COMMISSIONING A PROFINET RTG CRANE

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ABSTRACT

Electrical and Automation Engineering
Valkeakoski

Author	Roope Kujala	**Year** 2020
Title	Commissioning a Profinet RTG crane	
Supervisor(s)	Mika Oinonen	

TIIVISTELMÄ

Insinöörityön tavoitteena oli luoda sisäinen käyttöönotto-ohje Konecranesin Profinet RTG nostureille. Työn toimeksiantajana toimi Konecranes Finland Oy, joka valmistaa nostolaitteita moniin eri käyttötarkoituksiin.

Aluksi työssä käydään läpi kenttäväyliä yleisesti sekä tutustutaan nosturin rakenteeseen. Seuraavaksi perehdytään nosturiverkon vaatimuksiin ja vertaillaan Profibus ja Profinet verkkoja nosturissa. Lopuksi käydään läpi Profinet RTG nosturin käyttöönotto.

Työssä tutkittiin ensimmäistä Profinet RTG projektia, ja seurattiin sen käyttöönottoa läheisesti. Ohje kirjoitettiin käyttöönotosta saatujen tietojen perusteella sekä soveltamalla vanhojen projektien soveltuvia osuuksia.

Työn tuloksena onnistuttiin luomaan ohje Profinet RTG nosturin käyttöönoton tueksi. Ohjetta tullaan jakamaan projektista riippuen sitä tarvitseville tahoille.

Avainsanat käyttöönotto, Profibus, Profinet, RTG-nosturi

Sivut 32 sivua, joista liitteitä 0 sivua

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ABSTRACT

The goal of the thesis project was to create commissioning instructions for the Konecranes Profinet RTG cranes. The commissioning party was Konecranes Finland Oy, a manufacturer of lifting equipment for multiple different purposes.

This thesis starts by going through an overview of fieldbuses and the RTG crane structure. Next, the requirements of the crane network are reviewed and the Profibus and Profinet networks on a crane are compared. Finally, commissioning process of a Profinet RTG crane is gone through.

In this thesis project, the first Profinet RTG project was examined and its commissioning was closely followed. The instructions were written based on the information gained from the commissioning process along with applying applicable information from previous projects.

As a result, a set of instructions was created to support the commissioning process of Profinet RTG cranes. Depending on the project, the instructions will be distributed to the parties concerned.

Keywords commissioning, Profibus, Profinet, RTG-crane

Pages 32 pages including appendices 0 pages

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1 INTRODUCTION

This thesis was made for Konecranes, a world leading manufacturer of lifting equipment, serving customers on fields such as manufacturing and process industries, ports, shipyards and container terminals. As of 2019, the Konecranes corporation has 18000 employees in 50 countries with a revenue of EUR 3.3 billion (Konecranes, n.d).

The thesis focuses on one of the port cranes, an RTG, or rubber tyred gantry crane. The RTG crane combines intelligent systems with a robust construction, giving the customers means to improve their reliability and productivity while simultaneously reducing maintenance costs. (Merimaa, 2014, p. 1)

Container traffic has grown from 225 million TEU, or 20 feet equivalent units, to nearly 800 million TEU over the course of the 21st century (The World Bank Group, n.d.), which has caused an incentive to increase container handling efficiency as lowering the time spent per container saves a lot of time in the long run. In order to compete in the field, constant improvements need to be made from productivity, sustainability and safety points of view.

Konecranes RTG has evolved from Profibus communications to Profinet. The goal of this thesis is to explore both systems and implement instructions to assist commissioning Profinet RTG cranes. These instructions will be shared internally to commissioning engineers, helping them to troubleshoot more effectively on site.

2 OVERVIEW TO BUS TECHNOLOGY

After the first relays were invented in 1835, automation started to really take off (History-Computer.com, n.d.). The second world war spiced up the development of automated tools by focusing efforts on anti-aircraft guns. They require precise control, interoperability with radar and calculations to estimate the aircrafts' future positions (Bennett, 1991, p. 20). After the war it became obvious that real systems are non-linear, contain errors and are susceptible to noise. Control system development was still highly focused on warfare, specifically missile guidance in the mid-20th century (Bennett, 1991, p. 22). Only after the introduction of the digital computer steps to industrial automation started to take place in the early 1970s (Bennett, 1991, p. 23).

Another leap in technology was the replacement of pneumatic 3-15psi control signals by 4-20mA signals in the 1950s (Precision Digital Corporation, n.d.). This technology is still used today when an analog input is required, such as when measuring temperature.

PLCs were first introduced to the automotive industry in the United States in 1986 with their goal being to replace relay logic systems. PLCs started off with ladder logic, still available today, due to it being very similar to relay control. (Alton, 2014)

In the 1980s, HART or Highway Addressable Remote Transducer was introduced where a digital message was modulated on top of the 4-20mA current message (Aalto University, 2014, p. 2). Another big change was the introduction of BITBUS, Intel designed fieldbus in the early 1980s which became standardized in 1991 in IEEE-1118 (Bitbus, n.d.).

The idea of all industrial network buses is to reduce wiring costs and complexity. They are specifically designed to establish communication between PLCs and field-level sensors and actuators. Bus connections replace the point-to-point wiring requirement from sensor to the controller I/O. Another common use case is to have the I/O be remote at the factory floor level and connect it to the PLC's CPU, that is in a control cabinet, via a bus. (Werver Training and Consultancy Ltd, n.d.) In this project, the primary use case of network buses is remote I/O as it is an effective way to reduce cabling length which in turn improves the signal quality of sensors, especially analog ones.

2.1 Examining wireless possibilities

In the future wireless technologies could become more used in cranes but currently wired ethernet connections are the go-to solution. A wired ethernet has multiple benefits over the wireless one. With the Cat6 cable, theoretical speeds of up to 10Gb/s are achievable when compared to Wi-Fi's 866.7 Mb/s. Latency is also lower on wired connections and the risk of dropping connection is a lot lower as Wi-Fi tends to lose the signal every now and then. (Hoffman, 2017) Very short signal drops do not really matter when using Wi-Fi on a computer or on a phone but in a crane, the effects are instantly noticeable.

Wireless connections' latency is a major problem. It is not constant. Even if both a wired and a wireless connection would have similar minimum latency, wireless connection's latency tends to fluctuate a lot. (Palomäki, 2018) Figure 1 shows response times between 2.4 GHz, 5GHz and wired ethernet connections.

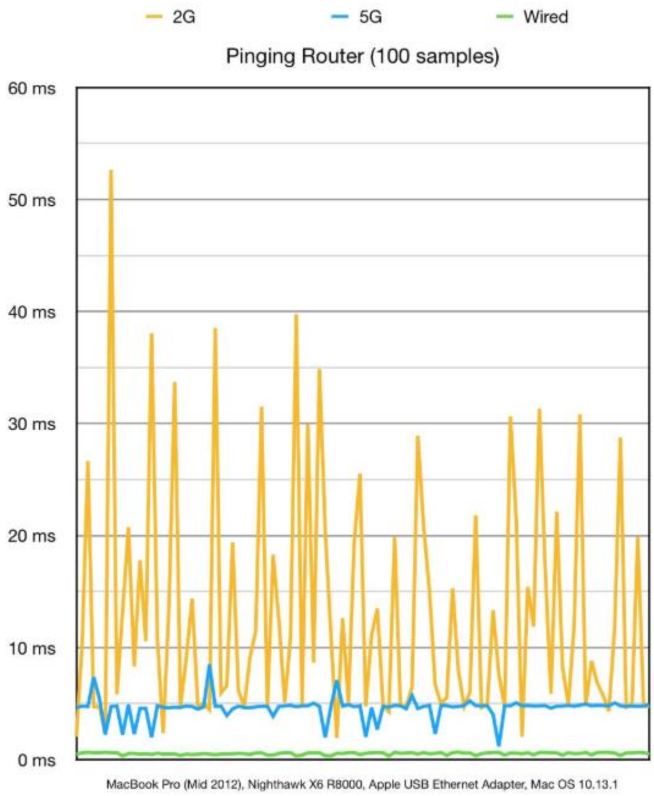

Figure 1 Wi-Fi versus wired response times (Palomäki, 2018)

PLC programs often utilize timers for many different tasks. The use case is often reading a sensor value, waiting for a specified time and activating something. Now, if the sensor is wirelessly connected, the actual time taken by the entire task from sensor to activation varies based on latency and in some cases, can prevent activation altogether.

Another issue is network congestion. 5GHz Wi-Fi has a real-world distance of around 60 meters and it does not penetrate solid objects well which the entire crane consists of (Centurylink, n.d.). This would force 2.4Ghz to be used instead, which happens to be a very congested band with routers, smartphones and many IoT devices. Adding dozens of cranes in a port to the network would not improve the situation. (Ngo, 2016)

With all the caveats listed above, it is safe to say that the current wireless technology should not be used in applications that require safety, reliability and fast response times.

2.2 Profibus DP

Profibus DP or Process Field Bus Decentralized Periphery is a data transfer protocol. It transmits data via a medium which is often RS-485 serial on shielded, twisted pair cables or optical fiber (Siemens, 2009, p. 19). Profibus DP is mostly used to connect PLCs, remote I/O and frequency converters. On the field, Profibus can be recognized by its purple cabling. (Aalto University, 2014, p. 5)

The Profibus DP network consists of master and slave devices connected to the bus. It is bi-directional in nature, which means that a master device requests a slave device which then responds. The message of the master device is broadcasted to all devices on the bus so addressing needs to take place in order for the correct slave to send its response. All Profibus network devices have an assigned address which is set via a configuration tool or mechanically by using rotary or dip switches. (ISA, n.d., p. 5) Figure 2 shows how the Profibus DP address is configured.

