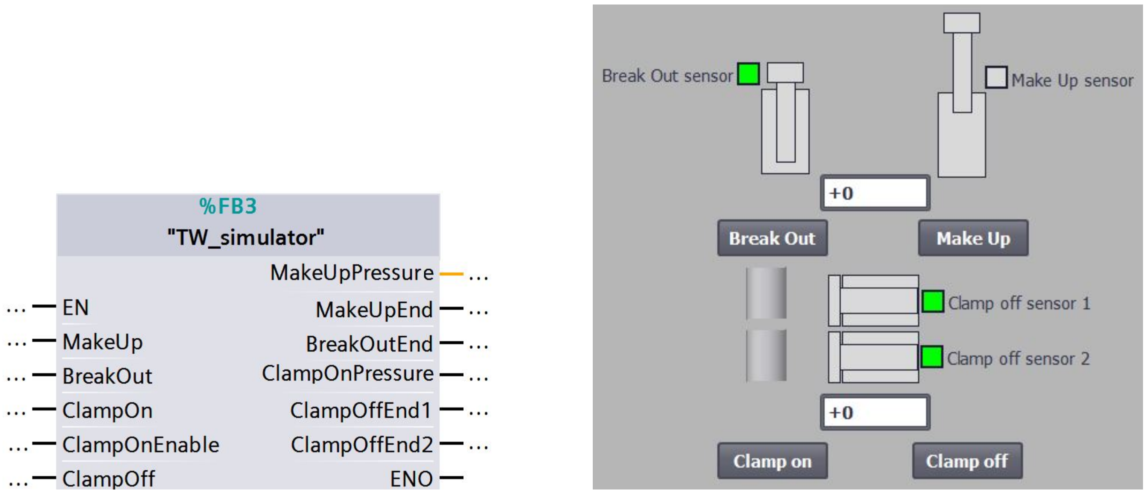
The control system flow and code are described in a simplified manner in upcoming sections, the code is attached in appendix E.

6.3.1 Torque Wrench Simulator

Throughout the programming and testing, no hardware has been available for testing. Therefore a model of the TW system has been developed to simulate machine movement and sensor readings.

The TW simulator communicates with the control system through TW IO DB1 by reading and acting upon outputs and writing sensor information back to it.
The TW simulator uses two internal variables. ClampPos which is the clamp cylinder position, where 0 corresponds to clamped off and 100 corresponds to clamped on position. TorquePos which is the torque cylinder position where 0 corresponds to break out position and 100 corresponds make up position.
These variables are changed if the correct output signals are activated on the PLC, simulating that the hydraulic function is active and running to endstop.

Based on the current function position and active outputs, endstop sensor signals and pressure transmitter signals are simulated.



(a) TW simulator function block (b) HMI representation of Torque Wrench simulator

Figure 6.7: Torque Wrench simulator

6.3.2 Auto Sequences

In normal operation, the TW is used by executing auto sequences for its make up or break out functionality. In the new auto sequences seen in figure 6.8, only clamp on function is timed as opposed to the old sequences presented on page 26 where all functions except (make up) were timed.

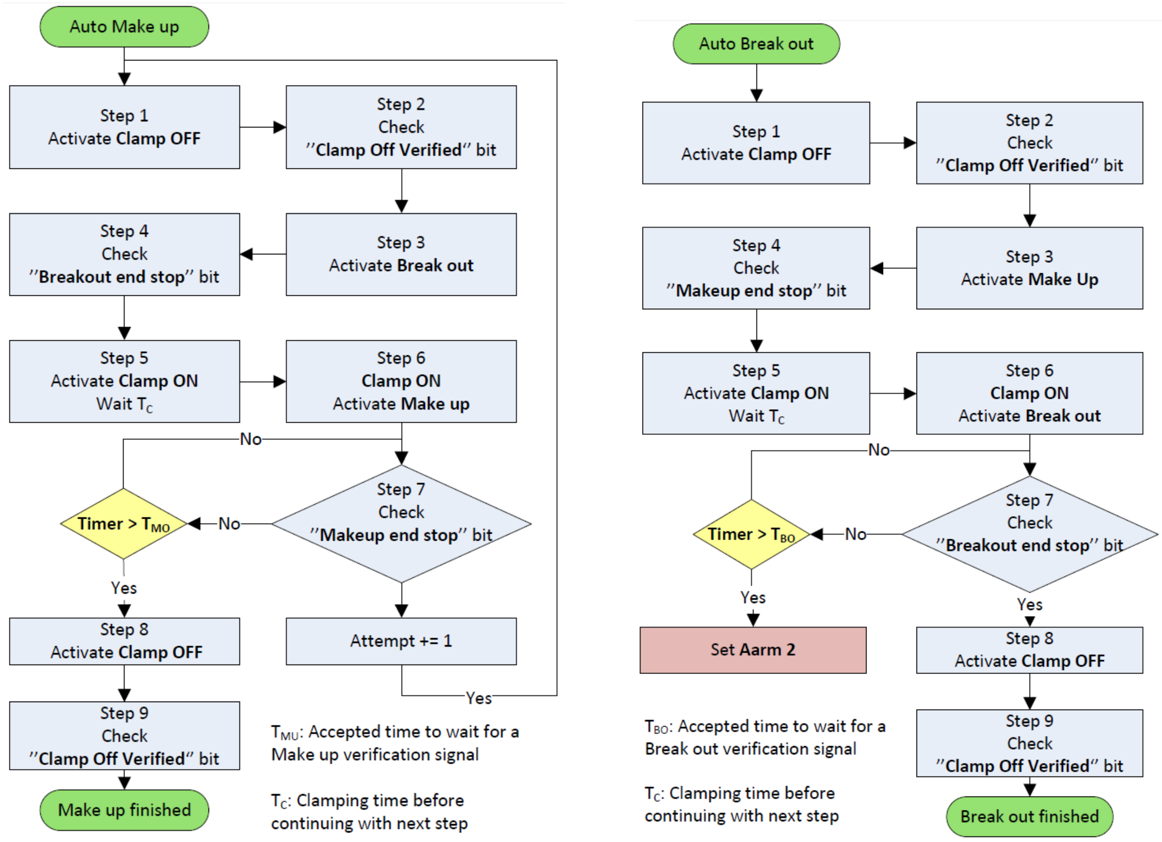
As seen in figure 6.8 there are many similarities between the two auto sequences. Both auto sequences will be running the functions clamp on and off and make up and break out. These has therefore been programmed as separate Function Blocks(FB) to reuse code. Further information on these is found in section 6.3.3.

Both auto sequence FBs (figure 6.9a and 6.9b) has the following inputs; an activation input (bAtive) if this is set high the auto sequence starts, if not the internal states of the auto sequence is reset. The other input is a structure (sVerification) containing several "verification" bits. There is one bit for each sub sequence and they are activated by the sub sequence that it is executed successfully.

The output of each auto sequence is a structure (sActivate) which contains a bit for each sub sequence. These bits are used to turn the sub sequences on and off. To use the correct auto sequence activation output, a Function (FC) has been made to select the output from the active auto sequence only, the block is seen in figure 6.9c.

In addition the make up sequence has a counter (iAttempt) output that is an integer showing how many times the make up sequence has been running after each other continuously, this will happen when the make up sub sequence are able to run all the way to make up endstop. The full torque has then not been applied to the drill pipe and a new stroke is needed.

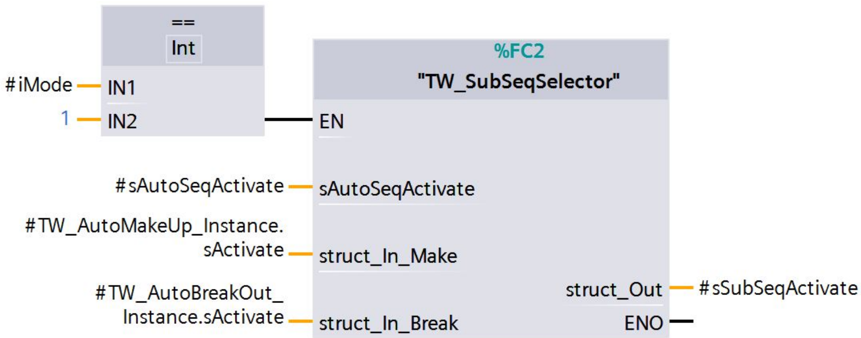
The break out sequence has an alarm output bit (bAlarm) that is set if the break out position was not obtained within a defined time.



(a) Auto Make up (b) Auto Break out

Figure 6.8: Auto sequences

(a) Auto Make up (b) Auto Break out

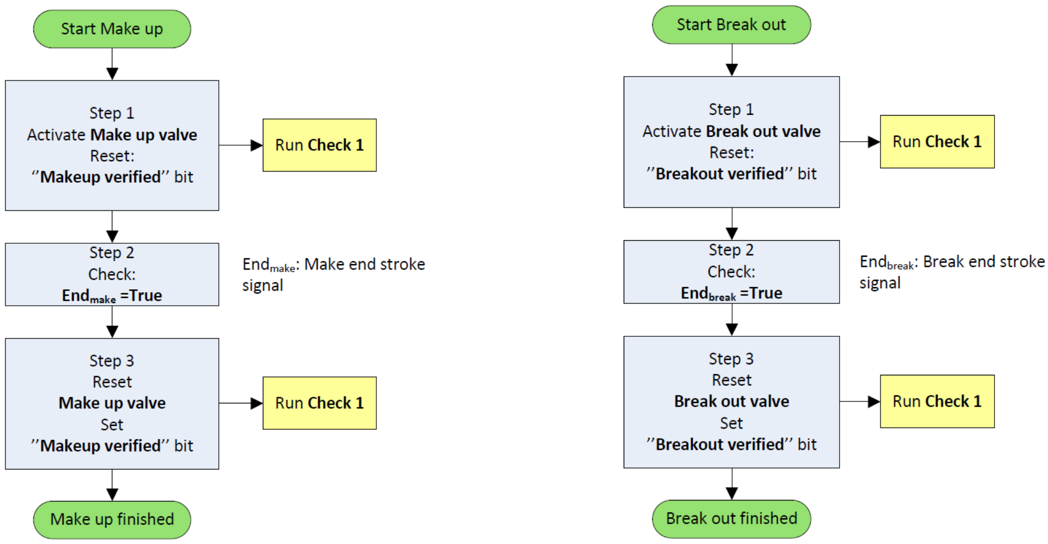


(c) Output selector

Figure 6.9: Auto sequences blocks

6.3.3 Sub Sequences

Make Up And Break Out sub sequence

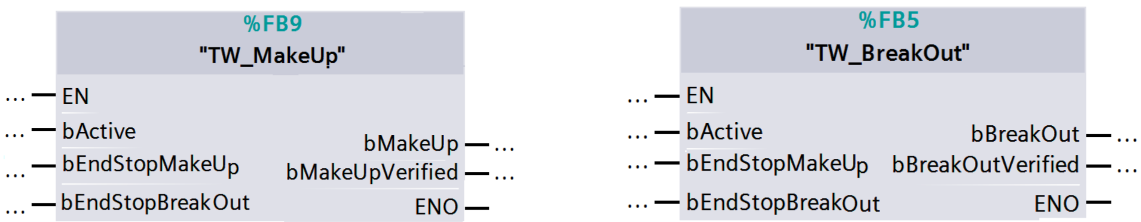


(a) Auto make up (b) Auto break out

Figure 6.10: Auto sequences for make up and break out

Both sub sequences use the make up and break out endstop signals (bEndSyopMakeUp and bEndStopBreakOut) as input as well as an activation bit (bActive).
The output of the sub sequences is a verification bit (bVeriefied) to indicate that the sub sequence is completed. There is also output bits used to activate the different hydraulic valves (bBreakOut and bMakeUp).
Both sequences contain an internal variable (iStates) to keep track of the active state.

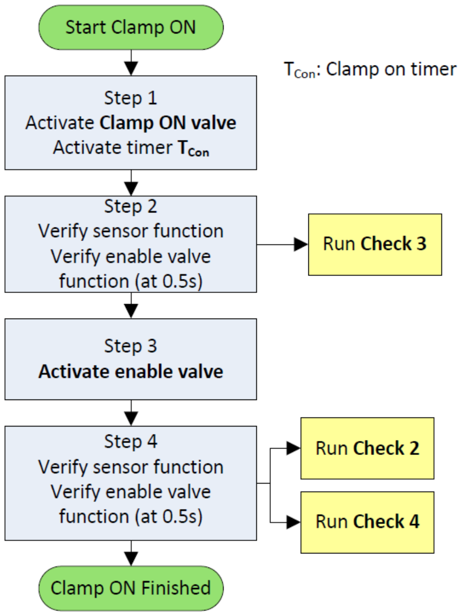
If the activating bit is not true, the internal state of the sequence is reset and both outputs are set as false. If the sequence is activated, it starts to run through the steps as shown in figure 6.10. A check is called up inside the sub sequences, see section 6.3.5 for further explanation.



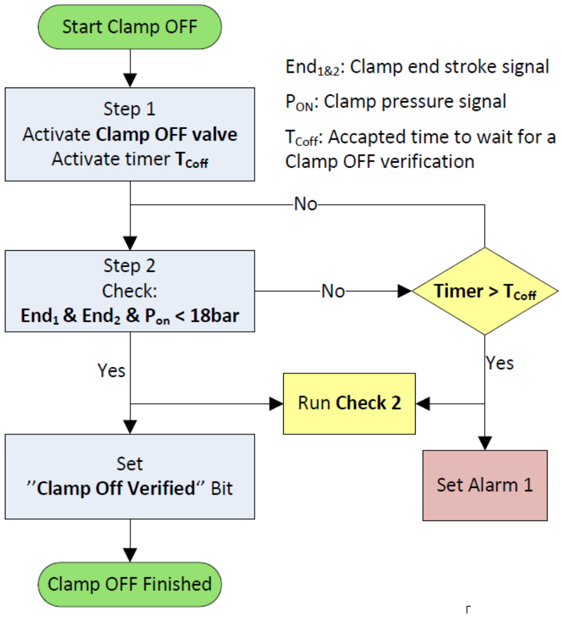
(a) Sub sequence make up (b) Sub Sequence break out

Figure 6.11: Sub sequences block in FBD for make up and break out sub sequences

Clamp on and off sub sequence



(a) Sub sequence clamp On

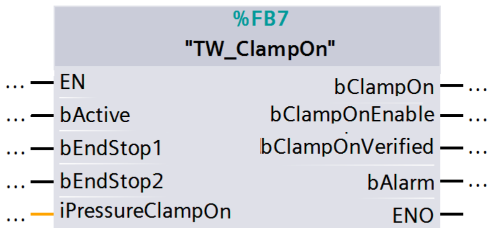


(b) Sub sequence clamp Off

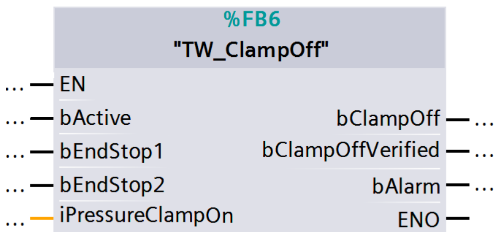
Figure 6.12: Sub sequences for clamp

Both sub sequences use an activation bit (bActive), the clamp endstop signals (bEndStop1 and bEndStop2) and pressure from the clamp on pressure transmitter (iPressureClampOn).
The output of the clamp on only contains outputs for activating valves (bClampOn and bClampeOnEnable). Clamp off sub sequence contains one output for controlling a valve (bClampOff), a verification bit to indicate that the sequence is complete (bVerified) and an output used to trigger an alarm (bAlarm) as the sub sequence contains an integrated check. The alarm output on clamp on block is not in use.
Both sequences contain an internal variable (iStates) to keep track of the active state.

If the activating bit is not true, the internal state of the sequence is reset and all outputs are set as false. If the sequence is activated, it starts to run through the steps as shown in figure 6.12. Checks are called up inside the sub sequences, see section 6.3.5 for further explanation.



(a) Sub sequence Clamp on



(b) Sub sequence Clamp off

Figure 6.13: Sub sequences block in FBD for Clamp on and off sub sequences

6.3.4 Output Controller

The output controllers object is to activate correct valves depending on the operational mode, active sub sequences, output from sub sequences or commands from the HMI.

The controller contains inputs for what operational mode it is in (Mode), a structure containing bits for active sub sequences (sSubSeqActive), structure with outputs set by the sub sequences (sSubSeqOutput) and a structure with functions manually activated from HMI (sManualOutput).

Based on the operational mode and the active sub sequence it uses information either from sSubSeqOutput or sManualOutput to turn on or of the outputs.

The outputs (bMakeUp, bBreakOut, bClampoOff, bClampOn and bClapOnEnable) goes directly to the output channel for the respective valve.

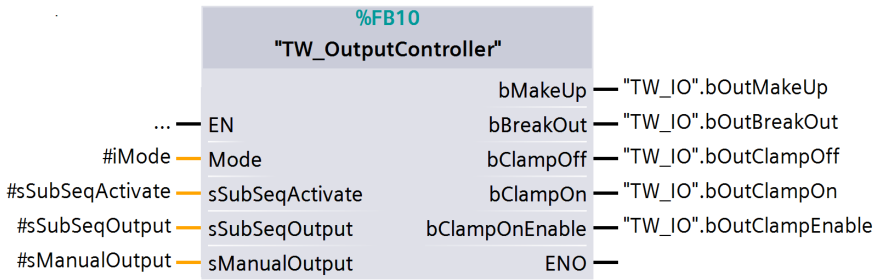


Figure 6.14: Sub sequences for clamp

6.3.5 Checks

To verify sensor input and operational consistency, checks have been incorporated. All checks if possible have been made as separate FC to be able to re-use and to keep the program structure in the main program as simple and clean as possible. The FC checks have no in or outputs but info such as sensor input and outputs (alarm bits) are defined directly in the FC. Each check results in triggering or resetting relevant alarm bits.

Check 1

Check one serves to verify if both Make Up and Break Out endstop sensors are on at the same time, if they are the alarm bit is set, if not it is reset.

```
IF ("TW_IO".bInputBreakOutEnd & "TW_IO".bInputMakeUpEnd) = TRUE THEN
    "TW_Alarms_DB".Alarm3 := TRUE;
ELSE
    "TW_Alarms_DB".Alarm3 := FALSE;
END_IF;
```

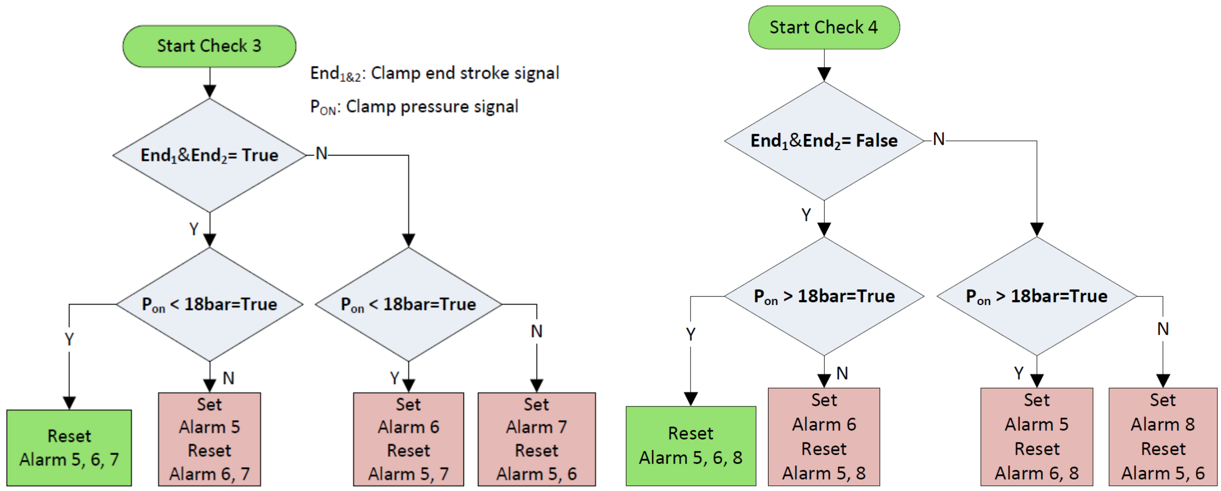
Check 2

Check two looks at the clamp senors to check if they has the same status, if they are the alarm bit is reset, if not it is set.

```
IF "TW_IO".bInputClampOffEnd1 = "TW_IO".bInputClampOffEnd2 THEN
    "TW_Alarms_DB".Alarm4 := FALSE;
ELSE
    "TW_Alarms_DB".Alarm4 := TRUE;
END_IF;
```

Check 3 and 4

Check 3 and 4 are run in the clamp on sub sequence. The objective of the checks is to check the enable valve functionality as well as consistency between the clamp end stroke sensors and clamp on pressure transmitter.



(a) Enable valve closed check (b) Enable valve open check

Figure 6.15: Flow diagram for enable valve checks

Only one outcome is acceptable. The alarms may indicate different situations. Some alarms are a clear indication of component failure, while other alarms may be expected to happen from time to time. In these situations, the function should be reactivated so the check may be performed again. If the alarm is to be triggered too often, a message that further checking is necessary should be incorporated, this has not been done.

6.3.6 Alarms

The system should trigger alarms if unwanted events arise. Some alarms may be of high criticality and may stop the operation while others are more of information to the operator about an abnormal situation.

Following is a list of alarms incorporated into the HMI.

ID	Alarm Text	Description
01	Clamp Off failed	If clamp off sequence is has run too long without a clamp off confirmation signal.
02	Break Out failed	If Break out has been running for too long in auto sequence without getting a break out confirmation signal. This could either be caused by the torque wrench not being able to break out the pipe or due to error with the break out endstop sensor.
03	Sensor discrepancy - Make/Break endstops	Only one of the make up and break out endstop sensor should be active on the same time. Both are active at the same time. This can be due to a loose flag or another object triggering the sensor, fault in the sensor or fault in the communication link.
04	Sensor discrepancy - Clamp 1 and 2 endstops	Both clamp cylinder sensors should be in the same state but are not. As switching distance is short, after a while in standby modus one of the cylinders may have moved enough to lose contact. Small objects behind the clamp jaw could prevent one of the cylinders from retracting all the way.
05	Sensor discrepancy - Clamp endstops and pressure sensor	One or both clamp sensors are active while clamp pressure is $>$ 18bar. Possible causes: - Pressure sensor fault (If enable valve is closed) - Clamp sensor fault (If enable valve is open)
06	Sensor discrepancy - Clamp endstops and pressure sensor	No clamp sensors are active while clamp pressure is $<$ 18bar. Possible causes: - Pressure sensor fault (If enable valve is open) - Clamp sensor fault (If enable valve is closed)
07	Enable valve - Faulty open	Clamp on valve signal high and Clamp enable valve signal low while both clamp proximity sensors and clamp pressure sensor indicates that there is pressure downstream of the enable valve
08	Enable valve - Faulty closed	Clamp on valve signal high and Clamp enable valve signal high while both clamp proximity sensors and clamp pressure sensor indicates that there is no pressure downstream of the enable valve

The alarms listed above has been incorporated as HMI alarms to display them in the test control system. As the discrete alarms in WinCC only are able to use bits in a word as trigger bits and the alarms in the control system are single bits, an "Alarm compiler" FC has been made to move each alarm bit into a word that contains up to 8 alarm bits.

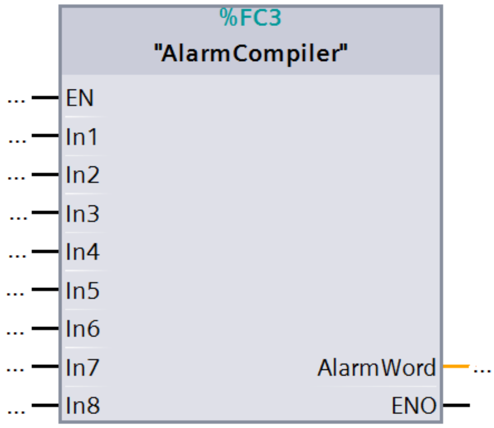


Figure 6.16: Alarm bit to word compiler

An excerpt of the "AlarmCompiler" FC code is shown below. The first input is masked into the first bit of the output word. This is repeated for all 8 inputs and output word bits.

```
IF #In1 THEN
    #AlarmWord := #AlarmWord OR W#2#0000_0001;
ELSE
    #AlarmWord := #AlarmWord AND W#2#1111_1110;
END_IF;
```

For each new input the mask is increased.

6.3.7 HMI

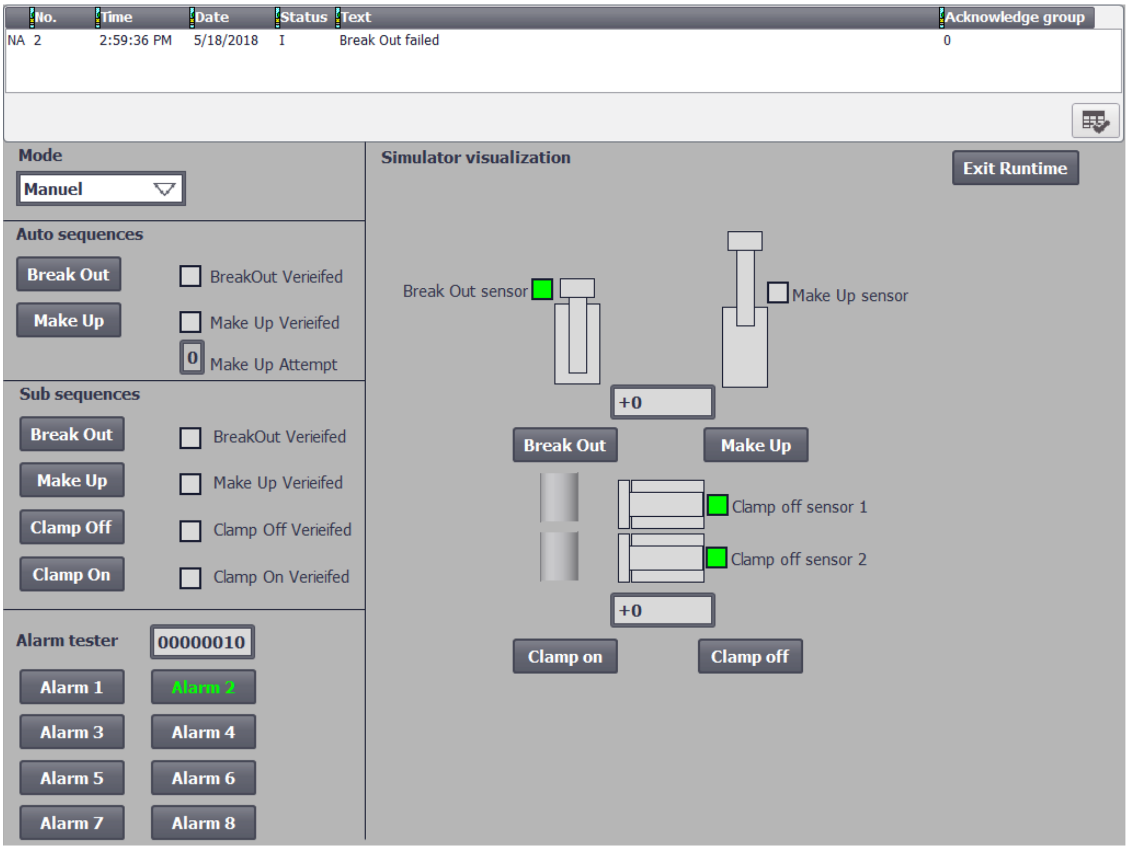


Figure 6.17: HMI used for test and development

There is three different modes to be selected. Manuel, Auto Sequence and Sub sequence. The Manual mode lets the user press the buttons on the TW simulator to manually drive the functions. In Auto sequence the two auto sequences is available, see section 6.3.2. In Sub sequence mode the sub sequences can be activated and run independently, see section 6.3.3.

