OULUN AMMATTIKORKEAKOULU

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DESIGN OF WIRE HARNESS TEST SYSTEM

Commissioned by Proventia Oy

DESIGN OF WIRE HARNESS TEST SYSTEM

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Opinnäytetyön aiheena oli suunnitella sekä rakentaa johtosarjatestauspöytä Proventian käyttämille johtosarjoille. Työ suunniteltiin Proventian tarpeiden mukaan, ottaen huomioon myös johtosarjavalmistajan työvaiheet sekä testaustoimintaperiaatteet. Testauspöytä otettiin valmistumisen jälkeen käyttöön Proventian laadunvalvonnassa. Testauspöydän tarkoituksena on estää viallisten johtosarjojen joutumista asiakkaiden jälkiasennettaviin pakokaasunpuhdistusjärjestelmiin. Työhön kuului perehtyminen johtosarjoihin, niiden testaamiseen sekä testauspöydän rakentaminen. Työssä otettiin huomioon myös testauspöydän jatkokehittämisen mahdollisuus, sekä mahdollisuus toimittaa helppokäyttöinen testausjärjestelmä myös johtosarjavalmistajalle.

Raportissa käydään läpi johtosarjojen suunnittelua, standardeja, testausmenetelmiä, yleisiä vikoja johtosarjoissa, testipöydän suunnittelemista, rakentamista, sekä sen ohjelmoimista. Lopuksi esitetään opinnäytetyön saavutettu hyöty laadunvalvonnassa.

Asiasanat: IPC, johtosarja, jälkiasennus, laatu, testaussysteemi, testiohjelma, testipiste

ABSTRACT

Oulu University of Applied Sciences
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The subject for this thesis was to design and build a wire harness testing system for the wire harnesses used by Proventia. The product was designed according to Proventia's needs, also considering the manufacturing process and testing principles of the wire harness manufacturer. The finished testing system was introduced in Proventia's quality control. The purpose of the testing system is to prevent faulty wire harnesses from getting into customers retrofitted exhaust gas cleaning systems. The work included getting acquainted with the wiring harnesses, testing them, and building a testing system. The work also took consideration to the possible further development of the testing system, and the possibility to supply an easy-to-use testing system to the wiring harness manufacturer as well.

In this report covers the design of wire harnesses, standards, testing methods, common defects in the wiring harnesses, designing, building, and programming the testing system. Finally, the achieved benefit of the thesis in quality control is presented.

Keywords: IPC, quality, retrofit, test point, test program, testing system, wire harness

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1 INTRODUCTION

Proventia Oy's retrofit team has identified the need to ensure the condition of joints and wires of the wiring harnesses of retrofitted products in order to guarantee the quality of the products for customers. This thesis introduces the design of a wiring harness testing system, which can be delivered to Proventia's wiring harness suppliers as well as to Proventia's own premises.

The function of the wiring harness test system is to perform a test on a frequently used wiring harnesses and to establish a quality guarantee for one of the most critical parts of the exhaust gas cleaning system in accordance with customer requirements and customer satisfaction. The wiring harness test system should also have the ability to test multiple different wiring harnesses and be a functional quality assurance solution for testing new kits at a later date.

2 PROVENTIA OY

2.1 Background

Proventia Group Oy started its operations in 2000 as a development company, including subsidiaries specialized in environmental, energy and other technologies. One of these subsidiaries was Finnkatalyt Oy, established in 1994. It produced solutions such as exhaust aftertreatment systems for small petrol engines. In 2007, Finnkatalyt became Proventia Emission Control Oy, and the company shifted its focus to large diesel engines. (1.)

In 2012, Proventia focused on the emission control business. At the same time, the management of Proventia Group and Proventia Emission Control were merged in a single organisation. In 2015, Proventia expanded its business operations from exhaust aftertreatment systems to modular test solutions and thermal components, and Proventia Emission Control became Proventia Oy in 2017. (1.)

The company's goal is to be a leading supplier of technology for the engine, machine, and vehicle industries in selected niche markets. The company focuses on two business areas: test solutions and powertrain systems and components. Proventia's vision is zero emissions. (1.)

Proventia's headquarter locates in Oulu, Finland. Proventia has two factories in Finland and one in Czech Republic. The company employs over 150 employees. (1.)

2.2 NOxBUSTER® City

Proventia's NOxBUSTER® City is an emission control system that can be retrofitted to heavy vehicles already in service, such as buses, garbage trucks and trucks. NOxBUSTER® City reduces emissions up to Euro VI emissions. (2.)

This retrofit exhaust gas cleaning system combines a DPF (diesel particulate filter) with an SCR (selective catalytic reduction) system that utilizes AdBlue additive and catalyst to reduce nitrogen oxides. The SCR system consists of an SCR catalyst, a urea dosing system, urea tanks, mixers and lines, various sensors, wire harness and a control unit as seen in Figure 1.

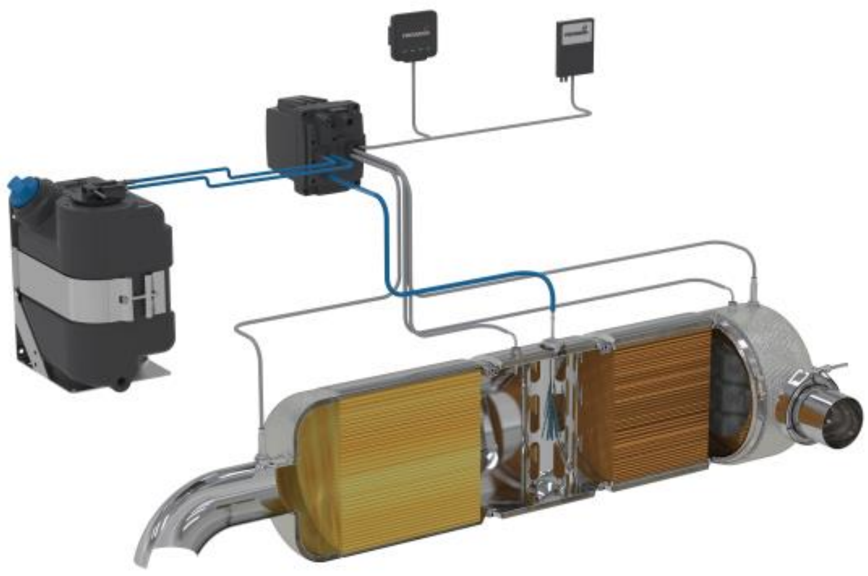


Figure 1. NOxBUSTER City (2.)

Proventia also offers an optional Proventia PROCARE™ Drive telematics system, which provides information about the emission reductions and system operation on the vehicle's daily route. (2.)

3 PRELIMINARY STUDY

3.1 Wiring harnesses

Cable harness, also known as wire harness or wiring harness is an organized set of wires, terminals and connectors that carry electricity or a signal bundled together throughout the entire vehicle, therefore playing a critical role in connecting a variety of components. The conductors are bundled, for example with a protection sock. Cable harness size can vary from small 20cm long or shorter cables to a 10m or longer multi branch harnesses like in figure 2.

Figure 2. Larger multi branch wire harness. (10.)

Cable harnesses are commonly used in automotive and retrofit systems like in figure 1 as well as in construction machinery, aircrafts, and spacecrafts.

Connectors in a wire harness consist of 4 or 5 different parts as seen in figure 3. Main part is the housing of the terminal. Housings have either clips or threads on them for the mating connectors. Larger housings might even have possibilities to attach them mechanically from the bolt holes in the frame of the connector. Depending on the connector, it will have either female or male pins in it. This means that the pin of the connector will either go inside the opposite pin or vice versa. In some connectors these can also be called a receptable or plugs, receptable being the female and plug being the male connector. Pins are also commonly known as terminals.

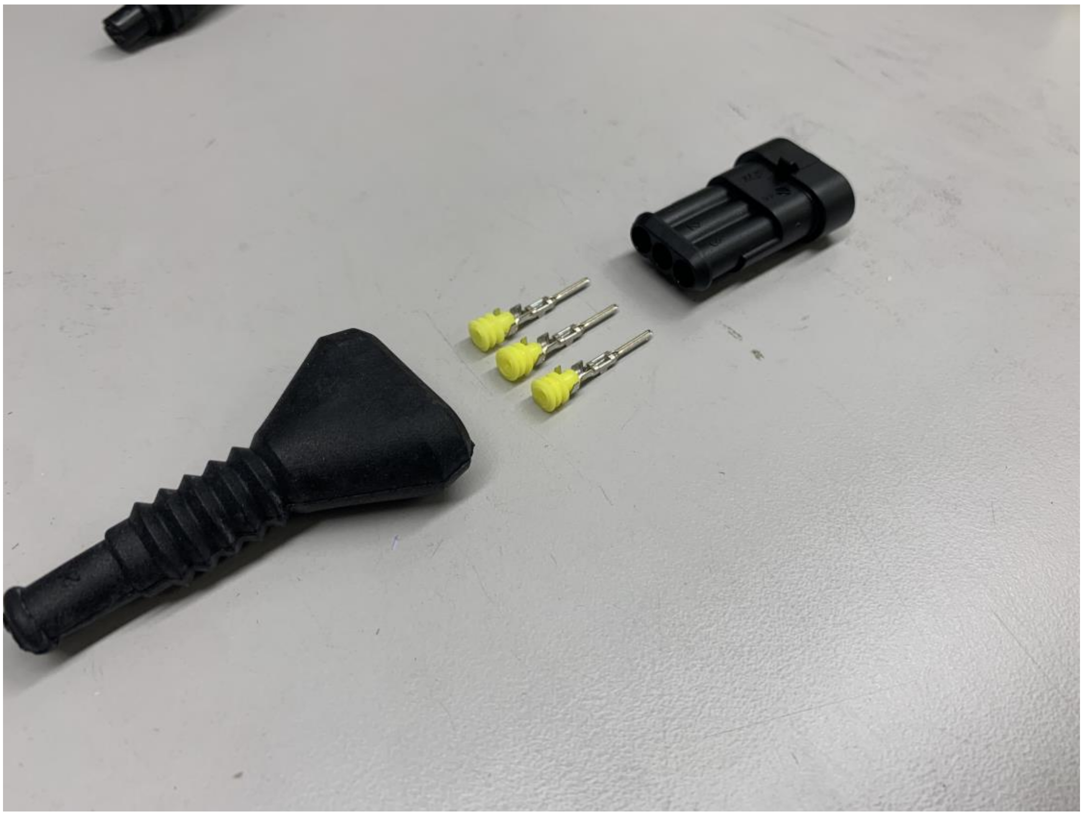


Figure 3. Parts of a 3-way Superseal Tyco AMP connector (10.)

Pins for the connectors are usually determined by the housing type. In the connector in figure 3, only one type of pin is meant to be used due to the locking of the pin inside the connector and the "gender" of the pin.

Pins have a slot for the wire seals, like the yellow ones in figure 3. The wire is pushed through the wire seal and then crimped into the pin. Lastly the wire seal is also lightly crimped in the pin, making sure that it will not move while the pin is pushed into the terminal. Wire seals are one part of the connector that makes it sealed from dust, water, etc.

The assembly of the connector is finished by sliding the boot of the connector on the connector, covering the back side of the terminals (figure 3). This boot also covers the wires that are fed through the wire seals.

If only two wires would be used in a 3-way connector (or 3 wires in a 4-way connector), the empty slot would be covered with a cavity plug (figure 4).

Figure 4. Cavity plug sealing an empty pin slot (10.)