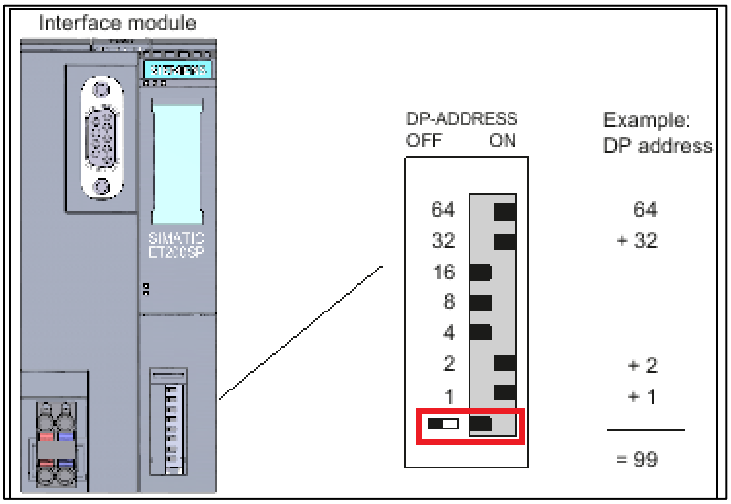

Figure 2 Configuring Profibus device address (Siemens, 2017.)

Each Profibus network can have addresses ranging from 0 to 127, however only 1-125 can be used for operational devices as 0, 126 and 127 have their own uses. (ISA, n.d., p. 5-6)

Profibus has evolved over the years. It got listed to IEC 61158 in 2000. The first iteration of Profibus is Profibus FMS (Fieldbus Message Specification) on which further versions build upon. (National Instruments Corp. 2019)

First version that is still widely used today is DPV0, which allowed communications between masters and slave devices along with diagnostic reporting. DPV1 started to support more I/O devices such as intelligent drives and many Profibus PA (Process Automation) instruments. The latest version is DPV2, which allows motion control applications through just the Profibus connection, removing the need for an additional bus. All versions are backwards compatible. (ISA, n.d., p. 5) Figure 3 shows Profibus DP extensions.

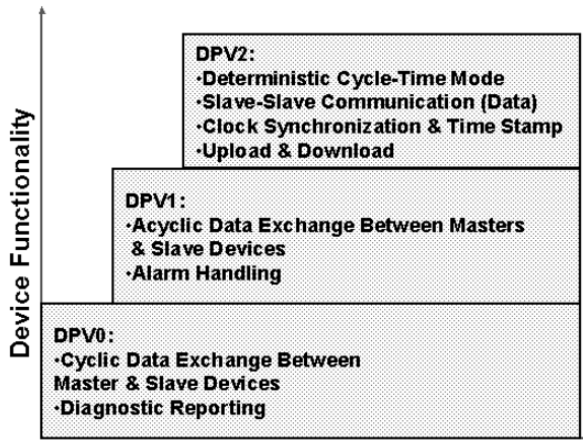

Figure 3 Profibus DP extensions (ISA, n.d., p. 3)

3 OVERVIEW TO PROFINET

3.1 General features

Profinet is a network which is used for data exchange between controllers, for example PLCs, and devices such as drives, sensors and process instruments. Three different communication channels are used in Profinet networks. These are Real-Time (RT), Non-Real-Time (NRT) and Isochronous Real-Time (IRT). (Profinet University, n.d.)

Real-Time channel aims to reduce jitter and latency, but the lack of encapsulation process prevents communication between different local area networks. Basically, this means that it uses MAC address for device communications instead of the name and IP address. RT has some delays and jitter caused by network switches. (Profinet University, n.d.)

Non-Real-Time channel has higher latency and jitter than RT but can be used to access devices across multiple different networks and even the internet. (Profinet University, n.d.)

Isochronous Real Time channel reduces the switch delays of RT by adding specific set of rules for Profinet traffic. One example is to have certain amount of bandwidth just for IRT channel while the rest allows all traffic. This bandwidth reservation can be scaled to be just enough for IRT traffic to flow through, leaving the rest for regular traffic. (Profinet University, n.d.)

Profinet nodes have three roles: Devices, Controllers and Supervisors. Devices communicate real-time information to controllers but do not communicate with other devices. Example of a device would be a sensor, a valve, an actuator or a switch. Controllers are often PLCs which read and write values to devices in real-time and collect information about them. Supervisors work in the background and have tasks about diagnostics, system configuration and troubleshooting. Supervisors are usually software and are often included in the controller's configuration program, such as TIA portal. (Profinet University, n.d.)

3.2 Network features

Profinet works on multiple different mediums as it is based on ethernet standard IEE 802.3. Profinet supports copper ethernet cables, fiber optic cables, Power Over ethernet (PoE) and Wireless communications. (Profinet University, n.d.)

Switches can be both managed and unmanaged. Unmanaged switches tend to be cheaper but lack in diagnostic information. They are only capable of showing if there is ethernet traffic and direct said traffic out of the correct port. Managed switches allow for higher configuration, they support multiple protocols and give access to multiple different pieces of diagnostic information, such as used bandwidth and number of retries. Managed switches are more expensive but are suggested to eliminate downtime. (Profinet University, n.d.)

Each Profinet device and controller is assigned a unique name and IP address. All of them also have a unique MAC address set by the manufacturer. In addition, all I/O devices have manufacturer specific hardware and/or firmware version numbers. Communication with MAC addresses (RT) is faster than through IP addresses but replacement component will have a different, unconfigurable MAC address whereas the IP address can be configured. (Thomas, 2016, p. 19)

Link layer discovery protocol, or LLDP is supported on all Profinet devices. LLDP enables the device to send out its own identity information through all its ports every few seconds. This information is stored in the Discovery Management Information Base (MIB) and can be read through SNMP or per controller's request. The entire Profinet network can be mapped by reading the LLDP information. (Profinet University, n.d.)

3.3 Topologies

Profinet topologies are very flexible and can basically be connected in any way. Networks usually consist of many different topologies joined together as a hybrid solution. Line or bus topology is when Profinet cabling goes from one device to another in a chain-like fashion. Ring topology is an alternative to line, where both ends are connected. In star topology, all devices are connected to one central switch. In tree topology, multiple star connections are combined by interconnecting the central switches. Mesh topology provides the best redundancy as every single device is interconnected with one another.

Bus or line connection is the cheapest to install, requiring no additional switches. It can also be easily extended to include further devices. The drawbacks are that a cable failure, or in some cases, a device failure at any point will prevent communications from the fault onwards.

Because in ring topology both ends of the line are connected, a single failure will not cause communication loss from functional devices. Extending a ring network is more difficult than in line topology as more connections need to be made.

Star topology requires one central switch where all devices connect to. A single device failure does not affect the rest of the system, but the central hub's failure will cause the entire network to collapse. If there are free ports available, the addition of new devices is very simple. Existing devices can also be removed without compromising the operation. The central hub needs to have the capacity to withstand all traffic at once and the networks performance is dependent by the hub's efficiency. (Intellegens Inc., n.d.)

As tree topology interconnects multiple star topologies, its complexity increases. Higher complexity means more difficult configuration and setup and increased costs. Redundancy is better than in bus or star topologies. (Miller, 2020) Best option for many networks is a hybrid topology which may be using all the topologies above and their design is based on physical locations and the features of the components. In some cases, an existing bus topology can be made more redundant by connecting it in a ring fashion, requiring only one cable addition in many cases. Figure 4 below demonstrates the topologies described above.

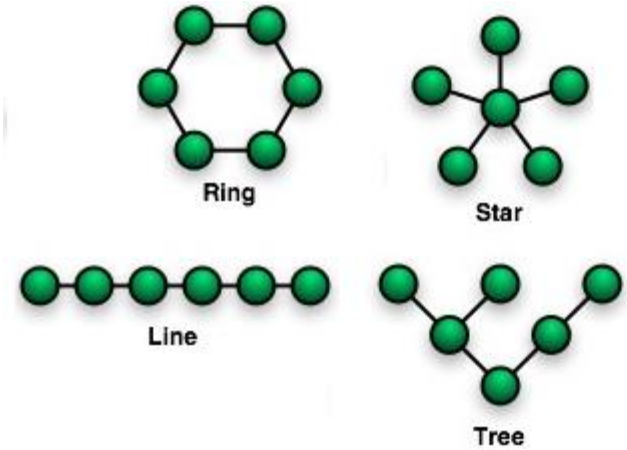

Figure 4 Examples of common network topologies (Davis, 2012)

4 DESCRIPTION OF RTG

RTGs or Rubber Tyred Gantry cranes are lifting equipment that are operated in ports. RTG crane is used to help loading and unloading ships. Containers carried by cargo ships are unloaded with STS (Ship-To-Shore) cranes onto terminal trucks. Terminal trucks then transport containers near the container stack, where an RTG places them into the stack and vice versa. RTGs are designed to working around just the container stacks. They move on top of the stacks moving containers from one stack to another along with truck loading and unloading. (Sulli, 2019, p. 3) As their name suggests, they utilize rubber wheels for high mobility. The crane is operated by one person. The basic structure of an RTG crane is demonstrated below in Figure 5.