The alarm buttons and the 8 digit display is used to manually activate alarms is monitor that the alarms in the alarm word is set correctly.

On the right side of the screen the cylinders are used as a graphical illustration of the simulator, and shows the state of the functions. The grey/green boxes are the status of the endstop sensors. Green meaning that the senor is activated.

Chapter 7

Signal Strength Test

A test has been conducted to document the effect of distance and antenna orientation on signal strength. To record the signal strength, the wireless system was set in "Site survey" by using Modbus commands sent from the PLC. The results were then recorded by historical data in WinCC and exported to an excel file for post-processing.

The test was conducted outside MHWirth offices in Kristiansand. The gateway was placed in 3rd floor in the location shown on the map (figure 7.1a). The gateway antenna was oriented in the horizontal plane pointing approximately 120° (Southeast). The sensor node was brought to four different places with different properties, the sensor node was then kept in different orientations to for 2 minutes at the time, obtaining stable measurements for each position/orientation combination.

(a) Test locations (b) Location 2

Figure 7.1: Signal strength test

Following is a table describing the different properties of the four locations shown in figure 7.1a.

Location	Distance	Description
Gateway	-	3rd floor close to window. PLC and power supply in close proximity <30cm and several wifi networks in the area.
1	140m	Between buildings. Almost free line of sight, the corner of office building blocks the signal 5m before the gateway.
2	230m	Free line of sight.
3	280m	Several bushes and some building in between sensor and gateway.
4	110m	A lot of structure and wifi networks between sensor and gateway.

Table 7.1: Test location description

Results

In Site Survey mode the gateway is measuring the received signal strength relative to the ambient noise floor [41]. The received packages are categorized in one of three categorize: Green, Yellow, Red. Where Green is a strong signal and Red is a weak signal. If no signal is received it is logged as a lost package. The results show how many of the last 100 packages that belong in each category.

Results can be seen i figure 7.2 on page 62. The y-axis shows the number of packages in the different categories and is logged with respect to sensor location and antenna orientation on the x-axis. Numbers along the x-axis notes the pointing direction of the antenna in the horizontal plane. The △ means that the antenna is pointing vertically.

Interpretation

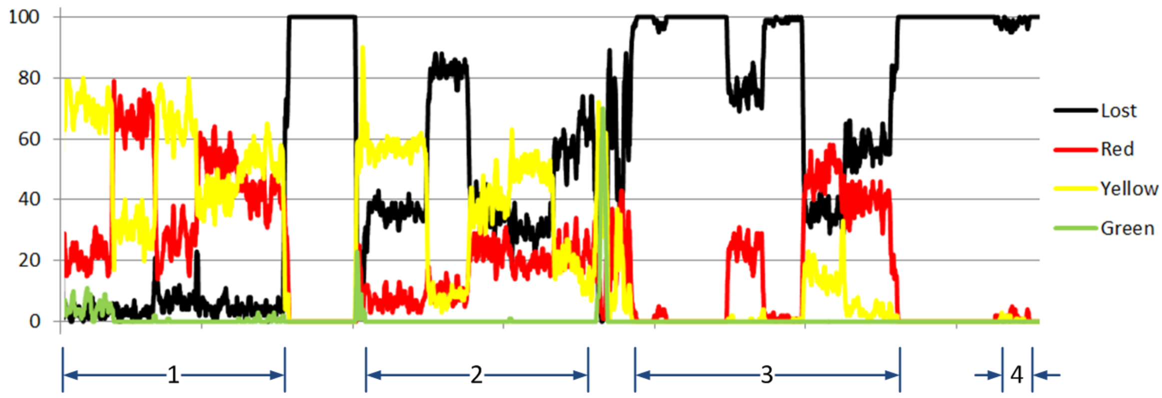
The results that appear in this test are generally showing bad performance. The signal is only strong and reliable enough in location 1 to be used for the applicable application. In the other locations, the signal is too unreliable and would result in high power consumption as the sensor node needs to repeat messages as well as a slow response time. A simpler site survey was done in 2017 with the same system, however, the sensor node only had a small internal antenna. This test was done in the test tower shown in figure 7.1b. The distance was approximately 50m and the gateway was kept away from noise sources. In this test, the results appeared to be good, green and yellow above 50% for all places that were tested, even without free line of sight.

The current test is not a good representation of how the final environment will be. A similar test to the one presented in the report should be repeated, only this time with the test location in the test tower. Following is a list of potential sources to the bad signal strength found in this test:

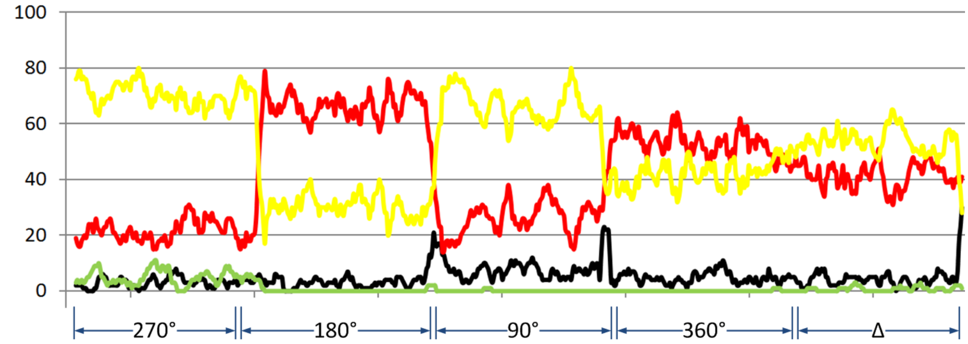
- A high noise floor at the gateway. Power source placed extremely close and a lot of wifi networks in close proximity
- All antenna placements are very close the ground and objects are always within the Fresnel zone[1] of the radio signal
- Gateway mounted inside behind a window

It should be pointed out the significance a low antenna placement (Freznel xone) can have on signal strength. This can be observed at the end of graph 7.2c. The results are unacceptable all the time until the sensor is picked up for moving to next location, the signal strength then raises 100% within green and yellow category by only moving the sensor a half meter above the ground.

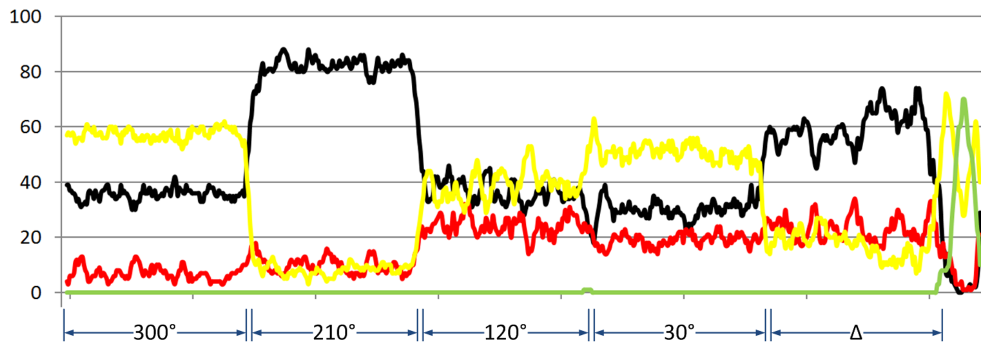
[1]Freznel zone is the area which may influence a transmitted signal an cause multi-path fade. The area is shaped as a lobe between transmitting and receiving point



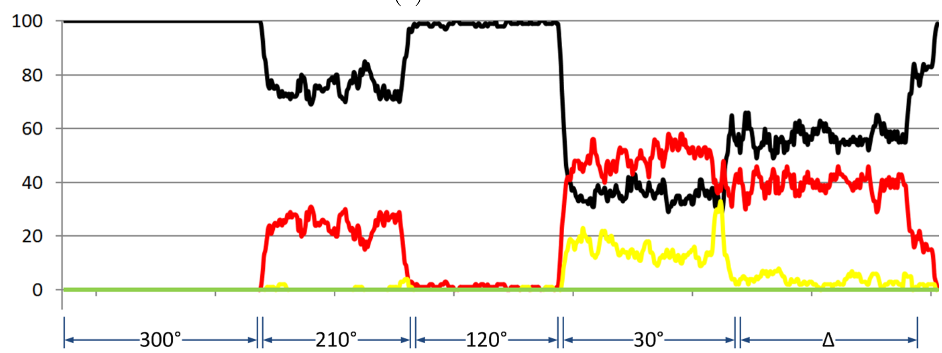
(a) Complete signal strength test log



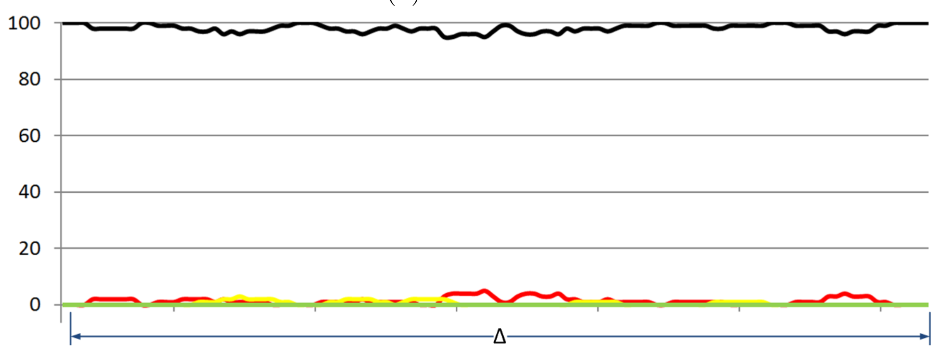
(b) Location 1



(c) Location 2



(d) Location 3



(e) Location 4

Figure 7.2: Signal strength test result

Chapter 8

Results

In the following sections the main findings throughout the project are summarized and are reflecting the main objectives of section 1.2 (Objective).

Technology

The wireless technology itself is mature enough to incorporate into drilling equipment communication networks, however when introducing criteria such as harsh environment, explosive atmosphere, safety systems, communication speed $\geq$300ms and battery powered, the available product becomes few. Of the three evaluated systems, only two were found suitable with respect to the given performance data. Out of this two, Banner was seen as the most versatile solution and were therefore used in the further development.

Concept

The final concept uses only inductive sensors as sensing devices. Avoiding mechanical moving switches and sensors decrease the possibility of errors due to contamination and stuck objects. The sensing is done on the cylinders which should give good and repeatable measurements. Making precise measurement will increase the stroke length of the cylinders and in return make the machine more efficient. With the selected sensor nodes from Banner, it is possible to move the transmitter away from the sensing location, making the sensor placement flexible as well as increasing possibility for antenna orientation.

Implementation

The physical implementation does not require any large mechanical changes. The clamp cylinders need a new end cover, the rest of the design may be kept as it is. This makes the concept easy to implement on old TW as an update.

The software implementation is shown by producing new sequences for the TW that acts on the new sensor information, the auto sequences can now run without timers and sequence times can be reduced.
Acquisition of new sensor information is obtained by Modbus TCP communication between PLC (S-1500) and the Banner wireless system. As well as collecting sensor information, it is shown that the PLC can change parameters of the Banner system, this makes it possible to change the sample and report rate depending on the current operation, saving power when high communication speed is not needed.

Testing

The signals strength test that was done in this project did not show good results. However, the tests indicate that this is mainly because of a bad (low) sensor placement as well as a noisy EM environment.

Consequences

It is found that by introducing endstop sensors for the TW cylinders the hydraulic design found on the TW can be reduced significantly. In addition to this, two wired pressure transmitters placed on the TD may also be removed, resulting in fewer sources of errors on the TW and less cabling in total on the TD.

The cost consequences depend on what system that is analyzed. The TW as a separate module becomes more expensive, however, the cost of the total system is hard to anticipate. With a conservative view, the final cost of the new sensors would only be marginally more expensive and it may very well be that the total manufacturing, installation, and maintenance cost in total would be lower.

The operational sequences should be more efficient with the new sensors and faster auto sequences can be anticipated, however, this requires a stable and fast wireless system, something that still requires some testing.

Chapter 9

Conclusion

The results show that the selected wireless system may be used for the TW application. While being the most versatile and fastest wireless sensor solutions, the Banner system still does not meet specifications for several other applications where the needed update rate may be higher or the sensor is using to much power.

When finalized, the wireless TW may benefit from reduced sequences times, added safety as the clamp position can be directly read of and decreased system complexity. However further work remains before this can be realized:

- Further test signal strength in a more realistic environment.
- Mount sensors and sensor nodes on TW, test to verify proper behavior.
- Integrate host system communication into TW control system. Change sample and report rate depending on the operational mode. Integrate alarms and safety functions with regards to communication with the host system.
- Replace the DXM100 gateway with a DX80 gateway for the possibility to operate in zone 2. This will require communicating over Modbus RTU instead of TCP.
- Battery lifetime estimation based on power consumption test and the calculated anticipated TW usage.

When the mentioned items are completed, the system may be tested in its real operational environment.

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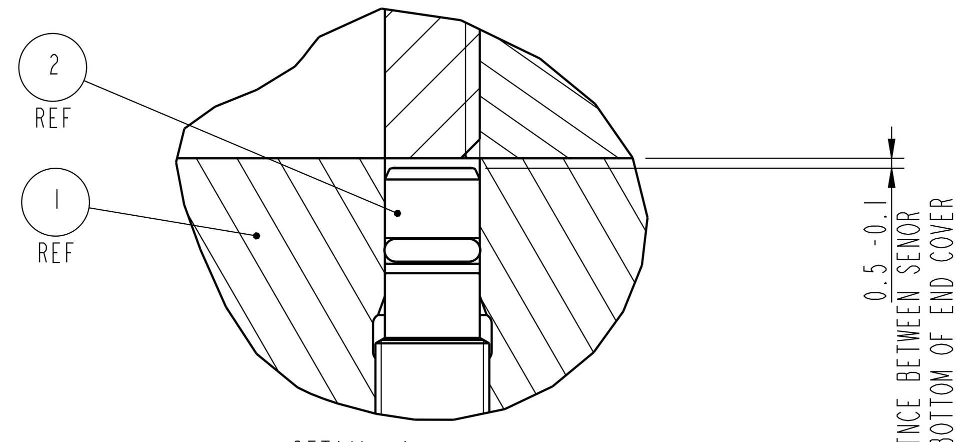
Appendix A

Drawings

Attached drawings:

Drawing No.	Description
192553_00	Wireless Torque Wrench
192553_01	Bracket
192553_04	Retainer
192553_06	End Cover
192553_07	Prox Bracket
192553_08	Flag



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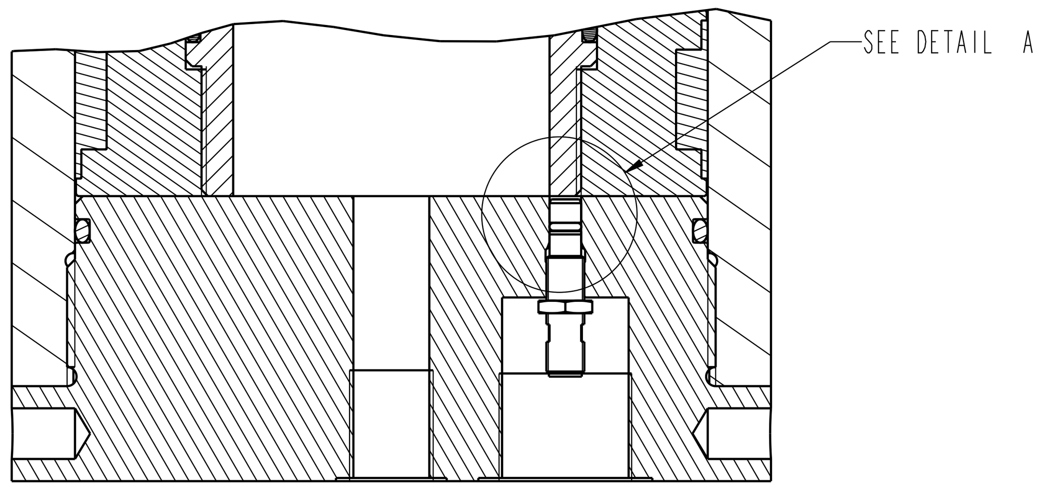

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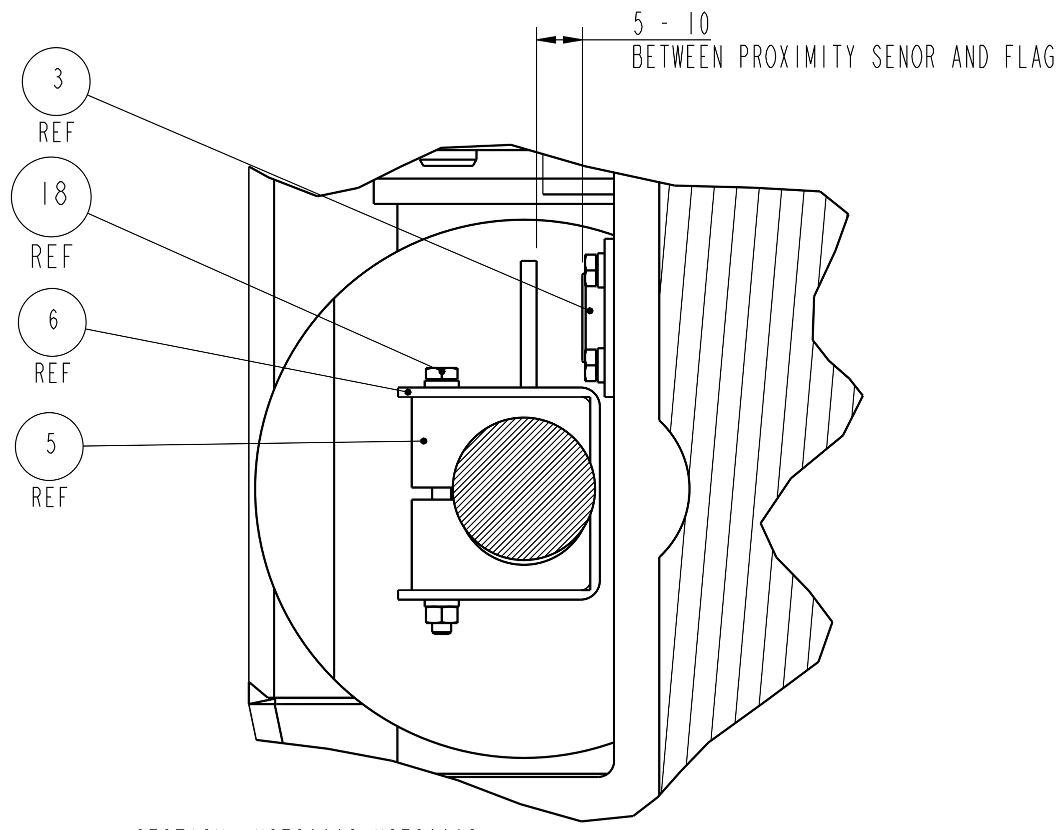

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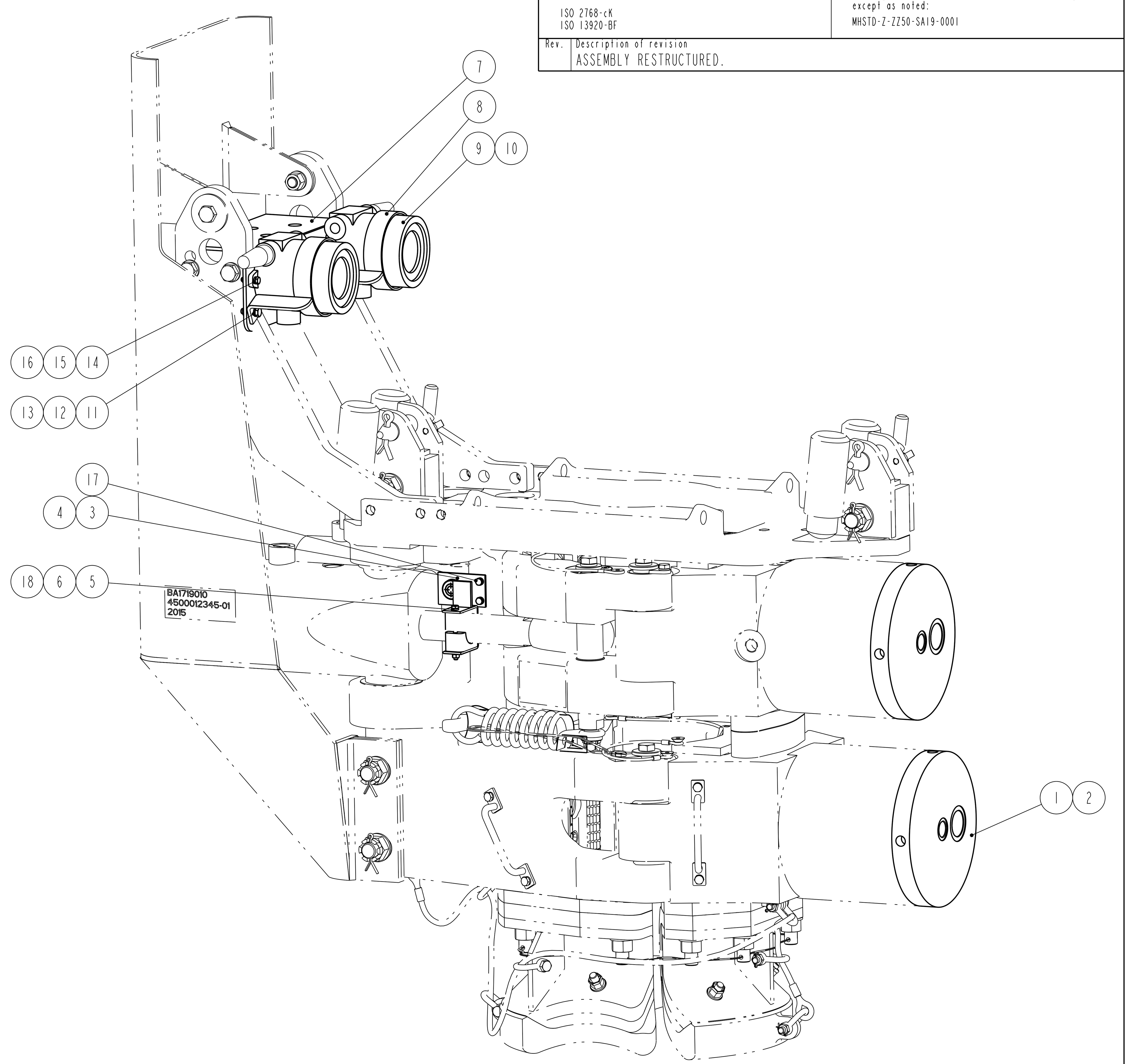

