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Automated Testing Process for D-Fend Water Trap

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Abstract

In this thesis testing methods were explored and developed in order to implement automated product testing. General Electric (GE) Healthcare Finland is designing a new, fully automated, assembly line and this project was one part of that line. The aim was to modify current testing methods to be performed by an ABB YuMi robot while maintaining product quality compliance.

The project encompassed creating a new testing metric. This included researching current testing methods that were performed manually and developing a new system that could be performed by a robot. New testing metrics needed to be explored to replace a manual visual examination. Designing additional equipment and methods to aid the robot was also necessary.

A new testing metric and process proposal have been submitted to GE Healthcare Finland for review and are awaiting approval to be executed. Testing was done at a workbench and some designs are merely concepts of possible solutions.

Keywords	Automation, testing, water trap

Contents

Abbreviations and Terms

ABB	ASEA Brown Boveri. Electrical equipment manufacturer. Operates in robotics, automation and power technology. Producer of the YuMi robot line.
D-Fend	D-Fend Pro and D-Fend Pro+ (unless indicated otherwise). A GE Healthcare product. A removable filter used to protect gas testing sensors from liquid condensation.
DUT	Device under test. Refers to the unit being tested.
GE	General Electric.
MV	Machine Vision. Automated process that uses image-based input as guidance. Used primarily in industry. Distinct part of computer vision that deals with known or expected imaging.
PTFE	Polytetrafluoroethylene.
Unit	The term used to refer to the production unit. In this instance the D-Fend.

1 Introduction

General Electric Healthcare Vallila is the Helsinki branch of GE Healthcare Finland and part of General Electric's Healthcare division. They were recently awarded a bid to design a fully automated production line for the D-fend Pro series of moisture traps used in their medical monitoring devices.

A major aspect of producing medical equipment is quality assurance control. Product failures can not only have a negative impact on customer relations or a business's image, but in this case they can lead to health issues. GE's internal documentation specifies that every one of these devices is individually tested. [1.]

The project behind this thesis was to provide a solution to automate the testing aspect of the production. Currently the testing process is carried out by up to four workers utilizing a visual inspection after performing a manual test. The goal was to redesign the testing procedure in a way that it could be accomplished faster and more accurately utilizing a single robot.

Automation is the use of control systems for operating machines. Human workforce is reduced in either the control or function side or both. The control side is replaced by various control systems and the function side is replaced by task performing machines such as robots. Control systems can vary from a programmable logic controller to a simple thermostat to turn a heater on or off. Benefits of automation include machines able to perform repetitive tasks with more accuracy, speed and consistency of human counterparts. Labor cost and expense reductions or redistribution of labor force also contribute to increased productivity. Further, automated machines can be used to perform tasks that are either dangerous or overly demanding. The largest disadvantage of automation is currently the initial cost. This can include, purchasing new equipment, research and development, and possibly completely redesigning a plant.

2 Theoretical Background

One of the product lines GE Healthcare Vallila produces is gas monitoring modules for the CARESCAPE family of patient monitors.

Figure 1. CARESCAPE respiratory modules. [2.]

These Spectrolite modules can be easily plugged into the different CARESCAPE monitors such as the B650 and B450. The capnography and spirometry sensors in the modules provide monitoring of ventilation and anesthesia delivery. Capnography waveform displayed on the monitoring device allow visual inspection of changes in a patient's carbon dioxide (CO2) levels. The modules at GE utilize sidestream capnometers. [3.]

> Sidestream capnometers withdraw a continuous sample of gas through a capillary tube from the patient's airway to the monitor. A water trap removes particles of water before measurement takes place. [4].

That water trap is the D-Fend Pro and D-Fend Pro+ (see figure 1) grey and green respectively. It is a plastic housing that clips onto the module and is easily removed and replaced if needed (figure 1 and 2). Gas passes into a sealed chamber comprised of a catch cup for condensed liquid and a filter. A polytetrafluoroethylene (PTFE) membrane acts as filter. Gas continues to the sensor and liquids and any unwanted particles and moisture are left in the cup. Testing has shown the filter capable of separating 99.98% of particles as small as 0.15 µm. [3.] The cup can also be emptied and replaced easily.