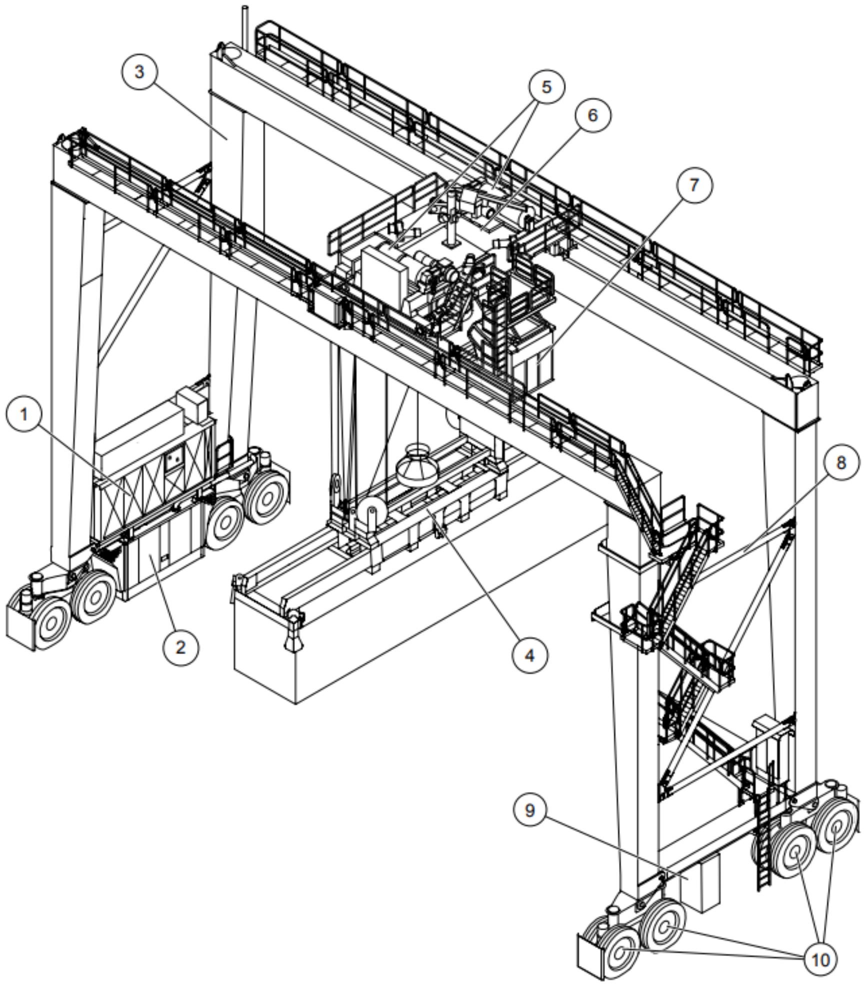

Figure 5 Structure of an RTG crane. 1. Electrical equipment room 2. Main diesel alternator 3. Gantry 4. Head block and telescopic spreader 5. Hoists 6. Trolley 7. Operator Cabin 8. Leg frame 9. Ground maintenance station 10. Bogies with rubber-tired wheels (Operator's Manual, 2016).

4.1 **Mechanical structure**

The gantry of the RTG consists of two main girders attached to leg frames with bolted flange joints on either side. Both main girders have welded rails to support trolley wheels with ramps at both ends to stop the trolley in emergency situations. Each leg frame consists of two vertical legs and a sill beam between their lower parts. The leg frame's rigidity is achieved with one diagonal and two horizontal bracing beams between the legs on both sides. Two or four bogies are mounted under the sill beam on either side and have four or eight wheels on them respectively. Main girders, legs, and the sill beams are box girders with internal diaphragms, which help keeping the original shape. (Operator's Manual, 2016)

4.1.1 Hoist

Hoist consists of two identical electrically synchronized main hoist motors and optionally auxiliary hoist motors. Hoisting machinery is mounted on top of the trolley where it is connected to the headblock via ropes. The two main hoists are responsible of lifting and lowering the load but also the load's vertical tilting, trim. Auxiliary hoist motors are responsible for sway prevention, horizontal fine positioning and slew. (Operator's Manual, 2016)

4.1.2 Trolley

A trolley is a rail-mounted assembly that moves on rails on top of the main girders. The hoist equipment, the trolley travel equipment, the electrical cubicle, and the cabin are attached to the trolley (Operator's Manual, 2016). Figure 6 shows the main components of the trolley.

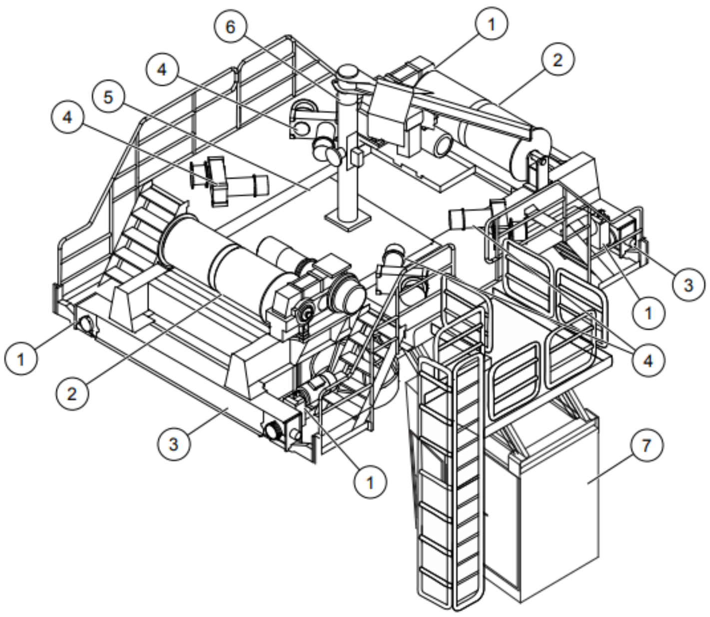

Figure 6 Trolley's structure. 1. Trolley traveling machinery 2. Hoisting machinery 3. End carriages 4. Auxiliary winches 5. Trolley frame 6. Service hoist 7. Operator's cabin (Operator's Manual, 2016).

4.1.3 EROOM

RTG crane's electrical room is an enclosed, weatherproof container which houses most of the crane's main electrical components. EROOM is around the size of a 20 feet cargo container. It houses, for example, all the frequency converter drives, main PLC and Crane monitoring system (CMS) computer. It is air conditioned and has radiators to ensure a stable temperature and humidity inside. (Sulli, 2019, p. 11)

4.1.4 Cabin

The cabin is mounted under the trolley for better visibility. It has all the necessary controls for port operations, such as crane movement, a crane control panel (HMI), hoisting, lighting and terminal operating system (TOS) access. It can also have many accessories, such as monitors with live camera feed. (Operator's Manual, 2016)

4.1.5 Bogies

The bogie layout depends on the wheel amount. RTGs have either 8 or 16 wheels.
16-wheel cranes have eight bogies with two tyres each. Each corner has two bogies which are connected to a common equalizer beam. Each wheel pair has one driven wheel and one idle wheel. Figure 7 shows the bogie layout of a 16-wheel RTG. (Operator's Manual, 2016)

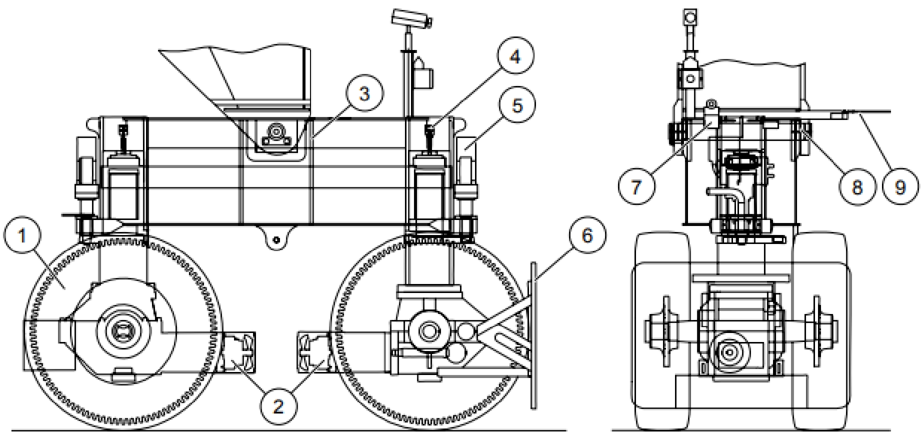

Figure 7 16-wheel Bogie layout. 1. Gantry wheel 2. Gantry travel machinery 3. Bogie frame 4. Assembly of the encoder 5. Pivot locking device 6. Wheel fender 7. Collision avoidance detector 8. Joint bogie 9. Catwhisker collision protection (Operator's Manual, 2016).