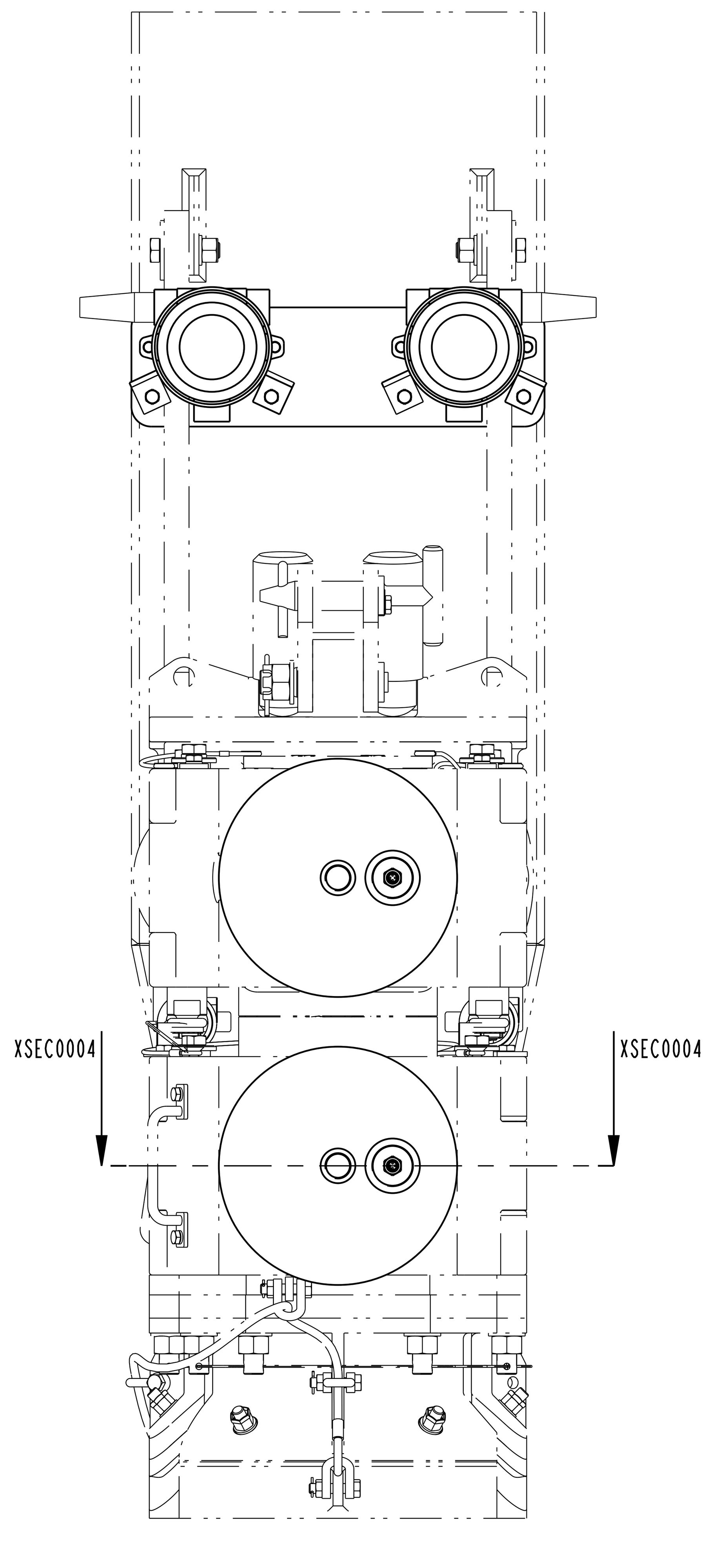

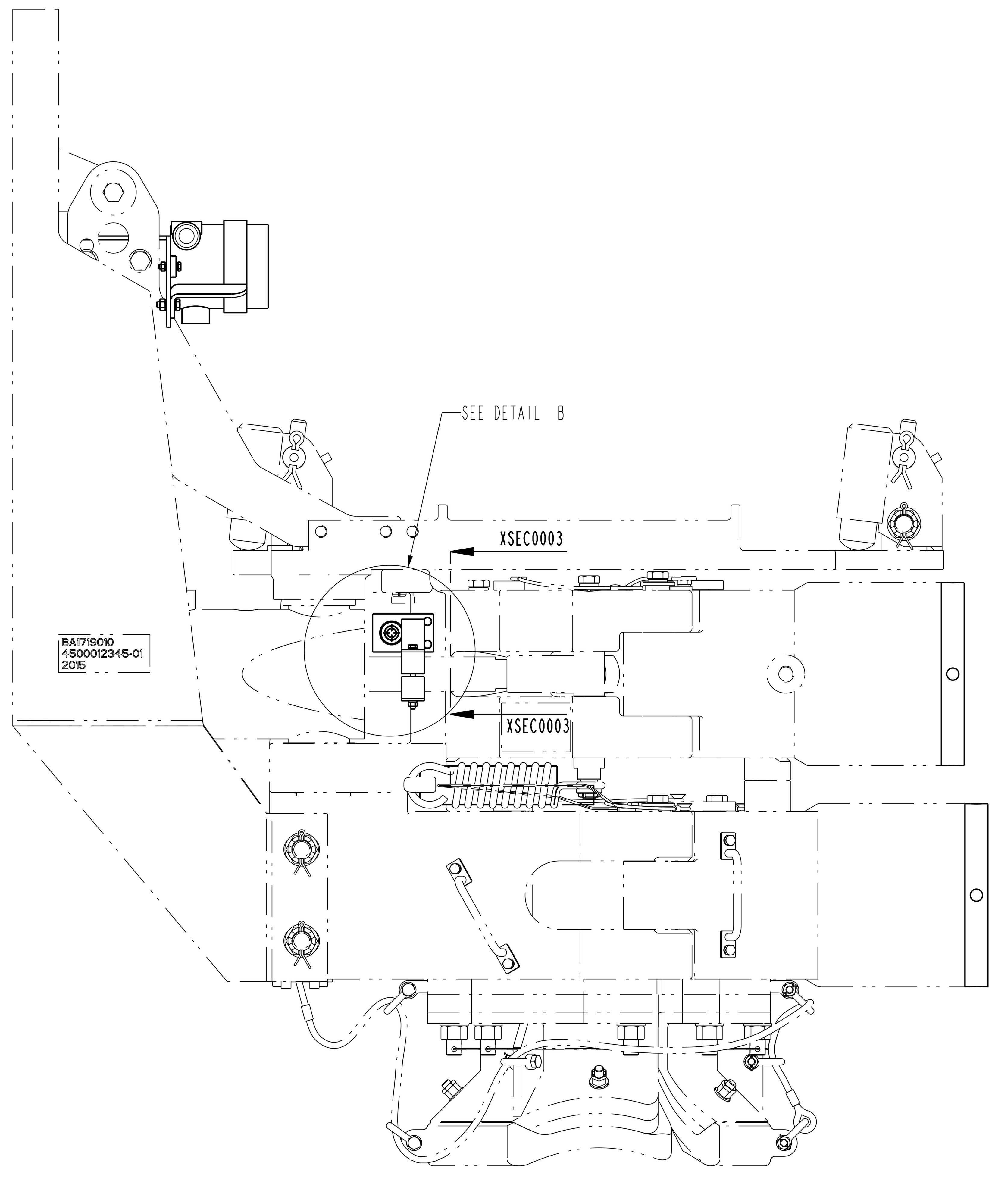

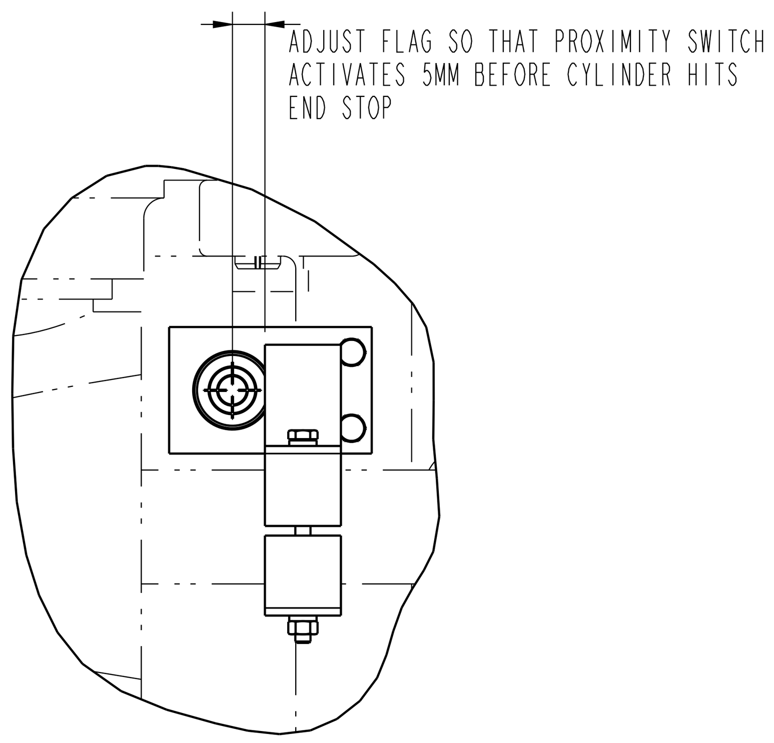

DETAIL B
SCALE 1:2.5

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Tolerances except as noted:	Welding, Materials and Non-destructive testing except as noted:
ISO 2768-cK ISO 13920-BF	MHSTD-Z-ZZ50-SA19-0001

Rev.	Description of revision
	ASSEMBLY RESTRUCTURED.

Qty.	Item	Description	Specification	Unit weight[kg]	Part No. Drwg No.
2	18	HEX HEAD SCREW	M06x80, ISO 4017, A4-80	0.0	38765
4	17	HEX HEAD SCREW	M06x12, ISO 4017, A4-80	0.0	38748
4	16	HEX HEAD SCREW	M06x25, ISO 4017, A4-80	0.0	38754
6	15	HEX NUT	M06, ISO 4032, A4-80	0.0	39326
16	14	NORDLOCK WASHER	NL06 SS-254SMO	0.0	19495
4	13	HEX HEAD SCREW	M08x25, ISO 4017, A4-80	0.0	38780
4	12	HEX NUT	M08, ISO 4032, A4-80	0.0	39328
8	11	NORDLOCK WASHER	NL08 SS-254SMO	0.0	19014
2	10	ANTENNA	BANNER DOME ANTENNA	0.0	////
2	9	SENSOR NODE	BANNER DX99	1.8	////
2	8	RETAINER	STEEL ASSEMBLY	0.5	192553_04
1	7	BRACKET	STEEL ASSEMBLY	4.5	192553_01
2	6	FLAG	STEEL ASSEMBLY	0.2	192553_08
2	5	PIPE CLAMP	RAVG 542	0.1	57123
2	4	PROX BRACKET	3x50x80, 1-4401	0.1	192553_07
2	3	PROXIMITY SENSOR	NJ15-30GK-N-10M	0.2	////
2	2	PROXIMITY SENSOR	BES 516-300-S315-S4-N	0.0	////
2	1	END COVER	ø240 L=90, S355J2, 192553_06	24.5	192553_06

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WIRELESS TORQUE WRENCH ASSEMBLY

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Scale	1:5
Projection	
Specification	ASSEMBLY
Total weight[kg]	56.3
Part No. Drwg No.	192553_00
Rev.	
Sheet	1 of 1

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N.D.E NOTE

THE CATEGORY OF WELDING ON THIS DRAWING IS **SECONDARY** UNLESS NOTED OTHERWISE, e.g.

S DENOTES SECONDARY
P DENOTES PRIMARY
E DENOTES SPECIAL

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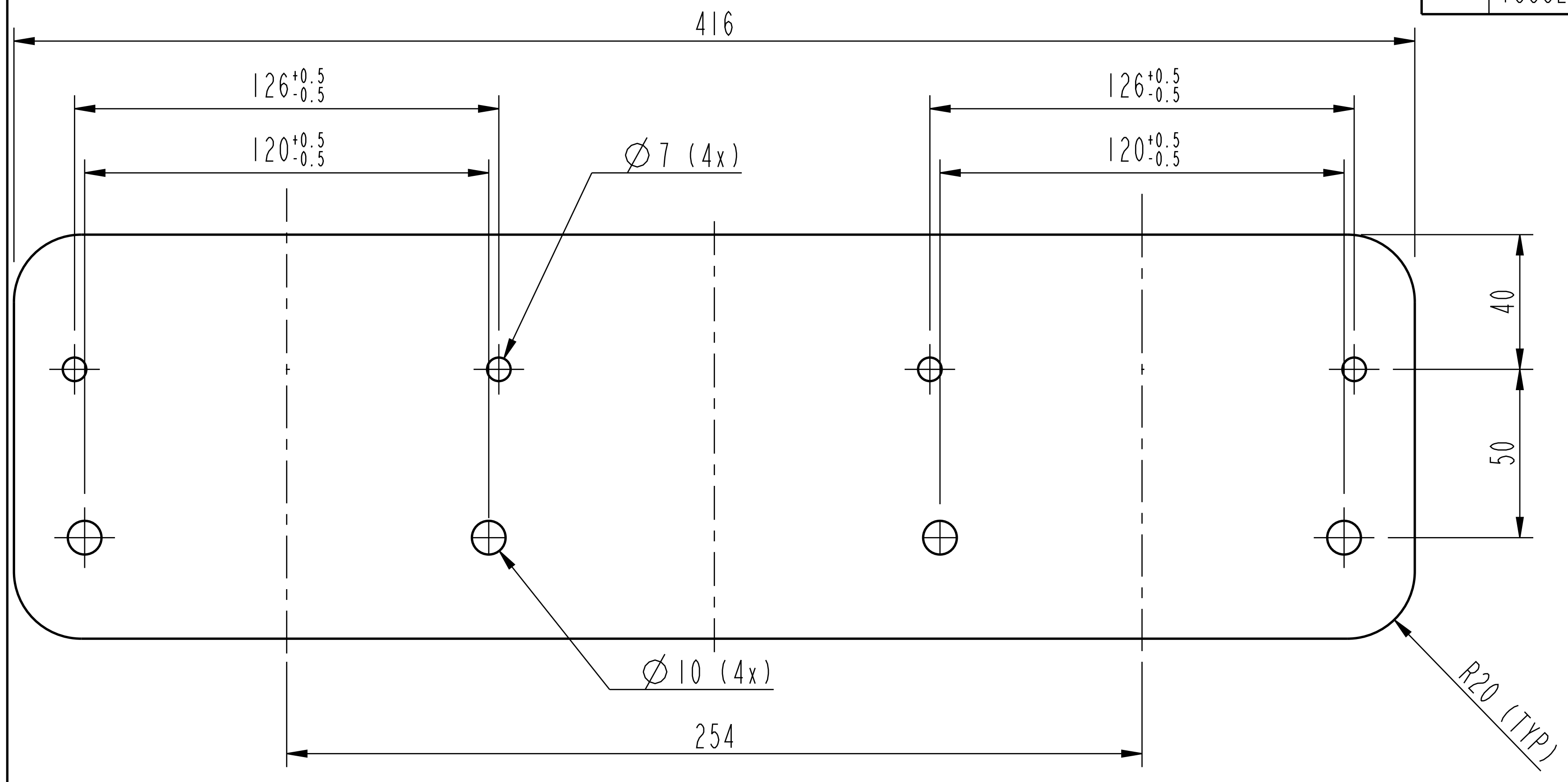
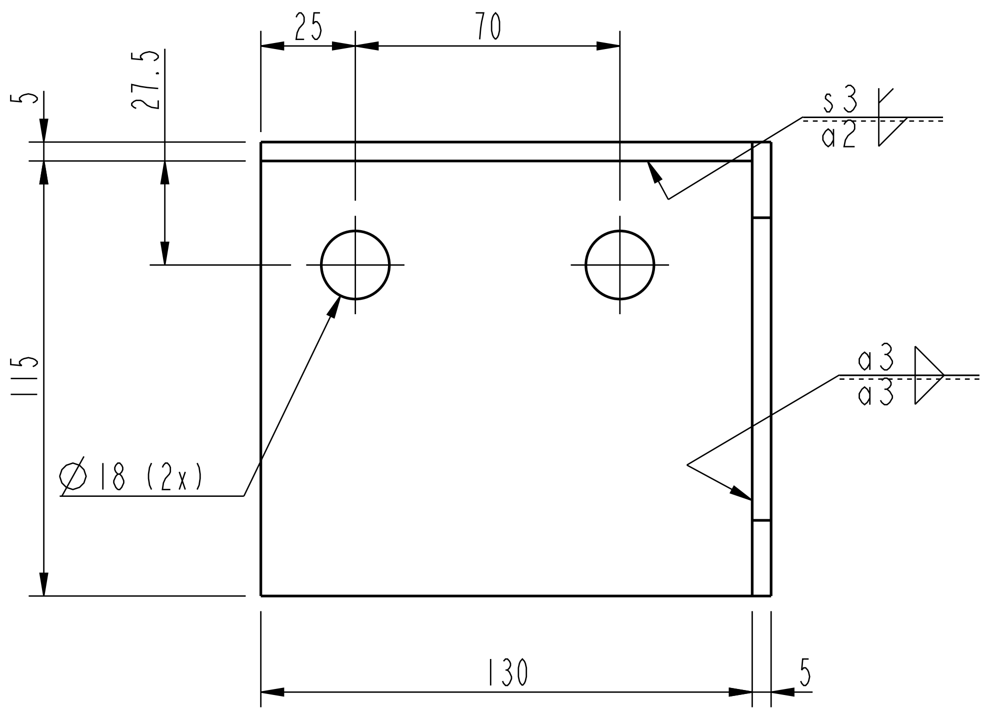
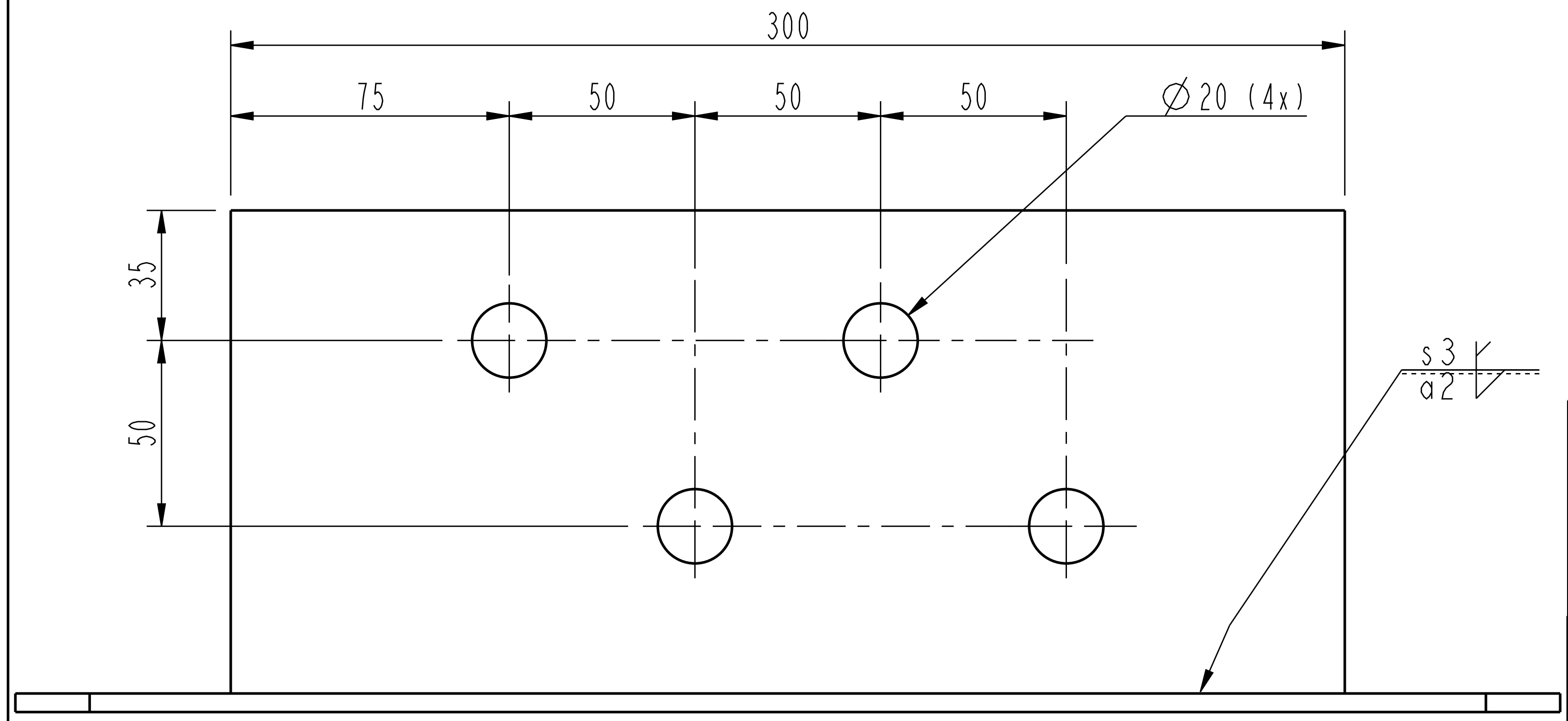
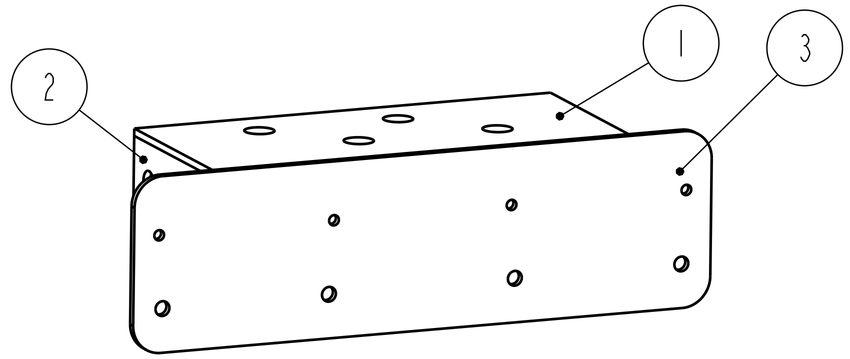
Rev.	Description of revision
	ISSUED FOR CONSTRUCTION









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2	2	PLATE	5x115x130, S235JR	0.6	
1	1	PLATE	5x130x300, S235JR	1.5	

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BRACKET
STEEL ASSEMBLY

Specification: STEEL ASSEMBLY

Format: A3 | Scale: 1:2

Projection

Total weight[kg]: 4.5

mhwirth

Part No. Drwg No.: 192553_01 | Rev.: | Sheet: 1 of 1

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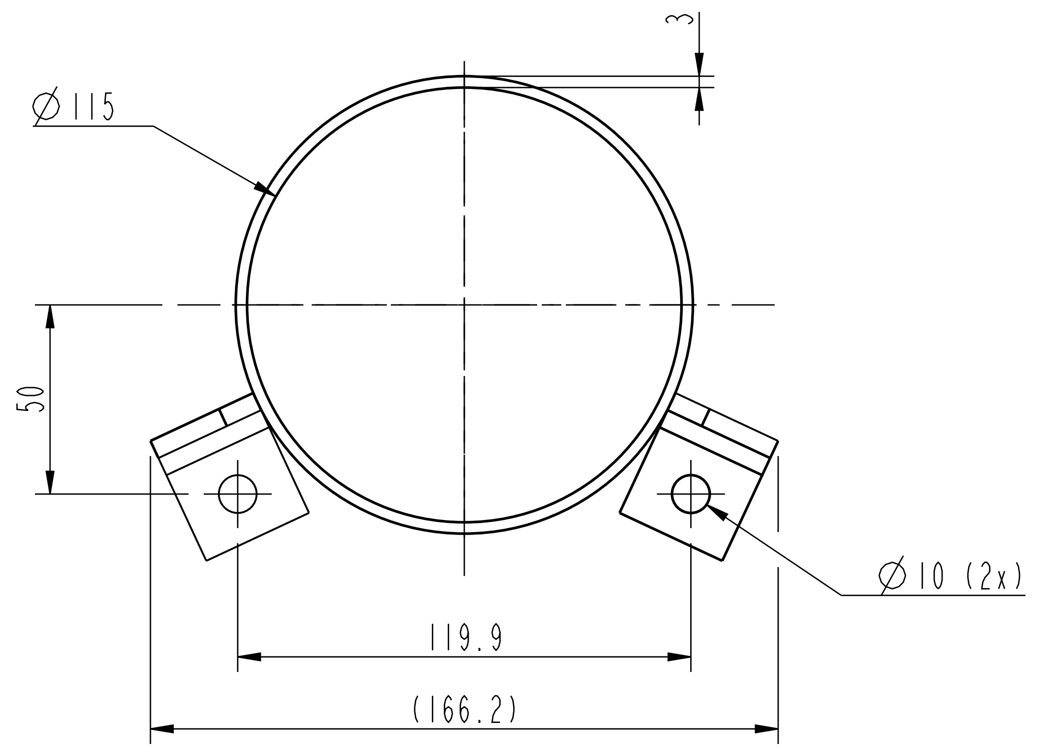
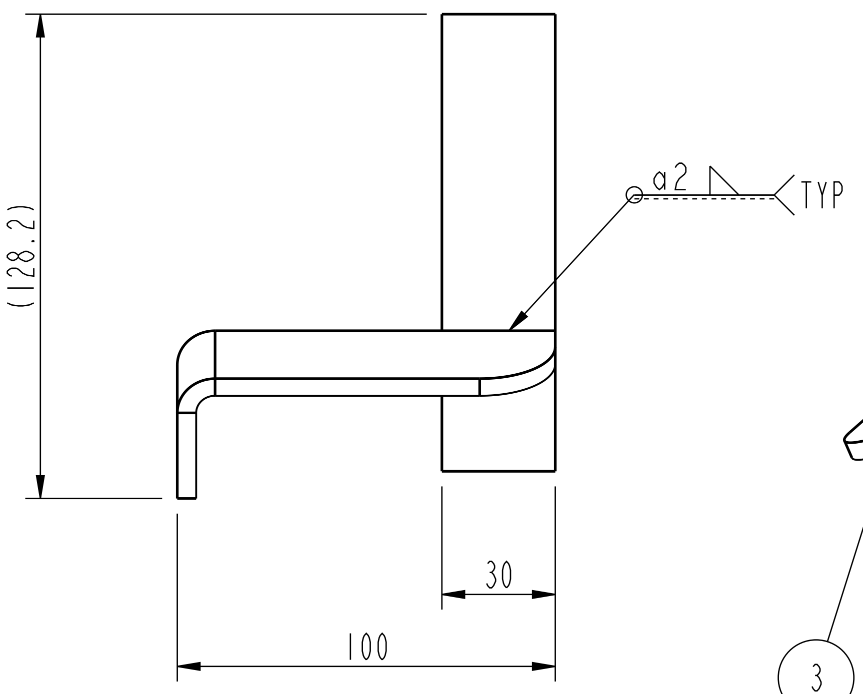
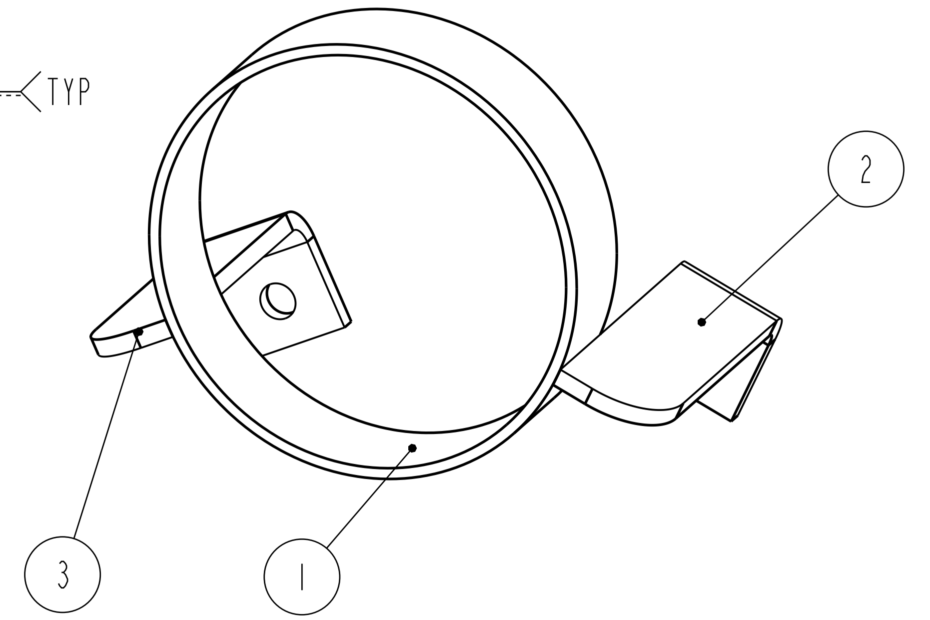
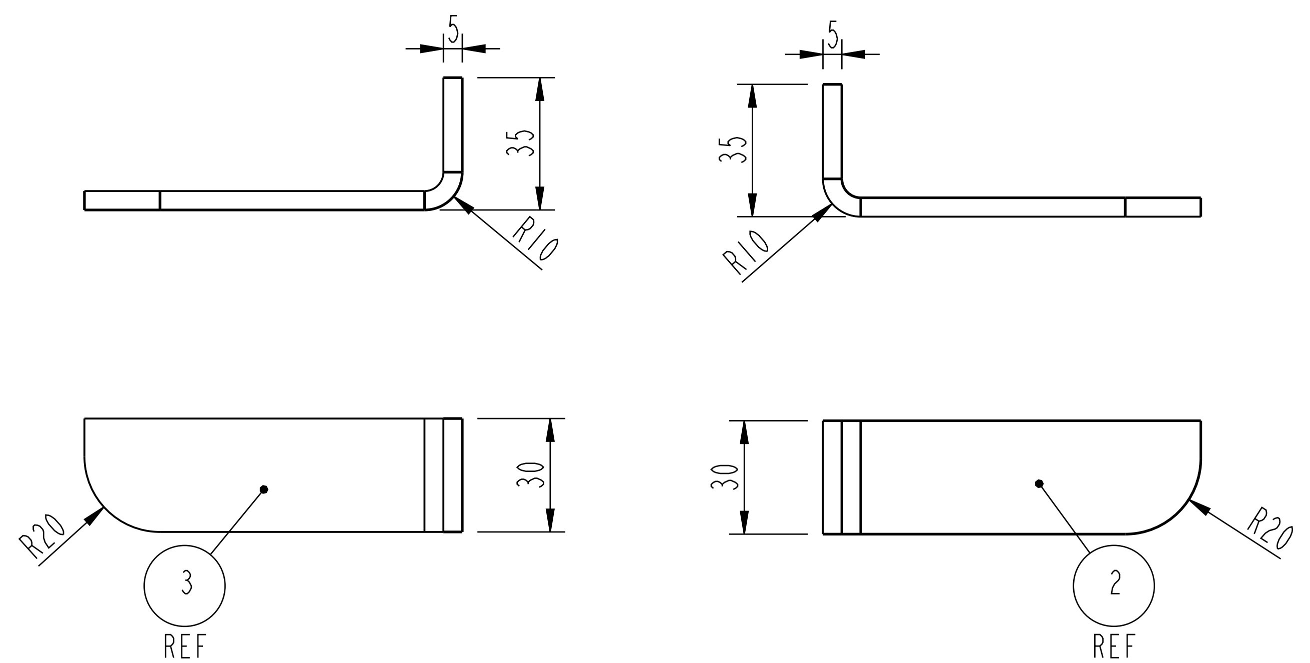
Rev.	Description of revision
	ISSUED FOR CONSTRUCTION









