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TEST PROTOCOL FOR WÄRTSILÄ 20DF AUTOMATION SUBASSEMBLY

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TIIVISTELMÄ

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Tuotannon kehitysosasto kehitti uuden moottorin automaation alikokoonpanokonseptin tasoittaakseen W20 sekä W20DF moottoreiden kokoonpanoaikoja. Tämän kehityksen johdosta myös alikokoonpanon testiprotokollaa on kehitettävä.

Työn tarkoituksena oli tehdä uusi testiprotokolla Wärtsilä 20DF:n alikokoonpanon testaukselle. Protokolla sisältää kolme elementtiä: testiohje, testi ohjelmistokonfiguraatio sekä moottorin turvallisuusmoduulin konfiguraatio. Kaikki nämä elementit suunniteltiin, suoritettiin, testattiin sekä pilotoitiin. Pilotoinnin aikana järjestettiin myös sisäinen koulutus.

Työn aikana kohdattiin pieniä haasteita mutta kokonaisuutena työn suoritus meni melko sujuvasti. Kaiken kaikkiaan työn tulokset olivat hyviä, testi on systemaattinen sekä kattava.

ABSTRACT

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A new engine automation subassembly concept was developed by the production improvement department to even-up the assembly lead times of the W20 and W20DF engines. Therefore, also the test protocol for the subassembly needed development.

The purpose of the work was to make a new test protocol for Wärtsilä 20DF subassembly testing. The protocol includes three elements: test instruction, test software configuration and Engine Safety Module configuration. All of these three elements were planned, executed, tested and piloted. Also the internal training was held during the piloting phase.

Some minor challenges were encountered during the work process but to conclude the thesis, it went through rather smoothly. Overall, the end result of the deliverables was good, the test is systematic and comprehensive.

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1 INTRODUCTION

The thesis was made for the Product Management and Engineering department in Wärtsilä. The need of a test protocol came from the Production improvement department. This department is developing the production of the Wärtsilä engines.

A new automation subassembly concept was developed to balance the production times of two different engine types in the same production line. The engine types are Wärtsilä 20 and 20DF. The W20DF engine is equipped with a gas feed and pilot fuel system so there is about a double amount of automation related work. It was seen that the production times can be balanced by making as complete an automation subassembly as possible and by moving the assembly work to the supplier.

For the complete automation subassembly also the test protocol needed to be developed, within this the thesis. The making of the test protocol requires three elements: test instruction, test software configuration and Engine Safety Module configuration. In addition to previous ones the protocol needed to be tested and piloted. The piloting phase included a training to internal process developer who can then train the supplier. Before the test instruction could be made, it needed planning and scope definition. Both configurations were made based on the test instruction.

2 WÄRTSILÄ OYJ ABP

Wärtsilä is a global leader in advanced technologies and complete lifecycle solutions for the marine and energy markets. Wärtsilä's net sales totalled EUR 5 billion with approximately 18,800 employees in 2015. The company has operations in over 200 locations in more than 70 countries around the world.

2.1 Wärtsilä Marine Solutions

Marine Solutions enhances the business of its marine and oil & gas industry customers by providing innovative products and integrated solutions that are safe, environmentally sustainable, efficient, flexible, and economically sound. Solutions are developed based on customer needs and include products, systems-and services.

2.2 Wärtsilä Energy Solutions

Wärtsilä Energy Solutions is a leading global supplier of flexible baseload power plants of up to 600 MW operating on various gaseous and liquid fuels. The portfolio includes unique solutions for peaking, reserve and load-following power generation, as well as for balancing intermittent power production. Wärtsilä Energy Solutions also provides LNG terminals and distribution systems. In 2015, Wärtsilä has 58 GW of installed power plant capacity in 175 countries around the world.

2.3 Wärtsilä Services

Wärtsilä Services supports its customers throughout the lifecycle of their installations by optimizing efficiency and performance. It provides the most comprehensive portfolio of services and the broadest service network in the industry, for both the energy and marine markets. /1/

3 W20DF 4-STROKE ENGINE

Wärtsilä W20DF is a medium speed four-stroke dual-fuel engine which can be run on natural gas, marine diesel oil or heavy fuel oil (Figure 1). The fuel type can be changed from fuel oil to gas and vice versa during engine operation. W20DF is mainly used in marine applications as a mechanical drive prime mover for smaller applications or as a generating set for all type of liquefied natural gas applications. W20DF is available with 6, 8 and 9 cylinder configurations so the power range of the engine is from 0,9 MW to 1,6 MW. A speed range is 1000 – 1200 rpm with 50 Hz or 60 Hz applications. /2/

Due to the use of gas as a fuel, the engine is equipped with combustion control. That means that the electronic fuel injection control is required which is implemented in the UNIC C3 engine control system.



Figure 1. W20DF from operating side and non-operating side /2/

4 UNIC C3 ENGINE CONTROL SYSTEM

The UNIC C3 automation system is an embedded engine management system. UNIC C3 is a highest level of Wärtsilä UNIC automation system levels. Compared to UNIC C1 and C2, C3 has a functionality for electronic fuel injection control.

The system has a modular design, and some parts and functions in the UNIC C3 configuration are optional depending on application. The system is specifically designed for the demanding environment on engines. The rugged design allows the system to be directly mounted on the engine, which will give a very compact design without components to be mounted in dispersed external cabinets or panels, and allows the engine to be delivered fully tested at the factory.

The UNIC C3 system is handling all tasks related to start/stop management, engine safety, fuel management and speed/load control, and the system utilizes modern bus technologies for safe transmission of sensor- and other signals.

The position of the cabinet, containing the LDU, WIP and control buttons, may vary on a Wärtsilä 20DF engine. If the turbocharger is located at the Free End of the engine, then the cabinet is at the Driving End (Flywheel End). UNIC C3 is a modular system, which consists of the following major parts:

- LCP – Local Control Panel contains push buttons for local engine control, as well as two graphical displays (WIP-11 & LDU) for local reading of the most important engine parameters. All sensors on the engine are connected to the UNIC C3 system, and the information from these is displayed on WIP-11 (most important measurement) and on LDU (all sensor data, but also other information such as engine modes, possible failures and an event log).
- MCM – Main Control Module handles all the start/stop management and speed/load control functions of the engine, but also (optionally) the control of a number of devices on the engine.

- ESM – Engine Safety Module handles fundamental engine safety, and is the interface to the shutdown devices and some local instruments. It constitutes also the major hardware signal interface to the external systems.
- CCM – Cylinder Control Module handles all the injection and combustion monitoring of 3 cylinders per module.
- PDM – Power Distribution Module distributes, filters, and handles fusing of the module supply (2 x 24 VDC) and the valve drive supply (2 x 24 VDC).
- IOM – Input/output Module handles measurements and controls distributedly on the engine where the sensors/devices are located. IOM communicates with other IOMs and the MCM over CAN. The number of modules varies according to cylinder number, engine type and application.
- WCS – The Wärtsilä CAN switch (WCS) is used in Wärtsilä engine automation systems to safely connect the maintenance tool to the on-engine automation system. The switch is equipped with four CAN-channels for switching, and one CAN-channel dedicated for configuration and diagnostics of the CAN switch itself. In the UNIC C3 automation systems it might be used for the load sharing CAN bus and for the maintenance tool connection. /3/