8-wheel cranes have four bogies with two tyres each. Each corner has one bogie with two wheels which are connected to a common equalizer beam and a connection rod. The outer wheel is the driven and the inner one is idle. The connection rod turns the inner wheel when outer wheel turns. (Operator's Manual, 2016)

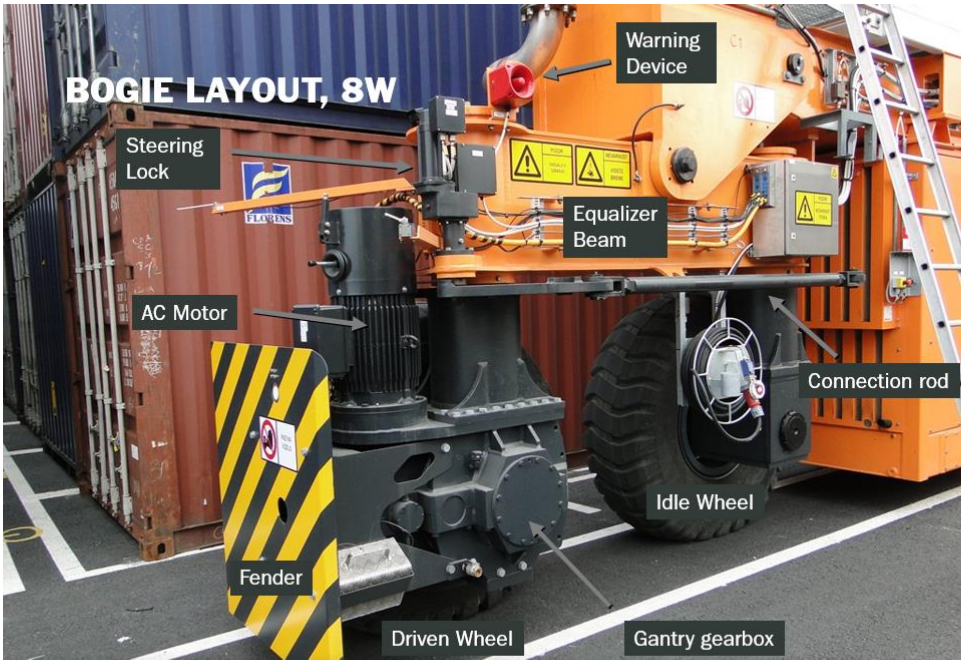

Figure 8 8-wheel Bogie layout (Rubber tired gantry cranes, 2012).

Bogies in normal position are called long travel. Long travel is the normal operation where the crane moves along the container stack. (Operator's Manual, 2016) When the bogies are turned 90 degrees, this is called cross travel. Cross travel is used when moving from one stack to another on a different pair of runways. (Operator's Manual, 2016)

An intermediate step is also possible, which allows the crane to be rotated around its vertical central axis. This option, along with necessary long and cross movements, allows the crane to be moved onto another stack which is not parallel to the previous one. (Operator's Manual, 2016)

The fourth option is called park, where the outer bogies of each corner are turned 90 degrees into a cross travel form and the inner bogies are left for long travel. This prevents the crane from moving in high winds when not in use and has greater holding force than with just the mechanical brakes. (Operator's Manual, 2016) Figure 9 below shows different gantry wheel positions for a 16-wheel RTG crane. 8-wheel RTG's wheel positions are similar.

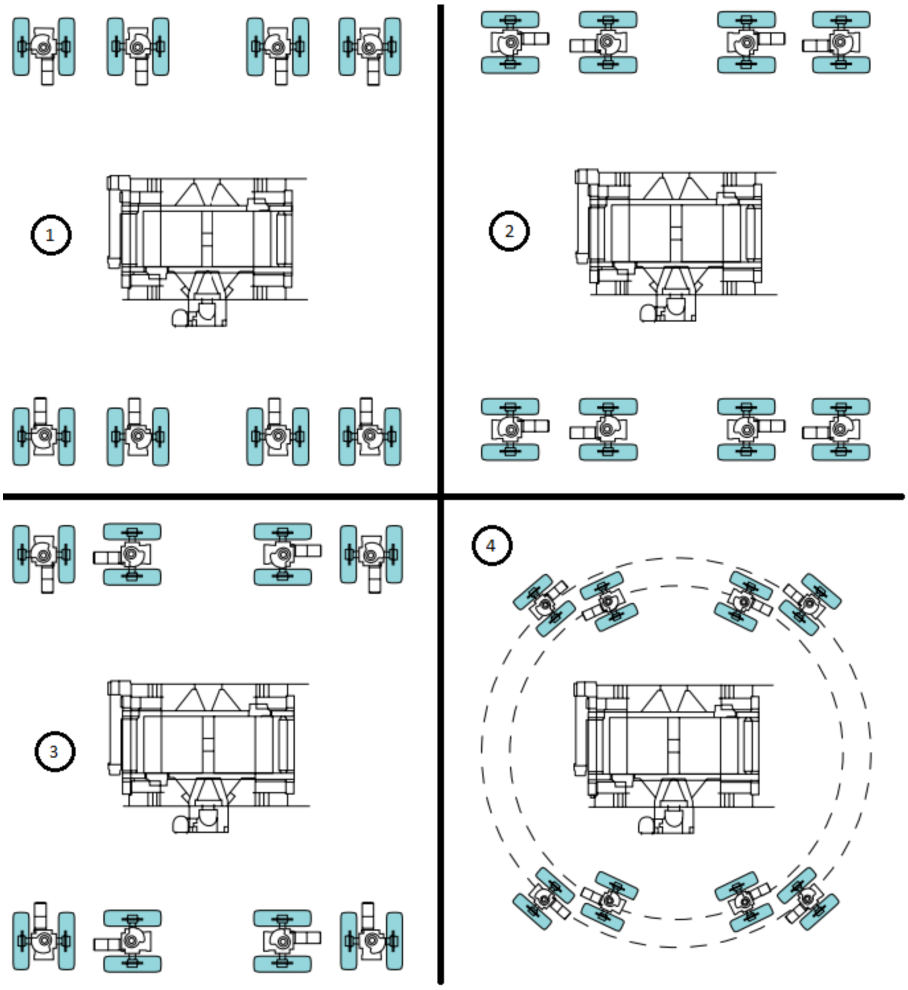

Figure 9 Gantry wheel positions. 1. Cross 2. Long 3. Park 4. Turn (Operator's Manual, 2016).

Unwanted rotation of the bogies is prevented with a steering lock – a pivot that locks the bogie in place. A mechanical bolt is driven through a hole in a locking ring that rotates with the bogie. (Operator's Manual, 2016)

4.1.6 Headblock

Headblock is supported by the main and auxiliary hoists' ropes and hangs directly under the trolley. It consists of eight pulleys, four for main hoists and four for auxiliary hoists along with a cable basket where the electric cable coils up to. (Operator's Manual, 2016)

4.1.7 Spreader

The spreader is the part which connects the crane to the container. It is attached to the headblock via manual twistlocks. It is lowered on top of the container and guided in place by flippers or fixed guide arms. The container is locked into place with the use of twistlocks. The spreader's telescopic structure allows its width to be changed, which in turn lets it grab different sized containers (Sulli, 2019, p. 5). Some spreaders have a so-called twinlift or tandem feature which allows lifting of two containers of the same size simultaneously. Spreader is controlled via the PLC's I/O, but it supports CAN bus as well. Both the headblock and the spreader can be seen in the Figure 10.

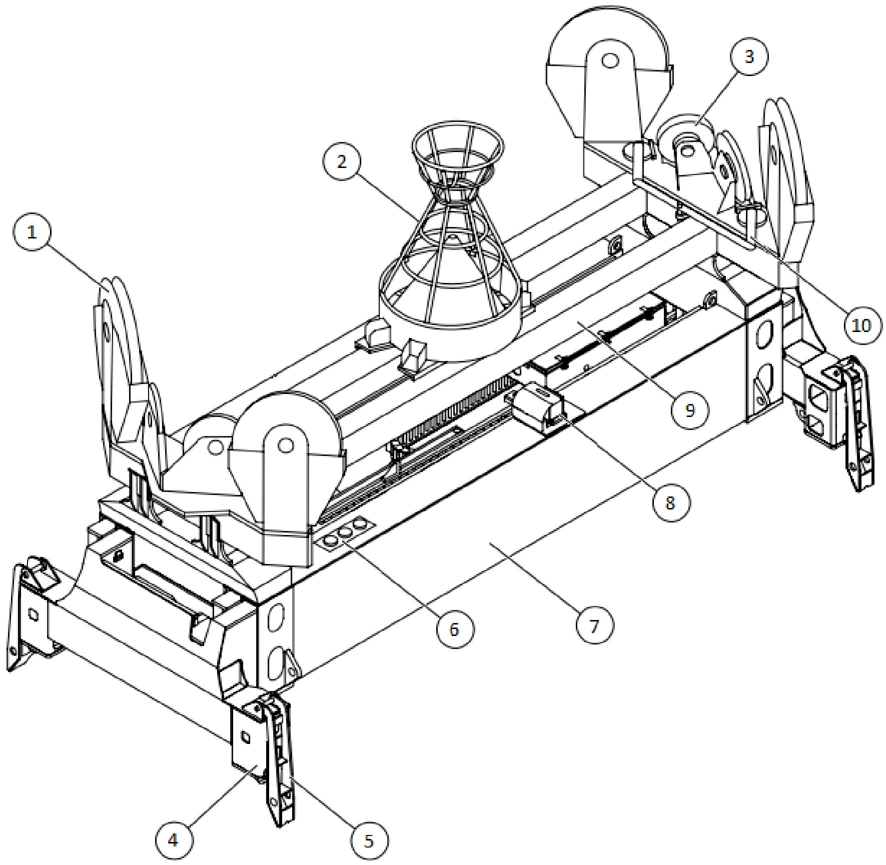

Figure 10 Structure of headblock and spreader. 1. Main hoist pulleys 2. Cable basket 3. Auxiliary hoist pulleys 4. Twistlocks 5. Fixed guide arm or flippers 6. Status indication lights (twistlocks unlocked/locked, spreader landed) 7. Spreader frame 8. Control socket 9. Headblock frame 10. Manual locking mechanism (Operator's Manual, 2016).