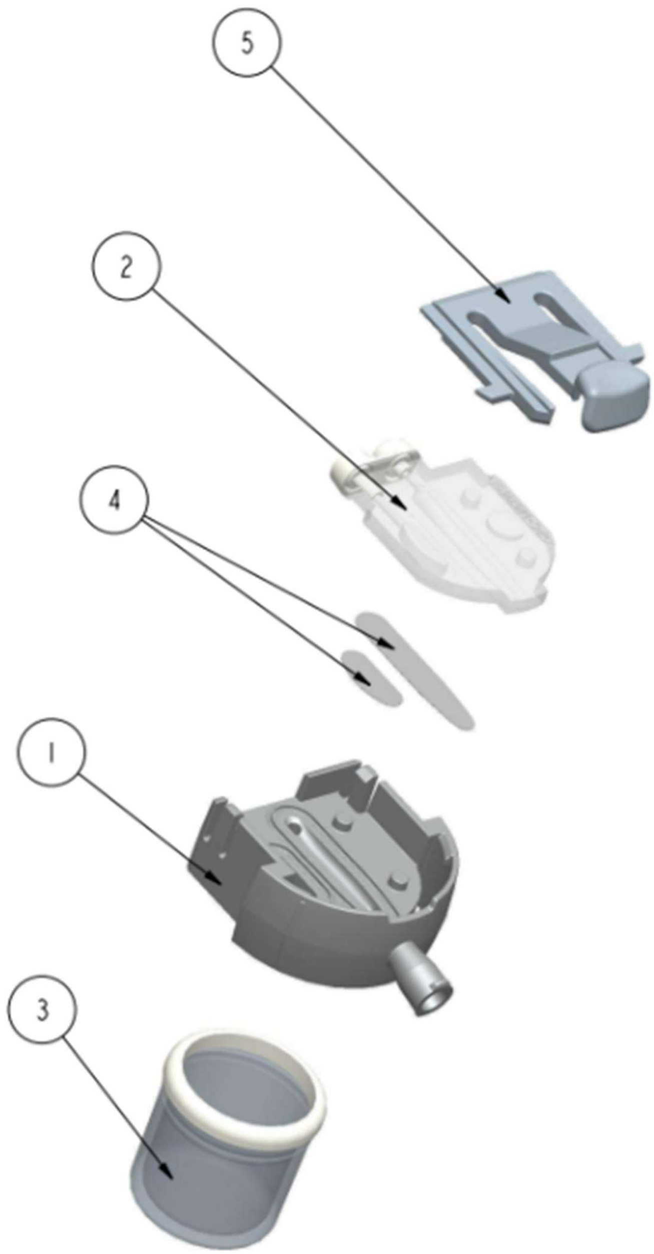

Figure 2. Components of the D-Fend Pro unit. [5].

The input tube connects to an internal channel in the main housing (1) which is open at the top and has a hole at the other end. There's a secondary output for side flow. The clear plastic piece (2) that the filter membranes (4) are welded together to form the filter. Liquid and mucus that are separated from the gas are collected in the removable catch cup (3). The top of the unit is covered by a clip (5) that allows the unit to easily be fitted into a monitor and replaced as needed (see figure 1).

YuMi is a robot built by ABB that is specialized in small parts assembly.

Figure 3. ABB YuMi robot. [6.]

As seen in figure 3, it is dual-armed and has a small physical footprint. Each arm is able to flex on seven axes and can support up to 500 g. The arms have a reach range of 500 mm and can move at a top speed of 1,500 mm/sec. The hands can be fitted with various pincher or suction grippers depending on task requirements. Camera sensor in the arms can also allow it locate and pick up parts without them being organized prior to reaching the YuMi's workspace. [7.] GE Healthcare Vallila is already utilizing this robot in its respiratory module production line and is planning on adding additional units in the future. [8.]