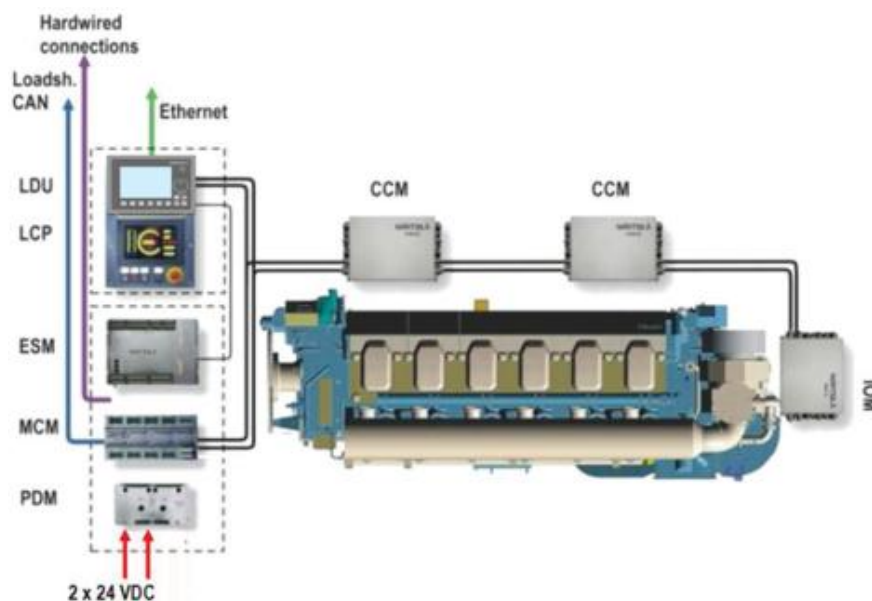


Figure 2. General overview of the UNIC C3 system on W20DF engine /3/

5 W20DF AUTOMATION SUBASSEMBLY

5.1 Driver for the Subassembly

The W20DF engine is equipped with the UNIC C3 embedded engine automation system and the classic W20 diesel engine is equipped with the UNIC C2 system. The main differences of the UNIC C3 to the UNIC C2 are electronic fuel injection and cylinder specific control. Thus it requires a lot more sensors, valves and actuators per cylinder (Figure 3)

All Wärtsilä 20 products which are made in the Vaasa factory are produced in the same production line. The lead time of the engine production line is as long as the longest lead time. The W20DF automation assembly takes twice as much assembly time in the engine production line as the traditional W20 diesel engines automation due to more complex automation system. Thus the balancing of the automation assembly time was selected as one development area.

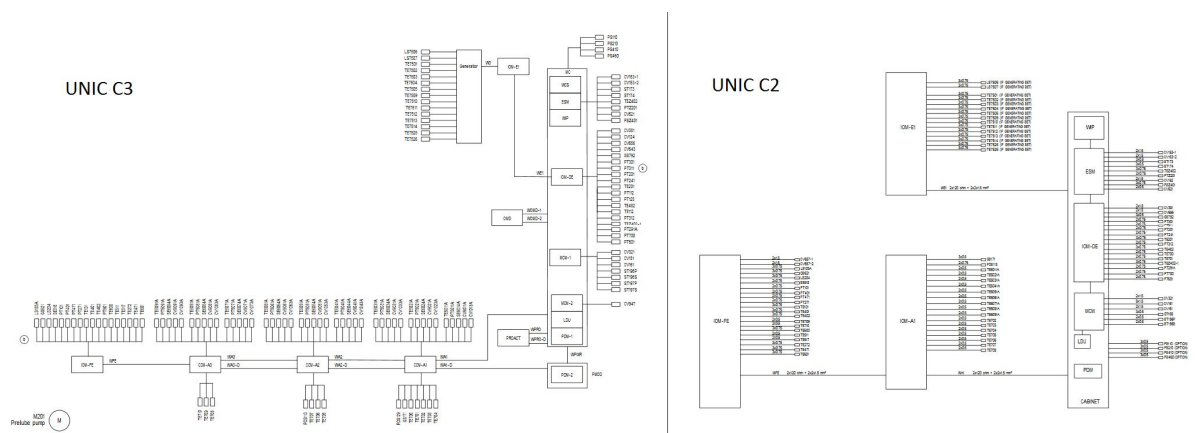


Figure 3. UNIC C3 and UNIC C2 cabling and sensor differences

There are also other benefits than the balancing of the production time when the assembly is made before the engine production line. The work in process will be decreased and more complete pre-test procedure can be made before installing the automation parts on the engine. In that way it is easier to identify possible hardware failures, installation errors and other quality defects before critical point of production of the engine.

5.2 Mechanical Design

The subassembly consists of four main parts (Figure 4): 1. exhaust gas pipe module, 2. main cabinet, 3. side module and 4. power module. An optional IOM module (5.) can also be installed below the main cabinet. Parts are installed on the jig as pre-assembled and pre-connected modules (Figure 5). The exhaust gas pipe module is used as a center of the subassembly. All the automation modules are installed to the exhaust gas pipe module. The jig is the accurate reconstruction of the W20DF engine block so the whole the module can be lifted and installed as one piece on the engine in the main assembly. The main attachment points of the subassembly to the engine block are cabinet bracket, exhaust gas pipe module and power module bracket.

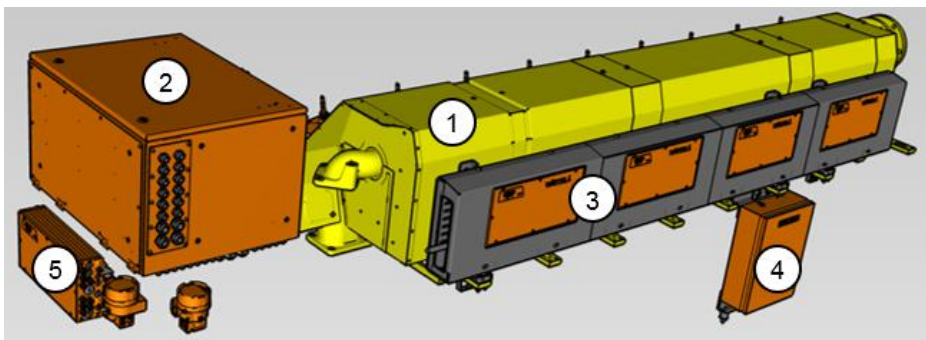


Figure 4. Parts of W20DF automation subassembly

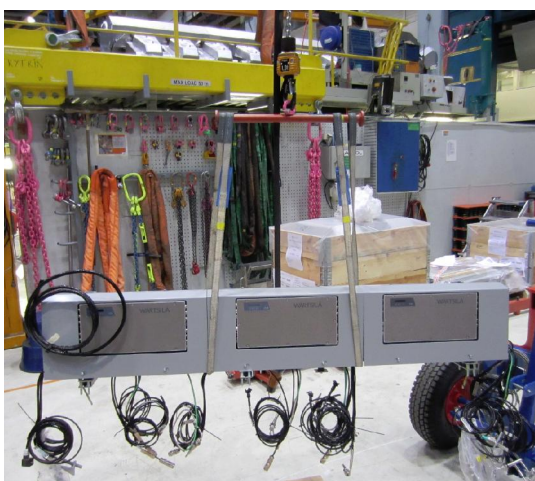


Figure 5. Lifting of pre-assembled side module

5.3 Electrical Design

Module specific wiring, sensors, actuators, solenoids and cables are installed to the modules before mechanical assembly to the automation subassembly. The cabling is made on the jig after the mechanical assembly of the electrical modules. Cable routes are made with brackets so the cabling can be fastened to the brackets and those can be installed on the engine. In that way the module can easily be installed on the engine without need to fasten cables separately (Figure 6).