4.2 Automation

Crane automation covers a wide range of features some of which help the operator in normal tasks and some which take control of some motions normally performed by the operator. Fully autonomous operation is also an option.

Auto-steering is a feature where virtual rails are generated for the crane. The crane is constantly measuring its position with GPS antennas or by other means, and can steer, slow down, and stop without operator input. When the crane reaches the end of the block, the crane automatically slows down to a stop. When long travelling, the crane is automatically steered so that it stays on its lane, so that the operator does not need to do steering corrections. (Rubber tired gantry cranes, 2012)

Stack collision prevention uses one or more trolley mounted laser scanners to scan stack profile. It slows down the load movements when close to other containers. This feature can be extended to optimize route from truck to stack target. Crane will automatically move the container optimized path to the target under operator's supervision. Loading and unloading are left to be done manually. (Rubber tired gantry cranes, 2012)

Normally the operator needs to manually report all container movements to the terminal operating system (TOS). This can be automated, preventing lost containers and streamlining operators' work. This can be further improved with auto positioning feature where, after enabled, the crane will automatically stop at next pick up location, provided by TOS.
In Auto-truck guiding, automatic traffic lights mounted in the crane structure are used to signal the truck driver of correct position. Traditionally this is handled by honking horns or other means of communication. This also prevents the load from being lowered if truck cabin is detected under it, increasing safety. Another safety feature is truck lift prevention, where the truck's tires are monitored, and hoisting is stopped when lift is detected. (Rubber tired gantry cranes, 2012) This can happen if the truck driver forgets to open corner locks, leaving the container attached to the truck.

Multiple image recognition features are available as well. Auto-truck ID detection reads the licence plate of the truck being handled and reports it to the TOS. Container IDs can be detected in a similar manner, reducing the risk of mishandling. (Rubber tired gantry cranes, 2012)

4.3 Power supply

Cranes can have multiple different power sources. The original implementation included using a diesel generator to power up a crane's movements (Kalmar, n.d. p. 2). Communication between the generator and the PLC is established via a CAN bus. The bus allows important values such as engine speed, load, torque, fuel rate, and many others to be read by the PLC and other devices in the network. The diesel generator can be improved by replacing it with a variable speed generator instead. The variable speed generator changes its RPM (revolutions per minute) based on the load instead of having a fixed RPM value. This lowers both fuel consumption and emissions (Kalmar, n.d. p. 2).

A more environmentally friendly solution is a hybrid model, where a diesel generator is supplemented with a battery pack. This works similarly to a hybrid car, where braking energy is stored into the batteries. This can drastically increase fuel economy and reduce emissions even further (Konecranes, n.d. p. 4).

All-electric solutions are available as well. These utilize power supply from their operation location. Along with zero on-site emissions, all-electric solutions also greatly reduce the noise created. Cable reel connects to a power supply station and draws current from there. Reel winds and unwinds depending on the distance from the supply station. This allows the crane to work over long distances on both sides of the station (Konecranes, n.d. p. 8). Another electric solution is called busbar. In this system, the crane is fitted with a current collector that moves alongside an electrified fence (Konecranes, n.d. p. 10).

All-electric solutions have a common problem: how is the crane powered when it needs to be moved away from stack for maintenance or to another stack? This is tackled in a couple of ways. One option is to have a small auxiliary diesel generator which can be used to move the crane when it is not powered by a busbar or a cable reel (Konecranes, n.d. p. 8). Another option is to have the battery storage be large enough to store enough power to move the crane around in the port while disconnected (Kalmar, 2019).

Braking energy is traditionally directed into braking resistors where it dissipates as heat. This obviously wastes energy and there are alternate options available. Excess energy can be fed back into the grid via a network braking unit with high efficiency. Another option is to store braking energy into onboard battery storage (Konecranes, n.d. p. 4). Both options are efficient methods of saving energy.

Because trolley moves along main girders, its power supply cannot be stationary. This is solved with a cable track, linking the gantry to the trolley. Use of cable track requires special, flexible cables to be used especially when fiber optics are used (Siemens, 2009, p. 215). Figure 11 below shows a closeup of a cable track in an RTG.

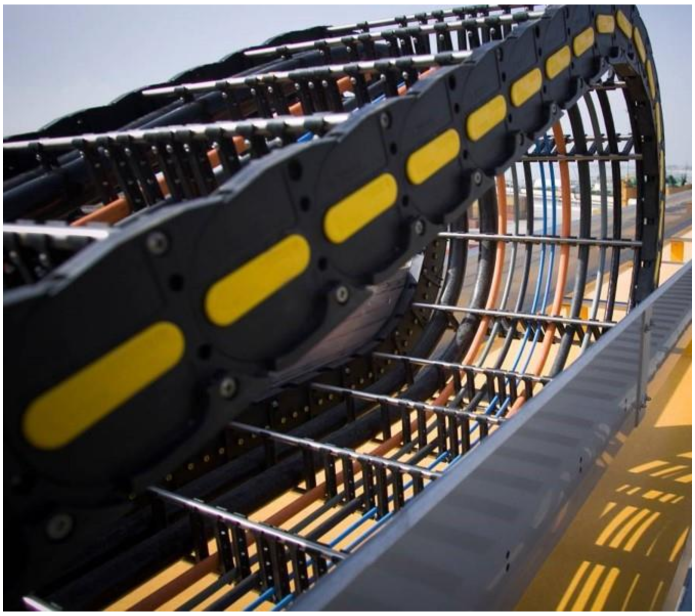

Figure 11 RTG trolley cable track (Rubber tired gantry cranes, 2012)

5 OVERVIEW TO NETWORK

Given the large size, complexity and multiple operational locations within the crane, the network needs to be designed to match these requirements. Gantry crane essentially has two sides and a trolley that moves between them. Because only one PLC CPU, located in the E-room, handles crane operations, it would be difficult to have all I/O devices wired from the opposite access side individually to the E-room. Same applies for the moving trolley as its cable track can only fit a limited number of cables. This is solved by using remote I/O units, located in the trolley and access side respectively. These remote units can communicate with the CPU via just one Profinet connection, greatly reducing the wiring complexity and I/O cable lengths.

5.1 Network design requirements

When designing the crane network, one important thing to keep in mind is the speed. Profinet supports 100Mbps by default but by correctly choosing devices, switches, controllers and mediums, 1Gbit/s can be achieved. Both values are high when compared to Profibus' 1.5 or 12Mbps. (Henning, 2020) Higher speeds allow for more data to flow through at any given time but latency is not necessarily reduced. The speed choice needs to be made based on the need for higher bandwidth and the increased costs. For example, Phoenix Contact managed industrial ethernet switches cost USD299 and 499 for 10/100Mbps and 10/100/1000Mbps respectively. (Digikey, n.d.; Digikey, n.d.) This means that 1Gbit/s costs roughly 67% more than 100Mbps. In a large project, such as a harbour crane, this cost drastically affects the production costs as every single component needs to support 1Gbit networking.

Network load means the ratio of used bandwidth and the maximum available bandwidth (Profibus User Organization, 2014, p. 100). If the network load is over 50%, measures to reduce the load are suggested to be taken. (Profibus User Organization, 2014, p. 118). Each Profinet device causes some load to the network and this load depends partly on its update time. The more often a device is updated, the more strain it causes on the network. Figure 12 shows the effects of update time on load.

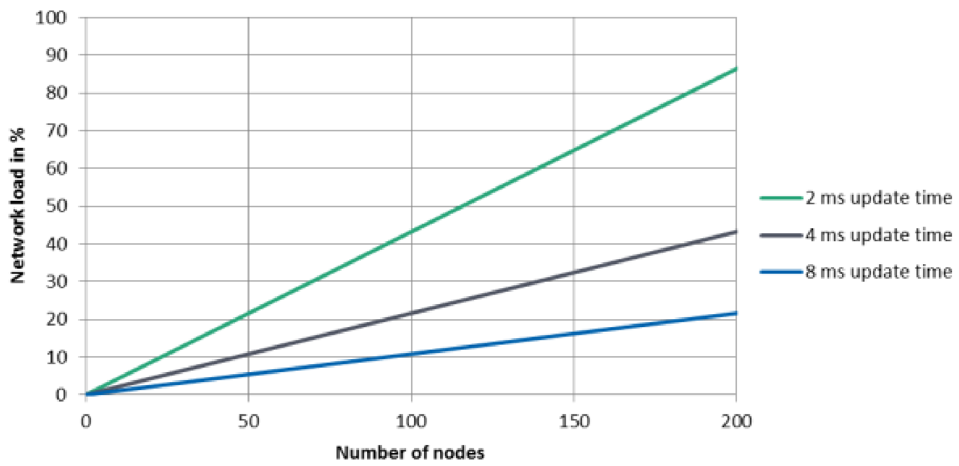

Figure 12 Cyclic PROFINET network load (Profibus User Organization, 2014, p. 106)

Based on these values, it can be estimated that a network of 100 Profinet devices with a 4ms update time, around 22% of the bandwidth is used for just Profinet communications. This value is still within the suggested limits, but the network supports other kinds of traffic too. For example, video feed from a camera could be taking up bandwidth as well.