Qty.	Item	Description	Specification	Unit weight[kg]	Part No. Drwg No.
1	3	PLATE	5x30x125.4, S235JR	0.1	
1	2	PLATE	5x30x125.4, S235JR	0.1	
1	1	HOLLOW PIPE	ø121/115 L=30, S355J2G3	0.3	

--

RETAINER
STEEL ASSEMBLY

Format: A3
Scale: 1:2
Projection

mhwirth

Specification: STEEL ASSEMBLY

Total weight[kg]: 0.5

Part No. Drwg No.: 192553_04
Rev.:
Sheet: 1 of 1

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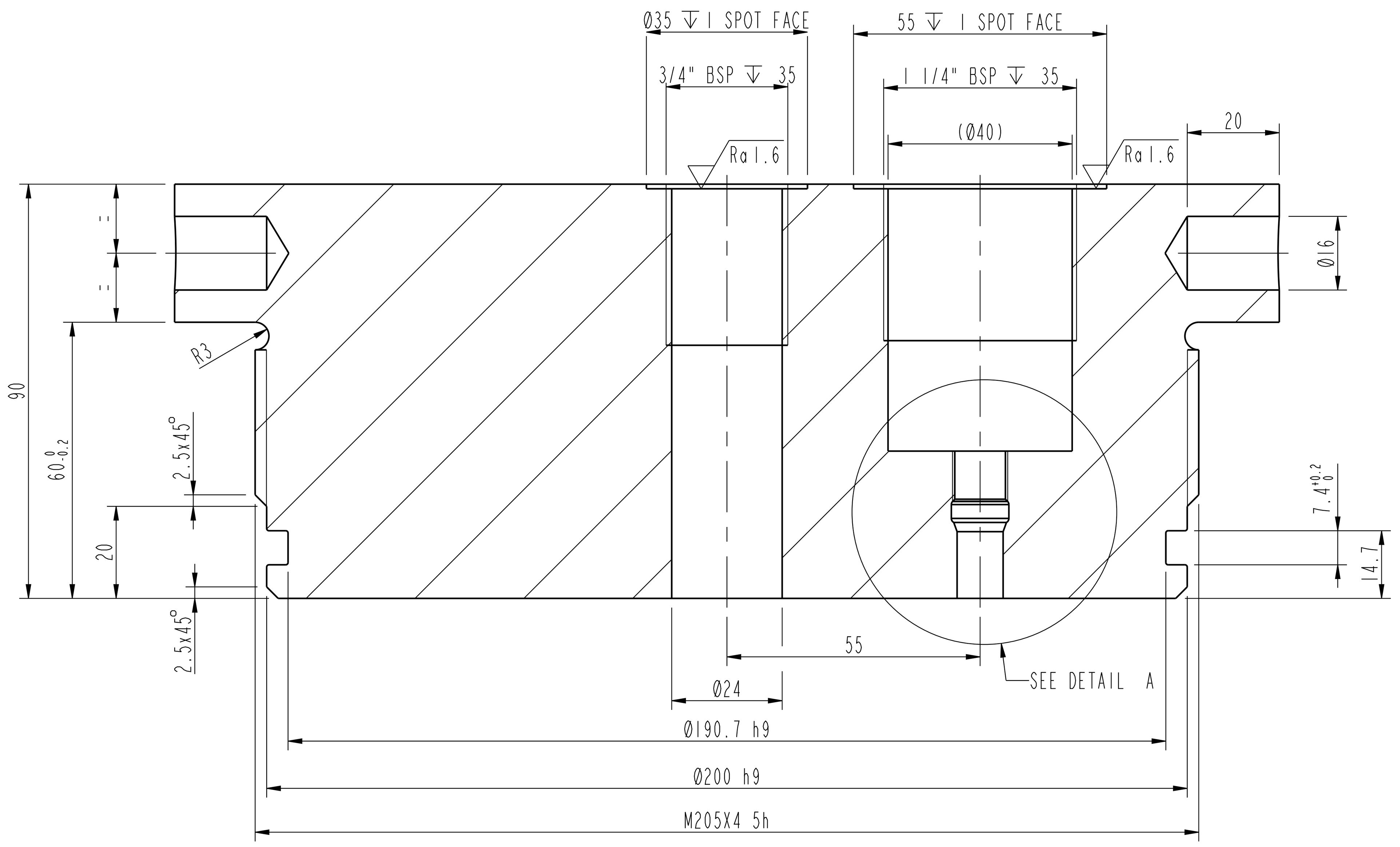
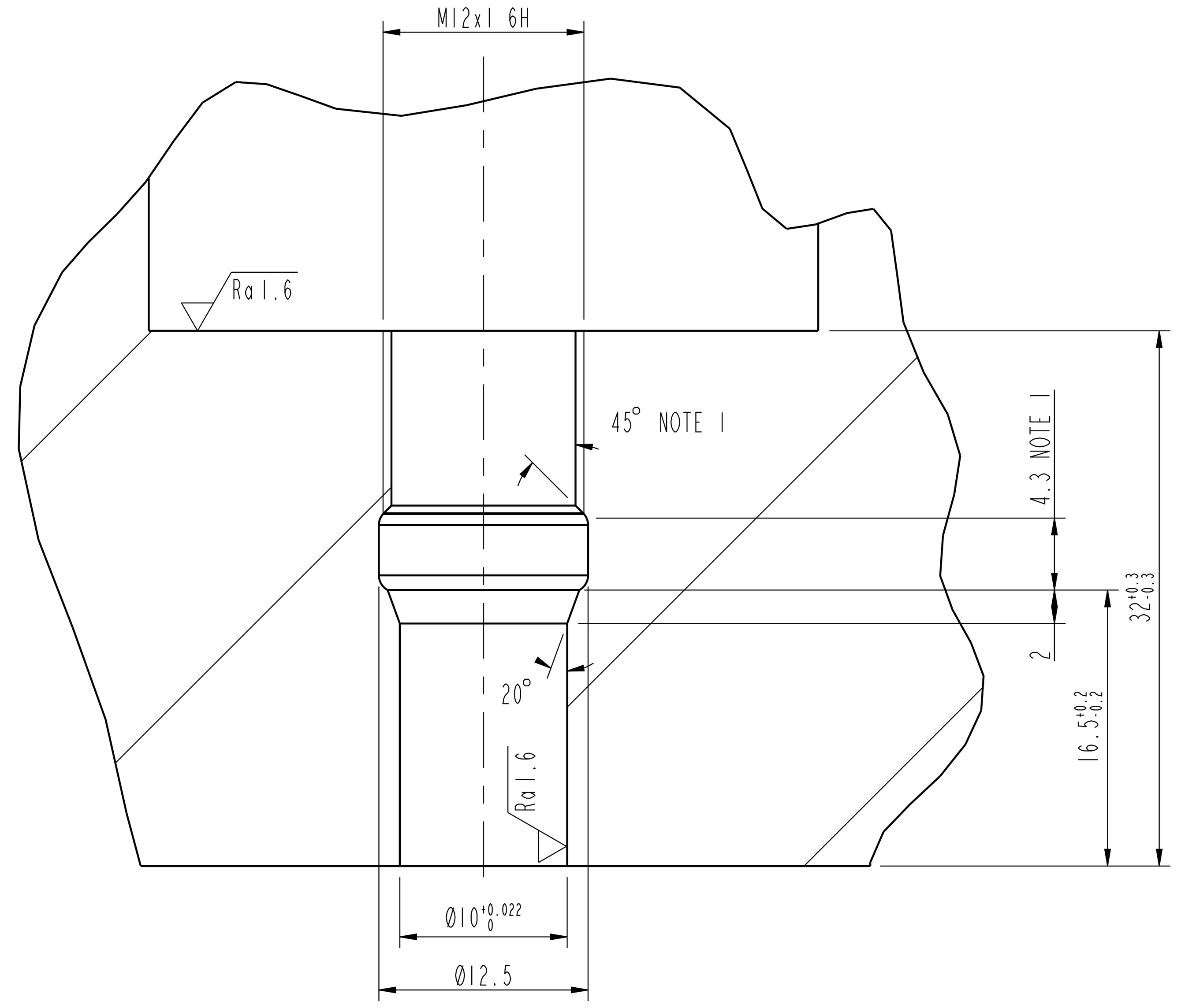
Tolerances except as noted:	Welding, Materials and Non-destructive testing except as noted:
ISO 2768-cK ISO 13920-BF	MHSTD-Z-ZZ50-SA19-0001

Rev.	Description of revision
	ISSUED FOR CONSTRUCTION

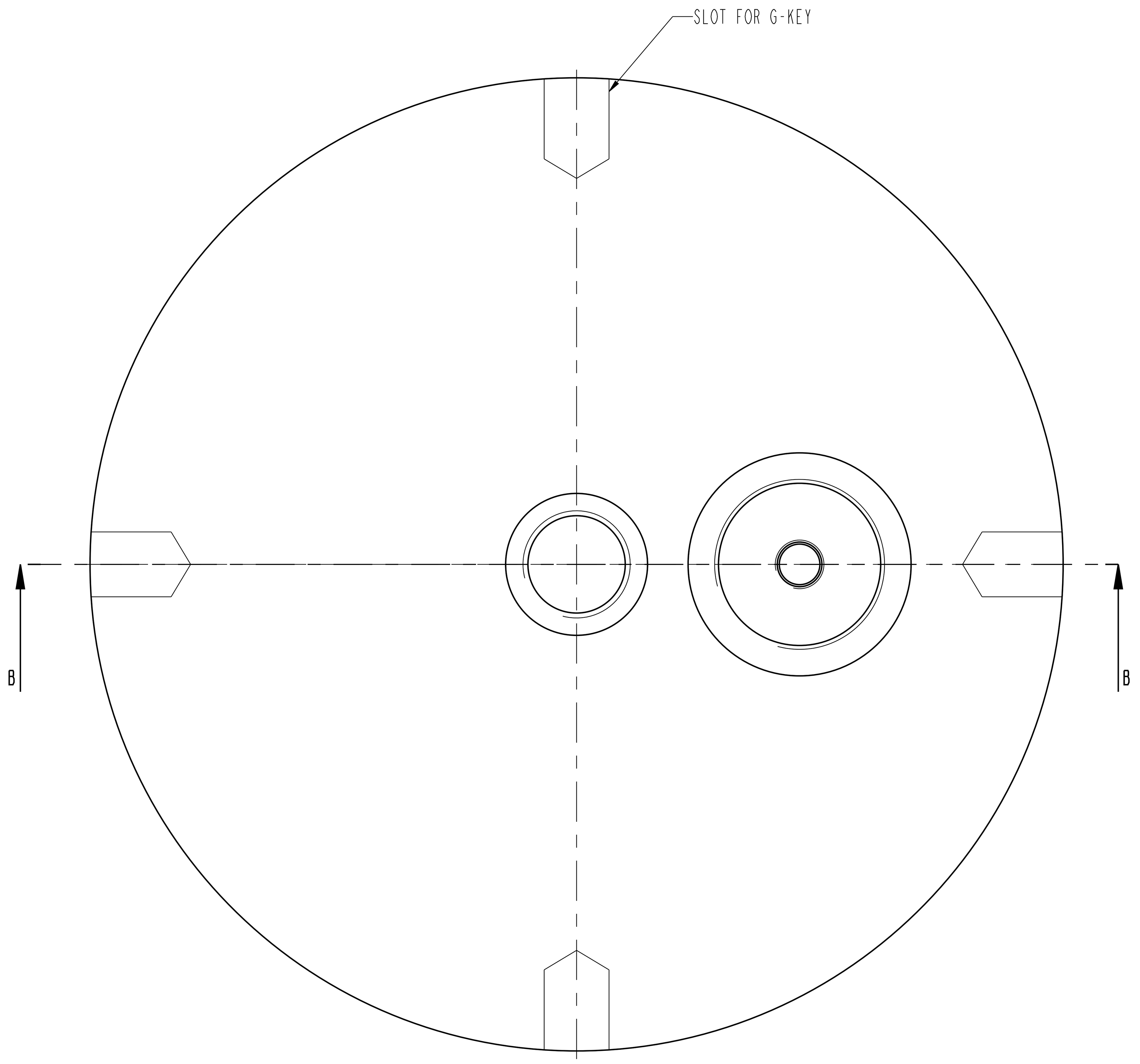


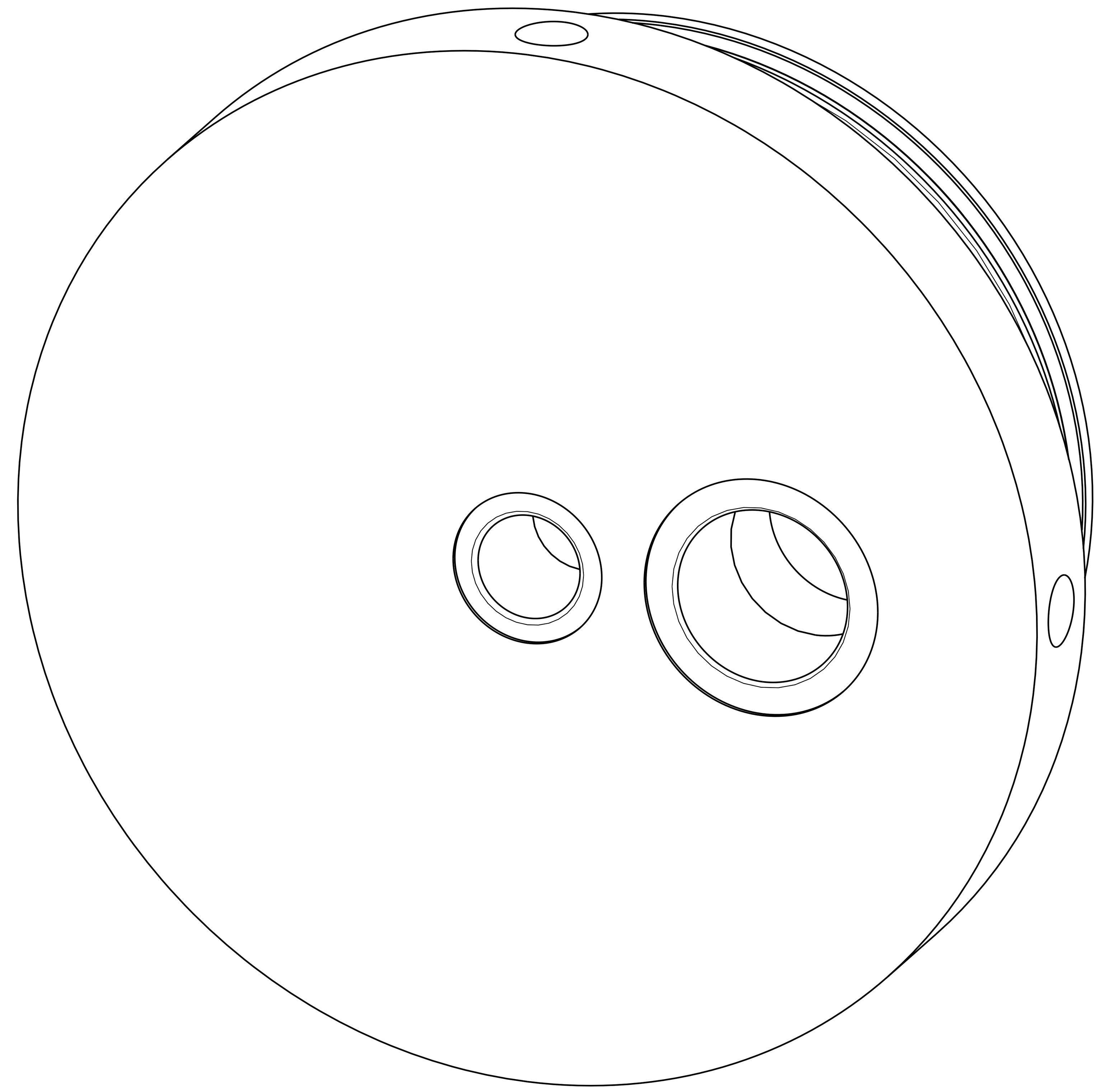
SECTION B-B



DETAIL A
SCALE 3:1

NOTE:
1. THREAD UNDERCUT ACCORDING TO DIN 76-1 D





---	Format	Scale	mhwirth		
END COVER DETAIL	A1	1:1	Part No. Drwg No.	Rev.	Sheet
Specification: ø240 L=90, S355J2	Total weight[kg]: 24.5	Projection	192553_06		1 of 1

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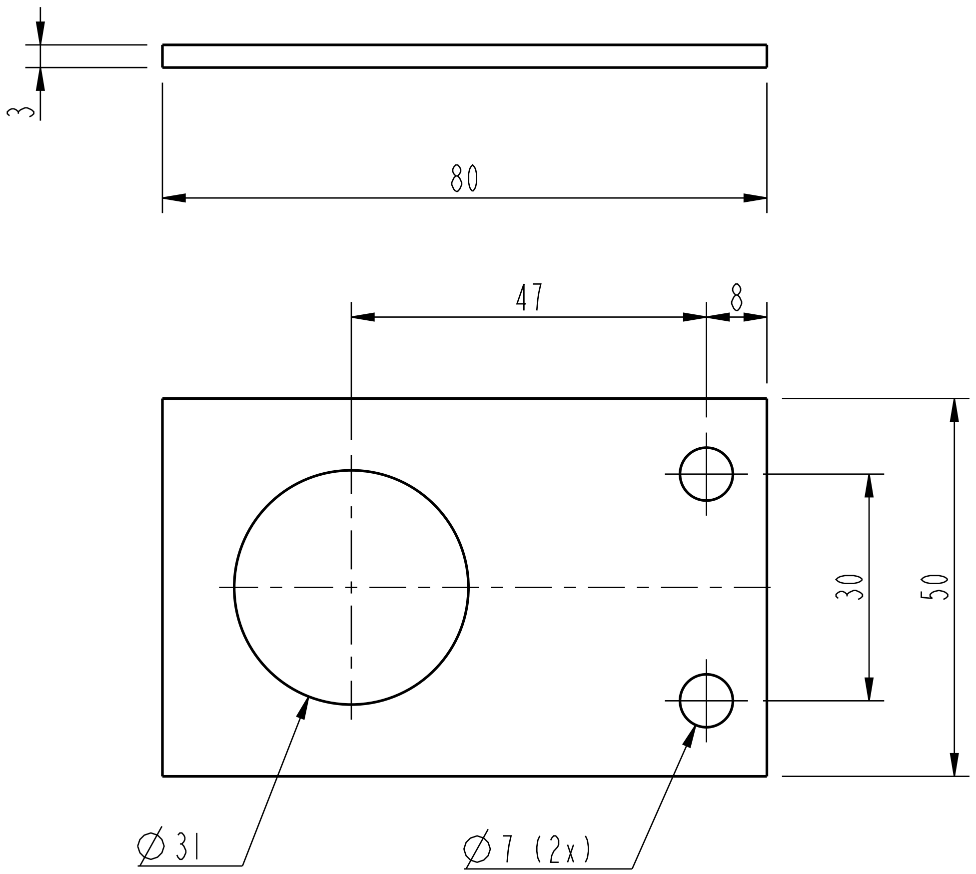
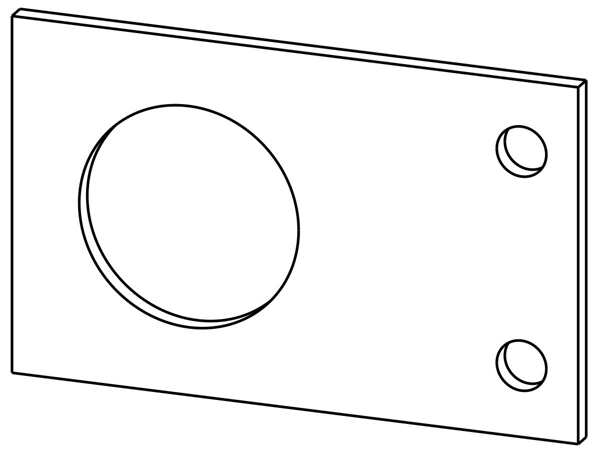
ISO 2768-cK
ISO 13920-BF

Welding, Materials and Non-destructive testing except as noted:
MHSTD-Z-ZZ50-SA19-0001

Rev.	Description of revision
	ISSUED FOR CONSTRUCTION





--
PROX BRACKET
DETAIL

Specification
3x50x80, 1-4401

Format	Scale
A3	1:1

Projection

Total weight[kg] 0.1

mhwirth

Part No. Drwg No.	Rev.	Sheet
192553_07		1 of 1

N.D.E NOTE

THE CATEGORY OF WELDING ON THIS DRAWING IS **SECONDARY***** UNLESS NOTED OTHERWISE, e.g.

S DENOTES SECONDARY
P DENOTES PRIMARY
E DENOTES SPECIAL

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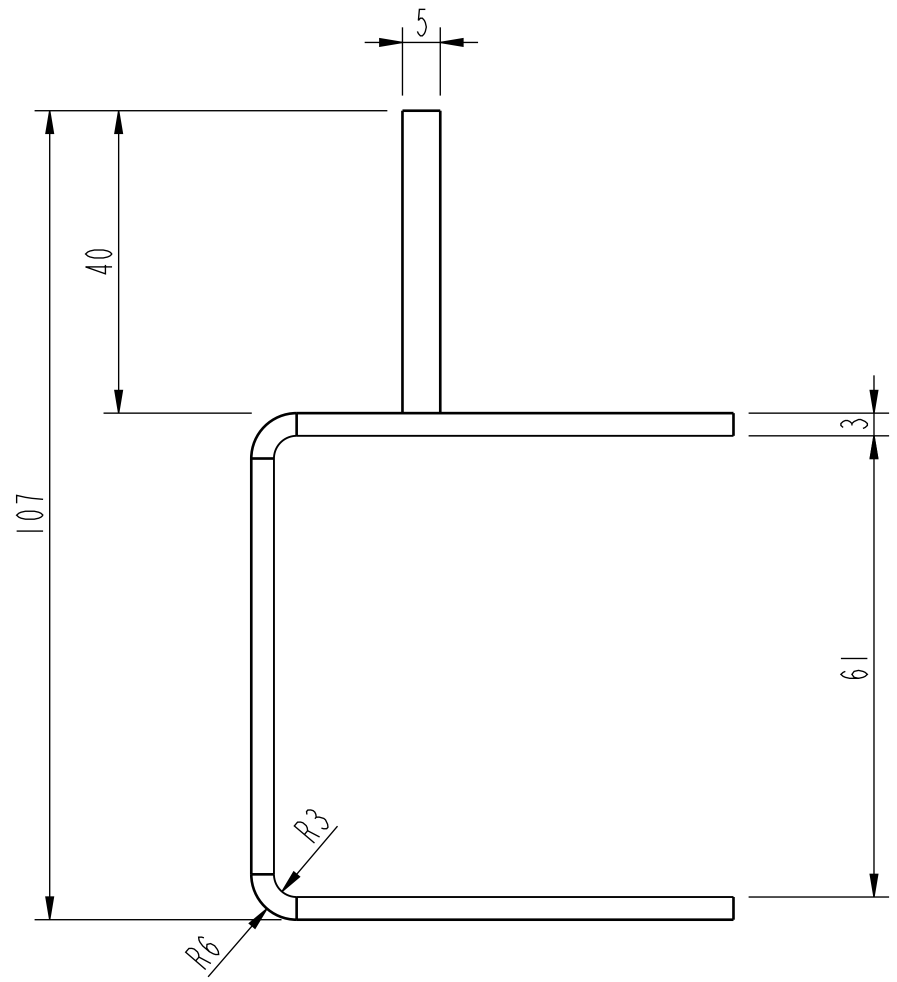
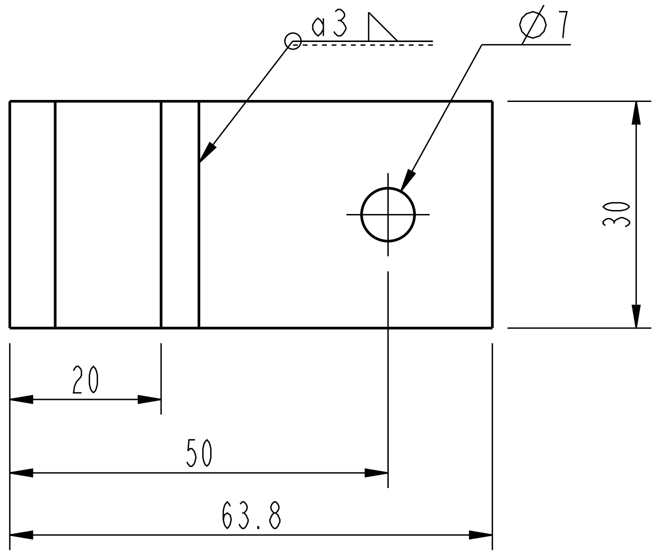
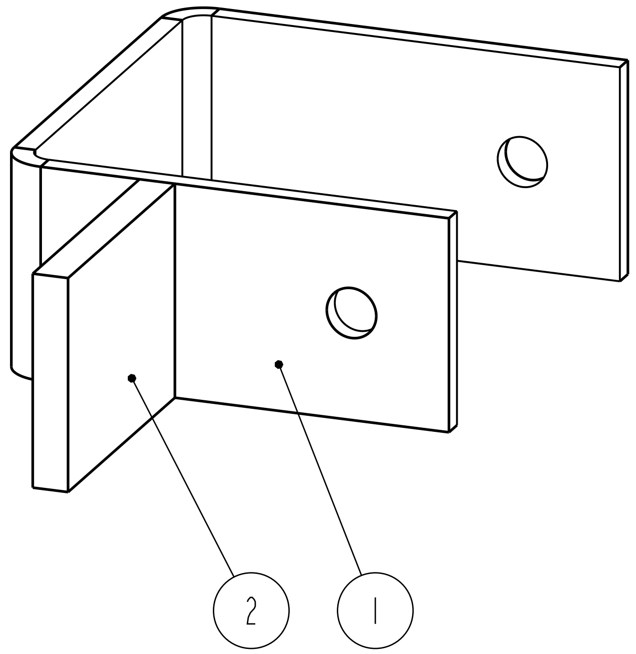
Tolerances except as noted:	Welding, Materials and Non-destructive testing except as noted:
ISO 2768-cK ISO 13920-BF	MHSTD-Z-ZZ50-SA19-0001

Rev.	Description of revision
	ISSUED FOR CONSTRUCTION







Qty.	Item	Description	Specification	Unit weight[kg]	Part No. Drwg No.
1	2	PLATE	5x30x40, S235JR	0.0	
1	1	PLATE	3x30x183, S235JR	0.1	

--

FLAG
STEEL ASSEMBLY

Format	Scale	Projection	Total weight[kg]	Part No. Drwg No.	Rev.	Sheet
A3	1:1		0.2	192553_08		1 of 1

Specification

mhwirth

Appendix B

Data Sheets

Data sheet included for the following components:

Component type	Model
Sensor node	Banner DX99
Gateway	Banner DXM100
Proximity sensor	BES 516-300-S315-S4-N
Proximity sensor	NJ15-30GK-N-10M

Sure Cross® DX99 FlexPower Node (Metal Housing)

Datasheet

The Sure Cross® wireless system is a radio frequency network with integrated I/O that can operate in most environments and eliminate the need for wiring runs. DX99 wireless networks are formed around a Gateway, which acts as the wireless network master device, and one or more Intrinsically Safe Nodes.