Many of the automotive connectors consist of the same parts as in figure 3.

3.1.1 Signals in wire harnesses

A car includes usually not one but multiple different wire harnesses. In a single vehicle there are different wire harnesses for airbags, door wirings, engine harnesses etc. The basic signals in these harnesses are the B+ (Battery +), B- (Battery -), and IGN (Ignition), making the components function in the first place. For example, the engine harness is connected to MAF (mass air flow sensors), oxygen sensors, engine controller and other engine sensors. Sensors such as the mass air flow sensors converts the amount of air drawn into the engine into a 0-5 volt or a PWM (pulse-width modulation) signal. There are different types of MAF sensors, but commonly used is the Hot Wire MAF Sensor (figure 5).

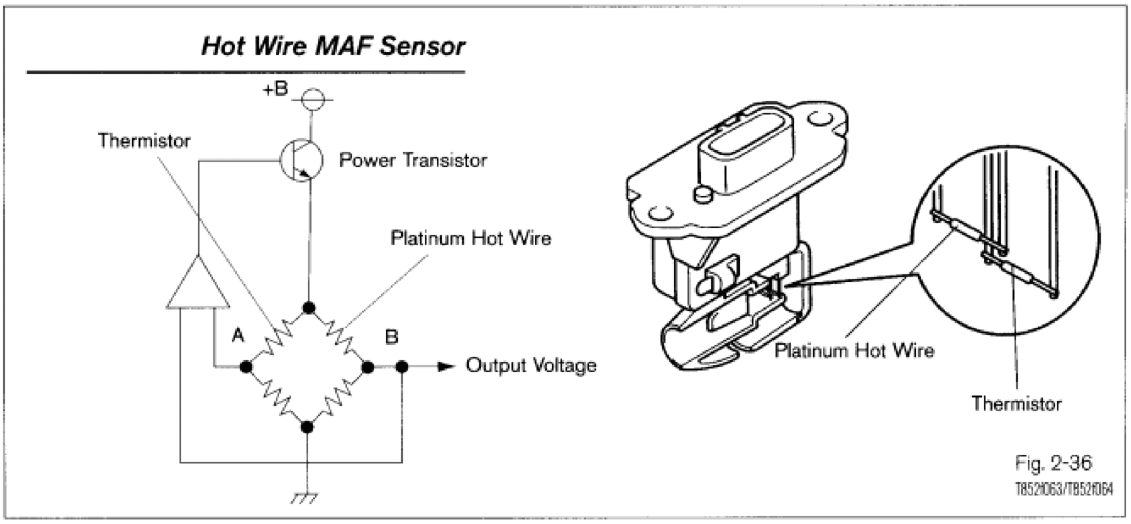


Figure 5. Hot Wire MAF Sensor (3.)

In a Hot Wire MAF Sensor “The thermistor measures the temperature of the incoming air. The hot wire is maintained at a constant temperature in relation to the thermistor by the electronic control circuit. An increase in air flow will cause the hot wire to lose heat faster and the electronic control circuitry will compensate by sending more current through the wire. The electronic control circuit simultaneously measures the current flow and puts out a voltage signal in proportion to current flow.” (3.) The output voltage signal from the MAF is crucial for the engine control unit to calculate the amount fuel injection is needed, when to ignite the cylinder and when to shift the transmission. As earlier mentioned, there are dozens of different harnesses in a single vehicle, therefore there are dozens of ECUs (electronic control units) such as airbags ACU (Airbag control unit), door wirings DCU (Door control unit) etc.. The communication between ECUs is often done via a CAN (Controller Area Network) bus. CAN messages can be transferred across a twisted pair cable. (4.) Therefore because most of the components used in Proventia’s retrofit products are controlled via CAN bus, testing the harnesses is very critical since malfunction in CAN bus can terminate not only the exhaust gas cleaning system but possibly also the whole vehicle.

3.1.2 Common defects

Even though manufacturing of wiring harnesses has been automated to a certain limit, manufacturing and assembly errors are still possible. Machines are used in manufacturing some harnesses for cutting, stripping, and marking the wire. For some pin types, cutting of the wires and crimping of terminals can be done by a machinery, but the connecting of the pins is done by hand. This leaves a risk of a user error for the manufacturer. When connecting one or multiple crimped wires to a tightly fitted connector, risk of loose connection or miswiring is possible. If a resistor is added in the connector, extra attention is needed. In figure 6 a poor connection of two wires and an uninsulated resistor has resulted in a short circuit in the connector.

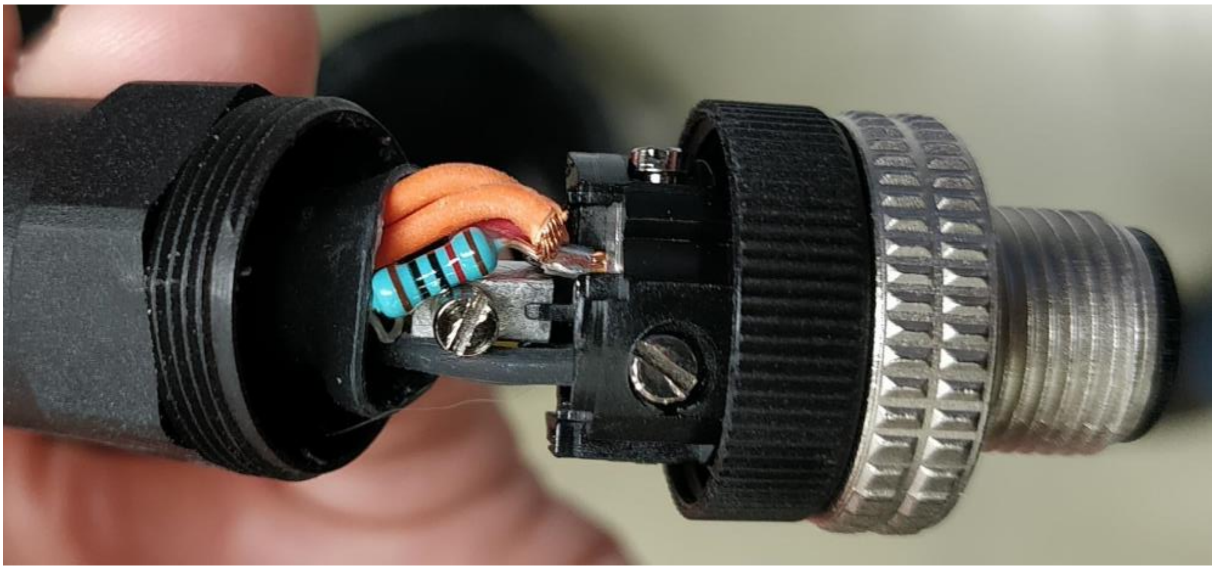


Figure 6. Short circuit in a connector (10.)

Due to rough assembly of a connector, wires can get damage that might be very hard to see (figure 7). In the IPC 620 standard in chapter 3.4 Damaged Insulation, defects of a damaged insulation have been described as;

- Any cuts or breaks in insulation
- Insulation thickness is reduced by more than 20%
- Uneven or ragged pieces of insulation are greater than 50% of the insulation outside diameter or 1.0 mm whichever is more
- Insulation is charred
- Insulation is melted into the wire strands (16, 3.4)

Even without a clearly visible damage to insulation, wire can lose conductivity or insulation due to heavy bending or compression. Bending is acceptable if the bends are not kinked. This tends to damage either the insulation or the wires inside.

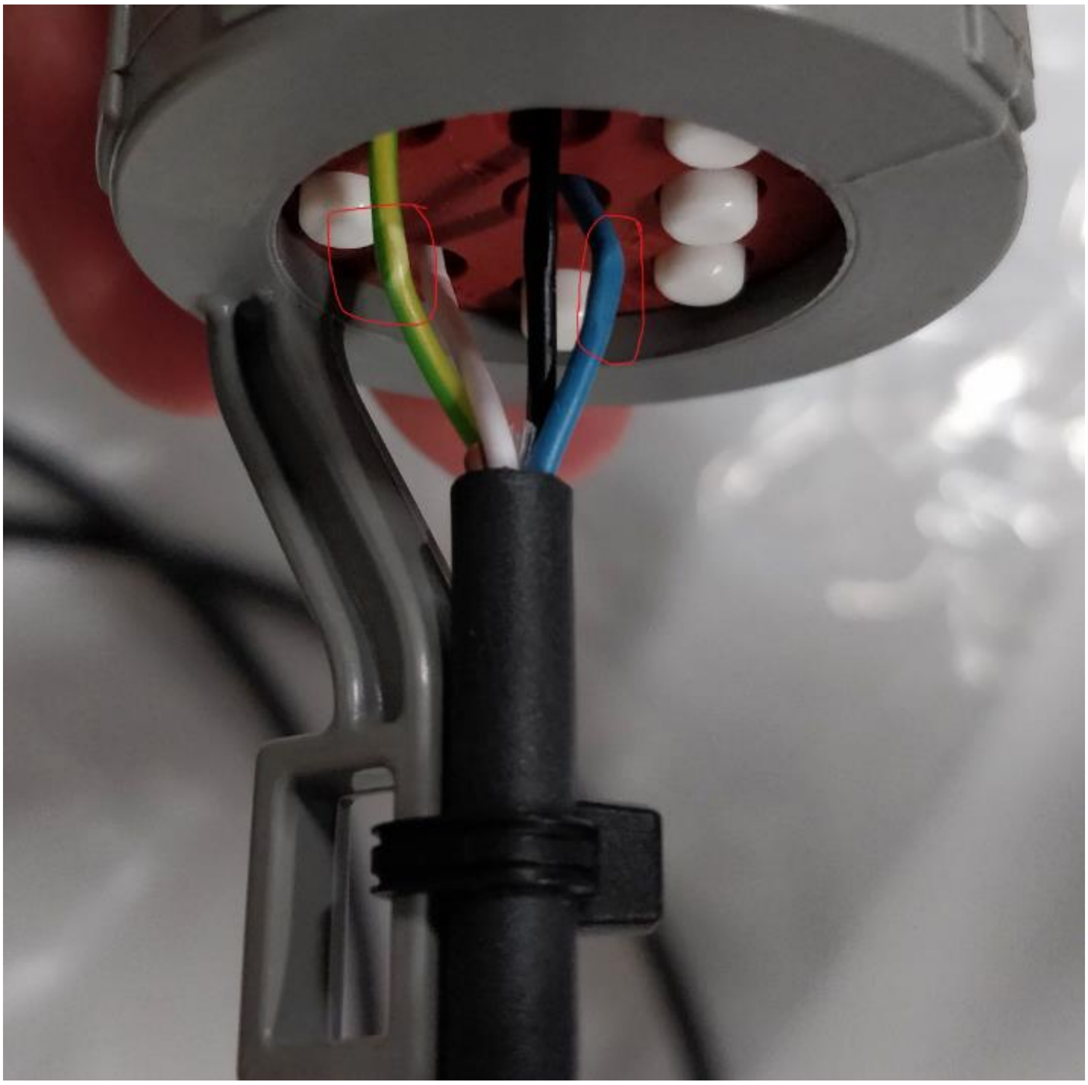


Figure 7. Reduced insulation thickness (10.)