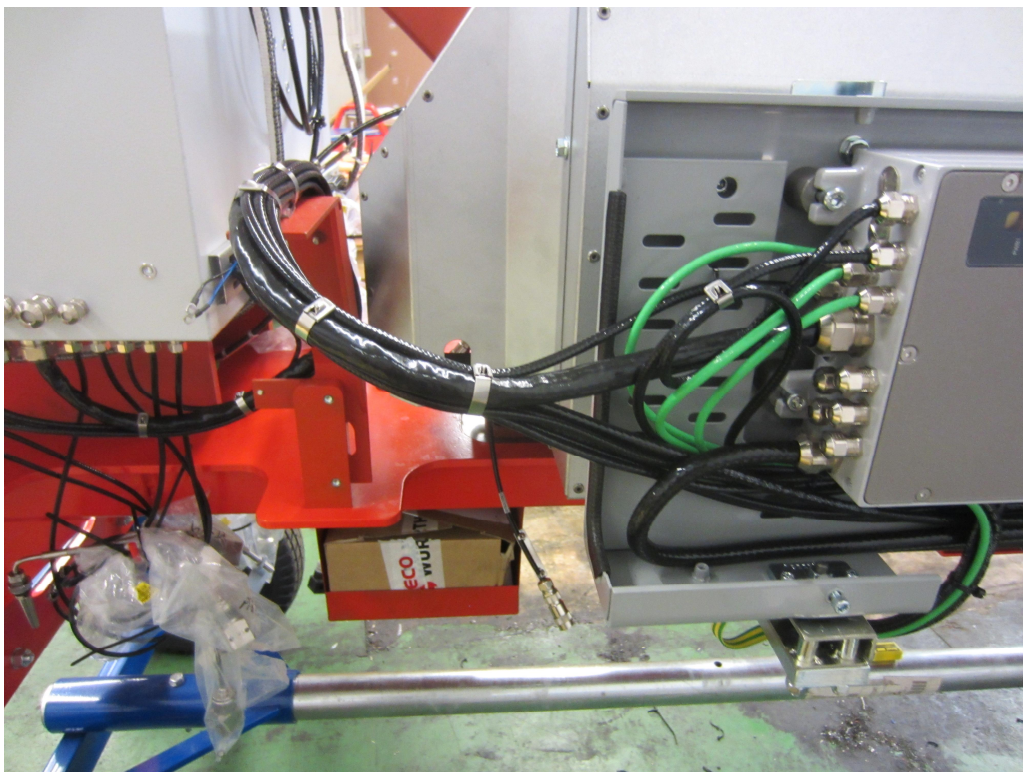


Figure 6. Cables fastened to the bracket for engine installation.

All the reasonable sensors, actuators, solenoids and cables are installed to the sub-assembly. In some cases, it is more reasonable to leave subassembly installation of the cable or sensor and make it in the main assembly. Reasons can be for example product bill of material related or pre-installation can cause more mechanical work than there will be electrical installation work. There are also cases when the component is installed to the other pre-assembly and only connector is included to the automation subassembly, for example pilot fuel injectors.

6 TEST PROTOCOL FOR W20DF AUTOMATION SUBASSEMBLY

6.1 Scope of the Test

The scope of the test protocol is intended to be as comprehensive as it can be for the subassembly (Figure 7). The main target is to include as much data gathering, measurements and testing in the test instruction as possible.

The scope of the test is to collect all relevant data from components, measure all the connected cables and wires, check and confirm the states of the modules and test the sensors, control buttons and the cablings of solenoids, valves and injectors.

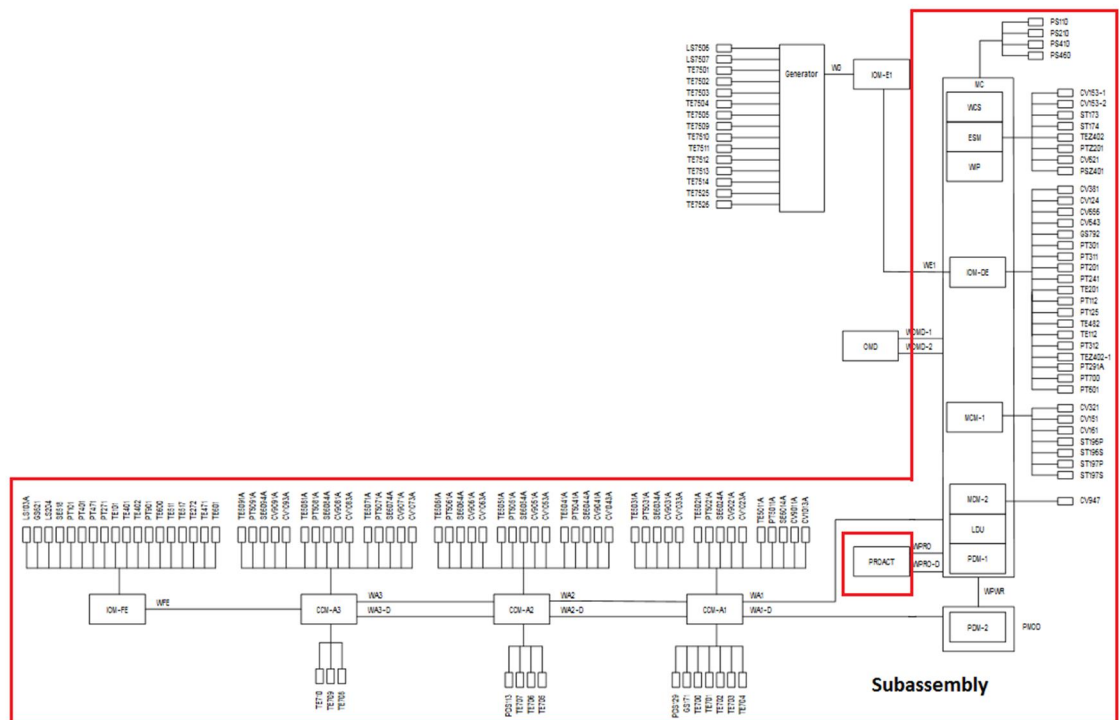


Figure 7. Components in the test scope

6.2 Test Instruction

6.2.1 General

The test instructions are in a form of a checklist. This reduces possibility to accidentally skip parts of it. The tester has to mark the check box and sign initials after every step. All the other elements of the instruction are locked but text fields to add measurement values and check boxes to mark when an item is checked. The table screen captures in this document are examples and more detailed description of the testing process is presented in the test instruction.

The cover page of the test instruction consists of four items. First there is the general information about the instruction and guidance where to store the completed test instruction. The second item is project details. All the engines are ordered for delivery projects so project information is needed to match the subassembly to the specific engine in the main assembly line. After the project information there is place for the tester's signature, date and place to know who the responsible person of the test was. The last item is the module serial number table (Figure 8). Serial numbers are collected for module traceability purposes.

Unit	HW Serial Number	HW version	Not applicable
ESM-20			<input type="checkbox"/>
WIP-11			<input type="checkbox"/>
PDM-20-1			<input type="checkbox"/>
PDM-20-2			<input type="checkbox"/>
LDU-20			<input type="checkbox"/>
MCM-11-1			<input type="checkbox"/>
MCM-11-2			<input type="checkbox"/>
IOM-10-DE			<input type="checkbox"/>
IOM-10-FE			<input type="checkbox"/>
WCS-10			<input type="checkbox"/>
WCP-10			<input type="checkbox"/>
CCM-20-A1			<input type="checkbox"/>
CCM-20-A2			<input type="checkbox"/>
CCM-20-A3			<input type="checkbox"/>

Figure 8. Example of module serial number table

6.2.2 Test Equipment and Additional Documents for Test

All the needed test equipment is listed in the first paragraph (Figure 9). The equipment is needed for various different type of measurements, simulations and tests. Two main tools for the test are a 24 VDC power supply to power up the UNIC system and laptop to download the test software and configuration. The laptop is also used for monitoring the simulations.