- Wireless industrial I/O device with two selectable discrete inputs and two analog inputs
- *Flex*Power® technology driven by one lithium primary battery integrated into the housing
- DIP switches for user configuration
- Frequency Hopping Spread Spectrum (FHSS) technology and Time Division Multiple Access (TDMA) control architecture ensure reliable data delivery within the unlicensed Industrial, Scientific, and Medical (ISM) band
- Transceivers provide bidirectional communication between the Gateway and Node, including fully acknowledged data transmission
- Lost RF links are detected and relevant outputs set to user-defined conditions
- DX99 Metal housings are certified for use in Class I, Division 1, Groups A, B, C, D; Class II, Division 1, Groups E, F, G; Class III, Division 1; and Zone 0 (Category 1G) and Zone 20 (Category 1D) when properly installed in accordance with the National Electrical Code, the Canadian Electrical Code, or applicable local codes/regulations

For additional information, updated documentation, and accessories, refer to Banner Engineering's website, *www.bannerengineering.com/surecross*.

Model	Frequency	Boost Voltage	I/O
DX99N9X1S2N0M2X0D2	900 MHz ISM Band	18 V	**Discrete Mode** Inputs: Two selectable discrete Switch Power: Two, Configurable **Analog Mode** Inputs: Two selectable discrete, two 0 to 20 mA analog Switch Power: One, Configurable
DX99N2X1S2N0M2X0D2	2.4 GHz ISM Band		
DX99N9X1S2N0M2X0D1	900 MHz ISM Band	10 V	
DX99N2X1S2N0M2X0D1	2.4 GHz ISM Band		

Model	Frequency	Boost Voltage	I/O
DX99N9X1S2N0V2X0D2	900 MHz ISM Band	18 V	**Discrete Mode** Inputs: Two selectable discrete Switch Power: Two, Configurable **Analog Mode** Inputs: Two selectable discrete, two 0 to 10V analog Switch Power: One, Configurable
DX99N2X1S2N0V2X0D2	2.4 GHz ISM Band		
DX99N9X1S2N0V2X0D1	900 MHz ISM Band	10 V	
DX99N2X1S2N0V2X0D1	2.4 GHz ISM Band		

These models ship with the battery disconnected. To install the battery, refer to the battery replacement instructions in this datasheet.

WARNING: Not To Be Used for Personnel Protection

Never use this device as a sensing device for personnel protection. Doing so could lead to serious injury or death. This device does not include the self-checking redundant circuitry necessary to allow its use in personnel safety applications. A sensor failure or malfunction can cause either an energized or de-energized sensor output condition.

Specifications

Radio Range[1]
900 MHz, 150 mW: Up to 4.8 km (3 miles)
2.4 GHz, 65 mW: Up to 3.2 km (2 miles)

Minimum Separation Distance
900 MHz, 150 mW: 2 m (6 ft)
2.4 GHz, 65 mW: 0.3 m (1 ft)

Transmit Power
900 MHz, 150 mW: 21 dBm (150 mW) conducted
2.4 GHz, 65 mW: 18 dBm (65 mW) conducted, less than or equal to 20 dBm (100 mW) EIRP

900 MHz Compliance
FCC ID TGUDX80 - This device complies with FCC Part 15, Subpart C, 15.247
IC: 7044A-DX8009

2.4 GHz Compliance
FCC ID UE300DX80-2400 - This device complies with FCC Part 15, Subpart C, 15.247
ETSI EN 300 328 V1.8.1 (2012-06)
IC: 7044A-DX8024

Discrete Inputs
Rating: See control drawing
Sample/Report Rates: DIP switch configurable

Discrete Input ON Condition
PNP: Greater than 8 V
NPN: Less than 0.7 V

Discrete Input OFF Condition (DX99 Models)
PNP: Less than 4.5 V
NPN: Greater than 2.2 V or open

Environmental Rating
IEC IP68 [2]

Operating Conditions[3]
−40 °C to +65 °C (−40 °F to +149 °F) (Electronics); −20 °C to +80 °C (−4 °F to +176 °F) (LCD)
95% maximum relative humidity (non-condensing)
Radiated Immunity: 10 V/m (EN 61000-4-3)

Shock and Vibration
IEC 68-2-6 and IEC 68-2-27
Shock: 30g, 11 millisecond half sine wave, 18 shocks
Vibration: 0.5 mm p-p, 10 to 60 Hz

Supply Voltage
3.6 V dc low power option from an internal battery

Power Consumption
Consumption: Application dependant

Housing
Glass and cast aluminium w/ chromating and chemically resistant paint (outside only)

Antenna Connection
Ext. Reverse Polarity SMA, 50 Ohms
Max Tightening Torque: 0.45 N·m (4 lbf·in)

Spread Spectrum Technology
FHSS (Frequency Hopping Spread Spectrum)

Interface
Indicators: Two bi-color LEDs
Buttons: Two
Display: Six character LCD

Wiring Access
Two 1/2-inch NPT ports, one 3/4-inch NPT port (internal threads)

Link Timeout
Gateway: Configurable via User Configuration Tool (UCT) software
Node: Defined by Gateway

Analog Input Rating (mA Models)
Rating for 4 to 20 mA models: 24 mA
Impedance: Approximately 20 Ohms
Analog Input 1 Sample/Report Rates: DIP switch configurable
Analog Input 2 Sample/Report Rates: 1 second / 16 seconds
Accuracy: 0.1% of full scale +0.01% per °C
Resolution: 12-bit

Analog Input Rating (V Models)
Rating for 0 to 10V models: 10 V
Impedance: Approximately 20 Ohms
Analog Input 1 Sample/Report Rates: DIP switch configurable
Analog Input 2 Sample/Report Rates: 1 second / 16 seconds
Accuracy: 0.25% of full scale +0.01% per °C
Resolution: 12-bit

Notes
To verify the analog input's impedance, use an Ohm meter to measure the resistance between the analog input terminal (AI*x*) and the ground (GND) terminal.

Certifications

CSA: Class I, Division 1, Groups A, B, C, D; Class II, Division 1, Groups E, F, G; Class III, Division 1 (Ex ia IIC T4 / AEx ia IIC T4)
Certificate: 2008243

LCIE/ATEX: Zone 0 (Category 1G) and 20 (Category 1D), Temperature Class T4 (II 1 GD / Ex ia IIC T4 Ga / Ex ia IIIC T82°C Da IP68) Certificate: LCIE 08 ATEX 6098 X

Special Conditions for Safe Use imposed by Intrinsic Safety Certificate LCIE 08 ATEX 6098 X: Ambient temperature range is −40 to 70 °C. Sure Cross® DX99 *Flex*Power devices can only be connected to Intrinsically Safe certified equipment or simple apparatus as defined by EN 60079-11. All connected equipment must comply with the Entity Parameters (Safety Parameters) listed in the *Control Drawings* (p/n 141513). The device must only use a lithium battery manufactured by XENO, type XL-205F.

1725

1 Radio range is with the 2 dB antenna that ships with the product. High-gain antennas are available, but the range depends on the environment and line of sight. Always verify your wireless network's range by performing a Site Survey.
2 Refer to the *Sure Cross® Wireless I/O Networks Instruction Manual* (p/n 132607) for installation and waterproofing instructions.
3 Operating the devices at the maximum operating conditions for extended periods can shorten the life of the device.

Sure Cross® DXM100-B1 Wireless Controller

Datasheet

The DXM100-B1 Wireless Controller is an industrial wireless controller that facilitates Industrial Internet of Things (IIoT) applications. As a communications gateway, it interfaces local serial ports, local I/O ports, and local ISM radio devices to the internet using either a cellular connection or a wired Ethernet network connection.

- Sure Cross® DX80 Wireless Gateway or MultiHop radio with 900 MHz or 2.4 GHz ISM bands available
- Logic controller with action rules and ScriptBasic programming
- Cellular modem Internet connectivity
- Automation protocols include Modbus TCP, Modbus RTU, and EtherNet/IP™
- Secure email and text Internet messaging for alarms, alerts, and data log files
- Data logging with removable SD card
- Interactive programmable user interface with LCD and LED indicators
- Universal, on-board I/O with analog and discrete I/O
- Industry standard RS-485, Ethernet, and USB communication ports
- Multiple managed power options with battery backup

WARNING: Not To Be Used for Personnel Protection

Never use this device as a sensing device for personnel protection. Doing so could lead to serious injury or death. This device does not include the self-checking redundant circuitry necessary to allow its use in personnel safety applications. A sensor failure or malfunction can cause either an energized or de-energized sensor output condition.

CAUTION: Electrostatic Discharge (ESD)

ESD Sensitive Device. Use proper handling procedures to prevent ESD damage to these devices. The module does not contain any specific ESD protection beyond the structures contained in its integrated circuits. Proper handling procedures should include leaving devices in their anti-static packaging until ready for use; wearing anit-static wrist straps; and assembling units on a grounded, static-dissipative surface.

Models

	Base	Radio Configuration
DXM100-	B1	R1

B1 = Modbus controller for data aggregation of sensors and wireless networks
Power: 12–30 V dc/ Solar/ Battery
Comms: RS-485, CAN, RS-232 w/flow or secondary RS-485
Inputs: (4) universal IN
Outputs: (4) NMOS OUT, (2) analog OUT (0–10 V or 4–20 mA)
Power Out: (2) Selected 5 V or 16 V switched power, (1) 5 V courtesy power

Blank = None
R1 = 900 MHz, 1 W PE5 Performance Radio (North America)
R2 = 900 MHz, 1 W HE5 MultiHop Data Radio (North America)
R3 = 2.4 GHz, 65 mW PE5 Performance Radio (Worldwide)
R4 = 2.4 GHz, 65 mW HE5 MultiHop Data Radio (Worldwide)
R5 = 900 MHz, 65 mW HE5L MultiHop Data Radio (Used for M-GAGE networks)
R8 = 900 MHz, Performance Radios approved for Australia/New Zealand
R9 = 900 MHz, MultiHop Radio approved for Australia/New Zealand

Some example models include, but are not limited to, the following:

Models	Description
DXM100-B1R1	DXM100-B1 Wireless Controller with DX80 ISM 900 MHz radio
DXM100-B1R2	DXM100-B1 Wireless Controller with DX80 ISM 900 MHz MultiHop radio
DXM100-B1R3	DXM100-B1 Wireless Controller with DX80 ISM 2.4 GHz radio

Specifications

MultiHop Radio Specifications

Radio Range[1]
900 MHz, 1 Watt: Up to 9.6 km (6 miles)
2.4 GHz, 65 mW: Up to 3.2 km (2 miles)

Antenna Minimum Separation Distance
900 MHz, 150 mW and 250 mW: 2 m (6 ft)
900 MHz, 1 Watt: 4.57 m (15 ft)
2.4 GHz, 65 mW: 0.3 m (1 ft)

Radio Transmit Power
900 MHz, 1 Watt: 30 dBm (1 W) conducted (up to 36 dBm EIRP)
2.4 GHz, 65 mW: 18 dBm (65 mW) conducted, less than or equal to 20 dBm (100 mW) EIRP

Spread Spectrum Technology
FHSS (Frequency Hopping Spread Spectrum)

900 MHz Compliance (1 Watt)
FCC ID UE3RM1809: This device complies with FCC Part 15, Subpart C, 15.247
IC: 7044A-RM1809

2.4 GHz Compliance (MultiHop)
FCC ID UE300DX80-2400 - This device complies with FCC Part 15, Subpart C, 15.247
ETSI EN 300 328: V1.8.1 (2012-04)
IC: 7044A-DX8024

Antenna Connection
Ext. Reverse Polarity SMA, 50 Ohms
Max Tightening Torque: 0.45 N·m (4 lbf·in)

Radio Packet Size (MultiHop)
900 MHz: 175 bytes (85 Modbus registers)
2.4 GHz: 75 bytes (37 Modbus registers)

RS-485 Communication Specifications

Communication Hardware (MultiHop RS-485)
Interface: 2-wire half-duplex RS-485
Baud rates: 9.6k, 19.2k (default), or 38.4k via DIP switches; 1200 and 2400 via the MultiHop Configuration Tool
Data format: 8 data bits, no parity, 1 stop bit

RS-232 Communication Specifications

Communication Hardware (MultiHop RS-232)
Interface: 2-wire RS-232
Baud rates: 9.6k, 19.2k (default), or 38.4k via DIP switches; 1200 and 2400 via the MultiHop Configuration Tool
Data format: 8 data bits, no parity, 1 stop bit

Power and I/O Specifications

Supply Voltage
12 to 30 V dc (use only with a suitable Class 2 power supply (UL) or a SELV (CE) power supply) or
12 V dc solar panel and 12 V sealed lead acid battery

Courtesy Power Out
One output at 5 Volts, 500 mA maximum
No short circuit protection

Solar Power Battery Charging
1 Amp maximum with 20 Watt solar panel

Switched Power Out
Two selectable 5 V or 16 V outputs
5 V: 400 mA maximum
16 V: 125 mA maximum

Power Consumption
35 mA average at 12 Volts

Construction
Polycarbonate; DIN rail mount option

Communication Protocols
Modbus RTU Master/Slave, Modbus/TCP, and Ethernet/IP

Counters, Synchronous
32-bits unsigned
10 ms clock rate minimum

Universal Inputs
Sinking/Sourcing discrete, 4–20 mA analog, 0–10 V analog, counter, and temperature 10 kOhm thermistor

Security Protocols
VPN, SSL, and HTTPS

Logging
8 GB maximum; removable Micro SD card format

Analog Outputs (DAC)
0 to 20 mA or 0 to 10 V dc output
Accuracy: 0.1% of full scale +0.01% per °C
Resolution: 12-bit

Discrete Output Rating (NMOS)
Less than 1 A max current at 30 V dc
ON-State Saturation: Less than 0.7 V at 20 mA
ON Condition: Less than 0.7 V
OFF Condition: Open

[1] Radio range is with the 2 dB antenna that ships with the product. High-gain antennas are available, but the range depends on the environment and line of sight. Always verify your wireless network's range by performing a Site Survey.

Environmental Specifications

Operating Conditions[2]
–40 °C to +85 °C (–40 °F to +185 °F) (Electronics); –20 °C to +80 °C (–4 °F to +176 °F) (LCD)
95% maximum relative humidity (non-condensing)
Radiated Immunity: 10 V/m (EN 61000-4-3)

Shock and Vibration
IEC 68-2-6 and IEC 68-2-27
Shock: 30g, 11 millisecond half sine wave, 18 shocks
Vibration: 0.5 mm p-p, 10 to 60 Hz

Environmental Rating
IEC IP20

Certifications

CE

Accessories

For a complete list of all the accessories for the Sure Cross wireless product line, please download the *Accessories List* (p/n b_3147091)

Cordsets
MQDC1-506—5-pin M12/Euro-style, straight, single ended, 6 ft
MQDC1-530—5-pin M12/Euro-style, straight, single ended, 30 ft
MQDC1-506RA—5-pin M12/Euro-style, right-angle, single ended, 6 ft
MQDC1-530RA—5-pin M12/Euro-style, right-angle, single ended, 30 ft

Static and Surge Suppressor
BWC-LFNBMN-DC—Surge Suppressor, bulkhead, N-Type, dc Blocking, N-Type Female, N-Type Male

Short-Range Omni Antennas
BWA-2O2-D—Antenna, Dome, 2.4 GHz, 2 dBi, RP-SMA Box Mount
BWA-9O2-D—Antenna, Dome, 900 MHz, 2 dBi, RP-SMA Box Mount
BWA-9O2-RA—Antenna, Rubber Fixed Right Angle, 900 MHz, 2 dBi, RP-SMA Male Connector

Medium-Range Omni Antennas
BWA-9O5-C—Antenna, Rubber Swivel, 900 MHz 5 dBi, RP-SMA Male Connector
BWA-2O5-C—Antenna, Rubber Swivel, 2.4 GHz 5 dBi, RP-SMA Male Connector

Enclosures and DIN Rail Kits
BWA-AH864—Enclosure, Polycarbonate, with Opaque Cover, 8 × 6 × 4
BWA-AH1084—Enclosure, Polycarbonate, with Opaque Cover, 10 × 8 × 4
BWA-AH12106—Enclosure, Polycarbonate, with Opaque Cover, 12 × 10 × 6
BWA-AH8DR—DIN Rail Kit, 8", 2 trilobular/self-threading screws
BWA-AH10DR—DIN Rail Kit, 10", 2 trilobular/self-threading screws
BWA-AH12DR—DIN Rail Kit, 12", 2 trilobular/self-threading screws

Misc Accessories
BWA-CG.5-3X5.6-10—Cable Gland Pack: 1/2-inch NPT, Cordgrip for 3 holes of 2.8 to 5.6 mm diam, qty 10
BWA-HW-052— Cable Gland and Vent Plug Pack: includes 1/2-inch NPT gland, 1/2-inch NPT multi-cable gland, and 1/2-inch NPT vent plug, qty 1 each

Antenna Cables
BWC-1MRSMN05—LMR100 RP-SMA to N-Type Male, 0.5 m
BWC-2MRSFRS6—LMR200, RP-SMA Male to RP-SMA Female, 6 m
BWC-4MNFN6—LMR400 N-Type Male to N-Type Female, 6 m

Long-Range Omni Antennas
BWA-9O8-AS—Antenna, Fiberglass, 3/4 Wave, 900 MHz, 8 dBi, N-Type Female Connector
BWA-2O8-A—Antenna, Fiberglass, 2.4 GHz, 8 dBi, N-Type Female Connector

Long-Range Yagi Antennas
BWA-9Y10-A—Antenna, 900 MHz, 10 dBd, N-Type Female Connector

Power Supplies
PSD-24-4—DC Power Supply, Desktop style, 3.9 A, 24 V dc, Class 2, 4-pin M12/Euro-style quick disconnect (QD)
PSDINP-24-13 —DC Power Supply, 1.3 Amps, 24 V dc, with DIN Rail Mount, Class I Division 2 (Groups A, B, C, D) Rated
PSDINP-24-25 — DC Power Supply, 2.5 Amps, 24 V dc, with DIN Rail Mount, Class I Division 2 (Groups A, B, C, D) Rated
BWA-SOLAR PANEL 20W—Solar Panel, 12 V, 20 W, Multicrystalline, 573 × 357 × 30, "L" style mounting bracket included (does not include controller)

Warnings

Install and properly ground a qualified surge suppressor when installing a remote antenna system. Remote antenna configurations installed without surge suppressors invalidate the manufacturer's warranty. Keep the ground wire as short as possible and make all ground connections to a single-point ground system to ensure no ground loops are created. No surge suppressor can absorb all lightning strikes; do not touch the Sure Cross® device or any equipment connected to the Sure Cross device during a thunderstorm.

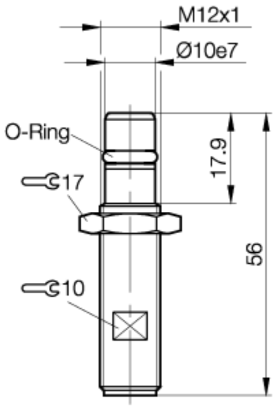
Exporting Sure Cross® Radios. It is our intent to fully comply with all national and regional regulations regarding radio frequency emissions. **Customers who want to re-export this product to a country other than that to which it was sold must ensure the device is approved in the destination country.** A list of approved countries appears in the *Radio Certifications* section of the product manual. The Sure Cross wireless products were certified for use in these countries using the antenna that ships with the product. When using other antennas, verify you are not exceeding the transmit power levels allowed by local governing agencies. Consult with Banner Engineering Corp. if the destination country is not on this list.

[2] Operating the devices at the maximum operating conditions for extended periods can shorten the life of the device.

BES 516-300-S315-S4-N
BHS004K

NAMUR

flush mountable



PX0211

Electrical data:

Connection	Connector S4 (M12)
Rated operational voltage DC	8.2 DC V
Rated insulation voltage (Ui)	75 DC
Rated protective resistance	1000 Ohm
Time delay before availability	10 ms
Inductance of oscillator coil	0,5 mH
Self capacitance of sensor max	30 nF
Switching output	NAMUR
Operating frequency (f)	1000 Hz
Switching current difference	0,3 mA
Supply voltage max DC (UB)	9 V
Supply voltage min DC (UB)	7,7 V
Current consumption d. max	1 mA
Current consumption und. max	4 mA
Permissible protec. resistance	550...1100 Ohm

Mechanical data:

Number of Wires	2-wire
Rated operating distance (sn)	1,5 mm
Diameter	M12x1 mm
Assured operating distance	0...1,1 mm
Mounting	flush mountable
Switch. travel difference max	10 %
Ambient temperature max	+70 °C
Ambient temperature min	-25 °C
Degree of polution	3
Sensing face material	POM
Housing material	corrosion resistance Steel
Repeat accuracy max. (R)	5 %

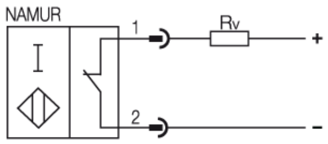
General data:

Explosion Proof	Ex II 2 G Ex ia IIC T6
Output indication	no
Degree of protection IP	IP68 per BWN Pr 20
Approval	CE, PTB 01 ATEX 2207 X
Features	pressure rated to 500 bar

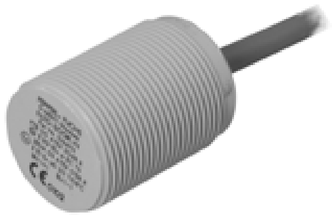
Additional information:

Basic standard IEC 60947-5-6, EN 60 079-0: 2006, EN 60 079-11: 2007

Wiring:



Pinout:
Pinout



0102

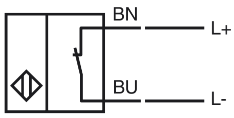
Model Number

NJ15-30GK-N-10M

Features

- **Comfort series**
- **15 mm non-flush**
- **Usable up to SIL2 acc. to IEC 61508**

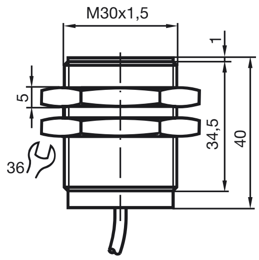
Connection



Accessories

BF 30
Mounting flange, 30 mm

Dimensions



Technical Data

General specifications		
Switching element function		NAMUR, NC
Rated operating distance	s_n	15 mm
Installation		non-flush
Output polarity		NAMUR
Assured operating distance	s_a	0 ... 12.15 mm
Reduction factor r_{Al}		0.4
Reduction factor r_{Cu}		0.3
Reduction factor r_{304}		0.85
Nominal ratings		
Nominal voltage	U_o	8 V
Switching frequency	f	0 ... 100 Hz
Current consumption		
Measuring plate not detected		≥ 3 mA
Measuring plate detected		≤ 1 mA
Functional safety related parameters		
$MTTF_d$		4560 a
Mission Time (T_M)		20 a
Diagnostic Coverage (DC)		0 %
Ambient conditions		
Ambient temperature		-25 ... 100 °C (-13 ... 212 °F)
Mechanical specifications		
Connection type		cable PVC , 10 m
Core cross-section		0.75 mm^2
Housing material		PBT
Sensing face		PBT
Protection degree		IP68
General information		
Use in the hazardous area		see instruction manuals
Category		2G; 1D
Compliance with standards and directives		
Standard conformity		
NAMUR		EN 60947-5-6:2000 IEC 60947-5-6:1999
Standards		EN 60947-5-2:2007 IEC 60947-5-2:2007
Approvals and certificates		
FM approval		
Control drawing		116-0165F
UL approval		cULus Listed, General Purpose
CSA approval		cCSAus Listed, General Purpose
CCC approval		CCC approval / marking not required for products rated ≤36 V

Release date: 2013-06-26 09:56 Date of issue: 2013-06-26 106487_eng.xml

ATEX 2G

Instruction	**Manual electrical apparatus for hazardous areas**
Device category 2G	for use in hazardous areas with gas, vapour and mist
EC-Type Examination Certificate	PTB 00 ATEX 2048 X
CE marking	CE 0102
ATEX marking	Ex II 2G Ex ia IIC T6 Gb
Directive conformity	94/9/EG
Standards	EN 60079-0:2009, EN 60079-11:2007 Ignition protection "Intrinsic safety" Use is restricted to the following stated conditions
Appropriate type	NJ 15-30GK...-N...
Effective internal capacitance C_i	≤ 140 nF ; a cable length of 10 m is considered.
Effective internal inductance L_i	≤ 100 µH ; a cable length of 10 m is considered.
General	The apparatus has to be operated according to the appropriate data in the data sheet and in this instruction manual. The EC-Type Examination Certificate has to be observed. The special conditions must be adhered to! Directive 94/9/EG and hence also EC-Type Examination Certificates apply in general only to the use of electrical apparatus under atmospheric conditions. The use in ambient temperatures of > 60 °C was tested with regard to hot surfaces by the mentioned certification authority. If the equipment is not used under atmospheric conditions, a reduction of the permissible minimum ignition energies may have to be taken into consideration.
Ambient temperature	The temperature ranges, according to temperature class, are given in the EC-Type Examination Certificate.
Installation, Comissioning	Laws and/or regulations and standards governing the use or intended usage goal must be observed. The intrinsic safety is only assured in connection with an appropriate related apparatus and according to the proof of intrinsic safety.
Maintenance	No changes can be made to apparatus, which are operated in hazardous areas. Repairs to these apparatus are not possible.
Specific conditions	
Protection from mechanical danger	When used in the temperature range below -20 °C the sensor should be protected from knocks by the provision of an additional housing.