Other common defects are;

- Miswiring in the connector
- Faulty / missing labelling of branches
- Damaged insulation of the wire
- Damaged insulation of the cable (shrink hose)
- Incorrect cable lengths
- Missing cavity plugs in the connector

All of these defects have been noticed during visual inspection and electrical measuring. As earlier mentioned, even though wiring harness manufacturing has been mainly automated, these common defects tend to be user errors during the assembly process of manufacturing wiring harnesses. This of course is understandable, since repeatable assembly job can be very tiring and by that lead to errors. However, when given a high attention to common defects found, the amount of errors

can be reduced highly during testing process. Some manufacturing errors can be removed completely by changing the manufacturing process or the components used in it. Therefore it is important to trace where the problem is because it may affect the manufacturing costs.
This is why a more efficient and reliable testing method had to be found.

3.1.3 Design

The electrical design process of wiring harnesses begins with the draft of vehicle specifications and the retrofitted product specifications. Considering for example the NOxBUSTER City, the system is almost always the same from a wiring harness perspective, meaning that the components and the connectors in the retrofitted system are the same. The differences begin to show in different vehicle manufacturers and the system of a specific vehicle. The structure can also vary within the different models of the same manufacturer.
Many things need to be considered when designing a wiring harness for a retrofit system such as NOxBUSTER City for an older vehicle;

- Preparing the electrical feature list
- Compiling electrical circuit diagram for the system
- Electrical power distribution and circuit protection
- Deciding on the number of wires in the harness
- Wiring harness layout and branches in the wiring harness
- Wiring harness routing, clamping and supports
- Selection of wire function, type, and rating
- Deciding the ground points
- The mechanical protection needed (heat, vibration, moving/rotating parts, sharp edges)
- The environmental protection needed (water, dust)
- Selection of connector types, pins, and housings (5.)

After the design of the wiring harness, next step is to provide the bill of materials for the wiring harness manufacturer. This can include the following parts;

- Wire sizing, types, and color
- Connectors – terminals, housing, seals, cavity plugs
- Marking of the wires
- Heat shrinking tubes, wiring harness protection sock

- Relays, fuse boxes
- Labeling of branches/wire harness serial number

3.2 Standards

A standard is a printed or digital publication where the specifications and requirements for a product, service, or system, for example, are precisely defined.
Standardisation means the development of best practices and solutions – the common methods, procedures, and requirements. Any expert of the field in question may participate in standardization work.
As established agreements, standards help us in many ways. It is hard to fathom life without them, and it would be difficult indeed to get through the day without the support and safeguards that standards provide. (6.)
Standards are not mandatory to use, but most companies use them because they are beneficial. They improve safety and compatibility, minimising surprises, and risks.
Standardisation is a voluntary cooperation among industry, consumers, public authorities, researchers, and other interested parties for the development of technical specifications based on consensus (7.).
Most wire harness manufacturers in Finland meet SFS-EN ISO 9001 and IPC/WHMA-A-620 standards in their production.

3.2.1 SFS-EN ISO 9001

SFS is a Finnish central organization for standardization. SFS is a member of the International Organization for Standardisation (ISO) and the European Organisation for Standardisation (CEN). Organisation for quality management system in accordance with the requirements of the international standard ISO 9001. It is the world's best-known tool for building and developing a quality management system. It is also suitable as a basis for a management system.
ISO 9001 standard helps;

- integrating quality management into strategy and operational planning
- increasing management engagement
- encourage staff to participate in quality development

- improve competitiveness by developing resource efficiency and cutting costs
- to produce products and services that meet customer requirements now and in the future
- improve customer satisfaction
- increase operational reliability (8.)

3.2.2 IPC/WHMA-A-620

IPC/WHMA-A-620 Requirements and Acceptance for Cable and Wire Harness Assemblies is a standard used in electronics manufacturing industry. IPC/WHMA-A-620 is part of the IPC Certification programs that was standardised by IPC and the Wire Harness Manufacturers Association (WHMA) as a joint project (Figure 8.).

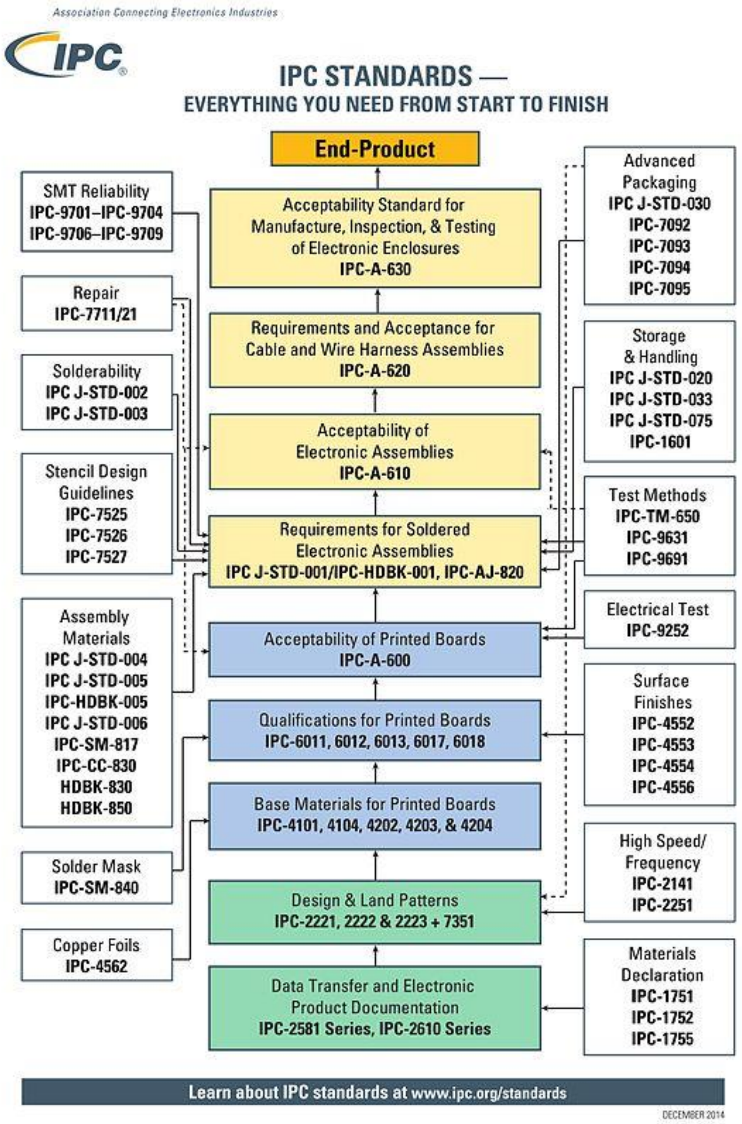


Figure 8. IPC Standard tree (9.)

The A-620 standard prescribes the acceptability criteria for manufacturing these critical connectivity products. It provides criteria for preparation of wires in wiring harness fabrication process, soldered terminations, crimp terminations, Insulation Displacement Connection (IDC), ultrasonic welding, splices, connectorisation, molding/potting, cable assemblies and wires, coaxial and twinaxial cable assemblies, wire bundle securing, harness/cables electrical shielding, harness/cables protective coverings, marking/labeling, hardware and wire/harness installation, solderless wrapping, and testing.

3.3 Testing methods

The designed life span of a wiring harness in an automotive vehicle is usually the same as the vehicles age is, therefore it is extremely important to test the wiring harnesses properly after the manufacturing process. Even the smallest fault in a connector can cause e.g., corrosion in the pins of the connector, making the whole wire harness unusable. Loose wire connection or poor crimping can be harder to detect visually but these faults are likely to appear quite soon due to rough handling of the cable during the installation or vibration of the vehicle when in use. Wire harnesses as well as the installation being fairly expensive, problems this small can become very big and expensive and lead into callbacks and a negative image of the company.
The IPC/WHMA-A-620 standard describes the acceptability criteria for producing and testing crimped, mechanically secured wire harness assemblies. Therefore, it is important to make sure the wiring harness manufacturer follows these criterias, so the visual and electrical defects can be reduced to the minimum. Testing process can roughly be divided to visual inspection, electrical tests, and mechanical tests.

Testing of the wiring harnesses at Proventia has been done with a multimeter so far. As previously mentioned, continuity and short test can be measured with a multimeter. Testing of wiring harness with test points more than 30 like in figure 9 take a lot of time with a multimeter. Measuring multiple harnesses with a multimeter not only takes a lot of time but also increases the risk of a user error.

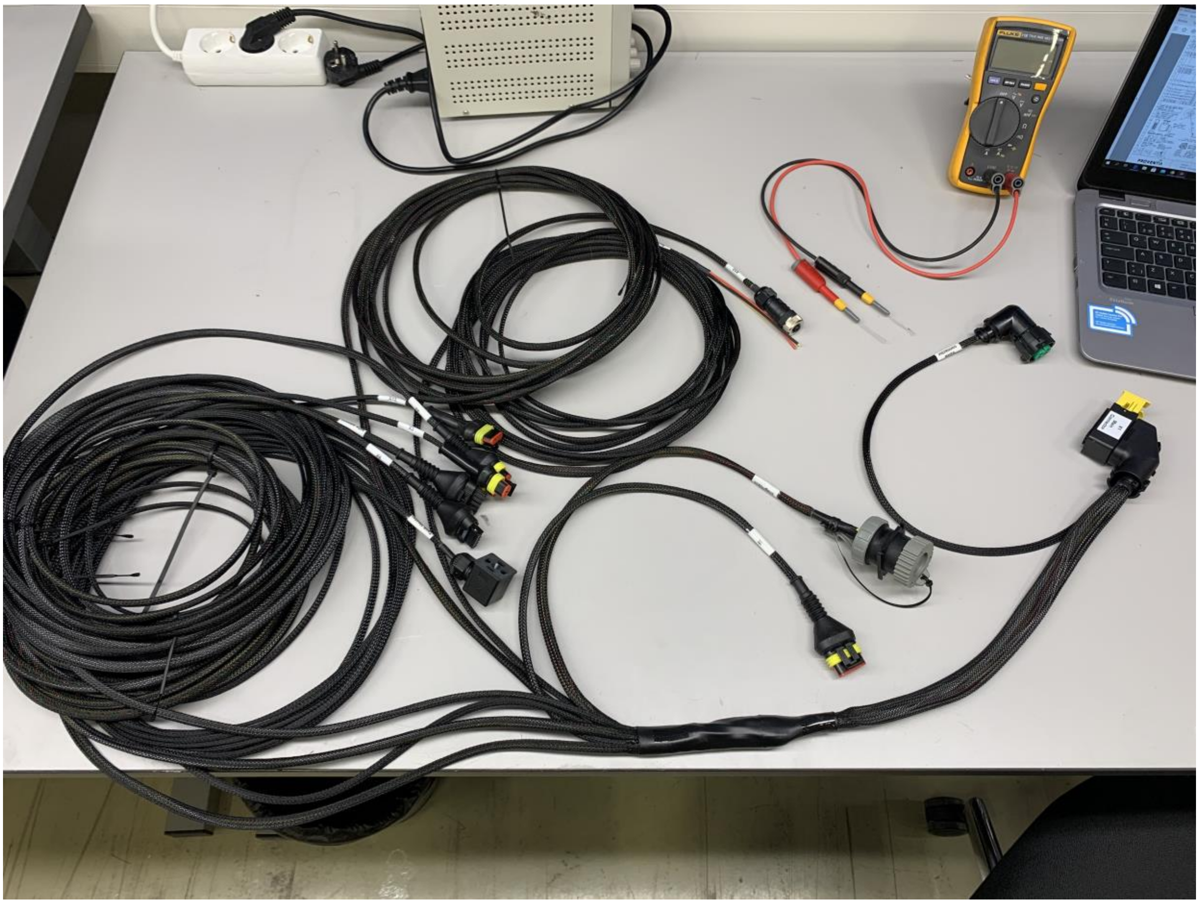


Figure 9. Wiring harness testing (10.)