The only needed measurement device is a traditional multimeter. The multimeter is mainly used for resistance and voltage measurements. Connected sensors are simulated with suitable simulation methods. Methods to simulate sensors are speed simulators, pressure simulator and heat gun blower. Cables with connectors for sensors are simulated with test sensors, resistors, indication lights and test solenoids with valves.

- 1 x Multimeter
- 2 x Power supply, 24 VDC, 5A
- 2 x Wärtsilä speed simulators (PAAE120306)
- 4 x 22 k Ω WBD resistors
- 1 x 5,6 k Ω resistor
- 9 x 24VDC indication lights
- 1 x Knock sensor (0051K000301)
- 1 x M8x25 bolt and nut
- 1 x M10 bolt
- 1 x Pressure simulator
- 1 x mA simulator
- 1 x Kvaser Leaf Professional HS CAN cable (PAAE081919)
- 1 x Heat gun blower
- 2 x Solenoid valves (PAAE086415)
- 1 x Ethernet cable
- 1 x Laptop with WECSplorerUT

Figure 9. Test equipment to perform the test

Among the test equipment, additional instructions are needed to perform complete test: UNIC download instruction are used when the test software is downloaded to the UNIC with the WECSplorer software tool. ESM-20 tuning wizard is an add-on on the WECSplorer, it is used when the safety configuration is downloaded to the Engine Safety Module. The Test Mode instruction are a guide how to use Test Mode in the WECSplorer. WIP setting instruction is for tuning the Wärtsilä Instrument Panel modules.

6.2.3 Before Testing

Before the testing starts, there are general checks which need to be made to confirm the quality of the installation work and a fluent flow of the tests. Some of the checks are based on historical knowledge, checks such as picking every connection to confirm the end sleeve crimping and the wire connection to the terminal. Also the ESM CAN termination resistor position check is based on historical knowledge.

Most of the checks are for connections. Connections are presented in the project specific wiring diagrams (Figure 10). Important points are presented in the checklist. Checklist points are for checking the wiring of all the connections, check specified wires are twisted, and it is ensured that the resistors, jumpers and diodes are correctly installed.

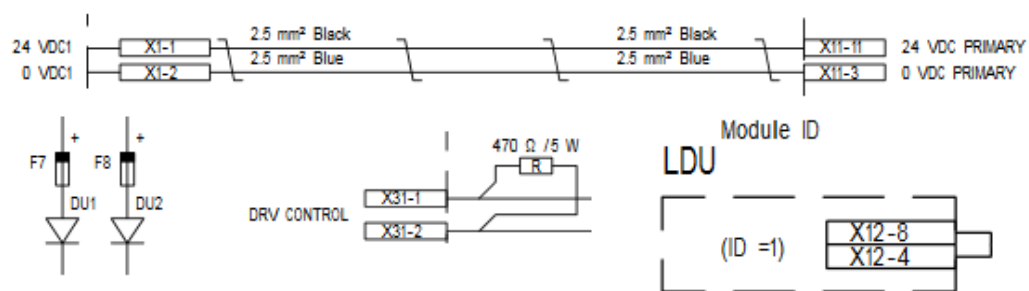


Figure 10. Examples of connections which need to be checked before testing

Some checks are based on Wärtsilä internal quality instructions. The instructions specify that all the specific markings need to be installed on the UNIC system. The required markings are UNIC type plate, name plates for the cabling and the connecting boxes, and welding precaution plates. Also the corrosion protection and cleaning of the connection boxes are stated in the internal quality instructions.

6.2.4 Resistance Measurements

Resistance measurements are performed before system is powered up. The purpose of resistance measurement is to ensure short circuit free system. Before the resistance measurements can be performed, PDM (Power Distribution Module) settings should be set according to the instruction. The settings are preset to detect earth fault failure in the powered system. These settings would affect the measurement values since there is a measurement circuit in the PDM.

Resistances are measured directly from PDM terminals (Figure 11). Terminals and expected resistance values are specified in the instruction. Expected resistance values depends on the measurement points. The resistance between plus and minus poles should be more than $100\ \Omega$, the structure of the system is such that the resistance should never go under that. The power distribution system of the UNIC is floating so minus and ground are isolated from each other. That is why the resistance between minus and ground should be very high, the expected value is more than $1\ \text{M}\Omega$.

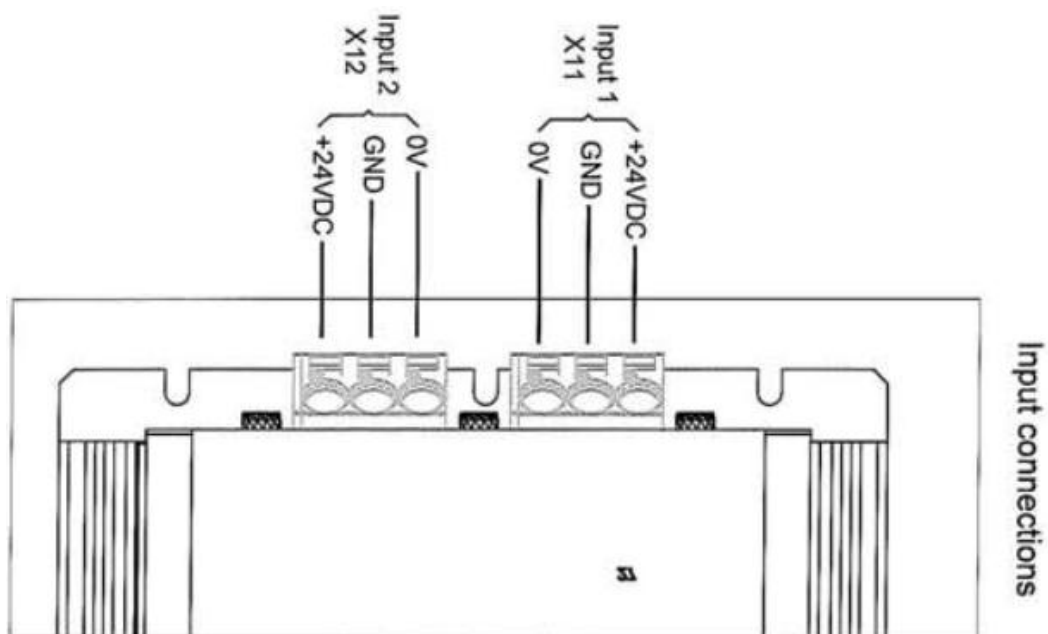


Figure 11. PDM input connections for power supply resistance measurements

CAN bus resistances are measured directly from MCM (Main Control Module) and ESM (Engine Safety Module) terminals. MCM is connected to the CAN bus and

ESM is connected to CANopen. The expected resistances depends on the product variations. The W20DF subassembly can be ordered with different module (node) options (Figure 12). The lowest resistance of $60\ \Omega$ is when all the modules are connected to the system, so there are $120\ \Omega$ termination resistors at the both ends. The expected resistance of $120\ \Omega$ is when one end is not connected to the last module. The highest expected resistance is when both ends are not connected, then the resistance should be more than $1\ \text{k}\Omega$ because both termination resistors are missing.