Release date: 2013-06-26 09:56 Date of issue: 2013-06-26 106487_eng.xml

Refer to "General Notes Relating to Pepperl+Fuchs Product Information".
Pepperl+Fuchs Group www.pepperl-fuchs.com USA: +1 330 486 0001 fa-info@us.pepperl-fuchs.com Germany: +49 621 776 4411 fa-info@de.pepperl-fuchs.com Singapore: +65 6779 9091 fa-info@sg.pepperl-fuchs.com
PEPPERL+FUCHS SENSING YOUR NEEDS

ATEX 1D

Instruction	**Manual electrical apparatus for hazardous areas**
Device category 1D	for use in hazardous areas with combustible dust
EC-Type Examination Certificate	ZELM 03 ATEX 0128 X
CE marking	CE 0102
ATEX marking	Ex II 1D Ex iaD 20 T 108 °C (226.4 °F)
Directive conformity	94/9/EG
Standards	IEC 61241-11:2002: draft; prEN61241-0:2002 type of protection intrinsic safety "iD" Use is restricted to the following stated conditions
Appropriate type	NJ 15-30GK...-N...
Effective internal capacitance C_i	≤ 140 nF ; a cable length of 10 m is considered.
Effective internal inductance L_i	≤ 100 µH ; a cable length of 10 m is considered.
General	The apparatus has to be operated according to the appropriate data in the data sheet and in this instruction manual. The EC-Type Examination Certificate has to be observed. The special conditions must be adhered to!
Maximum housing surface temperature	The maximum surface temperature of the housing is given in the EC-Type Examination Certificate.
Installation, Comissioning	Laws and/or regulations and standards governing the use or intended usage goal must be observed. The intrinsic safety is only assured in connection with an appropriate related apparatus and according to the proof of intrinsic safety. The associated apparatus must satisfy at least the requirements of category ia IIB or iaD. Because of the possibility of the danger of ignition, which can arise due to faults and/or transient currents in the equipotential bonding system, galvanic isolation in the power supply and signal circuits is preferable. Associated apparatus without electrical isolation must only be used if the appropriate requirements of IEC 60079-14 are met. The intrinsically safe circuit has to be protected against influences due to lightning. When used in the isolating wall between Zone 20 and Zone 21 or Zone 21 und Zone 22 the sensor must not be exposed to any mechanical danger and must be sealed in such a way, that the protective function of the isolating wall is not impaired. The applicable directives and standards must be observed.
Maintenance	No changes can be made to apparatus, which are operated in hazardous areas. Repairs to these apparatus are not possible.
Specific conditions	
Electrostatic charging	The connection cables are to be laid in accordance with EN 50281-1-2 and must not normally be subjected to chaffing during use.

Release date: 2013-06-26 09:56 Date of issue: 2013-06-26 106487_eng.xml

Appendix C

Sure Cross Configuration

Sure Cross configuration example with one NAMUR proximity sensor

Daniel Coward, 16.05.18

Utilities:
Banner DX99 node with antenna and battery
Banner DXM100 Gateway
Power supply
Proximity sensor NJ15-30GK-N-10M
SURE CROSS USER CONFIGURATION TOOL (2ND GEN) http://info.bannerengineering.com/_dav/cs/idcplg?IdcService=GET_FILE&RevisionSelectionMethod=LatestReleased&dDocName=B_4427326

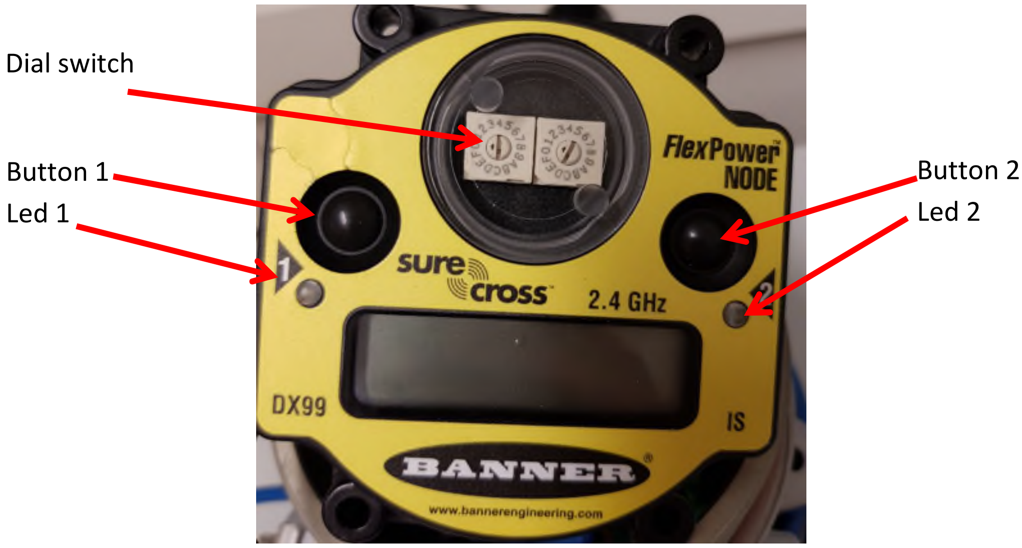
Binding procedure

Power-up sensor node and Gateway. Make sure antennas are connected.

Set node ID by turning the dial switch. Enter binding mode by pressing three times on button two on the sensor node. The screen should tell that you are in binding mode.

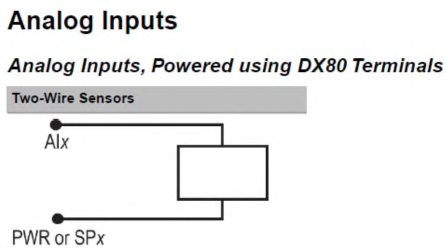
Set gateway in binding mode: ISM Radio -> Binding -> (select the sensor node ID you are binding) Enter

The sensor node will flash three times with both LEDs to to tell that it is bound, when binding is done, exit binding mode on gateway. After a while, only LED 1 on the sensor node should flash. If LED 2 flashes, there is no connection between Sensor node and gateway.



Sensor connection

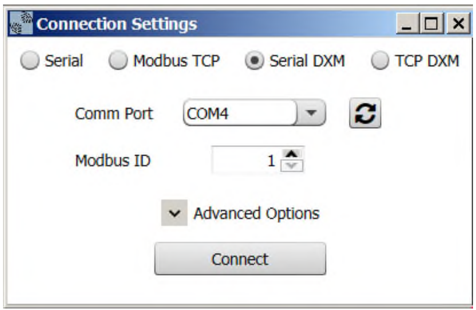
The sensor will be connected to sensor node input 3 that is the first analogue input(A1) and get power from Source Power 1 (SP1)



Connection

Open the software SURE CROSS USER CONFIGURATION TOOL (2ND GEN)

Go to Device->Connection settings and choose preferred connection settings.



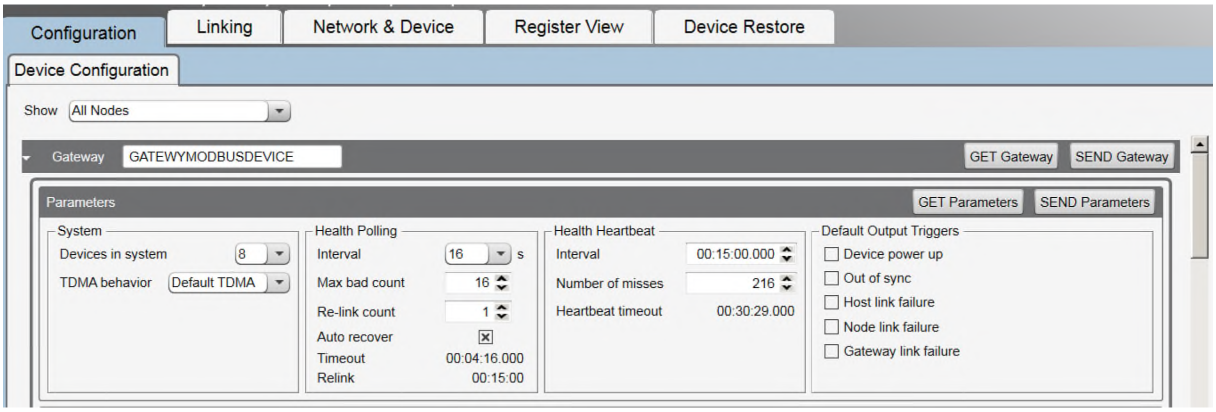
Connection is indicated in lower left corner of the window 

Node Configuration

Go to Configuration tab and press GET Gateway to read the setting of the gateway.

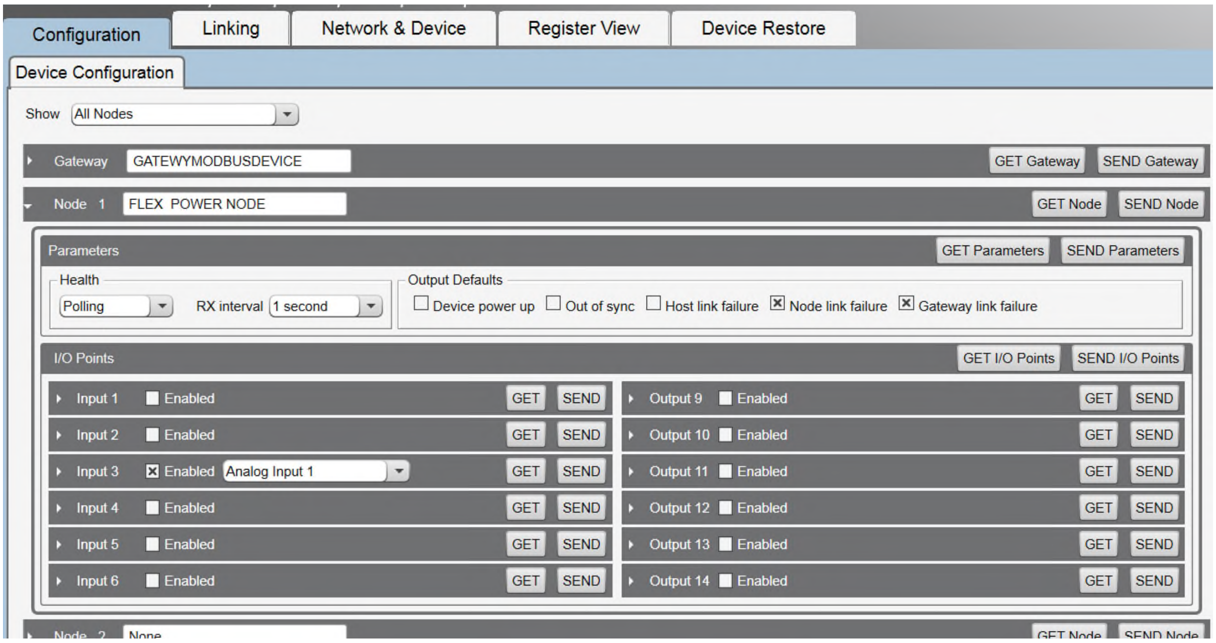
It is recommended to always GET parameters from gateway and nodes before changing parameters to see what the parameters are and to avoid the need for changing all parameters.

Most default settings can be kept, however it is advised to go as low as possible on “Devices in system” to obtain best system speed.



Press Get Node to obtain connection with node.

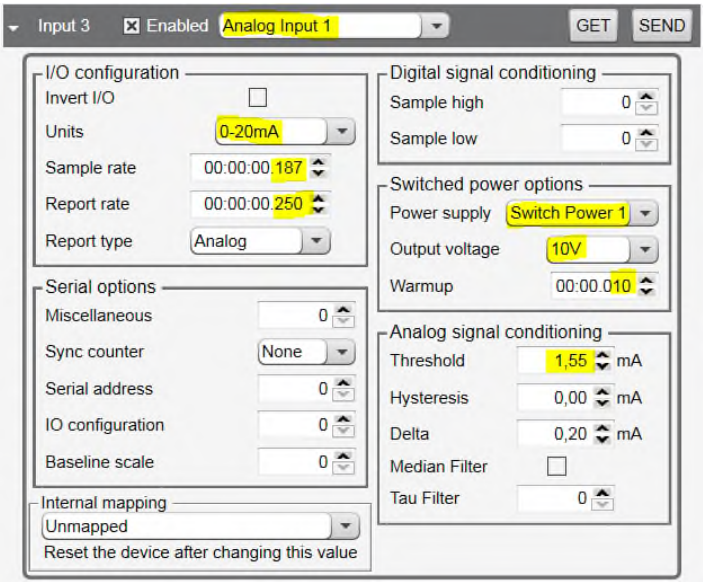
Press Get Parameters to get current node configuration



Go to the Input you want to configure and press GET to get current configuration.

Select Input type. Analog Input 1 is selected as the NAMUR senor to be used outputs an analogue signal.

Input	Select senor type
Units	Sensor signal type
Sample rate	Time between each sensor sample
Report rate	Time between each time the node sends a updated value to the gateway
Power supply	Power output on PCB inside node
Output voltage	Voltage used for senor
Warm up time	Time it takes before senor measurement is stable
Threshold	Used for triggering threshold, mostly used when the banner system is used as a standalone system or to activate an output on the senor node. When collecting data from the SureCross system by Modbus, the raw value will be read.



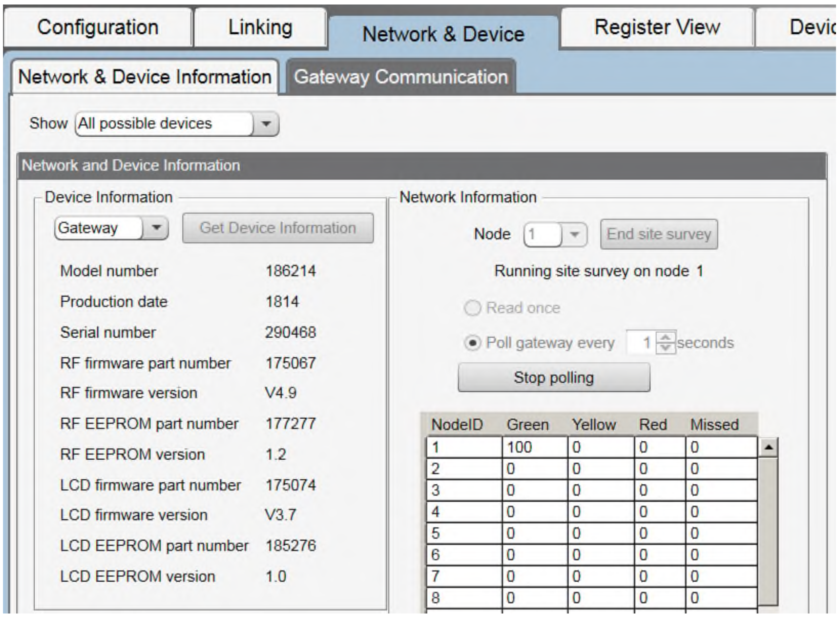
The yellow fields have been altered.

When finished, press SEND to send new input configuration. Send I/O points can be used if several I/O points have been changed.

Network information

Network & Device -> Network & Device Information

Device information: Select Gateway or the applicable node and press Get Device Information to see information about the current device.



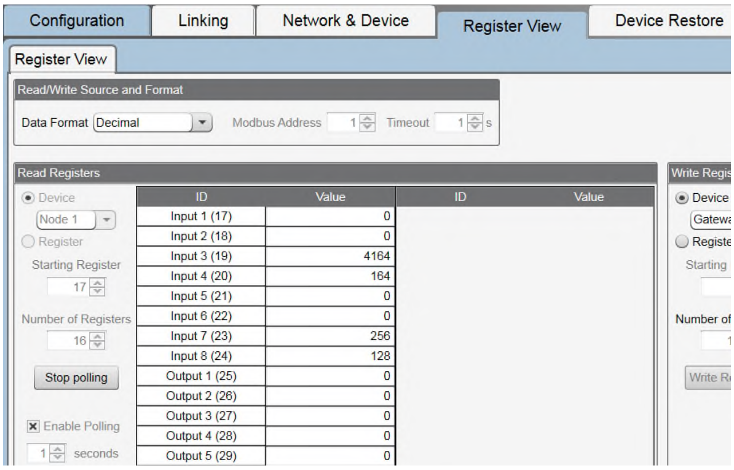
Network Information, Chose applicable device, select Start Site Survey, Poll gateway every X seconds, Star polling. The table will show the signal strength for the selected node.

Senor node registers

Go to Register View, select Device and the applicable device. Click Enable polling and Start polling.

The Value on Input 3 is the sensor value from senor configured in previous steps.

Input 8 is the "link loss signal" if < 128, there is a connection error between the selected node and gateway.



Appendix D

Modbus Communication PLC User Program

To keep appendix short, only selected pages containing self programmed code has been attached.

ModbusTest2 / PLC_1 [CPU 1511-1 PN] / Program blocks

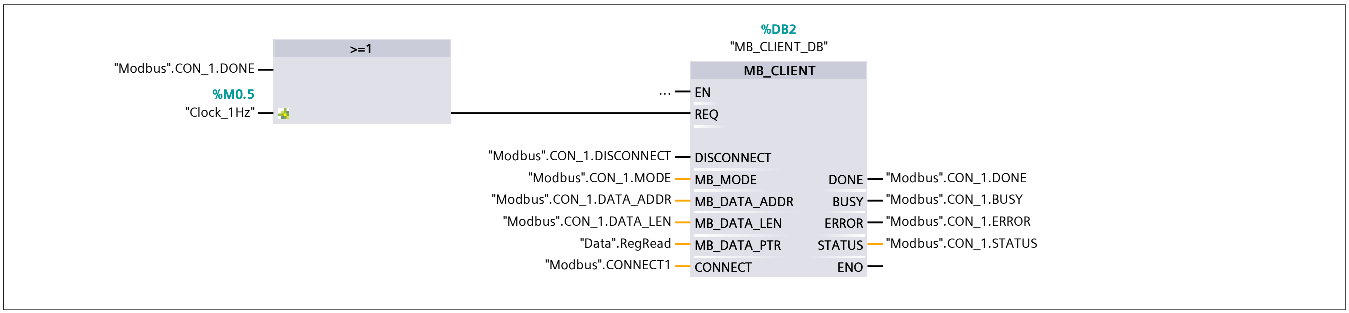
Cyclic interrupt [OB34]

Cyclic interrupt Properties					
General					
Name	Cyclic interrupt	**Number**	34	**Type**	OB
Language	FBD	**Numbering**	Manual		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Cyclic interrupt		
Name	**Data type**	**Default value**
▼ Input		
Initial_Call	Bool	
Event_Count	Int	
Temp		
Constant		

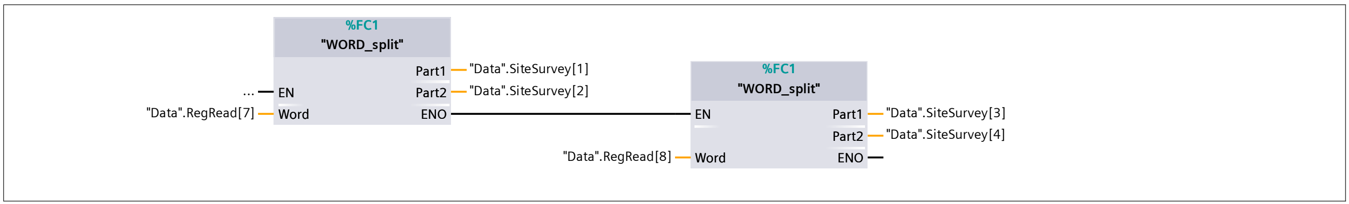
Network 1:

Read holding reg 40001 to 40048 (Gateway 1-16, Node1 17-32, Node2 33-48)



Network 2:

Sort site survey data



ModbusTest2 / PLC_1 [CPU 1511-1 PN] / Program blocks

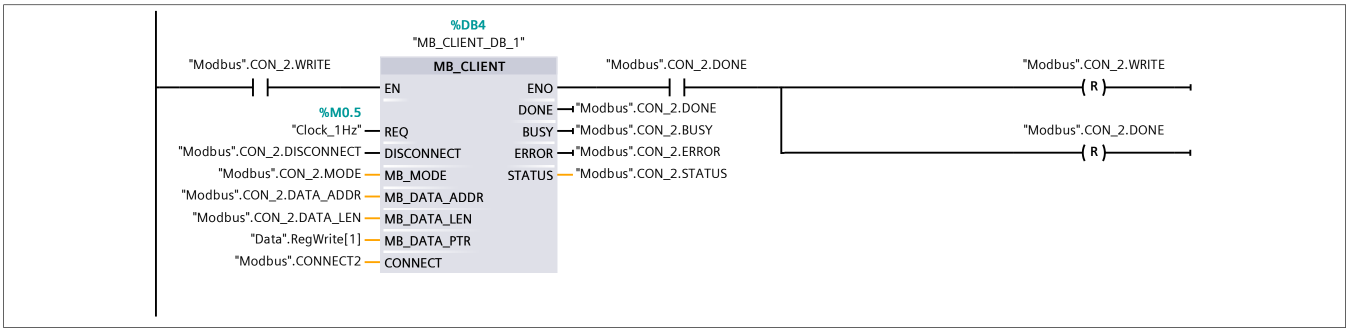
Main [OB1]

Main Properties					
General					
Name	Main	**Number**	1	**Type**	OB
Language	LAD	**Numbering**	Automatic		
Information					
Title	"Main Program Sweep (Cycle)"	**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Main		
Name	**Data type**	**Default value**
▼ Input		
Initial_Call	Bool	
Remanence	Bool	
Temp		
Constant		

Network 1:

Write data to host system



WORD_split [FC1]

WORD_split Properties					
General					
Name	WORD_split	**Number**	1	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
▼ Input		
Word	Word	
▼ Output		
Part1	Int	
Part2	Int	
InOut		
▼ Temp		
Part2temp	Word	
▼ Constant		
Shift	USInt	8
▼ Return		
WORD_split	Void	

```
#Part1 := #Word AND W#2#000_0000_1111_1111;
#Part2temp := #Word AND W#2#1111_1111_000_0000;
#Part2 := SHR(IN:=#Part2temp, N:=#Shift);
```

Data [DB3]

Data Properties					
General					
Name	Data	**Number**	3	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Start value	Retain
▼ Static			
▼ RegRead	Array[1..48] of Word		False
RegRead[1]	Word	16#0	False
RegRead[2]	Word	16#0	False
RegRead[3]	Word	16#0	False
RegRead[4]	Word	16#0	False
RegRead[5]	Word	16#0	False
RegRead[6]	Word	16#0	False
RegRead[7]	Word	16#0	False
RegRead[8]	Word	16#0	False
RegRead[9]	Word	16#0	False
RegRead[10]	Word	16#0	False
RegRead[11]	Word	16#0	False
RegRead[12]	Word	16#0	False
RegRead[13]	Word	16#0	False
RegRead[14]	Word	16#0	False
RegRead[15]	Word	16#0	False
RegRead[16]	Word	16#0	False
RegRead[17]	Word	16#0	False
RegRead[18]	Word	16#0	False
RegRead[19]	Word	16#0	False
RegRead[20]	Word	16#0	False
RegRead[21]	Word	16#0	False
RegRead[22]	Word	16#0	False
RegRead[23]	Word	16#0	False
RegRead[24]	Word	16#0	False
RegRead[25]	Word	16#0	False
RegRead[26]	Word	16#0	False
RegRead[27]	Word	16#0	False
RegRead[28]	Word	16#0	False
RegRead[29]	Word	16#0	False
RegRead[30]	Word	16#0	False
RegRead[31]	Word	16#0	False
RegRead[32]	Word	16#0	False
RegRead[33]	Word	16#0	False
RegRead[34]	Word	16#0	False
RegRead[35]	Word	16#0	False
RegRead[36]	Word	16#0	False
RegRead[37]	Word	16#0	False
RegRead[38]	Word	16#0	False

Name	Data type	Start value	Retain
RegRead[39]	Word	16#0	False
RegRead[40]	Word	16#0	False
RegRead[41]	Word	16#0	False
RegRead[42]	Word	16#0	False
RegRead[43]	Word	16#0	False
RegRead[44]	Word	16#0	False
RegRead[45]	Word	16#0	False
RegRead[46]	Word	16#0	False
RegRead[47]	Word	16#0	False
RegRead[48]	Word	16#0	False
▼ RegWrite	Array[1..2] of Word		False
RegWrite[1]	Word	16#0	False
RegWrite[2]	Word	16#0	False
▼ SiteSurvey	Array[1..4] of Int		False
SiteSurvey[1]	Int	0	False
SiteSurvey[2]	Int	0	False
SiteSurvey[3]	Int	0	False
SiteSurvey[4]	Int	0	False

Modbus [DB1]