5.2 Video feed network requirements

Camera feed's bitrate varies based on bit depth, resolution, frame rate and its compression. The uncompressed video bitrate can be easily calculated by multiplying all variables together. (Tabora, 2019) For example, a 1920*1080 video at 30 frames per second with 8bit colour has an uncompressed bitrate of 1920*1080*30*3*8=1 492 992 000 bits per second which is 1.49 Gbit/s. This bitrate is higher than most networks can handle and is the reason why IP cameras compress video automatically. H.264 is a commonly used compression format that IP cameras use to reduce bandwidth and storage requirements. Compression formats use multiple different tricks to reduce file size, most important one being reducing redundancy. This effectively means that the pixels that do not change between frames are not saved but instead told to not change. (Techquickie, 2014) After the compression process, the bitrate drastically lowers down to anywhere from a few hundred kilobytes to a few dozen megabytes (TDCatTech, 2019). With a constant resolution, higher bitrate allows for better quality and less compression artefacts but also takes up more storage or bandwidth (Techquickie, 2014). This means that the encoding bitrate needs to be carefully chosen for the application to ensure good enough quality while taking minimal amount of space. For example, YouTube recommends bitrate of 8Mb/s to 60Mb/s for 1080p 30FPS and 4k60fps videos respectively (YouTube Help Centre, n.d.).

After the video has been compressed, it needs to be decoded for it to be displayed on a screen. If the video file or stream is run through a computer, it can be easily decoded via a software like VLC media player. If the video is fed to the network via an IP camera that compresses it, decoding needs to take place before it can be displayed on a screen. Some screens and monitors have the capability to decode but some do not. When designing cameras as a part of the system, compatibility is another point to take into consideration. A camera system can have multiple different mediums, such as coaxial, glass fibre and copper which require adapters and converters between them. If a monitor has only traditional video inputs such as HDMI, VGA, DVI or DisplayPort, a decoder needs to be used to get video feed to show up on the screen. IP camera also introduces some latency to the system due to the delays caused by switches, encoding and decoding.

If the system involves multiple IP cameras or other components that use high bitrates, 100mb/s is probably not enough, and an alternate solution needs to be designed. One option is to have multiple different networks for different tasks, but this obviously increases complexity and makes troubleshooting and diagnostics more difficult.

Another option is to use Analog cameras instead of IP cameras. Analog cameras do not compress the video and effectively provide latency-free feed to the monitor. Drawbacks are lot less features as an analog camera functions basically just like a remote eye. (Robox Academy, 2018) The raw data from analog cameras can be transmitted over various mediums, such as coaxial, fiber optics and even HDMI, but the medium needs to be chosen based on the distance that needs to be covered. As calculated above, 1.49Gbit/s is required for Full HD video feed which is achieved by having SMPTE ST 292M or better specifications on all components and cabling between the camera and the monitor (Hudson & Welch, 2013, p.7).

Another thing to consider is safety. Profinet supports its own safety communication technology called Profisafe. Profisafe works by running a separate, individual layer alongside the standard Profinet traffic to increase the safety of the safety programs. This means that each message sent in Profinet contains Profisafe data which in turn reduces the chance to get dangerous failures from device or bus malfunctions (Profinet University, n.d.). Profisafe achieves this by implementing four safety measures: sequence and timeout error detection, authentication and cyclic redundancy check (Profinet University, n.d.). These measures allow Profisafe to be used in applications requiring a Safety integrity level (SIL) of 3 which means probability of dangerous failure of less than one per 10^9 hours or 114 115 years of operation (Profinet University, n.d.).

6 RTG NETWORKS

6.1 PROFIBUS

Profibus network provides an inexpensive and simple solution. The mediums in use are copper and fiber optics for long distances. Due to topology restrictions, most devices are in simple line topology with some repeaters and fiber optic couplers. As mentioned before, line topology has no redundancy and a single bus fault often prevents all communications further down the line. For example, if a motor circuit breaker breaks and shuts down a frequency converter, its bus is unpowered and no signal is passed further, preventing the rest of the devices on the same line from functioning. Figure 13 below shows one-line diagram of an example Profibus network.

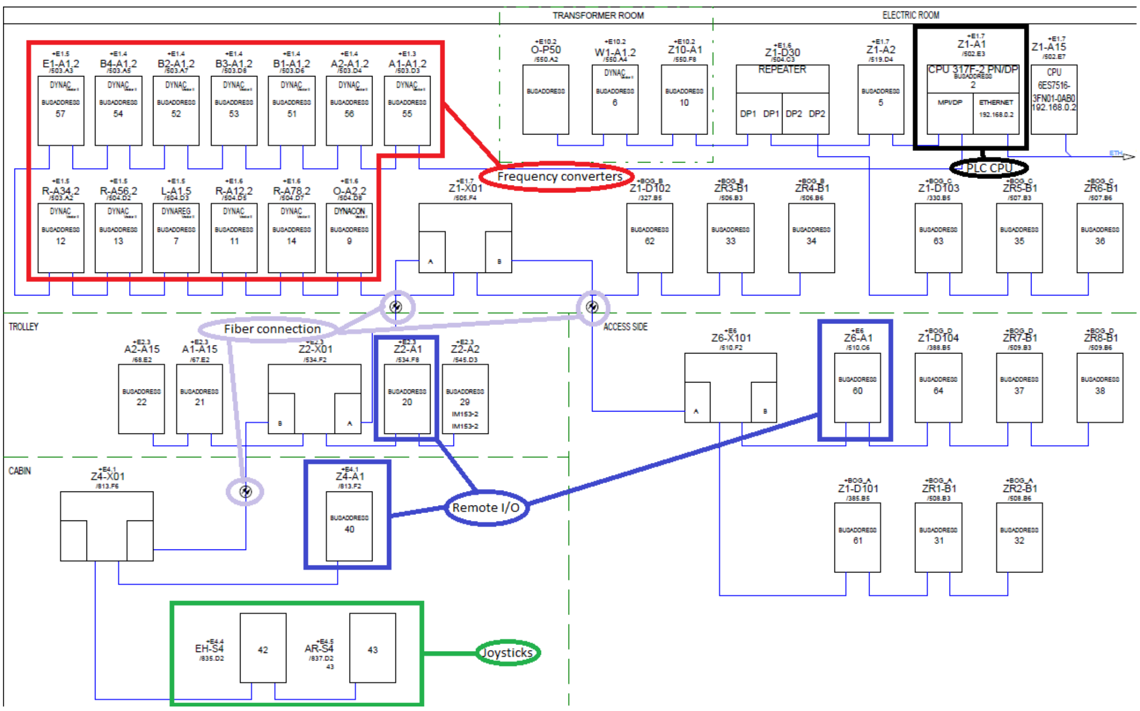

Figure 13 Profibus one-line diagram (E3 wiring diagram, 2020)

As can be seen in Figure 13, the dominating topology is line. From CPU to frequency converters and all the way to trolley remote I/O, there are a total of 34 devices in the same line. Two Profibus to optical converters further complicate the setup. This means that if A1-A1 has a bus fault, the remaining 33 devices would simply not work. Because those 16 devices include all the frequency converters, the entire crane would not operate. This kind of problem is common with the limited topology possibilities of Profibus.

Profibus commissioning tends to be slow too which is the main reason for moving to Profinet instead. Device addressing is often done by the means of physical switches instead of over the network. In practice, this means that devices with incorrect addresses need to be accessed physically which takes a lot of time, given the size of an RTG crane and the climbing involved. Profibus lines also need to have termination enabled on both ends. Usually the terminator is just a simple switch that needs to be enabled or disabled but again, it requires physical access.

6.2 PROFINET

In the Profinet network all Profibus devices are replaced with their Profinet counterparts and topologies are altered according to the greater flexibility allowed. New possibilities from topology point of view allow for much greater redundancy and shorter cabling but with increased complexity. Long distances are still covered with optical fiber. From Figure 14 below, the new Profinet network can be seen.

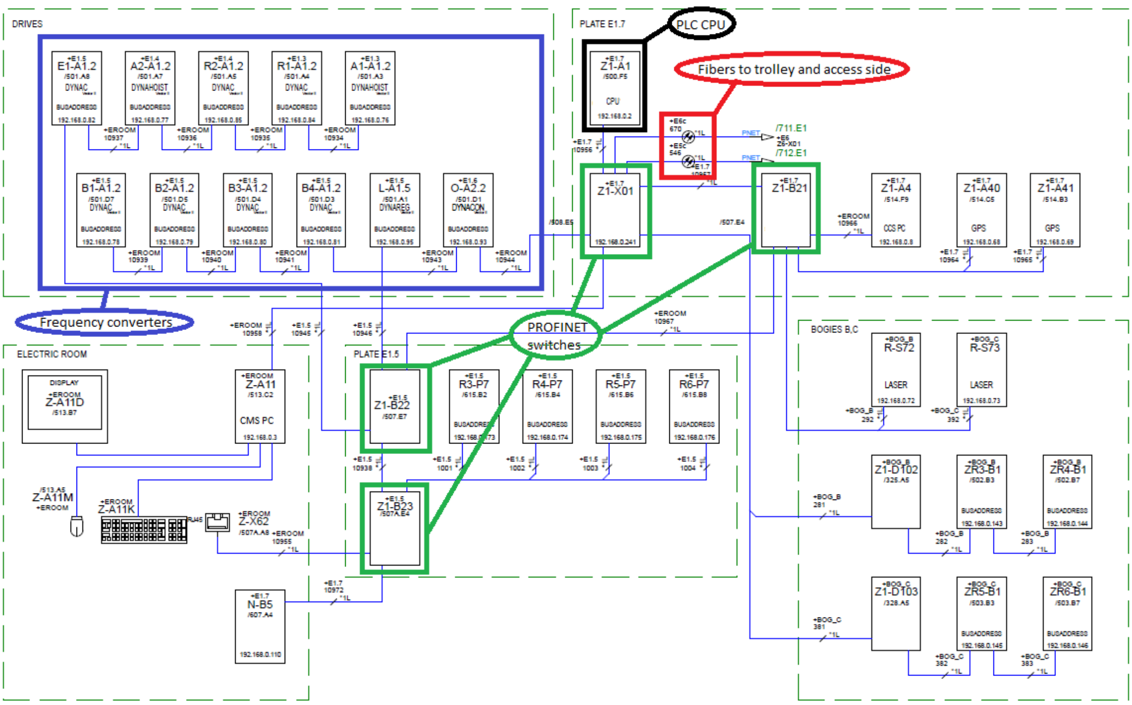

Figure 14 Profinet one-line diagram (E3 wiring diagram, 2020)

Even at a first glance, it can be seen that the more flexible topologies allow for much greater redundancy. There are no longer dozens of devices in the same line but instead only five at most. This improves troubleshooting quite a bit as less devices need to be checked for faults. These can be improved even further by modifying the drives' topologies into ring by adding an ethernet cable from A1-A1 and B1-A1 to any of the Profinet switches highlighted in green and modifying the software accordingly.