To further maximize YuMi's abilities all additional aspects of the testing will be motorized. This will entail an automated clamp to secure the unit under vacuum and a motor to lower the DUT into water for submersion. Additionally, electronic valves would be used to control the pneumatics within the testing system.

3 Testing Requirements

The first proposed testing change is the timing of the stress test. Instead of being performed as the final step in production it will take place directly after the membrane is welded on. By testing the device functionality before the housing attaching device failure will have a lower resource cost. This change further reduces costs by replacing the visual inspection of the membrane which was used to find larger faults from the sealing process. The new test will be all that is needed to determine if the unit will perform its function to specifications or not.

Removing the housing does bring about other challenges. The entire stress testing method needs to be redesigned. Covering the membrane with water for the test duration requires a new technique. The simplest way to do so now will be to submerge the unit under water. Without the built in clips of the housing new attachments are needed to hold the filter in place and ensure a sealed connection to the vacuum system.

The final challenge in automating the testing process is how it will be determined if a DUT passes or fails the quality assurance test. Machine Vision most closely resembles the current testing method and is certainly an option, however, that proposal is being outsourced to another vendor. The scope of this thesis was to focus on other potential methods.

Along with MV there were some other ideas that were immediately ruled out. Using a dye or other foreign substance in the testing process could have unintended consequences and did not comply with the product quality assurance guidelines.

3.1 Light Diffraction and Dispersion

The first idea to test was if the presence of water within the chamber could act as a prism and refract light projected through the unit. If so, could a light sensing diodes with lenses be used to detect the diffraction?

Each color of light that combines to form white light is a different wavelength. Because each color wave is moving at a different speed they will separate as the light waves move from one translucent medium to another – as long as they are not moving perpendicular to the new medium.

Photo sensitive diodes are able to generate charge from exposure to light
Lenses can be used to filter which wavelengths (colors) will reach the diode and therefore when an electrical charge will be present. If the received signal was different than what was expected the DUT would fail.

In order to test this theory water was injected into a DUT. Various amounts of water and at different chamber locations were tested. A light source was projected onto the plastic disc and the results studied. The light source was tested at various positions of the DUT. First, all flat surfaces were exposed to light at a 90 degree angle to avoid refraction from the plastic. Then the light source was tested at different angles to see if diffraction through the plastic would change results from the water.

Observation was done in two ways. White paper was placed around the DUT to capture light that projected through the plastic and water in order to better see if there was color separation. A microscope with camera was set at 42 degrees to capture any reflection within the water. 42 degrees is the angle at which light reflects when meeting water.

The camera, white surfaces and light source were held at constant positions during each testing attempt. The DUT was held in place by a clamp that could be easily manipulated to change the positioning. Any observances of color dispersion were immediately attempted to be replicated with a dry unit.

Color dispersion was observed. However, some instances were replicated with a dry unit and determined to be caused by the plastic medium of the disc. Other instances that were indicative of water were only present under a specific volume of water in a given location within the chamber.

Due to the size of the droplets the light needed to be extremely focused. The many different positions that droplets could be in also required the light source and detection methods to be in a multitude of different positions around the DUT. Although a half dome of lights and sensors could have been produced for testing purposes it wouldn't have fixed the bigger issue; not all instances of water within the chamber produced results. Therefore, this was not a viable testing metric.

3.2 Condensation

It was observed while carrying out other tests that fogging or misting would occur inside the DUT if the filter membrane was exposed to increased temperature. Condensation occurs when a substance changes phases from gas to liquid. Fogging is a result of temperature differences on either side of a (usually clear) surface. The gasses on the warmer side are cooled and change state to a liquid when they contact the cooler surface. [9.]

Evaporation of the water that leaked into the D-Fend chamber could be the cause of internal misting. The rate of water evaporation depends on the temperature, saturation (current humidity levels) as well as pressure. By adding a heat source to the surface the water was collected on evaporation could be accelerated. The controlled climate of the building provided an otherwise stable temperature, pressure and low humidity. Increasing the temperature within the chamber also had benefit of expanding the temperature difference of the sides of the clear plastic. This further increased the chance of condensation and detectable misting.