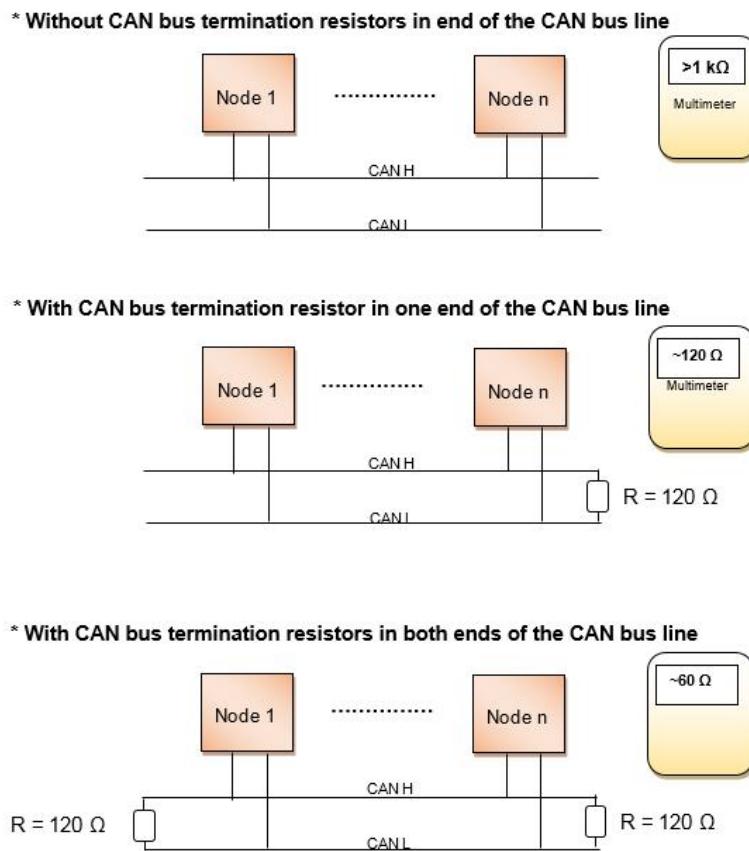


Figure 12. Resistance in CAN bus lines

The last resistance measurement is speed and phase signal resistances. The resistance is measured when sensors are not connected to the system so the expected value is only from CCMs (Cylinder Control Module). Value between the signal and minus pole should be between $0.5\ \text{k}\Omega$ and $5.0\ \text{k}\Omega$. Resistance between CCM minus and ground should be more than $1\ \text{M}\Omega$. The plus pole from CCM is not used for the sensor so measurement is not needed.

6.2.5 Module Power Distribution

The system can be powered up if the resistance measurements are done and the resistances are within the limits. Before powering the system up, the power supplies needs to be checked. The power supply output voltage should be UNIC's nominal 24 VDC and the polarity should be connected correctly.

When the UNIC is powered the module LEDs are to be checked. Both PDMs are connected to the power supplies so all the specified PDM LEDs should be lit before proceeding the tests (Figure 13). After the LED check the PDM earth failure detections to be reactivated by setting the knobs to defined values. The earth failure LED plus or minus should not lit.

	PDM-20-1	PDM-20-2
AUX 1	lighted	lighted
BUS 1	lighted	
BUS 2	lighted	
DRV 1		lighted
DRV 2		lighted
IN 1	lighted	lighted
IN 2	lighted	lighted

Figure 13. Example of PDM LEDs which to be lit when powering the system

If all power lines are working and earth failures are not detected in the PDMs the test can proceed. The next step is to check MCM, ESM, IOM and CCM LEDs. Power 1 and Power 2 LEDs should be lit green in all the modules, also Driver 1 and Driver 2 LEDs should be lit green in the CCMs (Figure 14).



Figure 14. LEDs of CCM

All the other LEDs in the modules are module internal diagnostic LEDs. ESM has diagnostic LEDs for fuses F1-F3, these should also be checked and lit green. There are Logic supply LEDs in the MCMs which should go green and Diagnostics LEDs in the all the modules except in the ESM which should blink red-yellow or yellow, depending on if the software is already downloaded to the module in the supplier.

The last module power distribution check is redundancy. UNIC has a redundant power supply to be able to stay powered-up with one power supply failure in the system. Redundancy is checked by disconnecting another power supply line. After disconnecting one power supply line, the power supply LEDs from particular line is to be checked and modules must stay powered up with the remaining power supply line. When the test goes through, the first power supply line is to be re-connected and other line to be tested.

6.2.6 Sensor Simulations

Before the simulations can be done, the test software configuration has to be downloaded to the UNIC. A few preparations need to be made before it can be downloaded to the system. Wire break detection resistors and test solenoids are connected to the ESM and the lube oil pressure sensor is pumped over the alarm and shutdown limit to be able to have failure free ESM during the tests. A 120 Ω resistor(s) needs to be added to CAN bus to ensure the optimal functionality of the bus if expected resistance is not 60 Ω .

After the preparations done the software and configuration can be downloaded to the system (Figure 15). After the download the ESM module test configuration to be downloaded to the ESM. The software and ESM configuration downloading is instructed in the additional documents.

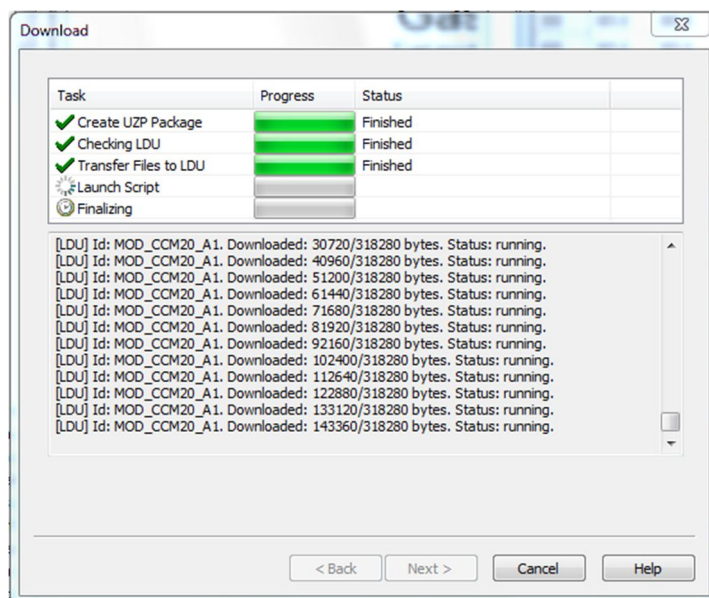


Figure 15. Software download to the CCM-A1

The first tests with test software are digital measurement signals. Digital signals are simulated with various methods depending on the type of the measurement. The level switch is simulated by immersing the sensor to the cup of water because it is a liquid level switch. Limit switches are simulated with metallic object since they are induction type of sensors. Jumper wires are used with difference switch connectors by connecting the jumper directly to the connector. The digital input status is changing in each sensor when sensor is simulated and the process value is read from the WECSplorer Wärtsilä software tool or the LDU (Local Display Unit).

There are two different type of temperature sensors on the assembly, PT-100 and thermocouple K type. Both temperature sensor types are simulated with the heat gun blower. Each sensor is heated up one at a time with the blower and the process value is read. Sensors are heated one at the time so crossed connections can be found. Traditional pressure sensors are simulated after temperature sensors with pressure simulator. The simulator is a pump with pressure gauge, it is connected to

the sensor and pressure is pumped up. The process value of the pressure sensors should be the same as gauge value when it is read from the WECSplorer or LDU.

Cylinder peak pressure sensor connectors are part of the subassembly. Cylinder peak pressure sensors are used to monitor the combustion in the engine cylinder. Sensor measures the highest peak pressure in the cylinder during combustion cycle. UNIC software measures the peak pressure in a configured window which is based on a 4-stroke cycle calculation and measurement from speed and phase sensors. Pressure is measured in a certain window in order to ensure that the real peak pressure is measured.