Wiring harnesses like in figure 10 can include a high-speed CAN bus connection with bus terminated inside one of the connectors with a 120 ohm resistor. It is important to check with a multimeter that the resistor is correct and installed correctly. Resistor inside a connector can easily be miswired to short circuit the CAN bus line, and therefore messing the system completely.

3.3.1 Visual inspection

As previously mentioned, visual inspection is an important part of the testing process of wiring harnesses. For the durability of the wire harness, it is important to make sure the designed protection of the wire harness and the correct assembly is done properly and as designed. The harsh conditions and environment where the wire harnesses are installed demand a lot of protection, durability, and reliability from the assembly. These demands require fair amount of visual inspection for multiple ways of protection used in the wire harnesses. For visual inspection, the following details should be checked;

- Correct labeling of the wire harness and the branches
- Correct connector
- Correct pin layout in the connector
- Correct fastening of the pins in the connector
- Correct sealing of empty pins (cavity plug)
- Correct length of the branches and open ends
- Flawless protection sock
- Correct installation of shrink hoses
- Correct color and size of the wire
- Condition of the insulation on the wire

Usually for visual inspection you do not need tools (excluding when opening some connectors), but to check the proper fit and the quality of the connector, it is a good principle to use a mating connector to make sure the pins of the connector are intact and proper. These commonly used mating connectors can later be used for measuring the wire conductivity etc.

3.3.2 Electrical test methods

IPC/WHMA-A-620 includes the standards for testing in Chapter 19. It covers both in-process testing and final acceptability requirements for electrical and mechanical testing. The mechanical testing includes the crimp height measuring and the pull test for crimped terminals. It must be considered that testing to this standard does not guarantee compliance with local regulations or national safety standards. The default requirements are identified either in the requirements column or, where requirements vary by class, in columns identified by class. Where specific values for these parameters have been agreed between the user and the manufacturer that deviate from the default requirements, the column “Other defined values” is provided as a means of communicating these changes. The criteria for classes are defined as follow;

- Class 1 – General Electronic Products

  Includes products suitable for applications where the major requirement is the function of the completed assembly
- Class 2 – Dedicated Service Electronic Products

Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically, the end-use environment would not cause failures.

- Class 3 – High Performance Electronic Products

  Includes products where continued performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support systems and other critical systems. (16.)

In the IPC standard electrical test methods include;

- Continuity test
- Short (circuit) test
- Dielectric withstand voltage (DWW) (high voltage test)
- Insulation resistance (high voltage test)
- Voltage Standing Wave Ratio (VSWR) (for coaxial cables)
- Reflection Coefficient (for coaxial cables) (16.)

As mentioned before, the use of IPC standard is not mandatory, and it does not guarantee compliance with local regulations or national safety standards. Electrical measurements of automotive wiring harnesses are low voltage tests; therefore continuity test and short test can be enough to verify the required functionality of the wiring harnesses.

3.3.3 Continuity test

Continuity test verifies that the electrical connection between two or more points are in accordance with the assembly drawings and wire listings. Measurement is done with a multimeter from pin to pin measuring every wire from the cable according to wire listing like in figure 4. If defined, a threshold can be set for resistance. Typical wire resistance threshold for a good connection can be decided less than 1 or 2 ohms. This of course depends on the cable length. Measured value lower than this is rated as pass. When measuring continuity e.g. with a Fluke 115 multimeter, the multimeter has a continuity beeper which turns on at <20 ohms and turns of at >250 ohms. This is a faster and easier way to measure continuity.

3.3.4 Short test

Short test also known as short circuit test detects unintentional connections such as miswiring or break/fray in the wire preventing the electrical system from functioning properly. Short test usually follows continuity test to detect any unwanted connections between two or multiple test points. Short test can be measured simultaneously while measuring continuity. While measuring from pin to pin, you can measure against every other pin in the harness to make sure there is no connection, where it should not be. For example in figure 10 after measuring continuity from pin to pin, you can measure from X1 pin 1 to every pin, except X5 pin 3 to make sure X1 pin 1 is not connected to anything else.

Wire	Color	Wire	From	Pin1	To	Pin2	Comment
1	wh	0.75 mm2	X1	1	X5	3	
2	wh	0.75 mm2	X1	2	X5	1	
3	wh	0.75 mm2	X1	3	X11	4	
4	wh	0.75 mm2	X1	5	X3	1	
5	rd rd	1.5 mm2 0.75 mm2	X1	6	X8	rd	
					XD	B	
					X12	3	
6	wh	0.75 mm2	X1	7	X3	2	
7	wh	0.75 mm2	X1	8	X13	3	
8	bk bk	1.5 mm2 0.75 mm2	X1	9	X8	bk	
					X6.7	"2"	
					X9	2	
					X12	1	
					X11	2	
					XD	A	
					X13	2	
9	wh	0.75 mm2	X1	10	X5	2	
					X5	4	
10	wh	1.0 mm2	X1	12	X9	1	
11	rd	0.75 mm2	X1	13	X2	1	
12	bk	0.75 mm2	X1	14	X2	2	
13	ye	0.75 mm2	X1	15	X11	3	
					XD	F	
					X12	2	
					X8	ye	
					X13	1	
					X6.7	"1"	
14	og	0.75 mm2 twisted	X1	16	X6.7	"4"	
					XD	C	
					X12	4	
15	gn	0.75 mm2 twisted	X1	17	X6.7	"3"	
					XD	D	
					X12	5	
16	ye	0.75 mm2	X6.7	"1"	X6	1	
					X7	1	
17	bk	0.75 mm2	X6.7	"2"	X6	2	
					X7	2	
18	gn	0.75 mm2 twisted	X6.7	"3"	X6	3	
					X7	3	
19	og	0.75 mm2 twisted	X6.7	"4"	X6	4	
					X7	4	
20	wh	0.75 mm2	X6	5	X6	2	
21	wh	0.75 mm2	X1	18	X1	16	

Figure 10. Example of a cable harness wire listing (10.)

3.3.5 Mechanical test methods

Mechanical test methods are also included in the testing chapter of IPC standard. According to IPC, mechanical tests also have default requirements identified by class as well as the ‘’other defined values’’. Mechanical test includes a so-called pull test and crimp height test, for which you can use many other different testing standards.

For the pull test force is applied to assess the mechanical integrity of the crimp connection. A motorized wire pull tester is commonly used for this test (figure 11).

Figure 11. Motorized wire pull tester (11.)

This test measures the pull-off forces of a crimped terminals according to IPC, UL, ISO, ASTM, SAE, MIL, and other testing standards. These standards determine the minimum tensile strength requirements for each wire size (figure 12).

Metric	JIS type	AWG/MCM equivalent		UL 486F-A-F	IEC 60999-1/2 EN 60947-1 DIN 46228-1/4	IEC 60352-2	UL486A/B (CU)	JIS C 2805	DIN EN 61238-1 (CU)	DIN EN 61210
0.2 mm²	-	24	0.21 mm²	20 N	10 N	28 N	22.3 N			28 N
0.25 mm²				20 N		32 N				
0.34 mm²	-	22	0.33 mm²	20 N	15 N	40 N	35,6 N			40 N
0.5 mm²	-	20	0.52 mm²	20 N	20 N	60 N	57.9 N			56 N
0.75 mm²	-			30 N	30 N	85 N	89 N			84 N
		18	0.82 mm²	30 N	30 N	90 N	89 N			
1 mm²	-			35 N	35 N	108 N				108 N
-	1.25 mm²							100 N (200 N)		
		16	1.31 mm²	40 N	40 N	135 N	134 N			
1.5 mm²				40 N	40N	150 N	134 N			150 N
-	2.0 mm²							100 N (290 N)		
		14	2.08 mm²	50 N	50 N	200 N	223 N			
2.5 mm²				50 N	50 N	230 N	223 N			230 N
-		12	3.31 mm²	60 N	60 N	275 N	312 N			
	3.5 mm²							540 N		
4 mm²				60 N	60 N	310 N	312 N			310 N
-	5.5 mm²							780 N		
6 mm²		10	5.26 mm²	80 N	80 N	360 N	356 N			360 N
-	8 mm²							980 N		
		8	8.37 mm²			370 N	401 N			
10 mm²				90 N	90 N	380 N	401 N		600 N	
-	14 mm²							1400 N		
16 mm²		6	13.23 mm²	100 N	100 N		445 N		960 N	
-	22 mm²							1800 N		
25 mm²		4	21.15 mm²	135 N	135 N		623 N		1500 N	
		3	26.67 mm²				712 N			
35 mm²		2	33.62 mm²	190 N	190 N		801 N		2100 N	
	38 mm²							2500 N		
		1	42.41 mm²				890 N			
50 mm²		1/0	53.48 mm²		236 N		1113 N		3000 N	
	60 mm²							3200 N		
70 mm²		2/0	67.43 mm²		285 N		1235 N		4200 N	
95 mm²		3/0	85.01 mm²		351 N		1558 N		5700 N	
	100 mm²							3900 N		
120 mm²		4/0	107.22 mm²		427 N		2003 N		7200 N	
		250 MCM	127 mm²				2225 N			
150 mm²	150 mm²	300 MCM	152 mm²		427 N		2448 N	4100 N	9000 N	
185 mm²		350 MCM	177 mm²		503 N		2670 N		11100 N	
	200 mm²							4400 N		
		400 MCM	203 mm²				2893 N			
240 mm²		500 MCM	253 mm²		578 N		3560 N		14400 N	
	250 mm²							4600 N		
300 mm²		600 MCM	304 mm²		578 N		4005 N		18000 N	
	325 mm²							4800 N		

Figure 12. Example list of pull test result requirements (12.)

Pull tester is a great way to ensure the quality of a crimped terminal. The result is quite clear, if the wire disconnects from the crimp with the standardised minimal tensile strength, the test fails.

Crimping height meter is another way to test the quality of a crimped terminal. The crimp height measuring system compared to a handheld unit, is much more consistent and reliable when it comes to repeatable crimp height measuring (figure 13).

Figure 13. Crimp height measuring system (13.)

Measuring the crimp height is a quick way to ensure the correct compression of a terminal around the wire's conductor. The conductor crimp height is measured from the top surface of the formed crimp to the bottom most radial surface (figure 14).

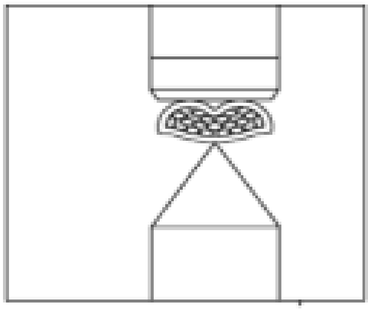


Figure 14. Crimp height measuring point (14.)

Crimp height is determined by the wire size and the manufacturer of the terminal. Manufacturer provides specific requirement table for correct crimp height (figure 15).