Testing was conducted by running the submersion test as normal. Post testing DUT was dried and the membrane was exposed to a higher temperature surface. The preliminary temperature source was the tester's finger. The clear plastic on the opposite side of the chamber was observed for water condensation. Results were recorded to be compared to visual confirmation of a leak.

Condensation was only visible in units that were produced with the black colored membrane. Units with the white membrane may have also had condensation but it was not readily visible. Further, detection of the condensation when visible to the human eye would have been very difficult to detect without Machine Vision. To complicate things further the presence of larger quantities of water within the chamber minimized and sometimes completely prevented any condensation.

Condensation within the DUT was not only inconsistent to detect, it was not a result of leaking. It occurred in both units that passed and failed a visual inspection. This could have been a result of water that evaporated prior to passing through the filter or humidity in the air already present within the chamber. This testing metric was abandoned.

3.3 Pressure Change

Change in vacuum pressure within the sealed system would indicate a lack of complete seal. If, during the submersion vacuum stress testing period, the testing system would be fully sealed the internal pressure (vacuum) should not change. If pressure change was detected, the seal was compromised and the DUT would fail.

The empirical form of the ideal gas law states that

$$\frac{PV}{T} = C \quad (1)$$

Since the temperature (T) is constant in our testing environment, and C is also a constant, any change in volume (V) would lead to a change in pressure (P).

Using a differential pressure sensor and software (LabVIEW) system pressure was monitored and plotted during testing. LabVIEW data was exported to spreadsheet software (Excel) was then used to plot and compare the data. Charts were used to more quickly compare multiple data samples and trends.

Consistency in testing technique were required to ensure data could be compared. Therefore, a strict protocol was established during testing and recording. First, the vent valve was left open while the DUT was attached and submerged. This allowed the system pressure to remain stable through any tubes being bent. Next, the vent valve and the valve connecting the DUT to the system were closed.

The DUT need to be kept separate from the vacuum source during this procedure because any volume that was introduced through a leak was compensated for by our source vacuum. This had an unfortunate drawback of having the vacuum pressure during testing be 90% of our source vacuum due to the volume between the valve and membrane being added to the system.

The differential pressure recording software was then reset to ensure the entire test would be captured. The vacuum source valve was then opened and immediately closed once vacuum was achieved within the system. The valve to connect the DUT to the system was then opened and the stress test period began. After the one minute test was complete the sampled data was exported to spreadsheet for later analysis. The vent valve was opened to re-pressurize the system and the DUT was removed from the water. After being removed from the test bench a visual inspection of the device took place and a pass or fail was recorded along with the data.

Data analysis was done in Excel. The raw data was first cut down to just the testing period. This was done by finding the point after which the system pressure finished dropping from the source vacuum level when the DUT valve was opened. The next 60 seconds of data composed the desired testing period.

Additional testing was also done with the DUT connected to the vacuum source before the testing period. This was done because the inconsistency in membranes flexing under stress. With the vacuum still connected the DUT valve would be opened so pressure would normalize to the source. The system was then sealed from the vacuum source and monitored for any change. Data from multiple tests were compared visually on charts as well as comparing trend-lines of the pressure change.

The first thing was to establish a baseline. This also served as an efficient method to test our system as we built it. After replacing a leaky sensor, using as rigid tubes as possible to reduce any change and then minimizing volume using smaller and shorter tubes our test system was ready.