The UNIC is detecting sensor failures from the peak pressure sensors with two different ways. First way is unreasonable measured peak pressure value which is measured while engine is running. Second way is to measure a correct mA value when pressure is not detected so the engine has to be stopped. This detection type is easier to simulate for the test. The cylinder peak pressure sensor signal is 4-20 mA and the connector of the peak pressure sensor can be simulated with a resistor. HW SF (hardware sensor failure) can be de-activated in the UNIC if the signal value is within 4 and 6 mA, this feature is built in the UNIC software. 5.6 k Ω resistor is used based on calculation below to match sensor failure detection range 4-6 mA. The resistor is in the standard resistor series E12 so it is easily obtainable.

$$R = \frac{U}{I} = \frac{24 V}{0,004...0,006 mA} = 6000 \dots 4000 \Omega$$

6.2.7 Local Control Tests

Local controls are tested after first part of sensor simulations. The first part is to check, test and calibrate local displays. One local display is WIP (Wärtsilä Instrument Panel) (Figure 16). WIP DIP switches and failure jumpers must be according to the project specific WIP settings and wiring diagrams to ensure the correct values and failure indication in the panel. When the checks are done, the speed simulator is connected to ESM. The speed simulator is simulating frequency to the speed input of the ESM. ESM processes the frequency value to the mA, mA is sent to the WIP via wiring. The frequency is to be set to the nominal speed value and WIP

speed bar and the value reading must be calibrated according to a separated instruction document. After the calibration, failure indications have to be checked. After checking, power supply failure to be simulated by disconnecting one power supply line. When the power supply line is disconnected, the failure indication symbol should light up on the WIP module and WIP failure should be activated in the WECSplorer or LDU. The second local display is LDU. Only the functionality of the rotary knob is tested in LDU since it is historically seen as a failure sensitive item.

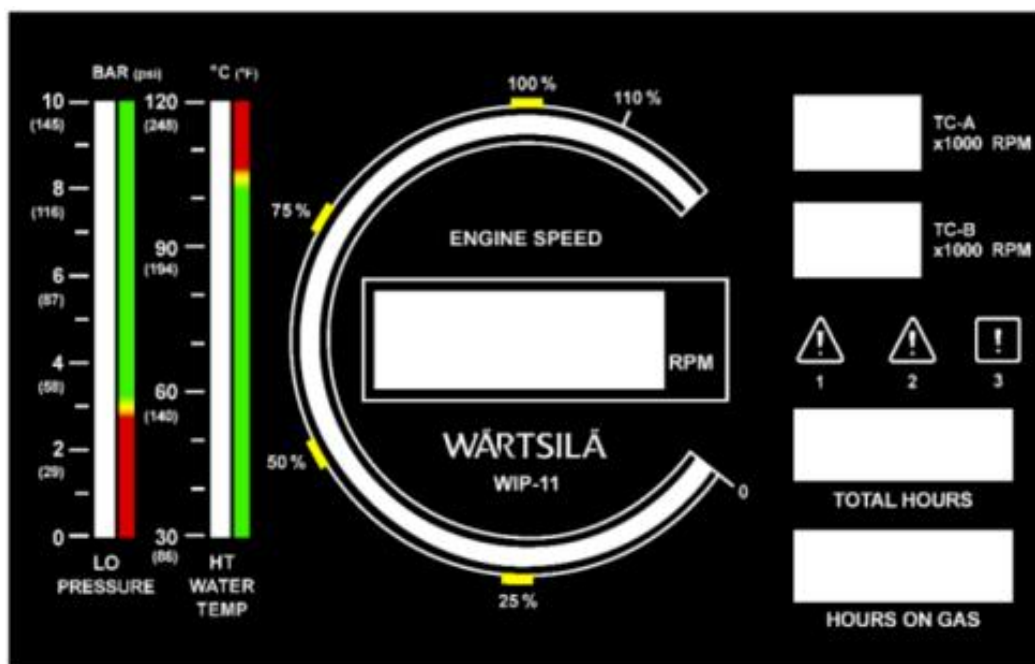


Figure 16. Front view of the WIP-11 display

Control buttons can be tested when the displays tests are done. The mode selector is tested before control buttons (Figure 17). There are four options to select in the mode selector. The first is Engine blocked, then the engine cannot be started or rotated at all with engine controls. The second selection is Local control. The engine can be operated locally with the local control selected. The third is Remote control, then the engine can be operated from the remote control system. The fourth selection is not used on this engine type so it is not connected. All these three are tested by rotating the mode selector and checking the control mode ISO-code indication from LDU.

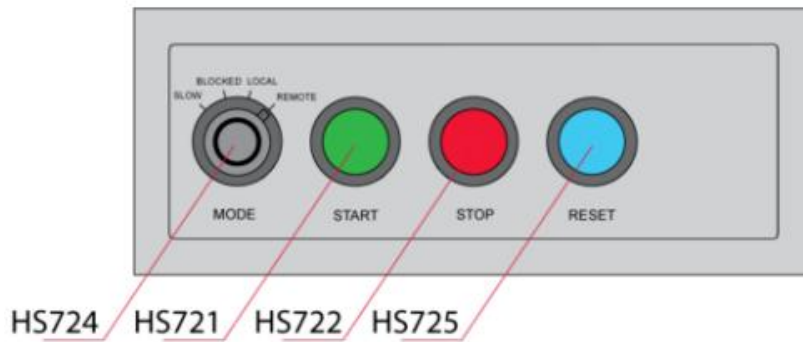


Figure 17. Mode selector HS724

When the mode selections are working the local control buttons can be tested. Start and Stop buttons are tested in every mode separately. The functionality requirement is defined in the table format (Figure 18). The signal values are confirmed from LDU. The reset button is tested in the Local mode, it activates the signal in LDU but also ESM reset the LED to be checked.

Test ID	Method																				
5.8.3.1	Check on the LDU screen that OS7304 (Remote stop signal) follows the table below.																				
	<table border="1"> <thead> <tr> <th>Local/Remote switch</th> <th>Stop button released</th> <th>Stop button pressed</th> <th>OK</th> </tr> </thead> <tbody> <tr> <td>Slow</td> <td>0</td> <td>1</td> <td><input type="checkbox"/></td> </tr> <tr> <td>Blocked</td> <td>0</td> <td>1</td> <td><input type="checkbox"/></td> </tr> <tr> <td>Local</td> <td>0</td> <td>1</td> <td><input type="checkbox"/></td> </tr> <tr> <td>Remote</td> <td>0</td> <td>0</td> <td><input type="checkbox"/></td> </tr> </tbody> </table>	Local/Remote switch	Stop button released	Stop button pressed	OK	Slow	0	1	<input type="checkbox"/>	Blocked	0	1	<input type="checkbox"/>	Local	0	1	<input type="checkbox"/>	Remote	0	0	<input type="checkbox"/>
Local/Remote switch	Stop button released	Stop button pressed	OK																		
Slow	0	1	<input type="checkbox"/>																		
Blocked	0	1	<input type="checkbox"/>																		
Local	0	1	<input type="checkbox"/>																		
Remote	0	0	<input type="checkbox"/>																		
	<table border="1"> <thead> <tr> <th>OK</th> <th>N/A</th> <th>Tested by:</th> </tr> </thead> <tbody> <tr> <td><input type="checkbox"/></td> <td><input type="checkbox"/></td> <td><input type="checkbox"/></td> </tr> </tbody> </table>	OK	N/A	Tested by:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>														
OK	N/A	Tested by:																			
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>																			

Figure 18. Example of local start button functionality requirement table

There are a few more things to check when the emergency stop button is tested. Emergency stop button activates the ESM LED and status in WECSplorer or LDU for indication. It also de-activates Driver power supplies. Driver supplies are for controlling electronic fuel injection. PDM must cut the power off from Driver supplies so that the fuel injection cannot continue when the emergency stop button is pushed. Also the stop solenoid wirings from the modules to the terminals are tested with emergency stop button. Solenoids are connected to terminals, the button is pushed so the solenoids must activate and ESM LEDs have to be red.