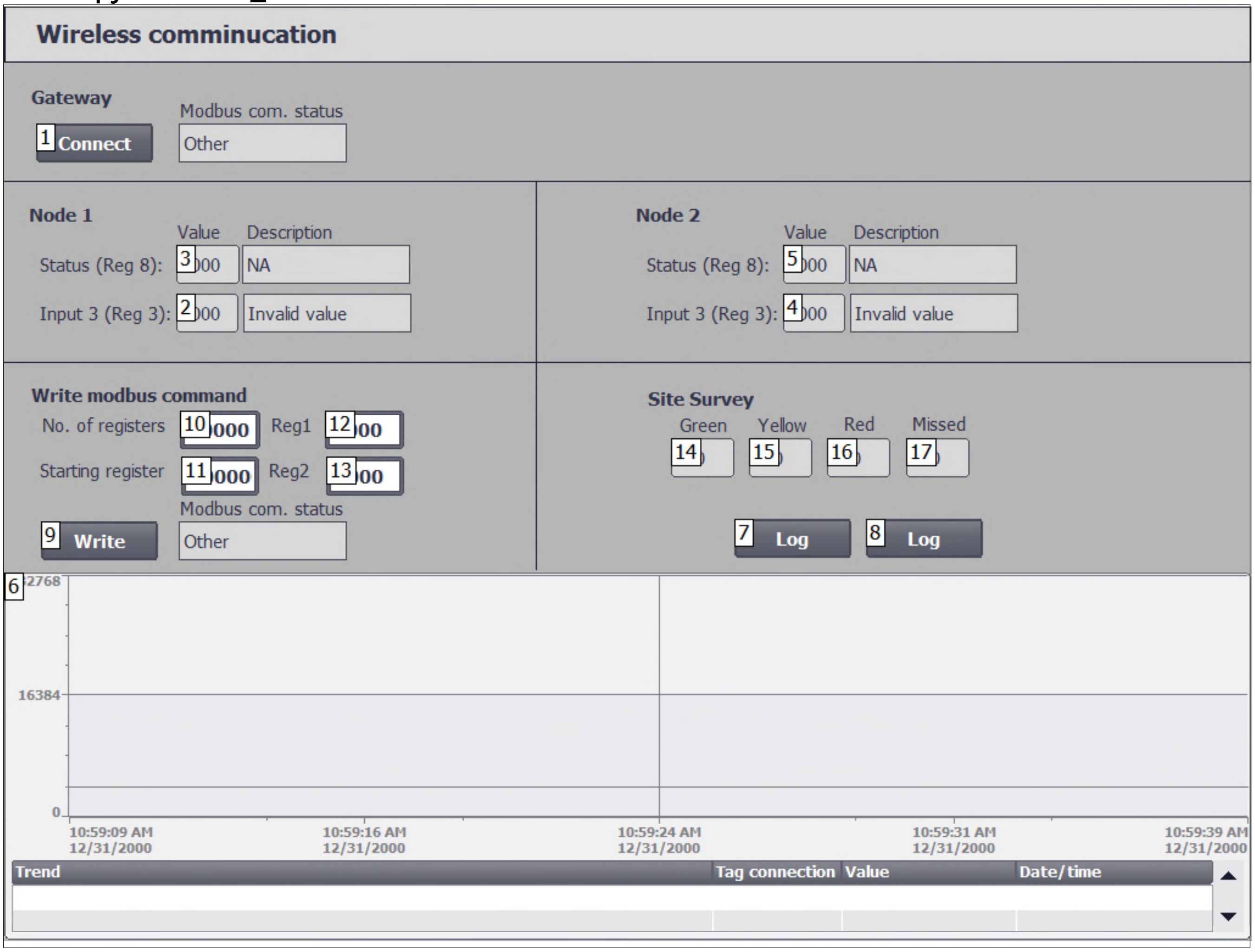
Modbus Properties					
General					
Name	Modbus	**Number**	1	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Start value	Retain
▼ Static			
▼ CONNECT1	TCON_IP_v4		False
InterfaceId	HW_ANY	64	False
ID	CONN_OUC	1	False
ConnectionType	Byte	11	False
ActiveEstablished	Bool	TRUE	False
▼ RemoteAddress	IP_V4		False
▼ ADDR	Array[1..4] of Byte		False
ADDR[1]	Byte	192	False
ADDR[2]	Byte	168	False
ADDR[3]	Byte	0	False
ADDR[4]	Byte	5	False
RemotePort	UInt	502	False
LocalPort	UInt	0	False
▼ CON_1	Struct		False
DISCONNECT	Bool	0	False
MODE	USInt	0	False
DATA_ADDR	UDInt	40001	False
DATA_LEN	UInt	48	False
DONE	Bool	false	False
BUSY	Bool	false	False
ERROR	Bool	false	False
STATUS	Int	0	False
▼ CONNECT2	TCON_IP_v4		False
InterfaceId	HW_ANY	64	False
ID	CONN_OUC	2	False
ConnectionType	Byte	11	False
ActiveEstablished	Bool	TRUE	False
▼ RemoteAddress	IP_V4		False
▼ ADDR	Array[1..4] of Byte		False
ADDR[1]	Byte	192	False
ADDR[2]	Byte	168	False
ADDR[3]	Byte	0	False
ADDR[4]	Byte	5	False
RemotePort	UInt	502	False
LocalPort	UInt	0	False
▼ CON_2	Struct		False
DISCONNECT	Bool	0	False

Name	Data type	Start value	Retain
MODE	USInt	1	False
DATA_ADDR	UDInt	40015	False
DATA_LEN	UInt	1	False
DONE	Bool	false	False
BUSY	Bool	false	False
ERROR	Bool	false	False
STATUS	Int	0	False
WRITE	Bool	false	False

Screen_1

Hardcopy of Screen_1



Name	Screen_1	**Background color**	182, 182, 182
Grid color	0, 0, 0	**Number**	1
Template		**Tooltip**	

Text field_1

Type	Text field	**Name**	Text field_1
X position	23	**Y position**	8
Width	252	**Height**	28
Layer	0 - Layer_0	**Font**	Tahoma, 20px, style=Bold
Text	Wireless comminucation		

Text field_2

Type	Text field	**Name**	Text field_2
X position	19	**Y position**	63
Width	71	**Height**	22
Layer	0 - Layer_0	**Font**	Tahoma, 15px, style=Bold
Text	Gateway		

Appendix E

Torque Wrench PLC User Program

To keep appendix short, only selected pages containing self programmed code has been attached.

TW_rev002 / PLC_1 [CPU 1511-1 PN] / Program blocks / TW_simulator

TW_simulator [FB3]

TW_simulator Properties					
General					
Name	TW_simulator	**Number**	3	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

TW_simulator			
Name	**Data type**	**Default value**	**Retain**
▼ Input			
MakeUpSignal	Bool	false	Non-retain
BreakOutSignal	Bool	false	Non-retain
ClampOnSignal	Bool	false	Non-retain
ClampOffSignal	Bool	false	Non-retain
ClampEnableSignal	Bool	false	Non-retain
▼ Output			
MakeUpPressure	Int	0	Non-retain
MakeUpEnd	Bool	false	Non-retain
BreakOutEnd	Bool	false	Non-retain
ClampOnPressure	Int	0	Non-retain
ClampOffEnd1	Bool	false	Non-retain
ClampOffEnd2	Bool	false	Non-retain
InOut			
▼ Static			
TorquePos	Int	0	Non-retain
TorqueCountTrigger	Bool	false	Non-retain
▼ R_TRIG_Instance_Torque	R_TRIG		
▼ Input			
CLK	Bool	false	Non-retain
▼ Output			
Q	Bool	false	Non-retain
InOut			
▼ Static			
Stat_Bit	Bool	false	Non-retain
ClampPos	Int	0	Non-retain
ClampCountTrigger	Bool	false	Non-retain
▼ R_TRIG_Instance_Clamp	R_TRIG		
▼ Input			
CLK	Bool	false	Non-retain
▼ Output			
Q	Bool	false	Non-retain
InOut			
▼ Static			
Stat_Bit	Bool	false	Non-retain
Temp			

Name	Data type	Default value	Retain
Constant			

```
//Check if clock changed
#R_TRIG_Instance_Torque(CLK:= "Clock_2Hz",
         Q=>#TorqueCountTrigger);

#R_TRIG_Instance_Clamp(CLK := "Clock_2Hz",
             Q => #ClampCountTrigger);

//Act on input
//MakeUp, Check cylinder pos, Only count up on clock ticks
IF (#MakeUpSignal = TRUE) AND (#BreakOutSignal = FALSE) AND (#TorquePos < 100) AND (#TorqueCountTrigger = TRUE) THEN
  #TorquePos := #TorquePos + 10;
END_IF;

//BreakOut, Check cylinder pos, Only count up on clock ticks
IF (#BreakOutSignal = TRUE) AND (#MakeUpSignal = FALSE) AND (#TorquePos > 0) AND (#TorqueCountTrigger = TRUE) THEN
  #TorquePos := #TorquePos - 10;
END_IF;

//ClampOn, Check cylinder pos, Only count up on clock ticks
IF (#ClampOnSignal = TRUE) AND (#ClampEnableSignal = TRUE) AND (#ClampOffSignal = FALSE) AND (#ClampPos < 100) AND (#ClampCountTrigger = TRUE) THEN
  #ClampPos := #ClampPos + 20;
END_IF;

//ClampOff, Check cylinder pos, Only count up on clock ticks
IF (#ClampOffSignal = TRUE) AND (#ClampOnSignal = FALSE) AND (#ClampPos > 0) AND (#ClampCountTrigger = TRUE) THEN
  #ClampPos := #ClampPos - 20;
END_IF;

//Pressure
IF #MakeUpSignal THEN
  // Statement section IF
  #MakeUpPressure := 200;
ELSE
  #MakeUpPressure := 0;
END_IF;

IF #ClampOnSignal AND #ClampEnableSignal THEN
  // Statement section IF
  #ClampOnPressure := 200;
ELSE
  #ClampOnPressure := 0;
END_IF;

//End position
IF #TorquePos <= 0 THEN
  // Statement section IF
  #BreakOutEnd := TRUE;
ELSE
  #BreakOutEnd := FALSE; //FALSE
END_IF;

IF #TorquePos >= 100 THEN
```

```
  // Statement section IF
  #MakeUpEnd := TRUE; //FALSE
ELSE
  #MakeUpEnd := FALSE;
END_IF;

IF #ClampPos <= 0 THEN
  // Statement section IF
  #ClampOffEnd1 := TRUE;
  #ClampOffEnd2 := TRUE;
ELSE
  #ClampOffEnd1 := FALSE;
  #ClampOffEnd2 := FALSE;
END_IF;

```

TW_rev002 / PLC_1 [CPU 1511-1 PN] / Program blocks / TW

TW_01 [FB4]

TW_01 Properties					
General					
Name	TW_01	**Number**	4	**Type**	FB
Language	FBD	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

TW_01			
Name	**Data type**	**Default value**	**Retain**
Input			
Output			
InOut			
▼ Static			
iMode	Int	0	Non-retain
▼ sManualOutput	Struct		Non-retain
bClampOff	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
▼ sAutoSeqActivate	Struct		Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
▼ sSubSeqActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
▼ sSubSeqVerification	Struct		Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
▼ sAutoSeqVerification	Struct		Non-retain
bBreakOut	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
▼ sSubSeqOutput	Struct		Non-retain
bClampOff	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain
▼ TW_BreakOut_Instance	"TW_BreakOut"		
▼ Input			
bActive	Bool	false	Non-retain
bEndStopMakeUp	Bool	false	Non-retain

Name	Data type	Default value	Retain
bEndStopBreakOut	Bool	false	Non-retain
▼ Output			
bBreakOut	Bool	false	Non-retain
bBreakOutVerified	Bool	false	Non-retain
InOut			
▼ Static			
iState	Int	0	Non-retain
▼ TW_MakeUp_Instance	"TW_MakeUp"		
▼ Input			
bActive	Bool	false	Non-retain
bEndStopMakeUp	Bool	false	Non-retain
bEndStopBreakOut	Bool	false	Non-retain
▼ Output			
bMakeUp	Bool	false	Non-retain
bMakeUpVerified	Bool	false	Non-retain
InOut			
▼ Static			
iState	Int	0	Non-retain
▼ TW_ClampOff_Instance	"TW_ClampOff"		
▼ Input			
bActive	Bool	false	Non-retain
bEndStop1	Bool	false	Non-retain
bEndStop2	Bool	false	Non-retain
iPressureClampOn	Int	0	Non-retain
▼ Output			
bClampOff	Bool	false	Non-retain
bClampOffVerified	Bool	false	Non-retain
bAlarm	Bool	false	Non-retain
InOut			
▼ Static			
tTimeClampOff	Time	T#5s	Non-retain
tTimerTime	Time	T#0ms	Non-retain
bTimerOn	Bool	false	Non-retain
bTimerStatus	Bool	false	Non-retain
iState	Int	0	Non-retain
▼ IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
▼ TW_ClampOn_Instance	"TW_ClampOn"		
▼ Input			
bActive	Bool	false	Non-retain
bEndStop1	Bool	false	Non-retain
bEndStop2	Bool	false	Non-retain
iPressureClampOn	Int	0	Non-retain
▼ Output			
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain

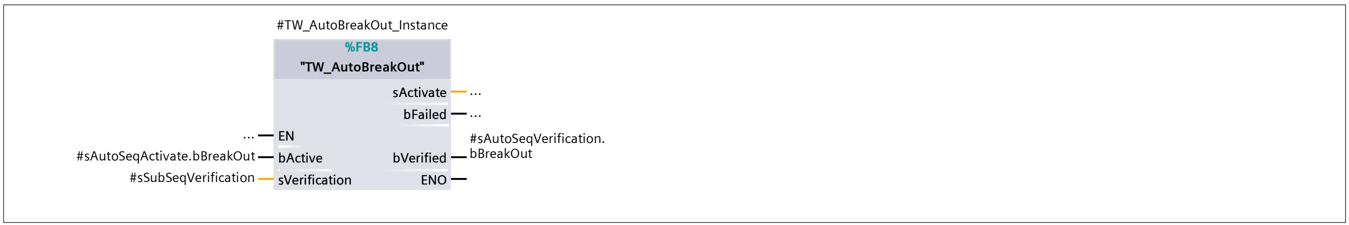
Name	Data type	Default value	Retain
bClampOnVerified	Bool	false	Non-retain
bAlarm	Bool	false	Non-retain
InOut			
Static			
tTimeClampOn	Time	T#5s	Non-retain
tTimerTime	Time	T#0ms	Non-retain
bTimerOn	Bool	false	Non-retain
bTimerStatus	Bool	false	Non-retain
iState	Int	0	Non-retain
IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
TW_AutoBreakOut_Instance	"TW_AutoBreak-Out"		
Input			
bActive	Bool	false	Non-retain
sVerification	Struct		Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
Output			
sActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bFailed	Bool	false	Non-retain
bVerified	Bool	false	Non-retain
InOut			
Static			
iState	Int	0	Non-retain
bClampTimerOn	Bool	false	Non-retain
bClampTimerStatus	Bool	false	Non-retain
bBreakCheckTimerOn	Bool	false	Non-retain
bBreakCheckTimerStatus	Bool	false	Non-retain
IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
IEC_Timer_0_Instance_1	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
TW_OutputController_Instance	"TW_OutputController"		

Name	Data type	Default value	Retain
Input			
Mode	Int	0	Non-retain
sSubSeqActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
sSubSeqOutput	Struct		Non-retain
bClampOff	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain
sManualOutput	Struct		Non-retain
bClampOff	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
Output			
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain
InOut			
Static			
TW_AutoMakeUp_Instance	"TW_AutoMakeUp"		
Input			
bActive	Bool	false	Non-retain
sVerification	Struct		Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
Output			
sActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bVerified	Bool	false	Non-retain
iAttempt	Int	0	Non-retain
InOut			
Static			
iState	Int	0	Non-retain
bClampTimerOn	Bool	false	Non-retain
bClampTimerStatus	Bool	false	Non-retain
bMakeCheckTimerOn	Bool	false	Non-retain
bMakeCheckTimerStatus	Bool	false	Non-retain

Name	Data type	Default value	Retain
▼ IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
▼ IEC_Timer_0_Instance_1	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
Temp			
Constant			

Network 1:

Auto sequence for break out

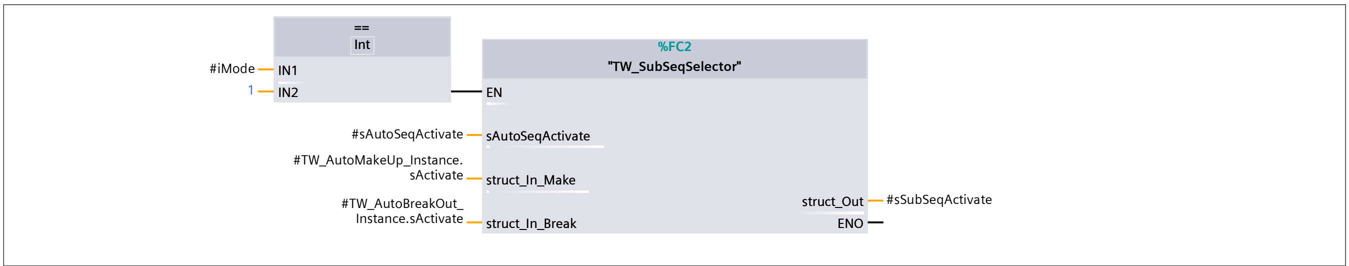


Network 2:

Auto sequence for make up

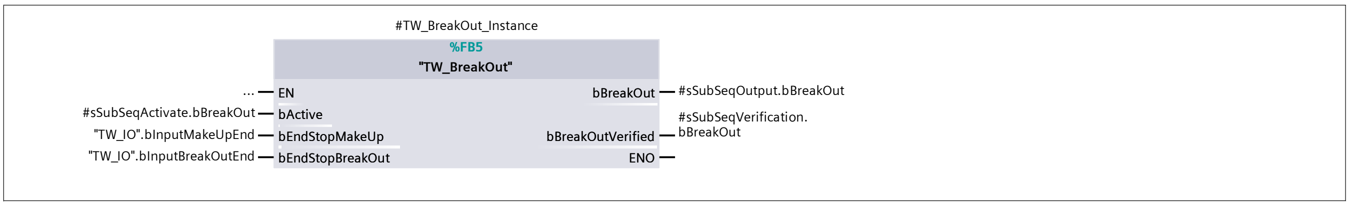
Network 3:

Selecting what autosequence to read results from



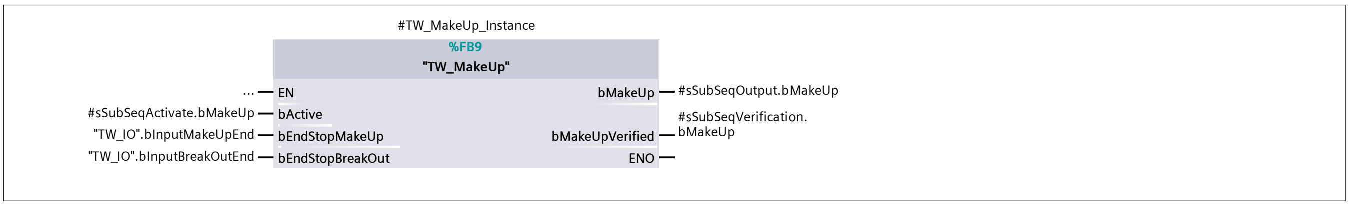
Network 4:

Break out sub sequence



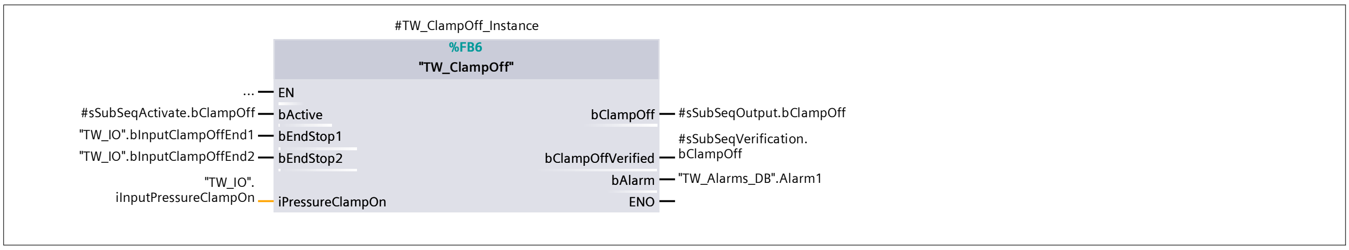
Network 5:

Make up sub sequence



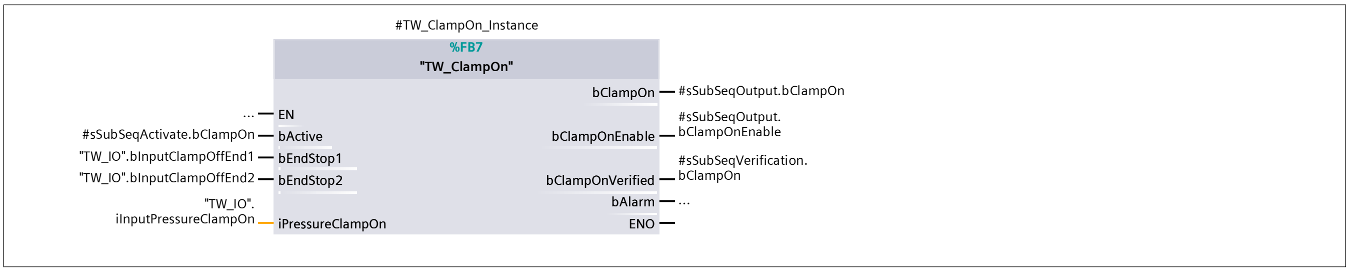
Network 6:

Clamp off sub sequence



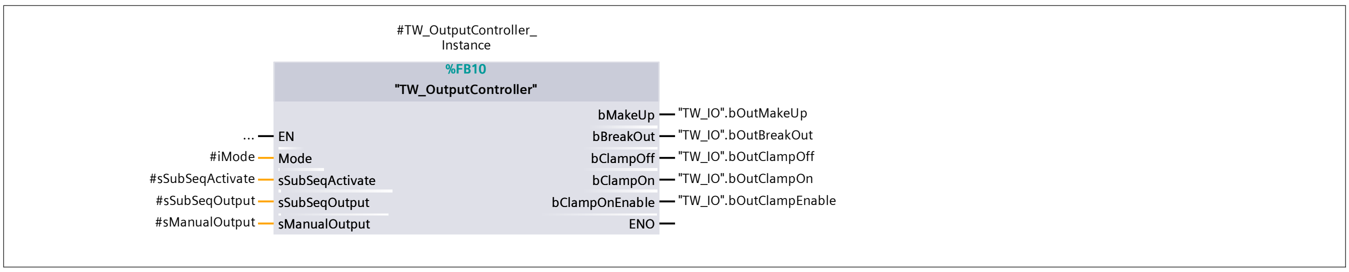
Network 7:

clamp on sub sequence



Network 8:

Controller for setting the correct outbout denooending on operational mode and active sequences



TW_AutoBreakOut [FB8]

TW_AutoBreakOut Properties					
General					
Name	TW_AutoBreakOut	**Number**	8	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
Input			
bActive	Bool	false	Non-retain
sVerification	Struct		Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
Output			
sActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bFailed	Bool	false	Non-retain
bVerified	Bool	false	Non-retain
InOut			
Static			
iState	Int	0	Non-retain
bClampTimerOn	Bool	false	Non-retain
bClampTimerStatus	Bool	false	Non-retain
bBreakCheckTimerOn	Bool	false	Non-retain
bBreakCheckTimerStatus	Bool	false	Non-retain
IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
IEC_Timer_0_Instance_1	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
Temp			
Constant			
tClampTime	Time	T#3s	
tBreakCheckTime	Time	T#10s	

```
//Sequence for Break out only

```

```
IF NOT #bActive THEN //If function is run but no Active signal, the stae should be 0. An nothing else happens
  #iState := 0;
  #bVerified := FALSE;
ELSE                 //If Active signal is true, the sequence starts to run
  #iState := #iState;

  //State structure
  CASE #iState OF

    0:  // Step 0
      IF #bActive THEN //Go to next state and reset activation bits
        #iState += 1;
        #sActivate.bBreakOut := FALSE;
        #sActivate.bClampOff := FALSE;
        #sActivate.bClampOn := FALSE;
        #sActivate.bMakeUp := FALSE;
        #bClampTimerOn := FALSE;
        #bClampTimerStatus := FALSE;
        #bBreakCheckTimerOn := FALSE;
        #bBreakCheckTimerStatus := FALSE;
        #bFailed := FALSE;
      END_IF;

    1:  // Step1
      #sActivate.bClampOff := TRUE;
      #iState += 1;

    2:  // Step2
      IF #sVerification.bClampOff = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bClampOff := FALSE;
        #iState += 1;
      END_IF;

    3:  // Step3
      #sActivate.bMakeUp := TRUE;
      #iState += 1;

    4:  // Step4
      IF #sVerification.bMakeUp = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bMakeUp := FALSE;
        #iState += 1;
      END_IF;

    5:  // Step5
      #sActivate.bClampOn := TRUE;
      #bClampTimerOn := TRUE;
      #iState += 1;

    6:  // Step6
      IF (#sVerification.bClampOn OR #bClampTimerStatus) = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bBreakOut := TRUE;
        #bClampTimerOn := FALSE;
        #bBreakCheckTimerOn := TRUE;
        #iState += 1;
      END_IF;
```

```
    7:  // Step7
      IF #sVerification.bBreakOut = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bClampOn := FALSE;
        #sActivate.bBreakOut := FALSE;
        #bBreakCheckTimerOn := FALSE;
        #iState += 1;
      ELSE
        IF #bBreakCheckTimerStatus = TRUE THEN
          #sActivate.bClampOn := FALSE;
          #sActivate.bBreakOut := FALSE;
          #bBreakCheckTimerOn := FALSE;
          #bFailed := TRUE;
          #iState += 1;
        END_IF;

      END_IF;

    8:  // Step8
      #sActivate.bClampOff := TRUE;
      #iState += 1;

    9:  // Step9
      IF #sVerification.bClampOff = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bClampOff := FALSE;
        #bVerified := TRUE;
        (* #iState += 1; *)
      END_IF;

    ELSE  // Statement section ELSE
      ;
  END_CASE;

  //Step5-6 Overlap timer
  #IEC_Timer_0_Instance(IN:=#bClampTimerOn,
              PT:=#tClampTime,
              Q=>#bClampTimerStatus);

  //Step 7 break out check timer
    #IEC_Timer_0_Instance_1(IN := #bBreakCheckTimerOn,
              PT := #tBreakCheckTime,
              Q => #bBreakCheckTimerStatus);



END_IF;
```