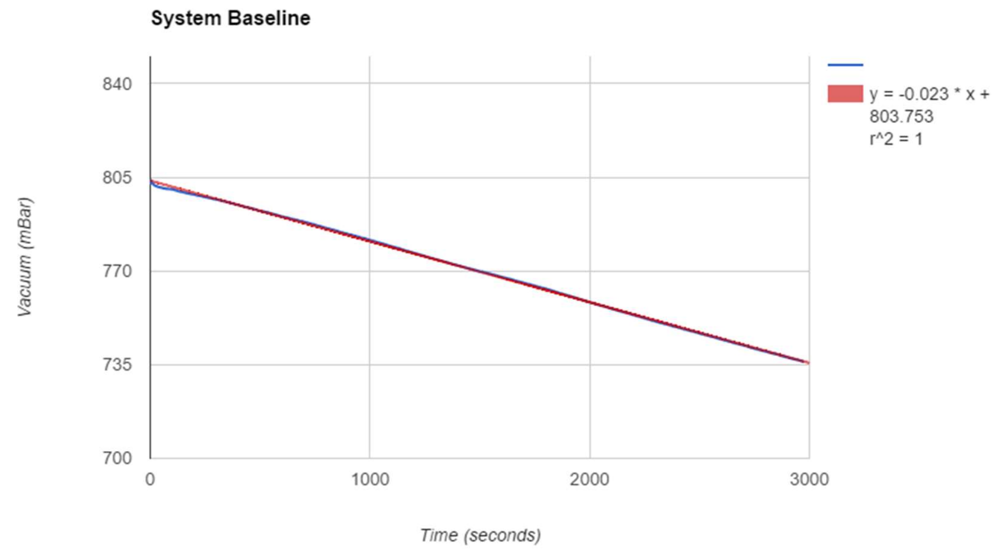

Figure 4. Pressure change over time in testing system.

The first thing of note in figure 4 is that there is pressure change over time. In the nearly 50 minute test the relative pressure changed by just under 70 mBar. There are two possible reasons for this. Either there is a small leak in the system or some of the tubes and joints compress a little over time. A linear trendline of y = -0.023x+803.753 with a coefficient of determination factor of r^2 = 1 tells us the change is fairly steady. Over one (1) minute that would result in a relative pressure change of 1.38 mBar. With this baseline comparisons between unit test results over a sixty second stress test can be made.

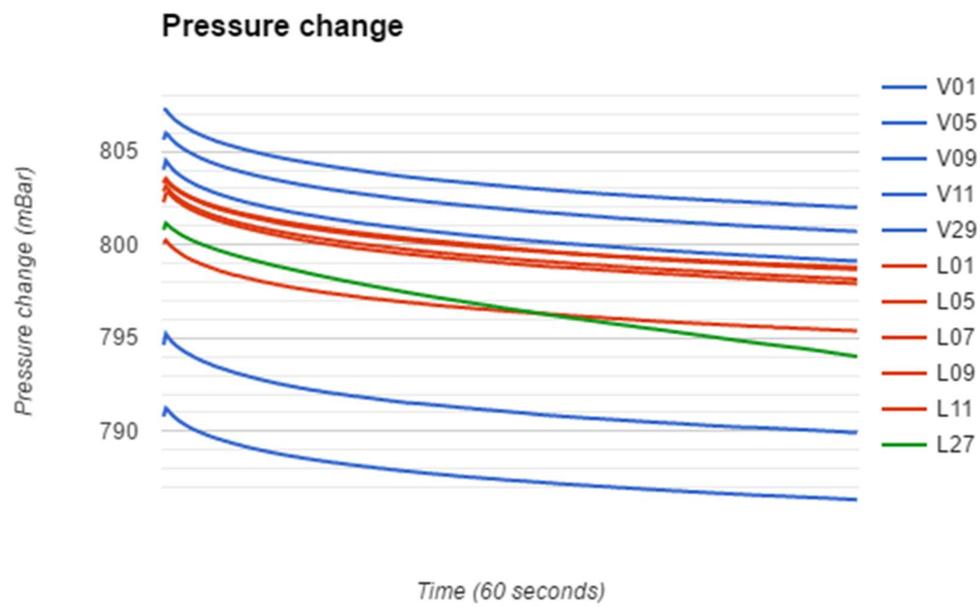

Figure 5. Relative pressure change of a small sample of tested units over the one minute test duration.