The main improvements come from improving Profibus system's setbacks. Addressing and terminal resistor changes consume a lot of time in Profibus systems. Those are completely removed with the Profinet introduction. The PLC CPU gives all devices names and IP addresses set in the software, warns about duplicate names or addresses and allows for easy modification of said values. Redundancy can be improved easily by modifying line topologies into ring just by adding one extra cable, which increases fault tolerance in the case of bus fault. Bus faults still prevent device communications further down the line which is why ring topology is highly suggested.

This design strikes a great balance between cost, complexity, redundancy and installation time. Multiple tree topologies provide great redundancy without increasing the cost or complexity too much. The amount of line topologies has been reduced, focusing mainly on operation critical devices. Complexity stays at manageable levels as not too many switches are used, and a single device can usually only be accessed via one route. Complexity and redundancy are directly proportional, but this design was found to bring most balanced results. Some small adjustments will be made to the future projects' topologies to reduce the number of managed switches used as only few devices need to be connected to them and most devices only require unmanaged switches.
Profinet system has some challenges too. Flexible topologies increase complexity of the system. Many of the switches need to be managed which increases the cost. Due to naming taking place via LLDP, connecting a wrong device to a wrong port causes errors and is quite easy for this kind of accident to happen. In this case there are two options: changing the port in software of physically moving the cable to its correct port. The latter one is preferable as wiring diagrams should always match the software's network configuration.

7 COMMISSIONING PROFINET RTG CRANES

RTG commissioning starts from the components and machinery arriving to the port and ends with the customer receiving a working, operational crane. Often multiple RTGs are ordered at once, sometimes dozens, which modifies the commissioning process as they are not necessarily built or commissioned one by one but instead in smaller batches. The limiting factor is the space available for storing unfinished cranes so that they do not interfere with normal port operations.

7.1 Assembly

Crane parts are shipped from many different locations. Steel structures are usually manufactured close to the customer to save on transportation costs. The RTG is highly modular which allows the parts to be manufactured at different places. Once all subassemblies have arrived on site, the commissioning process may begin.

The first step is building the gantry steel structure. This is done by utilizing a construction site crane to lift the vertical leg frames on top of bogies on both sides. After that, the main girders are lifted and bolted on top of the leg frames. Lastly, the trolley is placed on top of main girders. With an experienced crew, this part usually takes around a day or two per crane, depending how many cranes are built simultaneously.

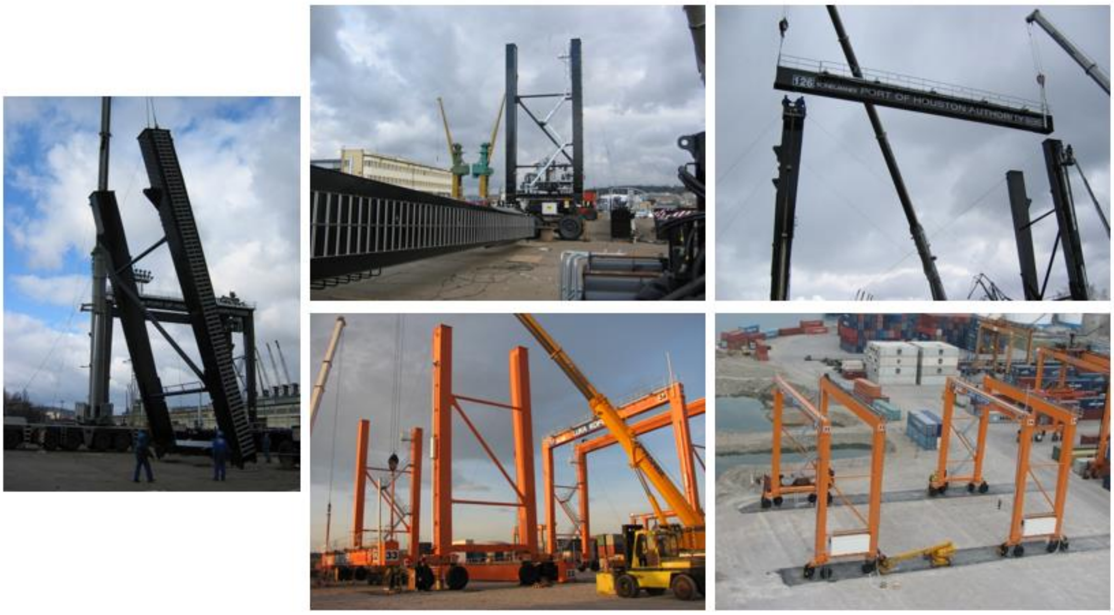

Figure 15 Mechanical assembly (Rubber tired gantry cranes, 2012)

After the mechanical assembly is finished, the electricians begin their work by connecting cables between locations. These cables are already shipped to the site at the correct length which makes the time-consuming process a lot faster.

7.2 Powering up

Once all cabling is done, the next goal is to power up the crane. This means measuring important power lines with an installation tester and starting the diesel generator. Once the generator is up and running, each circuit breaker's supply side is measured to ensure correct voltage value and then turned on and checking that correct devices are powered. This takes a long time but is necessary for the safety of personnel but to also reduce the risk of breaking components. Most electric errors are found during this part of the commissioning process.

7.3 **PROFINET**

After all the components and devices are powered and possible cabling errors are found and fixed, the following step is to shift focus from electromechanical tasks towards the software side of things. At this stage, all devices need to go online and have communications established between them.

7.3.1 LLDP

Profinet uses LLDP for its naming and addressing. This means that physical device names and ports need to match those set in TIA portal or similar software. More on LLDP in chapter **Error! Reference source not found.**.

For the basis of this thesis, only Siemens TIA (Totally Integrated Automation) ecosystem is considered.

7.3.2 Examples of LLDP in Profinet

The key idea of LLDP naming is that device names are assigned to specific switch ports in TIA. If the correct type of device is found from that port, the device gets named. If there is a connection error and two different devices have swapped ports, an error "Error on partner – Wrong partner port" is received. Last option is where two identical devices are mixed. The software does not recognize this as an error and names them normally. This may cause a lot of errors or even hidden, dangerous failures that may go unnoticed.

Below are some examples on how LLDP naming works in the Profinet environment.

Example 1

The following example demonstrates LLDP when everything is connected correctly.

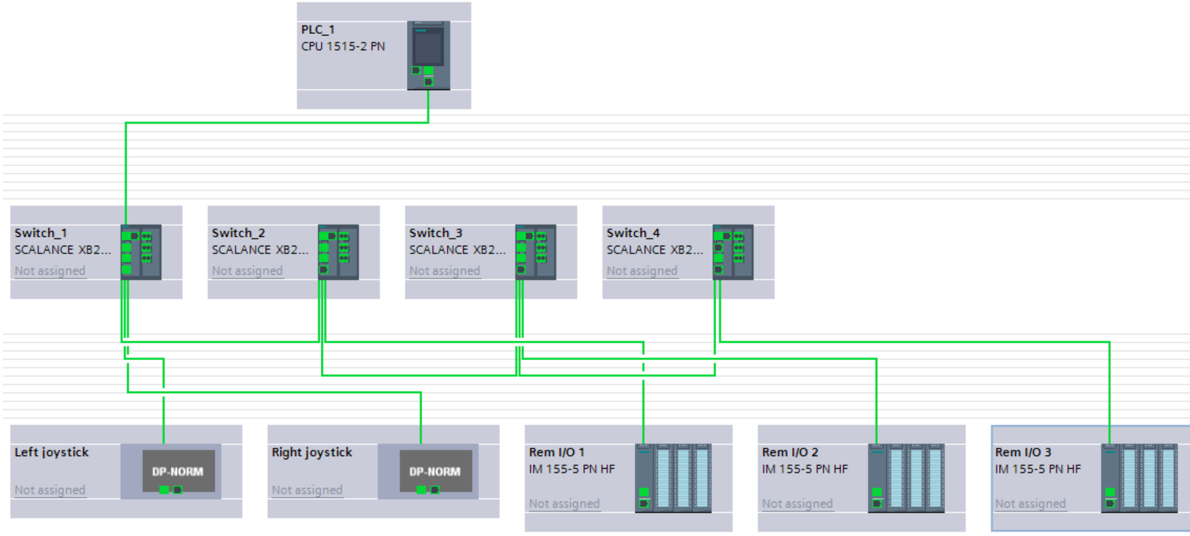

Figure 16 Correctly connected, working network

In Figure 16, a simple Profinet network can be seen. CPU is connected to Switch_1: port 1. Switch_1 has three other connections: Port 2 to Switch_2, Port 3 and 4 to Left and Right joysticks. Switches 2-4 are connected to each other with ports 1&2 and to remote I/Os with their port 3. After setting the CPU online, all devices get named, receive IP addresses and start functioning.