Series	Part Number	Applicator	Wire			Wire Barrel Crimp		Insulation Barrel Crimp
			No. of Wires	Wire Circular Mil Area (CMA)	Ref. Wire Size (mm² [AWG])	Width (Ref.)	Height	Width (Ref.)
6.3 [.250]	2238173-3	2150831-2	1	700	0.32 [22]	3.3 [.130]	1.17±0.05 [.046±.002]	4.06 [.160]
			1	1000	0.52 [20]		1.22±0.05 [.048±.002]	
			1	1600	0.82 [18]		1.30±0.05 [.051±.002]	
			1	2600	1.3 [16]		1.45±0.05 [.057±.002]	
			1	4100	2.1 [14]		1.65±0.05 [.065±.002]	
			1	6500	3.3 [12]		1.98±0.05 [.078±.002]	
4.8 [.187]	2238174-3	2150832-2	1	400	0.2 [24]	2.79 [.110]	1.02±0.05 [.040±.002]	3.81 [.150]
			1	700	0.32 [22]		1.07±0.05 [.042±.002]	
			1	1000	0.52 [20]		1.12±0.05 [.044±.002]	
			1	1600	0.82 [18]		1.22±0.05 [.048±.002]	
			1	2600	1.3 [16]		1.37±0.05 [.054±.002	

Figure 15. Example of a requirement table for crimp height (15.)

4 IMPLEMENTATION

As earlier mentioned, testing of wiring harnesses at Proventia has been done with a multimeter. This of course takes a lot of time and still leaves a risk for a user error during the measuring process. The goal for this thesis was to design and manufacture a wiring harness testing system that can test harnesses reliably, fast, and easily. In this chapter I will be going through the process of making the testing system.

4.1 Tester unit

There are multiple different companies that provide wire harness test equipments or systems. There are also different testers for different cables such as low and high voltage cables. Some testers work as a “stand-alone” without a PC and some require a PC connection. Usually most testers used with a PC are in a complete test system, that some companies also provide.

For our test system we decided to use a Weetech WK 260 MU-I tester (figure 16). This tester is an independent cable tester that can be used with or without a PC. It has the applications to test connection, short circuit and isolation test of cables or cable harnesses with up to 1,536 test points, and functional test of electric components such as relays, switches, and push buttons.

Figure 16. Weetech WK 260 MU-I wire harness tester (10.)

This particular tester is provided with 4 test point cards, which means that it has 256 test points available. WK 260 MU has slots for 8 test point cards in total, so it is expandable to 512 test points if needed. The tester can be expanded by a maximum of one expansion unit, giving an additional 1024 test points. It also has the possibility to use a specific test software called IVISion Studio for easy import of test programs and clear programming of complex test routines for the functional test. This test software was used to program the test program for this project.

4.2 Test table

For the wiring harness test system, a test table had to be designed. The table size was designed to fit users of all size. The worktop also had to be large enough to fit all the mating connectors on it. The design started off by designing the frame for the table. For the frame, few different material choices were thought. The chosen material for the frame ended up being 30x30x2mm S235 steel pipe. Frame design was drawn by Proventia's mechanical engineer, using Solidworks 3D design software. The frame was built by Proventia's mechanics in the prototype workshop. Frame was finished with a black paint job as a custom work.

The test table needed steel sheets to cover the worktop and the circuits inside the table. For this, stainless-steel sheets were designed, and ordered from a custom metal sheet manufacturer. For the sides of the test table, a simple shaped cut sheets were used. However most of the sheets had to be kinked, cut, and drilled. The space for the circuits was made by making a base plate below the worktop from the same stainless-steel sheet. This made the connection to mating connectors shorter while maintaining leg space under the test table.

50 pieces of 65x65mm square holes and 12 pieces of 122,4x65mm holes were cut in the worktop for the mating connectors. The holes were covered with 84x84mm and 154x84mm plastic plates where the mating connectors were installed. This made replacing and adding connectors very easy without having to disassemble the table that much.

Top part of the test table was also pre-cut and drilled for the tester unit and additional hooks for wire harness branches.

The steel sheet in the back of the test table was installed in such way that it can be detached to easily gain access in the circuits inside the test table.

The assembly picture of the test table can be seen in figure 17.

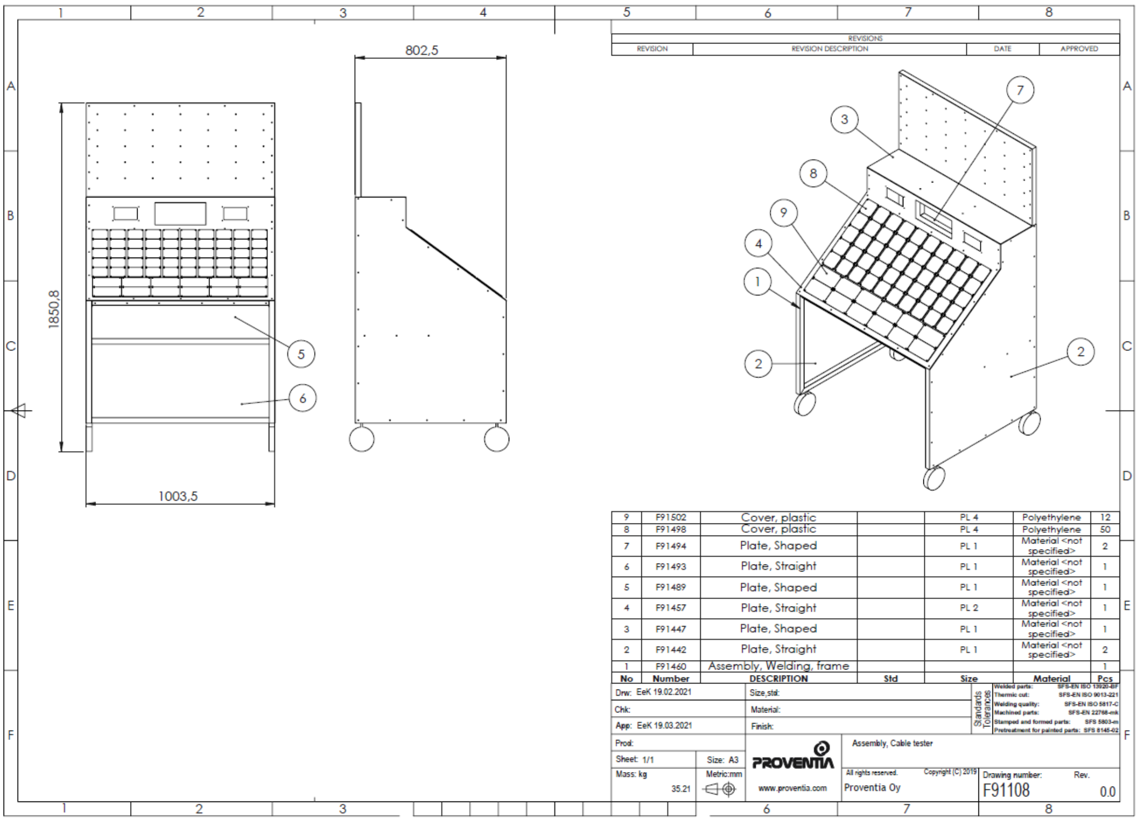


Figure 17. Assembly picture of the test table. (10.)

By making the test table from S235 steel pipe and stainless-steel sheets, the table remains light-weight weighing only 35kgs. With the lightweight of the frame and the wheels under it, moving the test table is easy and safe.

4.3 Circuits

As earlier mentioned, the circuits are protected inside the test table yet still left easily accessible from the back side. The circuits contain connection from the tester unit to the mating connectors. This of course is not wise or practical to wire directly, so terminal blocks and other connecting methods was used (figure 18).

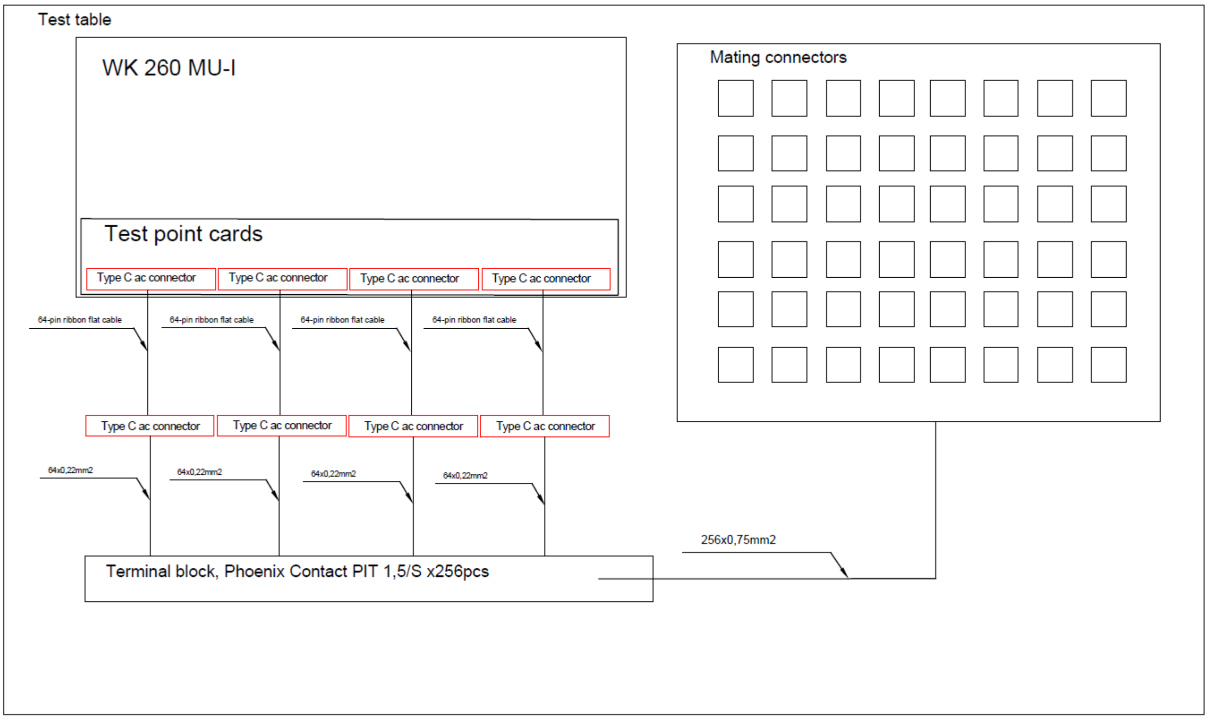


Figure 18. Overall picture of the designed circuit. (10.)

The tester unit's test point cards have a type C 64 pin ac connector for the test points in the test system. This connector required a 64-pin flat ribbon cable to be used. The flat ribbon cable having the outer diameter only 1,27mm thick, there are only few fragile wires inside the cable. Using these wires without a proper connector is unreliable. Therefore, to connect the ribbon cable to the terminal block and to the mating connectors, a small rack was made for the 64-pin type C connectors (figure 19).