In Figure 5, "V" series of units (in blue) are all units that passed the visual inspection after the test where as the "L" series units all had a visible leak (in red or green). There are a few things that are readily visible. First, because the vacuum source line is part of a larger network the actual vacuum pressure available for use can vary. This graph includes a small sample of unit test data relatively close to the required 800 mBar but there were several instances of units being tested anywhere down to 700 mBar. If this testing method were to be explored more an independent vacuum system would be needed. (Note; an independent vacuum system is most likely needed to meet testing specifications regardless.) Second, despite a variety of starting and ending points, the graphs appear quite similar to each other.

The curve of the graphs is also not in line with the baseline test. The baseline was a very linear angle whereas (for example V09) required a power trendline [f(x) = 808.126x^-0.002] for the best coefficient of determination (r^2 = 0.962). This is likely due to the membrane flexing under pressure. The stress-strain curve of PTFE follows a non-linear path as well and could explain the curve. [10.]

A quick count (verified in excel) finds that the relative pressure change for most units was within 0.5 mBar of 5.0 mBar. This large change is not in line with the expected 1.38 mBar of relative pressure change from the baseline test of the system and is also most likely due to the elasticity of the membrane. However, the biggest issues is that there is no correlation between units that passed or failed within this range. Even using the mean change there were near equal numbers of passes or fails on either side of the mean. Units with larger leaks, such as L27 (green), are an exception with a larger relative change of pressure (6.8 mBar in this case).

Change in relative pressure of the testing system is an insufficient testing metric. To ensure it meets the requirements, pressure monitoring of the testing system will need to be integrated into the final testing structure. Therefore monitoring pressure change of the DUT could still be used to more quickly fail units with larger leaks. This could be particularly useful for interrupting a test to prevent water from a larger leak entering the testing system. It could also be used as a prompt for the system to be purged. Further testing of the final completed testing system would be required to establish thresholds for relative pressure change to be used in either capacity.

3.4 Detecting Bubbles Passing Through Tubes

On a previous project at GE, a light-emitting diode and photosensitive diode were placed on opposite sides of a tube. Every time the contents within the tube would change between water and air the curve of water created by surface tension would disrupt the light. The disruption in light shining through the tube would affect the signal from the photosensitive diode. If water would pass through the D-Fend unit and into the testing system a similar sensor could be activated.

Water seepage into the testing system had been observed on some faulty units during testing. The task was to determine if it was possible to change the testing method so water from all leaks would enter the testing system. Once that proved to be an option testing would continue using the sensor hardware to study the accuracy of the test.

The same test bench was once again used to run the submersion vacuum stress test. The testing was also conducted in a similar fashion with valve procedures. The test was started the same way and pressure sensor readings were once again recorded for additional data.

The primary change was made at the end of the testing procedure. Instead of opening the vent valve and allowing the system to pressurize prior to lifting the DUT out of water the valve was left closed. This change allowed air to vent the system through the fend membrane. Water that was inside the chamber would move into the tubes and air would follow. Because there are two chambers and venting air would take the path of least resistance the test was performed on each chamber separately.

Results were once again not satisfactory. Very severe leaks continued to supply water to the test system as had been witnessed in prior tests. Large leaks that remained contained to the chambers in previous tests did supply water into the main test system tubes when the membrane acted as a post-test vent. Unfortunately smaller leaks, and some large leaks that occurred near the far end of the chamber failed to supply the tubes with water.

An additional issue that came up with this form of testing was the constant need to purge the testing system tubes of water. Although the proposed testing system does call for an air pressure system for purging the testing tubes it's preferred to keep water out of the system as much as possible.

A final idea was the possibility of using a centrifuge. A centrifuge works through sedimentation and centripetal acceleration. [11.] By spinning the DUT along a rotational axis the more dense substance inside of it, in this case water, would move away from the axis. If the DUT were placed in such manner that the outlets were away from the axis, the water would move towards the tubes and a vacuum could then be used to move the water into the tubes and past the sensor. Although the YuMi’s arms would be capable of holding and spinning the DUT, and manual waving of the unit produced encouraging results, it was rejected. YuMi's arms were needed for other tasks and other options were overly cumbersome and consumed too much time.