The last local control tests are optionally installed Emergency speed switches. Emergency speed controls are installed when the subassembly is for engines which are made for mechanical propulsion drives. The emergency speed setting selector includes two options: normal and emergency. In the normal mode the engine will follow analogue speed reference signal so it is active on the LDU when it is selected. In the emergency mode the engine will follow the speed increase/ decrease selector. When the emergency mode is selected, the increase and decrease signals to be tested and verified from the LDU.

6.2.8 Engine Safety Module (ESM) Tests

ESM related tests are included to many parts of the test procedure. Still there is an own part for signals which are connected to and handled by ESM. The first check is the ESM failure signal. The signal is simulated by causing a fault to the power supply. The fault has to be verified from the indication LED and WECSplorer.

Overspeed shutdown statuses are tested after the general ESM failure. The speed simulator is connected to primary speed sensor terminals and nominal speed is simulated to the ESM. The simulator frequency is increased towards the specified overspeed frequency limit. When limit is reached, the overspeed status of the primary speed sensor activates the indication LED in ESM and the status code in WECSplorer. The same procedure is performed for the secondary speed sensor.

Critical shutdowns are simulated by increasing temperature and decreasing pressure. The shutdown status of the engine coolant high temperature is tested by heating the sensor with heat gun blower. The sensor is heated to over the shutdown limit and the status is checked from the ESM indication LED and WECSplorer. The low limit of the lube oil pressure is simulated by decreasing the pressure from the pressure simulator. The status is checked from LED and WECSplorer. The last ESM test is Stop/shutdown status. The status is tested by pushing stop button from local control panel. The status is checked from LED and WECSplorer, also the stop relay for external interface to be measured and verified.

6.2.9 Speed and Phase Signal Tests

Speed and phase sensors will be connected the terminals in the main cabinet. Phase signal wirings continues to the CCMs in the side module. These signals are important from the point of view of engine functionality, for example the speed signal for speed/ load control and the phase signal for electronic fuel injection. Wirings are tested with a speed simulator which also simulates the phase signal. Both primary and secondary are tested separately, and the values are confirmed from LDU or WECSplorer. Values are checked in simulated Run mode from all the modules were the signals go.

The turbo charger speed sensor connector is tested with the same speed simulator. After the speed simulator has been connected, the value is increased to the specified kHz value. In this case the specified rpm value is checked from WIP and LDU or WECSplorer. If the WIP value is not as specified, WIP needs to be adjusted.

6.2.10 Hardware I/O tests

Hardware outputs are tested with the test mode. The test mode is a mode built in WECS-plorer which overrides control software output controls. It can be used in two different modes: HW I/O or CCM Control. In the HW I/O tests, the outputs can be controlled manually with digital or analogue values.

Control and solenoid output controls are tested in the test mode by changing the control value. When output is set, the specified relays for engine external interface to be measured with the multimeter and the activation of the solenoids is confirmed. Indication light is connected to the cable for the solenoid which is not connected to the subassembly. The indication light is indicating that the cable is correctly connected to the output when it is activated from WECSplorer.

Internal signal wirings are also tested in the test mode. For the button indications, values are set in the WECSplorer test mode. LEDs in the reset and start buttons are checked and relay output is measured with the multimeter. The stop output command for the ESM is checked from ESM indication LED.

6.2.11 Cylinder Control Module Control Tests

The electronic fuel injector and knock sensor cabling and connectors are tested with the second mode of the test mode: CCM (Cylinder Control Module) Control test. Indication lights to be connected to the fuel injector connectors, specified settings are set in the WECSplorer and then the tests can be done. The connector specific indication light is lit when test goes through all the injector connectors one at the time.

Knock sensor cabling and connectors are tested after injection tests. Knock sensors are piezo type. In this case the sensors are measuring the acceleration. It can be simulated with vibration. The vibration is made by mounting one bolt to the test sensor and the mounted bolt is scraped with other bolts threads. The test sensor is connected to every connector one at the time. The value is checked and sensor failure de-activation confirmed from the WECSplorer.

6.2.12 Stand-by Pump Control Relays

Stand-by pump control tests are for external stand-by pump connections. Stand-by pump controls are controlled by ESM Speed switches 3 and 4 (Figure 19. Speed switch LEDs in ESM). Speed switches are simulated by applying frequency to ESM engine speed inputs. The frequency for speed simulation to be increased slowly and ESM LEDs are lit when speed value is exceeding the value in ESM settings. When the LED is lit and the value is above the limit in the settings, the value is decreased and LED is unlit. Then the correct functionality of the stand-by pump controls is confirmed. If the subassembly is equipped with optional pressure switches they are tested too. Speed switch 3 is simulated above the activation limit and no pressure is applied to the pressure switch, the stand-by pump specific relay will activate and it need to be measured with the multimeter.

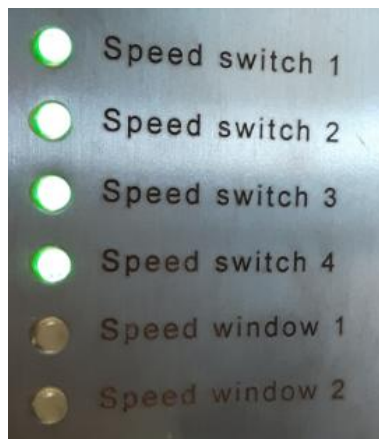


Figure 19. Speed switch LEDs in ESM

6.2.13 Test Completed

Test is complete when the completion list is checked (Figure 20). The equipment needs to be removed from the subassembly: power supplies, temporary installed resistors, jumpers and simulators. The important module serial number collection is double checked. The document is completely filled and the first page is printed out and put in the main cabinet. The first page is put in the cabinet for confirmation in the main production that the subassembly is correctly tested before assembling it on the engine.

Test ID	Test	OK	N/A	Tested by:
6.1.1.1	Check that module serial numbers in the test report and on the module cover are the same.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.1.1.2	Remove all external power supplies used during the test.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.1.1.3	Remove all temporary resistors used during the test	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.1.1.4	Remove all temporary jumpers used during the test	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.1.1.5	Remove all simulators used during the test.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.1.1.6	Check that the test report is filled in completely and copy the first page and put the first page inside the main cabinet.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 20. Examples of checks for completing the test

6.3 Test Software Configuration

The software version was chosen to be latest available UNIC C3 DF standard software with the latest W20DF configuration version. Usually the standard is used for project specific engine configurations and in this case it was the most reasonable base for the test software configuration. The standard includes the latest inputs and outputs together with all the options which are used in project deliverables. All the changes are configuration changes, so no software changes were needed for subassembly test software configuration. The test configuration is made to be compatible with the test instruction and components installed to the subassembly.

The process of making the test configuration was iterative, there were no guidelines how to configure the test configuration from all-inclusive software configuration. The configuration was downloaded to the UNIC many times during the process to ensure boot-up and smooth run of the system.

Extra software application modules were removed from the configuration since they are not used for test purposes. Only the applications critical from point of the test were left to the configuration, for example injection related applications. After the application removal all the removed applications related the ISO-codes were removed from the configuration, there by the configuration is as clean as possible from that sector. There were a few challenges, such as error floods in the log of the WECSplorer during the removal process. The reason was the removal of system dependent application module, application was put back in the configuration to fix the issue.

When unnecessary application from the point of view of the test were removed, and the configuration was still working, the extra I/O and safeties were removed. Hardware I/Os which were not needed in the test instruction procedure were removed. The main part of those I/Os are hardwired signals to the external system. After the HWs were removed the unneeded safeties were removed. All not test related safeties were removed except the power supply voltage level low and high safeties. These safeties indicate if the power supply used in the test is feeding too low or high voltage.