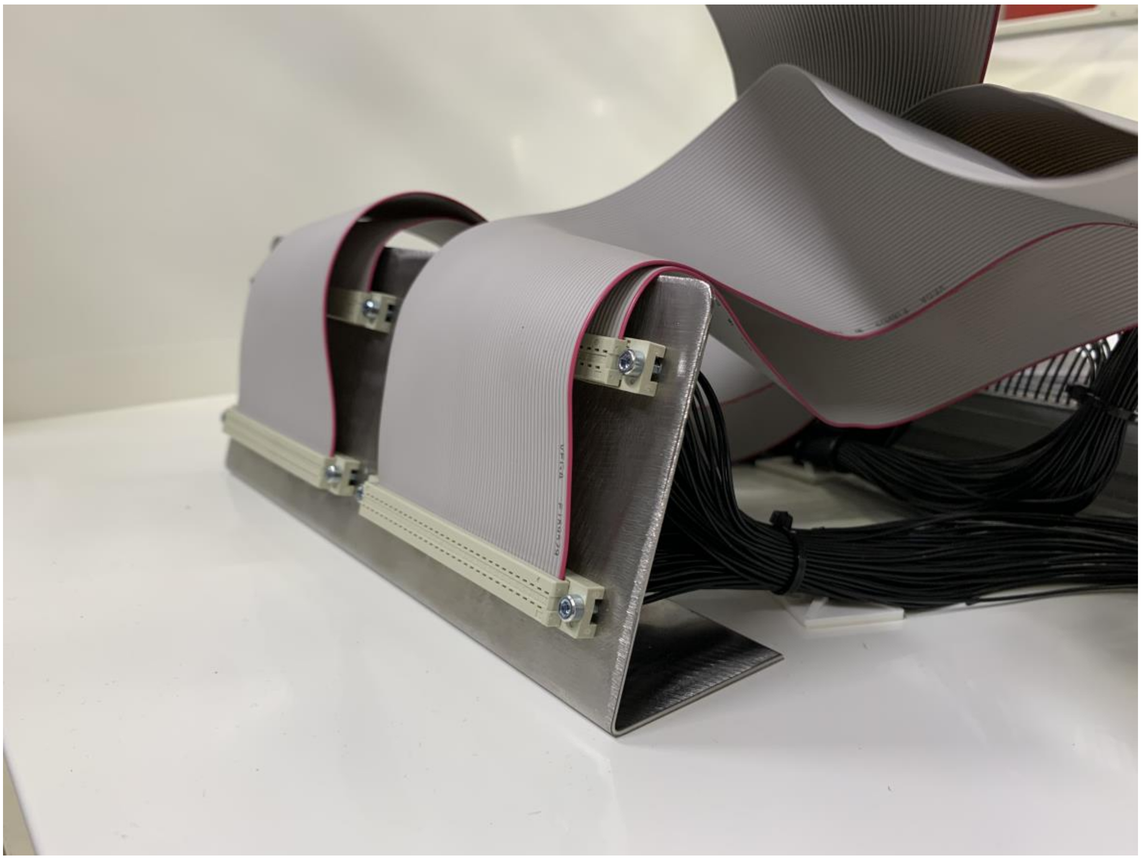


Figure 19. Rack for 64-pin type C connectors. (10.)

Here the connection to the terminal block was made easier by using a slightly thicker wire crimped and sealed with hot glue in the 64-pin type C connector. The wires were crimped with an insulated crimp bootlace. Spring-cage connection type terminal block were used for not having to strip or crimp the wires. Using these terminal blocks made adding connectors later on easier, due to the wire connection in the type C connector being difficult and not so easily accessible. The test table ended up needing 256 terminal blocks, due to 256 test points. These terminal blocks were installed on a din rail (figure 20).

Figure 20. Connection from the 64-pin type C connector to the terminal blocks. (10.)

Connection from the terminal blocks to the mating connectors were made with 0,75mm wire. Crimping the pins of the mating connectors was much easier and more reliable when they were connected with a thicker cable (figure 21).

Figure 21. Finished connections of the mating connectors. (10.)

While the connections were connected in order from the mating connectors to the terminal blocks, an excel sheet was filled for the pin table used later in programming. Space for additional 4 more test point cards circuits were left. Adding 4 more test point cards, another rack for 64-pin type C connectors, a din rail with 256 terminal block and wiring is only needed. Using different size of conductors does not affect the reliability of the measurements due to the small currents of the test system and the possibility to modify measuring parameters.

4.4 Connectors

As earlier mentioned, for the connectors the worktop contains 50pcs of 84x84mm and 12pcs of 154x84mm plastic plates. The mating connector were drilled and installed in these plates (figure 22).

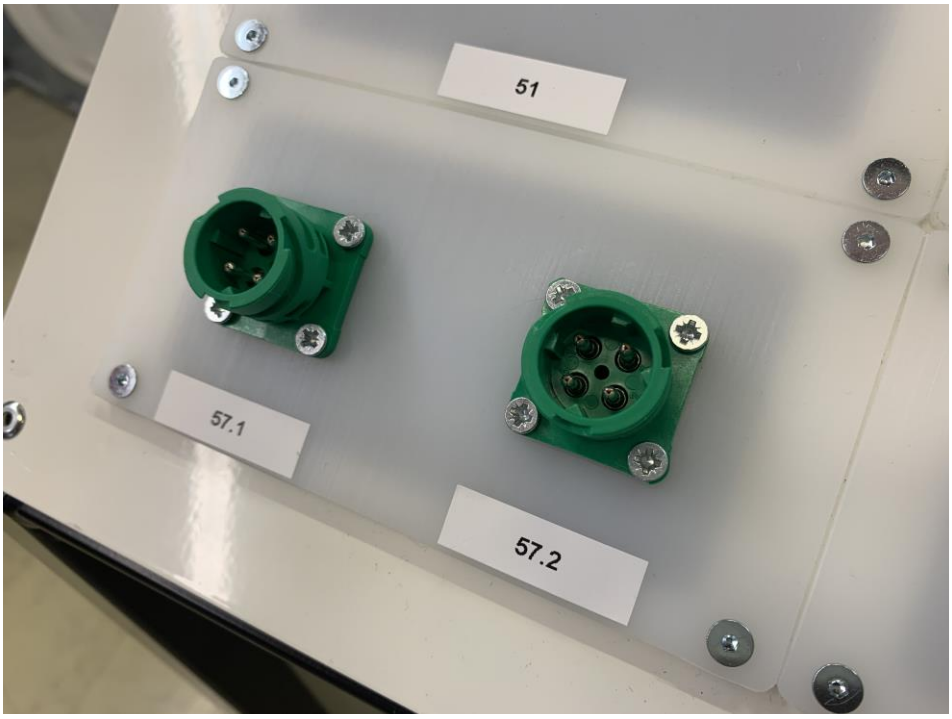


Figure 22. Installed mating connectors. (10.)

For this prototype, a total of 32 and 25 different mating connectors were used, having the capability to test at least 20 different wire harnesses. The mating connectors used are for commonly used connectors in the wire harnesses that Proventia uses in the retrofitted exhaust gas cleaning systems. With only 190 test points used so far, there are 66 test points and 32 plastic plates still available for different revisions or new wire harnesses (figure 23).

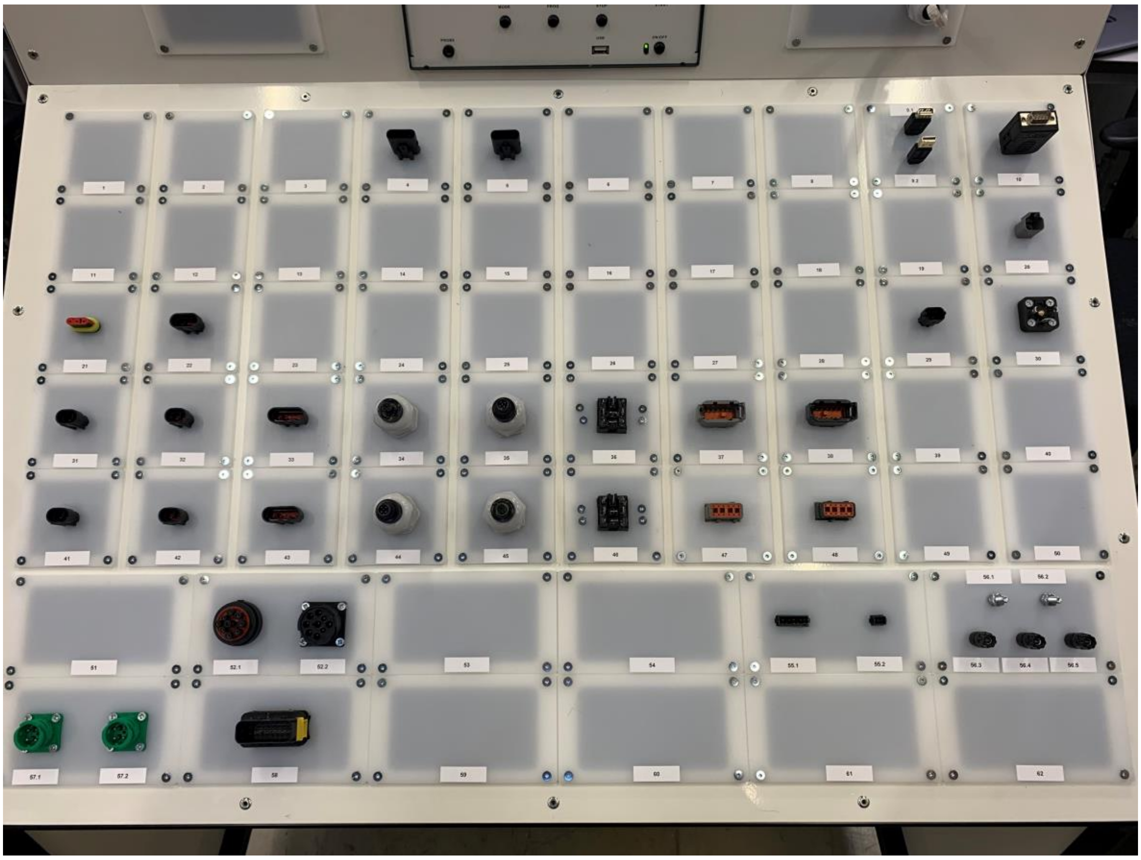


Figure 23. Work top with mating connector and reserve plates. (10.)

By using plastic plates for the base of the mating connectors, adding new connectors is easy by not having to disassemble the whole test table. Also fixing or switching a possible broken connector is made is easy this way. This solution gave durability and easy maintenance for the test table because the connectors will be going through heavy mechanical stress due to continuous plugging and unplugging of the connectors.

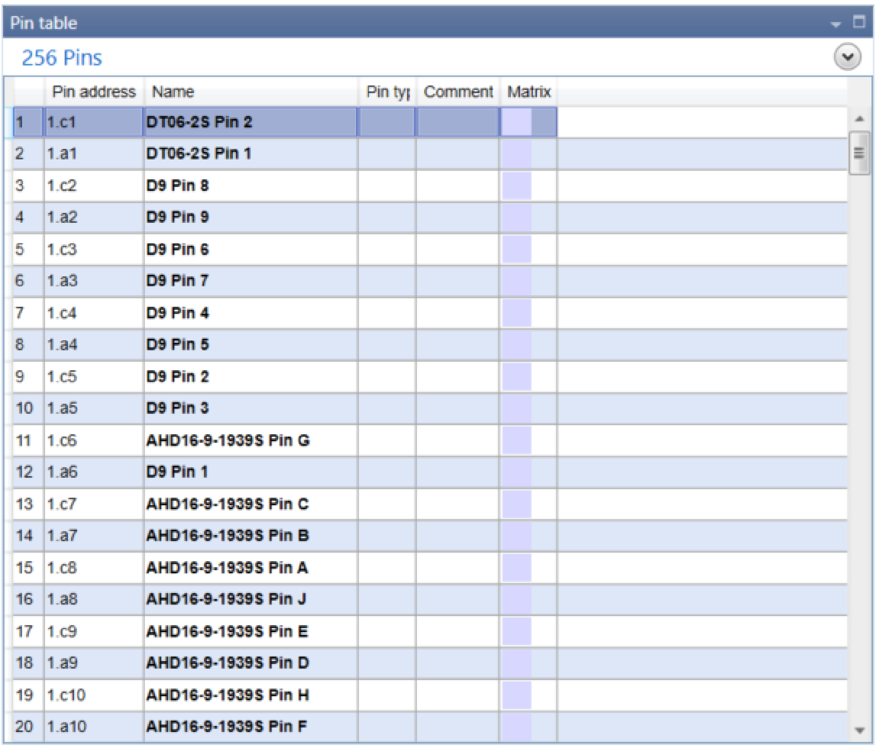
4.5 Programming

Programming a test program for WK 260 MU-I can be done in two different ways. The faster and the easier way is a convenient automatic programming function that “learns” from so-called golden samples. This means that the test object that the tester will “learn” has to be flawless and manufactured as designed. Programming the test program is done by connecting the test object to the connectors of the test system and choosing the Autoprog function from the WK 260 MU. This captures and saves the connections on the test object automatically.