Example 2

The following example demonstrates what happens when two ports are swapped by accident between two different types of devices.

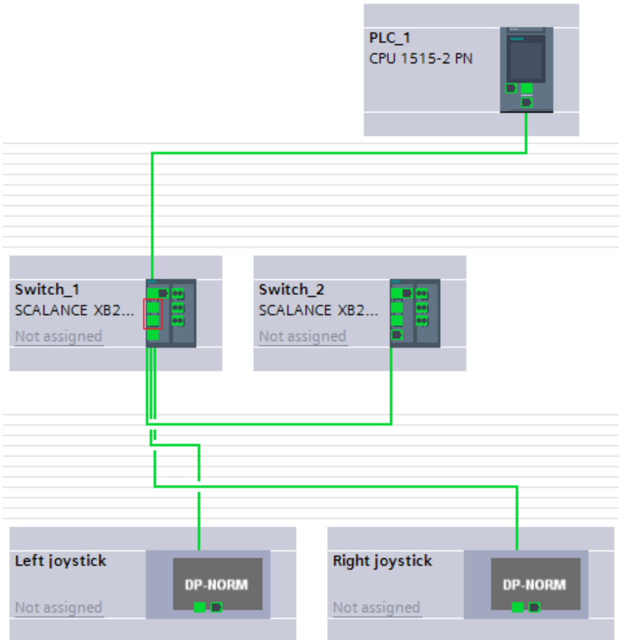

Figure 17 Network, where Switch_1 ports 2 and 3 have been accidentally swapped

In Figure 17, there is a connection error marked with a red square. Port 2 is supposed to be connected to Switch_2 but is now connected to Left joystick. This causes two errors: Port 2 expects a Switch to be found and Port 3 expects a Joystick to be found. The system outputs “Error on partner – Wrong partner port” errors for both ports.

Example 3

The following example shows what happens when ports are swapped between two identical devices.

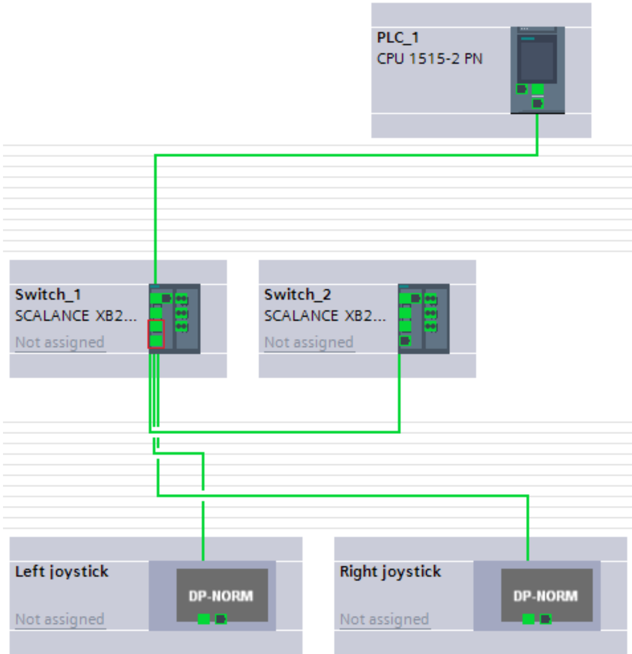

Figure 18 Network, where Switch_1 ports: 3 and 4 have been accidentally swapped

In Figure 18, the connection error is again marked with a red square. This time both ports are supposed to be connected to a joystick. Left joystick is supposed to be in port 3 and right in port 4 respectively. CPU finds the correct device from the correct port and gives them names. However, the outcome of this is that left joystick functions as the right and vice versa. There are no visible errors as CPU sees them as identical devices.

The same issue is present if two switches are mixed. In the Figure 16 network, if two switches connected to the remote I/Os are swapped, the actual inputs and outputs would be swapped with one another. This may cause dangerous scenarios if the remote I/O configuration is similar or just a multitude of faults and errors if they are very different from one another.

This possibility is the most dangerous and time consuming one as some faults may go undetected or cause strange, unexplainable behaviour. Example of strange behaviour would be if main hoist frequency converters, that are responsible for load horizontal tilting, end up swapped with one another. The result is that tilting would work the wrong way. This is mostly an inconvenience and not dangerous, but troubleshooting it is quite difficult. A maintenance or commissioning person might assume there is a problem with the software or hardwiring before considering the network at all.

7.3.3 PROFINET devices

Not all Profinet devices need to be configured in TIA. Some devices work as I/O devices and just need to be a part of the network but do not have to be configured in any way. A great example of this is anti-collision systems which just send their information over PROFINET instead of being hardwired to input cards.

Safety devices (Profisafe) are their own, separate type and they have a different way for naming and configuration. They are independently named and configured with TIA portal safety program.

7.3.4 Troubleshooting network errors during commissioning

During commissioning it is likely that there are a few different kinds of network errors. In large networks, pinpointing the error location can be difficult but luckily there are some tools to help.

7.3.4.1. Using Proneta to troubleshoot

Proneta is a free tool by Siemens that allows for Profinet network analysis and configuration. It scans the network and plots out its topology. This is useful because TIA portal shows what the CPU will think the network is and Proneta shows how the devices are **actually** connected and named. Proneta can be used to troubleshoot and reconfigure all devices in the network, while online, excluding Profisafe devices and devices that get their name from their own parameters.

Siemens PLCs support overwriting of I/O devices which automatically forces devices to have names set in TIA portal. When enabled, this feature allows for very quick device replacements as they are automatically named correctly if they are connected according to the wiring diagram.

7.3.4.2. Replacing already configured device vs. replacing a “new” device

New, unconfigured device should automatically be named and configured, assuming that: CPU overwrite is enabled and the device is connected to the correct port. Keep in mind that some “new” devices are preconfigured in the factory or by the manufacturer.

A configured device should also be automatically named, provided that it is connected to the correct port and CPU overwrite is enabled. If CPU overwrite is disabled or does not work, Proneta should be used to set the device's address and name and it should be connected to the correct port.

7.3.5 Common network issues during commissioning

The most common cause for network issues is incorrect connections where devices are not connected to ethernet and fiber optic ports assigned in the wiring diagram. After the connections (and TIA portal topology) are according to the wiring diagram, the network should work.

Some other issues are caused by devices that are not named by the CPU but instead from parameters. This is only an issue if TIA portal has a wrong device name set and it cannot overwrite it. These are fixed by changing the name in TIA portal to match the name in the parameters.

7.4 PLC software and Automation

Once the network is up and running, the crane is operational. At this point, the crane can be moved around. If the crane has busbar or cable reel supply, this is when it is connected, if possible. Electric supply removes the need to refuel the generator but takes up space from the container stacks. Communication with the port authority is very important here.

Next, all the features are checked, and the limits adjusted. For example, hoist upper and lower limits, trolley forward and backward limits and possible cable reel's limits are set as these cannot be done in the factory.

7.5 Final testing

Once all features from anti-collision to cabin seat heating have been tested to work as they should, a more operational phase takes place. A test weight used to ensure correct operation under overload and other special circumstances. An endurance test is conducted to simulate a normal workday for the crane. After the endurance test is completed successfully, the customer is provided with training and the crane is handed over.

8 CONCLUSION

The Profinet system is a major improvement to the previous Profibus network. It still has some challenges, mostly due to human error. If all the connections are made according to the wiring diagram, the system will instantly work and does not require any further configuration. Faulty connections, however, either prevent the operation altogether or cause unnoticed/unwanted errors.

Profibus is a great system to prevent human error in this regard due to the medium it uses. The Profibus cabling is difficult to rewire and its topology is very simple as well. Profinet, having RJ45 (and fiber optic) connectors allows for very easy, accidental rewiring.

During maintenance and troubleshooting, it is easy for the maintenance person to assume that the problem is in the network and change a single cable to a different port, causing even more trouble. This can possibly be avoided by excluding all devices from TIA portal topology view and manually naming each device one-by-one. This takes a lot of time but allows for the devices to be connected to any port and not just the specific one.

Adding a new device this way is also slower. If CPU is allowed to name devices, connecting a new, replacement device is as simple as connecting it to the correct port. If not, all new devices need to be manually named before they are seen by the CPU. Both options still require Profisafe devices to be independently named and configured for safety reasons.

The internal instructions are constantly updated based on the information gained from future projects. The current limitation with the instructions is that they have been written based on the first Profinet RTG project, possibly limiting how well they can be applied in the future.

However, even in their current form the instructions will be a helpful addition to the toolkit of a commissioning engineer. The instructions will be reviewed internally by a group of experienced engineers and improved based on feedback. Once they are approved, the work is moved to the documentation team who finalizes the language and visual aspects and releases version 1.0. It will then be distributed to the parties in need.

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