The LDU (Local Display Unit) was configured last. The LDU is used for verification of the status changes during the tests, thus it is important that it includes all the possible information. The LDU has a page structure, a certain amount of the data can be configured per page depending on the layout. For the test configuration the first page is configured as system info page, system related values can be found there such as software version, voltage level of every module and CAN states. The rests of the pages are filled in with pressure sensor values, cylinder pressure sensor values, knock sensor values, local control statuses, ESM statuses, speed and phase values of the related modules. Thus it easy to check change of status/ value during the test procedure.

6.4 ESM Test Configuration

There is a similar logic behind the ESM test configuration selection as in the test software. But in this case the pure W20DF standard ESM configuration is used for test purposes, there was no need to modify the standard parameter values (Figure 21). Standard nominal speed, lube oil pressure limit and speed switch values are the same as in the test instruction.

Parameter Name	Value	Unit
Frequency from speed sensor at nominal engine speed	620.0	Hz
Overspeed limit of nominal engine speed	115.0	%

Figure 21. Example of standard ESM parameter values

6.5 Test Rig Simulations for Configurations

Rig tests were performed after the test software and ESM configurations were finalized for the tests. The rig is a rack built simulation tool for the UNIC. It is equipped with UNIC modules, I/O simulation modules and PC with Minirig software for controlling I/Os. The minirig software simulates most of the real engine behaviors with the rig I/Os which are hardwired to the UNIC modules (Figure 22).

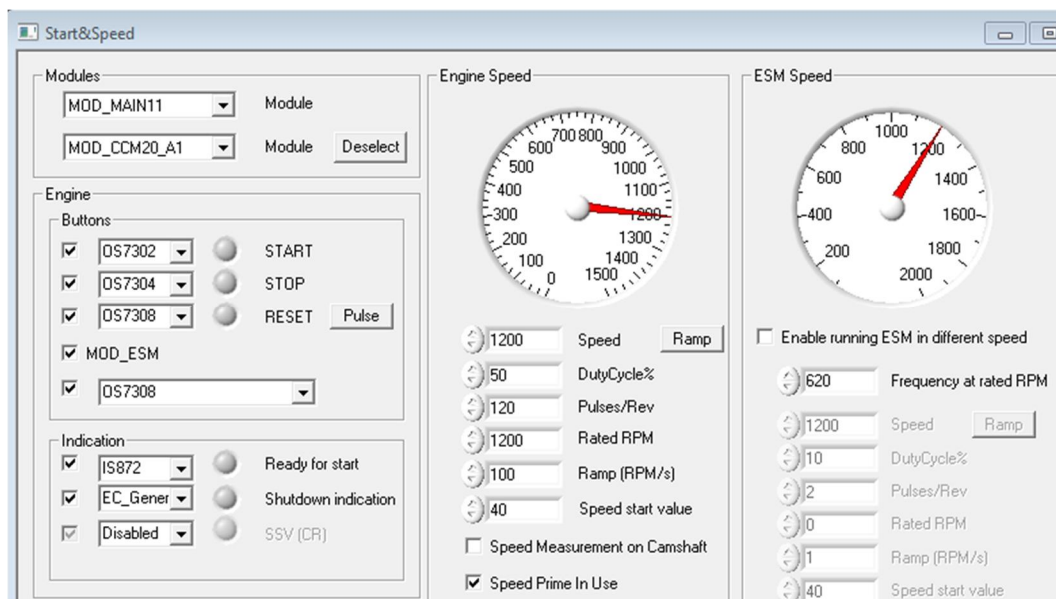


Figure 22. Simulations with Minirig

The purpose of the test is to ensure the functionality of the test configurations. Software and configurations were downloaded to the UNIC on the rig with WECSplorer. WECSplorer was set to Online, EDL (Enhanced Diagnostic Log) error log was confirmed to be clear. The preparations which were made in the test instruction paragraph sensor simulations were made with Minirig to get the WECSplorer into Stand-by mode. In this case the preparation is only ESM lube oil sensor mA simulation to exceed shutdown limit. The system was reset with Minirig output, WECSplorer status went to the Stand-by mode. When the Stand-by mode was achieved the system was simulated to the Run mode and EDL was confirmed to be clear. The last test was the LDU statuses and process values. All the possible statuses and values were simulated with Minirig and the correct values were confirmed from the LDU pages. After the tests all the minor configuration bug findings were fixed and re-tested.

7 PILOT TEST AND TRAINING

7.1 Tests with the Pilot Installation

To finalized all the deliverables for the subassembly testing, the real test was performed with a selected pilot installation. The pilot was a subassembly for W9L20DF engine. The subassembly was piloted as a concept so that the mechanical and electrical side together with test protocol were piloted in the same delivery project.

The piloting was performed together with the production process developer. All the errors in the test instruction and bugs in the test software configuration were gathered during the tests. The main findings were an extra sensor in the pressure measurement list, missing sensor from pressure measurement page from the LDU, wrong module specific ISO-codes for speed and phase signals and minor typos. The extra pressure sensor measurement was removed and speed and phase ISO-codes were corrected to the test instruction. The pressure sensor was added to the LDU configuration and correct ISO-codes for speed and phase signals were selected in the configuration. Functionality of the configuration corrections was confirmed in the test rig tests.

After the corrections to the test instruction and software configuration, the protocol was re-tested with the next pilot installation. The re-test was performed by the process developer. The protocol was reported to work well so no need for further corrections or modifications was needed.

7.2 Training of the Process Developer

The training of the process developer was performed simultaneously as a hands-on training with the pilot installation tests. Training need for the process developer was small due to great experience from the engine testing and assembly work. Only minor clarifications were needed during the piloting.

8 FINALIZATION AND NEXT STEPS

The first test configuration was for 9-cylinders subassembly. The test software configuration for other cylinder number were needed after the pilot tests and training had been held. Wärtsilä 20DF is available for 6, 8 and 9 cylinders so 6 and 8-cylinders test configurations were configured for subassemblies. The functionality of the configurations was ensured with the rig and after that during the first installations. The test protocol was ready for the production use.

The next step will be the training of the supplier. The training will be held by the process developer and support is given if needed. When the assembling and the testing of the subassembly are working with the supplier, the subassembly can be transferred to the them. The next steps on the engineering side is to make internal factory assembly test instruction to match with subassembly test.

In the future the possibility to add even more components to the subassembly can be investigated. There is potential to add classification depended sensors and separately installed I/P converters to the subassembly.

9 CONCLUSION

The purpose of the thesis was to make systematic test protocol for the W20DF sub-assembly for supplier testing. The previous test protocol included only low level tests where a lot of things were left out. The objective was to ensure the highest possible quality of the subassembly products from the supplier with as complete subassembly as possible. Judging from the feedback received, this was achieved.

The planning of the necessary content for the test instruction was the hardest part of the thesis. Easily seen hardware such as sensors, cables and cables with connectors, solenoids and control buttons were easy to identify as parts which needed to be included. The hard part was the wiring and cable connections in the cabinet, side module and power module. Therefore, a systematic review and evaluation was needed when the test needs were planned. The test software configuration was easier since the configuration had to be made directly for the items and the functionality needs of the test instruction.

The most interesting part of the thesis was piloting and training because of these parts were hands-on. During these it was interesting to see how theoretically made instruction work in real a subassembly. It was even surprising how well it worked. Overall everything went better than expected in the process of this thesis.

REFERENCES

- /1/ Wärtsilä Oyj Abp
<http://www.wartsila.com/about>
- /2/ W20DF engine description
Wärtsilä internal document
- /3/ UNIC C3 system description
Wärtsilä internal document

APPENDICES

1. Wärtsilä internal use only
2. Wärtsilä internal use only