The other way is to manually program using the test program editor on IVISion Studio programming software. This has to be done when testing a new version of wire harness, because new untested wire harnesses should not be programmed with Autoprog due to uncertainty of flawless connections. The test program editor uses TSL (Test Script Language) programming language that is used to describe the individual connections of a test object and the complete network made up of the connections and components of the test object.

Test programs can be transferred via network/LAN by using ethernet cable or it can be transferred with a USB drive. A movable ethernet cable was installed near the tester display through a cable gland, for quick and easy network/LAN transfer.

Before starting the programming, test point cards and pins had to be defined in the matrix configuration manager. Here you will determine the test point card type from the following three options: TM 260-64, TM 260-32I-32Kelvin, TM 260DC-128P. In this project we used the basic TM 260-64 test point cards which had 64 test point in each card, having the total of 256 test points/pins with 4 test point cards. After determining the 256 pins, a pin table had to be filled (figure 24).


Pin table

256 Pins

	Pin address	Name	Pin typ	Comment	Matrix
1	1.c1	DT06-2S Pin 2			
2	1.a1	DT06-2S Pin 1			
3	1.c2	D9 Pin 8			
4	1.a2	D9 Pin 9			
5	1.c3	D9 Pin 6			
6	1.a3	D9 Pin 7			
7	1.c4	D9 Pin 4			
8	1.a4	D9 Pin 5			
9	1.c5	D9 Pin 2			
10	1.a5	D9 Pin 3			
11	1.c6	AHD16-9-1939S Pin G			
12	1.a6	D9 Pin 1			
13	1.c7	AHD16-9-1939S Pin C			
14	1.a7	AHD16-9-1939S Pin B			
15	1.c8	AHD16-9-1939S Pin A			
16	1.a8	AHD16-9-1939S Pin J			
17	1.c9	AHD16-9-1939S Pin E			
18	1.a9	AHD16-9-1939S Pin D			
19	1.c10	AHD16-9-1939S Pin H			
20	1.a10	AHD16-9-1939S Pin F			

Figure 24. Pin table for the test system (10.)

The pin addresses were determined by the wiring between the mating connectors and the type C 64 pin connector which was done earlier. Pin type can be assigned as test point, LED, connector detection pin, ground switch pin ("power pin"), position measurement pin, and ID-chip. For this test system mostly pin type will be test point, and with this pin table only test point types were used.

Like many other programming language, TSL command must always be located between the header and end, to be compiled correctly. If a TSL command is incorrect or incomplete, this error is flagged with a wavy red underline and a red dot on the left side.

The test program for this project was made with the idea of it being user friendly. This means that the program starts with instructions for the user, where to connect each wire of the harness. This was done by using a command called "UIMessageConfirm". This command creates a window with the specified text to the display that has to be confirmed in order to advance (figure 25).

Figure 25. Instructions for the harness testing. (10.)

This was done to each branch of the wire harness. After the user confirms every connection the test will begin automatically. The connection test is done with the command "TestConnection('Name', "Pin1", "Pin2");". Name is the name of the connection/wire, pin1 being the first pin of the connection and pin2 being the second pin of the connection. Pin1 and Pin2 is replaced with the pin names given in the pin table eg. "D9 pin 5". The pin address can also be used for the code but using the name is clearer. If multiple connections are done from the same pin, the command can be copy pasted and modified so that the first pin is the same and the second pin is different or vice versa. Using the "TestConnection" command the program will perform the open and short test for the connection. “TestConnection” command will show results in the report after the test. If the test fails, it will tell the errors (open or short circuit or both) and the location of the error as well mark the test as failed (figure 26).

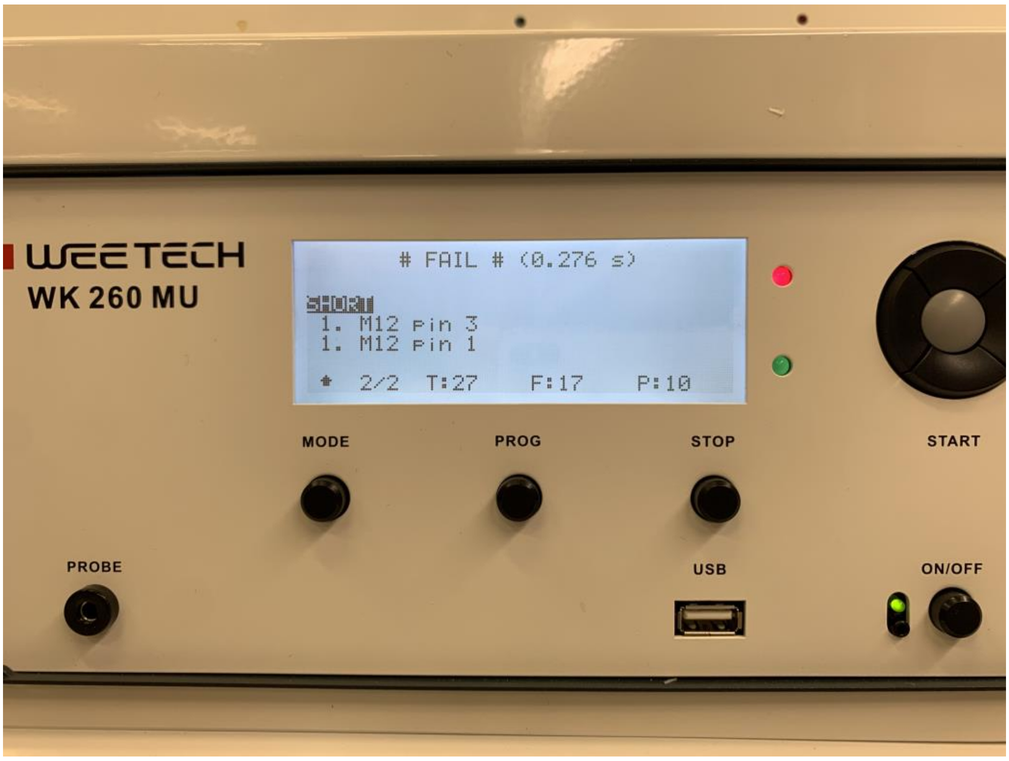


Figure 26. Failed test with a short circuit. (10.)

Wire harnesses that Proventia uses usually includes wiring for CAN bus. This in some cases requires a termination resistor to be used in the wire harness. This is usually inside one of the connectors in the harness. This was needed to test in this project, and it was done by using the command “TestResistor”. When using this command you will have to determine the name of the wire, first and second pin of the resistor, expected resistance value, upper tolerance, lower tolerance. Optionally you can also determine resistance offset, parameter for waiting period, optional parameter for measurement time, and parameter for maximum allowed power. Using the command “TestResistor” the tester will give reports from the tested resistor after the test is complete (figure 27).

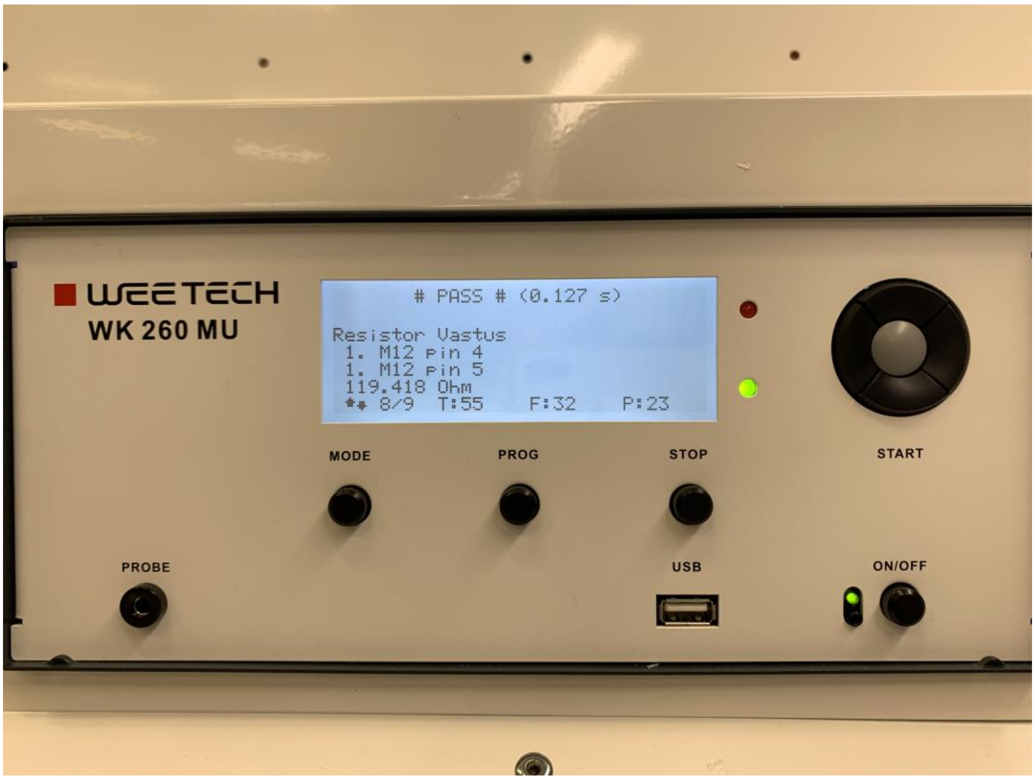
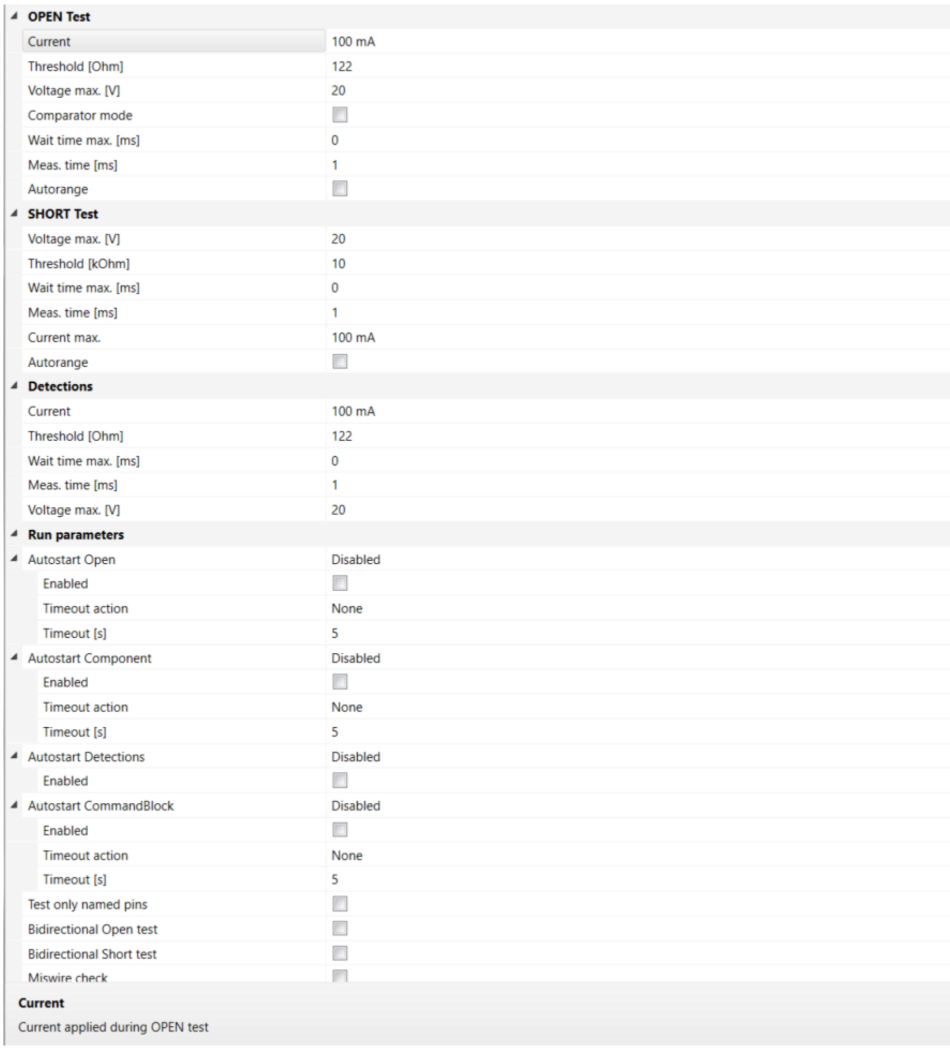


Figure 27. Result of the resistor test in the report. (10.)