TW_AutoMakeUp [FB11]

TW_AutoMakeUp Properties					
General					
Name	TW_AutoMakeUp	**Number**	11	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
bActive	Bool	false	Non-retain
▼ sVerification	Struct		Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
▼ Output			
▼ sActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bVerified	Bool	false	Non-retain
iAttempt	Int	0	Non-retain
InOut			
▼ Static			
iState	Int	0	Non-retain
bClampTimerOn	Bool	false	Non-retain
bClampTimerStatus	Bool	false	Non-retain
bMakeCheckTimerOn	Bool	false	Non-retain
bMakeCheckTimerStatus	Bool	false	Non-retain
▼ IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
▼ IEC_Timer_0_Instance_1	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
Temp			
▼ Constant			
tClampTime	Time	T#3s	
tMakeCheckTime	Time	T#10s	


```
0001 //Sequence Auto Make Up
0002
```

```
IF NOT #bActive THEN //If function is run but no Active signal, the stae should be 0. An nothing else happens
  #iState := 0;
  #iAttempt := 0;
  #bVerified := FALSE;
ELSE                     //If Active signal is true, the sequence starts to run
  #iState := #iState;

  //State structure
  CASE #iState OF

    0:  // Step 0
      IF #bActive THEN //Go to next state and initialize internal stat
        #iState += 1;
        #sActivate.bBreakOut := FALSE;
        #sActivate.bClampOff := FALSE;
        #sActivate.bClampOn := FALSE;
        #sActivate.bMakeUp := FALSE;
        #bClampTimerOn := FALSE;
        #bClampTimerStatus := FALSE;
        #bMakeCheckTimerOn := FALSE;
        #bMakeCheckTimerStatus := FALSE;
      END_IF;

    1:  // Step1
      #sActivate.bClampOff := TRUE;
      #iState += 1;
      #iAttempt += 1;

    2:  // Step2
      IF #sVerification.bClampOff = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bClampOff := FALSE;
        #iState += 1;
      END_IF;

    3:  // Step3
      #sActivate.bBreakOut := TRUE;
      #iState += 1;

    4:  // Step4
      IF #sVerification.bBreakOut = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bBreakOut := FALSE;
        #iState += 1;
      END_IF;

    5:  // Step5
      #sActivate.bClampOn := TRUE;
      #bClampTimerOn := TRUE;
      #iState += 1;

    6:  // Step6
      IF (#sVerification.bClampOn OR #bClampTimerStatus) = TRUE THEN
        #sActivate.bMakeUp := TRUE;
        #bClampTimerOn := FALSE;
        #bMakeCheckTimerOn := TRUE;
        #iState += 1;
      END_IF;
```

```

    7:  // Step7
      IF #sVerification.bMakeUp = TRUE THEN
        #sActivate.bClampOn := FALSE;
        #sActivate.bBreakOut := FALSE;
        #bMakeCheckTimerOn := FALSE;
        #sActivate.bMakeUp := FALSE;
        #iState := 0; //Restart sequence if hitting endstop
      ELSE
        IF #bMakeCheckTimerStatus = TRUE THEN
          #sActivate.bClampOn := FALSE;
          #sActivate.bMakeUp := FALSE;
          #sActivate.bBreakOut := FALSE;
          #bMakeCheckTimerOn := FALSE;
          #iState += 1;
        END_IF;

      END_IF;

    8:  // Step8
      #sActivate.bClampOff := TRUE;
      #iState += 1;

    9:  // Step9
      IF #sVerification.bClampOff = TRUE THEN //Wait for clamp off verification bit
        #sActivate.bClampOff := FALSE;
        #bVerified := TRUE;
      END_IF;

    ELSE  // Statement section ELSE
      ;
  END_CASE;

  //Step5-6 Overlap timer
  #IEC_Timer_0_Instance(IN:=#bClampTimerOn,
              PT:=#tClampTime,
              Q=>#bClampTimerStatus);

  //Step 7 break out check timer
    #IEC_Timer_0_Instance_1(IN := #bMakeCheckTimerOn,
              PT := #tMakeCheckTime,
              Q => #bMakeCheckTimerStatus);



END_IF;



```

TW_BreakOut [FB5]

TW_BreakOut Properties					
General					
Name	TW_BreakOut	**Number**	5	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
bActive	Bool	false	Non-retain
bEndStopMakeUp	Bool	false	Non-retain
bEndStopBreakOut	Bool	false	Non-retain
▼ Output			
bBreakOut	Bool	false	Non-retain
bBreakOutVerified	Bool	false	Non-retain
InOut			
▼ Static			
iState	Int	0	Non-retain
Temp			
Constant			

```
//Sequence for Break out only

IF NOT #bActive THEN //If function is run but no Active signal, the stae should be 0. An nothing else happens
  #iState := 0;
  #bBreakOutVerified := False;
  #bBreakOut := FALSE;
ELSE                 //If Active signal is true, the sequence starts to run
  #iState := #iState;

  //State structure
  CASE #iState OF

    0:  // Step 0
      IF #bActive THEN //Go to next state and reset verification bits
        #iState += 1;
      END_IF;

    1:  // Step1
      #bBreakOut := TRUE;
      #iState += 1;
      "TW_Check1_MakeBreak"();

    2:  // Step2
      IF #bEndStopBreakOut THEN //If in endstop position, go to next step
        #iState += 1;
      END_IF;

    3:  // Step3
      #bBreakOut := FALSE;
```

```
      #bBreakOutVerified := TRUE;
      "TW_Check1_MakeBreak"();

    ELSE  // Statement section ELSE
      ;
  END_CASE;

END_IF;
```

TW_ClampOff [FB6]

TW_ClampOff Properties					
General					
Name	TW_ClampOff	**Number**	6	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
bActive	Bool	false	Non-retain
bEndStop1	Bool	false	Non-retain
bEndStop2	Bool	false	Non-retain
iPressureClampOn	Int	0	Non-retain
▼ Output			
bClampOff	Bool	false	Non-retain
bClampOffVerified	Bool	false	Non-retain
bAlarm	Bool	false	Non-retain
InOut			
▼ Static			
tTimeClampOff	Time	T#5s	Non-retain
tTimerTime	Time	T#0ms	Non-retain
bTimerOn	Bool	false	Non-retain
bTimerStatus	Bool	false	Non-retain
iState	Int	0	Non-retain
▼ IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
Temp			
Constant			

```
//Sequence for Clamp Off only

IF NOT #bActive THEN //If function is run but no Active signal, the stae should be 0. An nothing else happens
  #iState := 0;
  #bClampOffVerified := False;
  #bClampOff := FALSE;

ELSE                    //If Active signal is true, the sequence starts to run
  #iState := #iState;

  CASE #iState OF

    0:  // Step 0
      IF #bActive THEN //Go to next state and reset verification bits and timer
        #iState += 1;
        #bTimerOn := FALSE;
```

```
        #bTimerStatus := FALSE;
        #bAlarm := FALSE;
      END_IF;

    1:  // Step1
      #bClampOff := TRUE;
      #bTimerOn := TRUE;
      #iState += 1;

    2:  // Step2
      IF (#bEndStop1 & #bEndStop2) = TRUE & #iPressureClampOn < 18 THEN //If in endstop position, go to next step
        #iState += 1;
      ELSE //Acts as Step 4
        IF #bTimerStatus = TRUE THEN
          #bClampOffVerified := FALSE;
          #bClampOff := FALSE;
          "TW_Check2_Clamp"();
          #bAlarm := TRUE;
        END_IF;
      END_IF;

    3:  // Step3
      #bClampOff := FALSE;
      #bClampOffVerified := TRUE;

    ELSE  // Statement section ELSE
      ;
  END_CASE;

  //Timer
  #IEC_Timer_0_Instance(IN := #bTimerOn,
              PT := #tTimeClampOff,
              Q => #bTimerStatus,
              ET => #tTimerTime);

END_IF;
```

TW_ClampOn [FB7]

TW_ClampOn Properties					
General					
Name	TW_ClampOn	**Number**	7	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
bActive	Bool	false	Non-retain
bEndStop1	Bool	false	Non-retain
bEndStop2	Bool	false	Non-retain
iPressureClampOn	Int	0	Non-retain
▼ Output			
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain
bClampOnVerified	Bool	false	Non-retain
bAlarm	Bool	false	Non-retain
InOut			
▼ Static			
tTimeClampOn	Time	T#5s	Non-retain
tTimerTime	Time	T#0ms	Non-retain
bTimerOn	Bool	false	Non-retain
bTimerStatus	Bool	false	Non-retain
iState	Int	0	Non-retain
▼ IEC_Timer_0_Instance	TON_TIME		Non-retain
PT	Time	T#0ms	Non-retain
ET	Time	T#0ms	Non-retain
IN	Bool	false	Non-retain
Q	Bool	false	Non-retain
Temp			
▼ Constant			
tCheckTime1	Time	T#500ms	
tCheckTime2	Time	T#2000ms	

```
//Sequence for Clamp Off only

IF NOT #bActive THEN //If function is run but no Active signal, the stae
should be 0. An nothing else happens
  #iState := 0;
  #bClampOnVerified := FALSE;
  #bClampOn := FALSE;
  #bClampOnEnable := FALSE;
ELSE                     //If Active signal is true, the sequence starts to run
  #iState := #iState;

  CASE #iState OF

    0:  // Step 0
```

```
      IF #bActive THEN //Go to next state and reset verification bits and timer
        #iState += 1;
        #bTimerOn := FALSE;
        #bTimerStatus := FALSE;
        #bAlarm := FALSE;
      END_IF;

    1:  // Step1
      #bClampOn := TRUE;
      #bTimerOn := TRUE;
      #iState += 1;

    2:  // Step2
      IF #tTimerTime >= #tCheckTime1 THEN //If check time then run checks
        "TW_Check3_EnableClosed"();
        #iState += 1; //next step if no fault found
      END_IF;

    3:  // Step3
      #bClampOnEnable := TRUE;
      #iState += 1;

    4:  // Step4
      IF #tTimerTime >= #tCheckTime2 THEN //If check time then run checks
        "TW_Check4_EnableOpen"();
        "TW_Check2_Clamp"();
        #iState += 1; //next step if no fault found
      END_IF;

     5:  // Step5
     IF #bTimerStatus = TRUE THEN
       #bClampOnVerified := TRUE;
     END_IF;

    ELSE  // Statement section ELSE
      ;
  END_CASE;

  //Timer
  #IEC_Timer_0_Instance(IN := #bTimerOn,
              PT := #tTimeClampOn,
              Q => #bTimerStatus,
              ET => #tTimerTime);

END_IF;
```

TW_MakeUp [FB9]

TW_MakeUp Properties					
General					
Name	TW_MakeUp	**Number**	9	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
bActive	Bool	false	Non-retain
bEndStopMakeUp	Bool	false	Non-retain
bEndStopBreakOut	Bool	false	Non-retain
▼ Output			
bMakeUp	Bool	false	Non-retain
bMakeUpVerified	Bool	false	Non-retain
InOut			
▼ Static			
iState	Int	0	Non-retain
Temp			
Constant			

```
//Sequence for Break out only

IF NOT #bActive THEN //If function is run but no Active signal, the stae should be 0. An nothing else happens
  #iState := 0;
  #bMakeUpVerified := False;
  #bMakeUp := FALSE;

ELSE //If Active signal is true, the sequence starts to run
  #iState := #iState;

  //State structure
  CASE #iState OF

    0:  // Step 0
      IF #bActive THEN //Go to next state and reset verification bits
        #iState += 1;
      END_IF;

    1:  // Step1
      #bMakeUp := TRUE;
      #iState += 1;
      "TW_Check1_MakeBreak"();

    2:  // Step2
      IF #bEndStopMakeUp THEN //If in endstop position, go to next step
        #iState += 1;
      END_IF;

    3:  // Step3
```

```
        #bMakeUp := FALSE;
        #bMakeUpVerified := TRUE;
        "TW_Check1_MakeBreak"();

      ELSE  // Statement section ELSE
        ;
    END_CASE;

END_IF;
```

TW_OutputController [FB10]

TW_OutputController Properties					
General					
Name	TW_OutputController	**Number**	10	**Type**	FB
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
Mode	Int	0	Non-retain
▼ sSubSeqActivate	Struct		Non-retain
bClampOff	Bool	False	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
▼ sSubSeqOutput	Struct		Non-retain
bClampOff	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain
▼ sManualOutput	Struct		Non-retain
bClampOff	Bool	false	Non-retain
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
▼ Output			
bMakeUp	Bool	false	Non-retain
bBreakOut	Bool	false	Non-retain
bClampOff	Bool	false	Non-retain
bClampOn	Bool	false	Non-retain
bClampOnEnable	Bool	false	Non-retain
InOut			
Static			
Temp			
Constant			

```


CASE #Mode OF
  0:  // Manual mode
    #bMakeUp := #sManualOutput.bMakeUp;
    #bBreakOut := #sManualOutput.bBreakOut;
    #bClampOff := #sManualOutput.bClampOff;
    #bClampOn := #sManualOutput.bClampOn;
    #bClampOnEnable := #sManualOutput.bClampOn;

  1:  // Auto Sequence mode
    #bMakeUp := #sSubSeqOutput.bMakeUp;
```

```
    #bBreakOut := #sSubSeqOutput.bBreakOut;
    #bClampOff := #sSubSeqOutput.bClampOff;
    #bClampOn := #sSubSeqOutput.bClampOn;
    #bClampOnEnable := #sSubSeqOutput.bClampOnEnable;

  2:  // Sub seqence mode
    #bMakeUp := #sSubSeqOutput.bMakeUp;
    #bBreakOut := #sSubSeqOutput.bBreakOut;
    #bClampOff := #sSubSeqOutput.bClampOff;
    #bClampOn := #sSubSeqOutput.bClampOn;
    #bClampOnEnable := #sSubSeqOutput.bClampOnEnable;

  ELSE  // Statement section ELSE
    #bMakeUp := 0;
    #bBreakOut := 0;
    #bClampOff := 0;
    #bClampOn := 0;
    #bClampOnEnable := 0;

END_CASE;

```

TW_SubSeqSelector [FC2]

TW_SubSeqSelector Properties					
General					
Name	TW_SubSeqSelector	**Number**	2	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
sAutoSeqActivate	Struct	
bMakeUp	Bool	
bBreakOut	Bool	
struct_In_Make	Struct	
bClampOff	Bool	
bMakeUp	Bool	
bBreakOut	Bool	
bClampOn	Bool	
struct_In_Break	Struct	
bClampOff	Bool	
bMakeUp	Bool	
bBreakOut	Bool	
bClampOn	Bool	
Output		
struct_Out	Struct	
bClampOff	Bool	
bMakeUp	Bool	
bBreakOut	Bool	
bClampOn	Bool	
InOut		
Temp		
Constant		
Return		
TW_SubSeqSelector	Void	

```
IF #sAutoSeqActivate.bMakeUp = #sAutoSeqActivate.bBreakOut THEN
  #struct_Out.bClampOff := FALSE;
  #struct_Out.bMakeUp := FALSE;
  #struct_Out.bBreakOut := FALSE;
  #struct_Out.bClampOn := FALSE;
ELSE
  IF #sAutoSeqActivate.bMakeUp = TRUE THEN
    #struct_Out := #struct_In_Make;
  END_IF;
  IF #sAutoSeqActivate.bBreakOut = TRUE THEN
    #struct_Out := #struct_In_Break;
  END_IF;
END_IF;
```

AlarmCompiler [FC3]

AlarmCompiler Properties					
General					
Name	AlarmCompiler	**Number**	3	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
In1	Bool	
In2	Bool	
In3	Bool	
In4	Bool	
In5	Bool	
In6	Bool	
In7	Bool	
In8	Bool	
Output		
AlarmWord	Word	
InOut		
Temp		
Constant		
Return		
AlarmCompiler	Void	

```
IF #In1 THEN
  #AlarmWord := #AlarmWord OR W#2#0000_0001;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1111_1110;
END_IF;

IF #In2 THEN
  #AlarmWord := #AlarmWord OR W#2#0000_0010;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1111_1101;
END_IF;

IF #In3 THEN
  #AlarmWord := #AlarmWord OR W#2#0000_0100;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1111_1011;
END_IF;


IF #In4 THEN
  #AlarmWord := #AlarmWord OR W#2#0000_1000;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1111_0111;
END_IF;

IF #In5 THEN
```

```
  #AlarmWord := #AlarmWord OR W#2#0001_0000;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1110_1111;
END_IF;

IF #In6 THEN
  #AlarmWord := #AlarmWord OR W#2#0010_0000;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1101_1111;
END_IF;

IF #In7 THEN
  #AlarmWord := #AlarmWord OR W#2#0100_0000;
ELSE
  #AlarmWord := #AlarmWord AND W#2#1011_1111;
END_IF;

IF #In8 THEN
  #AlarmWord := #AlarmWord OR W#2#1000_0000;
ELSE
  #AlarmWord := #AlarmWord AND W#2#0111_1111;
END_IF;
```

TW_Check1_MakeBreak [FC1]

TW_Check1_MakeBreak Properties					
General					
Name	TW_Check1_MakeBreak	**Number**	1	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
Output		
InOut		
Temp		
Constant		
Return		
TW_Check1_MakeBreak	Void	

```
//Check that not both Torque end stop sensors are on at the same time
//

IF ("TW_IO".bInputBreakOutEnd & "TW_IO".bInputMakeUpEnd) = TRUE THEN
  "TW_Alarms_DB".Alarm3 := TRUE;
ELSE
  "TW_Alarms_DB".Alarm3 := FALSE;
END_IF;


```

TW_Check2_Clamp [FC4]

TW_Check2_Clamp Properties					
General					
Name	TW_Check2_Clamp	**Number**	4	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
Output		
InOut		
Temp		
Constant		
Return		
TW_Check2_Clamp	Void	

```
IF "TW_IO".bInputClampOffEnd1 = "TW_IO".bInputClampOffEnd2 THEN
  "TW_Alarms_DB".Alarm4 := FALSE;
ELSE
  "TW_Alarms_DB".Alarm4 := TRUE;
END_IF;
```

TW_Check3_EnableClosed [FC5]

TW_Check3_EnableClosed Properties					
General					
Name	TW_Check3_Enable-Closed	**Number**	5	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
Output		
InOut		
Temp		
Constant		
Return		
TW_Check3_EnableClosed	Void	

```
IF ("TW_IO".bInputClampOffEnd1 AND "TW_IO".bInputClampOffEnd2) = TRUE THEN
  IF "TW_IO".iInputPressureClampOn < 18 THEN
    "TW_Alarms_DB".Alarm5 := FALSE;
    "TW_Alarms_DB".Alarm6 := FALSE;
    "TW_Alarms_DB".Alarm7 := FALSE;
  ELSE
    "TW_Alarms_DB".Alarm5 := TRUE;
    "TW_Alarms_DB".Alarm6 := FALSE;
    "TW_Alarms_DB".Alarm7 := FALSE;
  END_IF;
ELSE
  IF "TW_IO".iInputPressureClampOn < 18 THEN
    "TW_Alarms_DB".Alarm5 := FALSE;
    "TW_Alarms_DB".Alarm6 := TRUE;
    "TW_Alarms_DB".Alarm7 := FALSE;
  ELSE
    "TW_Alarms_DB".Alarm5 := FALSE;
    "TW_Alarms_DB".Alarm6 := FALSE;
    "TW_Alarms_DB".Alarm7 := TRUE;
  END_IF;
END_IF;
```

TW_Check4_EnableOpen [FC6]

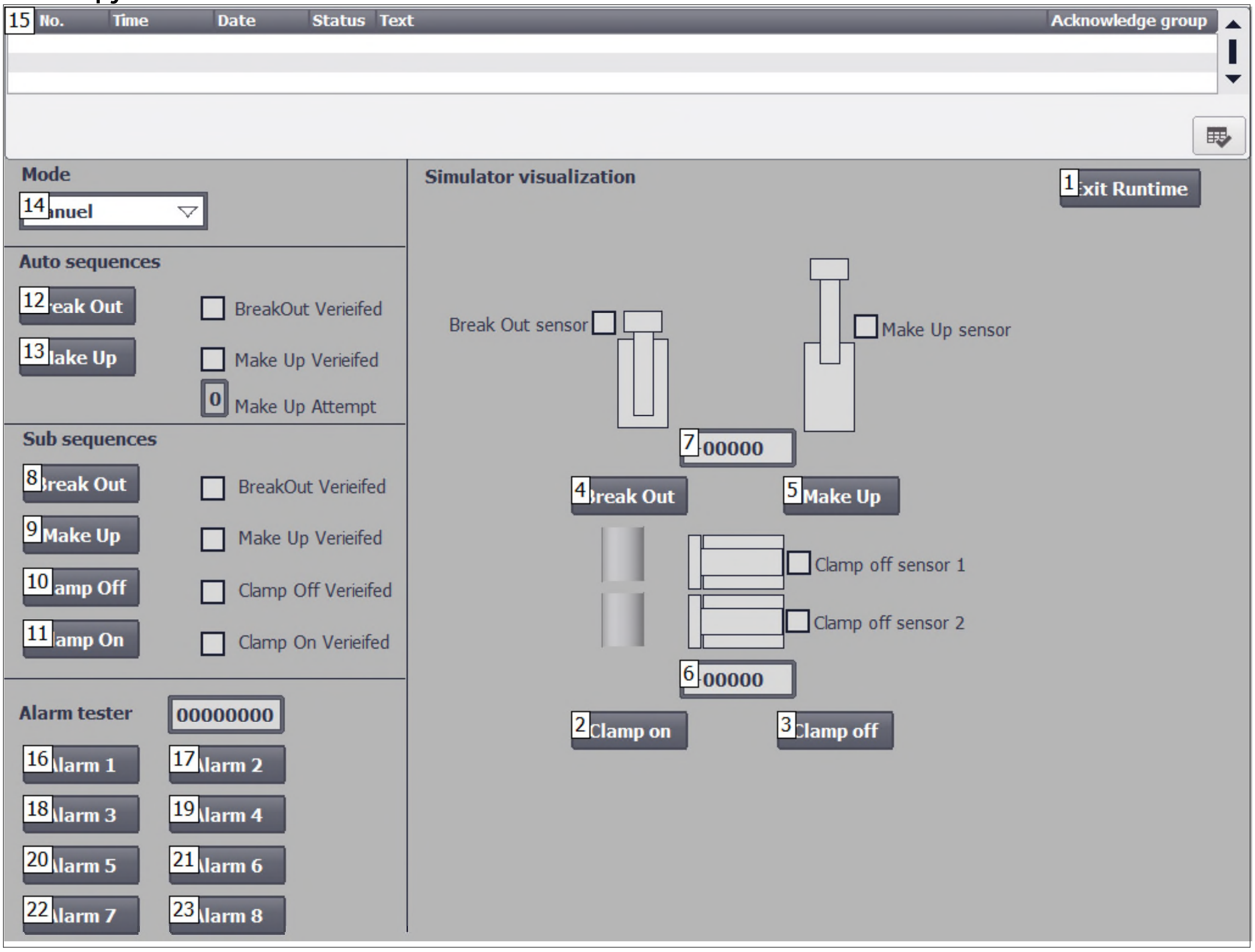
TW_Check4_EnableOpen Properties					
General					
Name	TW_Check4_EnableOpen	**Number**	6	**Type**	FC
Language	SCL	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
Output		
InOut		
Temp		
Constant		
Return		
TW_Check4_EnableOpen	Void	

```
IF NOT(("TW_IO".bInputClampOffEnd1 OR "TW_IO".bInputClampOffEnd2) = TRUE) THEN
  IF "TW_IO".iInputPressureClampOn > 18 THEN
    "TW_Alarms_DB".Alarm5 := FALSE;
    "TW_Alarms_DB".Alarm6 := FALSE;
    "TW_Alarms_DB".Alarm8 := FALSE;
  ELSE
    "TW_Alarms_DB".Alarm5 := FALSE;
    "TW_Alarms_DB".Alarm6 := TRUE;
    "TW_Alarms_DB".Alarm8 := FALSE;
  END_IF;
ELSE
  IF "TW_IO".iInputPressureClampOn > 18 THEN
    "TW_Alarms_DB".Alarm5 := TRUE;
    "TW_Alarms_DB".Alarm6 := FALSE;
    "TW_Alarms_DB".Alarm8 := FALSE;
  ELSE
    "TW_Alarms_DB".Alarm5 := FALSE;
    "TW_Alarms_DB".Alarm6 := FALSE;
    "TW_Alarms_DB".Alarm8 := TRUE;
  END_IF;
END_IF;
```

Simulation

Hardcopy of Simulation



Name	Simulation	**Background color**	182, 182, 182
Grid color	0, 0, 0	**Number**	1
Template		**Tooltip**	

Button_1

Type	Button	**Name**	Button_1
X position	866	**Y position**	133
Width	116	**Height**	32
Mode	Text	**Text OFF**	Exit Runtime
Text ON	Text		

Dynamizations\Event	
Event name	Click

Function list\StopRuntime

Mode	Runtime

Button_2

Type	Button	**Name**	Button_2
X position	465	**Y position**	579

HMI alarms

Discrete alarms

Discrete_alarm_1

Name	Discrete_alarm_1	**ID**	1
Alarm class	No Acknowledgement	**Alarm text**	Clamp Off failed
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_2

Name	Discrete_alarm_2	**ID**	2
Alarm class	No Acknowledgement	**Alarm text**	Break Out failed
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_3

Name	Discrete_alarm_3	**ID**	3
Alarm class	No Acknowledgement	**Alarm text**	Sensor discrepancy - Make/Break end stops
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_4

Name	Discrete_alarm_4	**ID**	4
Alarm class	No Acknowledgement	**Alarm text**	Sensor discrepancy - Clamp 1 and 2 end stops
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_5

Name	Discrete_alarm_5	**ID**	5
Alarm class	No Acknowledgement	**Alarm text**	Sensor discrepancy - Clamp end stops and pressure sensor
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_6

Name	Discrete_alarm_6	**ID**	6
Alarm class	No Acknowledgement	**Alarm text**	Sensor discrepancy - Clamp end stops and pressure sensor
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_7

Name	Discrete_alarm_7	**ID**	7
Alarm class	No Acknowledgement	**Alarm text**	Enable valve - Faulty open
Alarm group	<No alarm group>		

Alarm1-8

Discrete_alarm_8

Name	Discrete_alarm_8	**ID**	8
Alarm class	No Acknowledgement	**Alarm text**	Enable valve - Faulty closed
Alarm group	<No alarm group>		

Alarm1-8