The resistor in the connector also has to be set as connection, otherwise the program will show it as open connection. To pass the test a threshold had to be set for the connection with the resistor. This had to be slightly higher than the resistor used between the connection, since the wire has a small resistance too. These setting will be determined in the project parameters (figure 28).



OPEN Test	
Current	100 mA
Threshold [Ohm]	122
Voltage max. [V]	20
Comparator mode	☐
Wait time max. [ms]	0
Meas. time [ms]	1
Autorange	☐
SHORT Test	
Voltage max. [V]	20
Threshold [kOhm]	10
Wait time max. [ms]	0
Meas. time [ms]	1
Current max.	100 mA
Autorange	☐
Detections	
Current	100 mA
Threshold [Ohm]	122
Wait time max. [ms]	0
Meas. time [ms]	1
Voltage max. [V]	20
Run parameters	
Autostart Open	Disabled
Enabled	☐
Timeout action	None
Timeout [s]	5
Autostart Component	Disabled
Enabled	☐
Timeout action	None
Timeout [s]	5
Autostart Detections	Disabled
Enabled	☐
Autostart CommandBlock	Disabled
Enabled	☐
Timeout action	None
Timeout [s]	5
Test only named pins	☐
Bidirectional Open test	☐
Bidirectional Short test	☐
Miswire check	☐

Current

Current applied during OPEN test

Figure 28. Project measurement parameters. (10.)

In project measurement parameters you can determine parameters for open test, short test, detection, and run parameters. A check is required to ensure that the combination of these parameters allow a meaningful measurement. Enabling AutoStart for these tests was not necessary in this project, since it checks whether any error have been resolved in the event of errors having been output and fixing a miswiring during a test was not necessary.

The test program for a small 10 pin wire harness turned out to be very simple as seen in Figure 29.

```
//_________________________________________________
//
//  Customer:
//  Project:    Testipohja
//  Description:
//  Testsystem:  WK260 MU
//
//------------------------------------------------------------------------
//  Ver.   | Remarks/Changes              | Date       | Author
//------------------------------------------------------------------------
//  1.0    created                        19.04.2021    aleksi.tarvainen
//
//_________________________________________________




    _Question = 'Kytke X1->34. Paina start jatkaaksesi';
UIMessageConfirm( _Question, Size= NORMAL, TextColor='Black', BackColor='#FFFF00');


    _Question = 'Kytke K1->36. Paina start jatkaaksesi';
UIMessageConfirm( _Question, Size= NORMAL, TextColor='Black', BackColor='#FFFF00');


   TestConnection('CAN1_HI', "36. Relekanta pin 3", "34. M12 pin 4" );
   TestConnection('CAN1_LO', "36. Relekanta pin 9", "34. M12 pin 5" );
   TestConnection('B+', "36. Relekanta pin 4", "34. M12 pin 3" );
   TestConnection('B-', "36. Relekanta pin 8", "34. M12 pin 1" );
   TestConnection('IGN', "36. Relekanta pin 2", "34. M12 pin 3" );
   TestConnection('Vastus', "34. M12 pin 4", "34. M12 pin 5");
   TestResistor('Vastus', "34. M12 pin 4", "34. M12 pin 5", R= 120 Ohm, R0= 1 Ohm , Tol+= 10%, Tol-= 10%);


end.
```

Figure 29. Test program for a 10-pin wire harness (10.)

By starting with a small wire harness, the test program can be used as a template for bigger harnesses as it includes the basic commands to test wire harnesses.

4.6 Measurements

As previously mentioned, basic wire harnesses can be tested with the “TestConnection” and “TestResistor” commands. “TestConnection” will perform open and short tests and “TestResistor” will measure resistance within the given parameters.

However WK 260 MU provides many other measurements that can be measured such as;

- ConnectorDetection (these pins have to be defined as ConnectorDetection in the pin table)
- AlternativeWirePair (meaning that a parallel and crossover wire is possible)
- BusConnGroup (used to test connections in a bus system)
- TestCapacitor

- TestComponent
- TestDiode
- TestExternalCurrentToGround (measures and evaluates a current which flows through the ground jack respectively the ground jack from U1 feeding jack)
- TestExternalVoltage (tests whether there is an external voltage between the specified pin and system ground)
- TestExternalVoltageToGround (measures and evaluates a voltage to the ground jack respectively the ground jack from U1 feeding jack)
- TestSwitch (tests a switch between the specified pins, can test closed and open switches)
- TestZDiode (tests a Zener diode between the specified pins)
- DischargeCapacitance (discharges the capacitance between two pins)

In this project these measurements were not needed, therefore they were left out of the tests to be further examined later.

5 RESULTS

The time saved during the testing of a wire harness can be seen in the basic tests for each size of a wire harness. This includes the unpacking of the harness, measuring the harness, and repacking it. Even for a smaller or a medium sized harness, the time reduced was around 90% less with the test table than with the multimeter. As the harnesses get larger and more complex, the time saved is substantially more as seen in table 1.

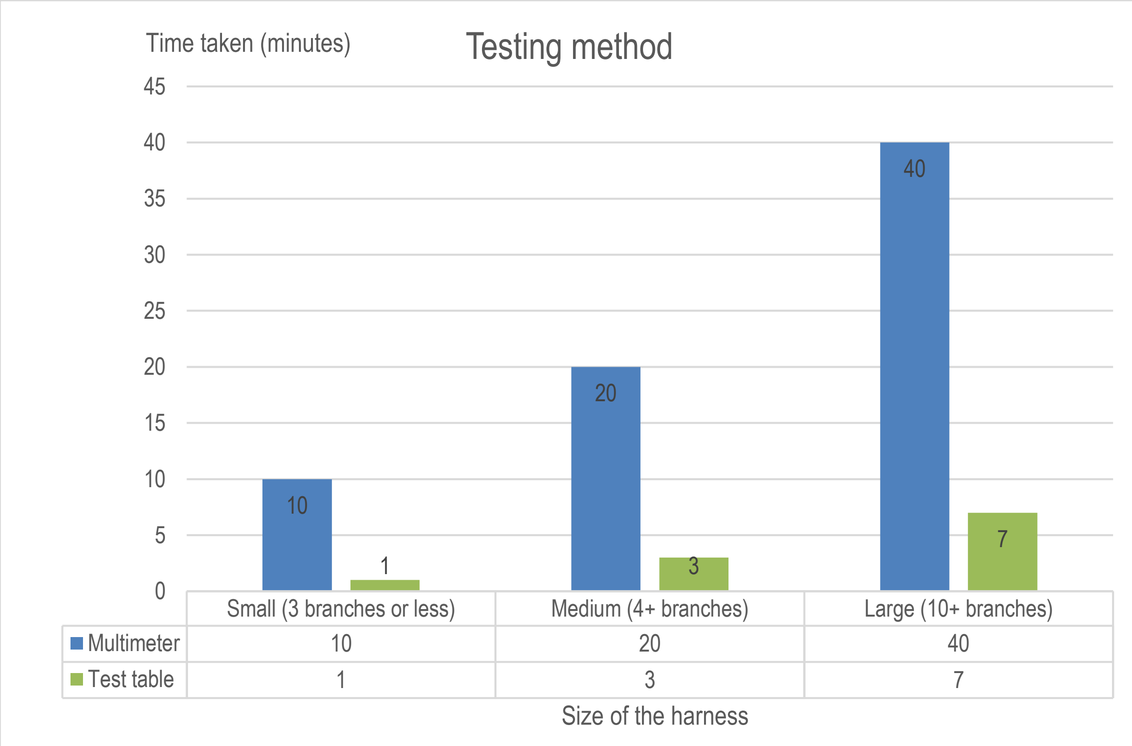


Table 1. Time saved with the test table. (10.)

The tests are usually done for a batch of wire harnesses rather than just one, the test system shows its efficiency by making sure that for each wire harness the exact same test is done faster, also making the measurements also more reliable.

It may take around four to seven hours for a mechanic to locate a problem in the retrofit system and precisely in the defected wire harnesses. When using only 10 minutes at the most to test a single wire harness successfully, the time and costs saved are proportionally huge. This does not even require the user of the test system to be a professional in any field.

For the test system, the test table was kept as lightweight and easily movable. With the goal of having possibilities to expand the tested wire harnesses, the test table has the capability to add more test points and/or mating connectors (figure 27).

Figure 30. Final testing system (10.)

The test program for this project was made simple and easily customizable to reduce any errors in the programming code when making different and testing programs for more complex wire harnesses. Testing programs in the future can be simply modified mostly by copy pasting from the test program of this project, keeping the next programs simple and similar as well.

6 CONCLUSION

As the result of this project, an efficient and a reliable test system was built. The goal was met as the tester unit was compatible with the mating connectors in the testing system. The test system was made with the intention of being user friendly with clear instructions to reduce user errors during wire harness measurements, while preventing faulty wire harnesses getting to customers and reducing the time used for the measurements.

In the future, the wire harness testing system could be expanded with further investigation to test actuators (including relays, switches, diodes etc.). This might include adding external voltage source in the test table. This could make testing e.g. the urea pumps possible with the testing system. The test table could also include some sort of mechanical or electrical testing device to measure lengths of the branches in the wire harnesses.

The subject for the thesis was interesting itself as it included the planning part of the product and the implementation. Also with much help from the experienced retrofit team, I had the chance to get more knowledge in the automotive industry and in the emission control systems. Proventia’s great work environment was a key factor in planning and manufacturing the testing system. This thesis was made in Proventia’s premises, which made documenting and working easier. However the use of custom work outside the company slightly delayed the planned schedule, which luckily did not affect the end result of the product.

Finally a big thank you to my thesis supervisor Ensio Sieppi and to Proventia’s personnel for all the help during the projects planning and implementation, while working with the equipment and machinery in the workshop. And a special thanks to my work supervisors Olli Kantola and Jaakko Kurikka for the help and support during the project.

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