3.5 Change in Mass

If the DUT leaks the additional water inside the unit would lead to an increase in mass. Software could be used to track DUT weight before and after stress testing and trigger a fail if change was detected.

Previous tests lacked the sensitivity to detect small amounts of water however even with a minimal weight change a milligram balance should be sensitive enough to show a change due to water. A readily available balances on site is capable of measuring 0.001 g resolution. At 21 degrees C, water has volume to weight ratio of

$$1\ \mathrm{g} : 1.0028\ \mathrm{ml} \quad (2)\ [12.]$$

With a resolution of 0.001 g, the balance would be able to detect 1 thousandth of that, as little as 1 μl of water within the unit. [13.] For reference, that converts to a 1 mm^3 droplet of water. This is in line with the smallest leaks found within the sample units.

This testing metric required a few additional steps in testing procedure. First, prior to submersion testing, a pre-test weight was taken for each unit available for testing. This data was also analyzed on its own. The average weight was 2.467 g. However, the D-Fend Pro units weighed slightly less than the D-Fend Pro+ units on average, 2.462 g to 2.473 g respectively.

After base data was collected on the weight of each unit stress testing continued as normal. Each unit was submerged and subjected to one minute of vacuum to test for leaks. Pressure change was also recorded for reference and a final post-test visual inspection was used as a baseline to compare and contrast results from the balance and weight change.

After the submersion stress test, the DUT was placed on an absorbent surface to dry while the rest of the batch was tested. Initially testing was done in batches of 10. After each batch had completed testing the surfaces were lightly patted dry and then the units were taken for post-test weighing.

Several lessons were learned through the errors of the first trial. Primarily, drying was of utmost importance. Not only removing the external water, but units that were not weighed immediately after testing risked having any water that leaked into the system evaporate out. External draining had to be done completely and in a quick manner. An air jet was added to the post-test process to mechanically drain the exterior of the units. It was also found that resetting and recalibrating the balance might occasionally lead to mixed results. To contest this each DUT was weighed immediately before and after submersion.

The balance had a 100% positive identification match with the visual baseline. Every unit that had visually detectable water also showed a change of weight. Unfortunately, even though the smallest leaks were detected many were indeed only large enough to change the mass by 0.001 g. With such a small margin of error there were a relatively large number of cases of false positive results in initial testing.

False positives are an acceptable outcome and a secondary test metric to reduce the number of false positive results was also within the project parameters. Since the balance results could be used to divide tested products into three (3) different groups, one for units that passed with no weight change, another for units that failed with a weight change larger than what was seen in false positive results and last a group with a small weight change that would undergo a secondary test. Unfortunately, at this point there were no other testing methods that were capable of detecting the smallest leaks that would make up a majority of the units requiring a second test.

The testing process needed to be improved. Primarily, the draining method needed to be completely effective as it was the most likely cause of false positive change in mass. Testing was repeated with all units that showed very small mass increase or change without a visual fail, with emphasis placed on the air pressure draining technique. It was noted that the corners near the tip as well as the indents between the outlets were easily left wet if not specifically dried.

Adding a few seconds to the draining process not only seemed to visually remove all water but it had the desired outcome on the balance. All false positive test results were eliminated. Further, all units that failed visual inspection continued to show a positive mass change.

Testing of any drying effects the air-jet might have on leaked water was also performed. The condensed air was aimed directly at the membrane and manipulated in such a way that water droplets inside the chambers could be seen moving but not in the direction of the openings. Primarily units with the smallest leaks were tested as they were the primary concern. No evidence was found that internal drying occurred and all units continued to show a positive change in mass. This trend continued even when internal drying was attempted between mass measurements.

Table 1. Sample of Mass Tests

DUT	Pre weight (g)	Post weight (g)	Change (g)	Visual leak
V11	2.467	2.467	0.000	No
V13	2.477	2.477	0.000	No
V15	2.472	2.472	0.000	No
V17	2.472	2.472	0.000	No
V19	2.470	2.470	0.000	No
V21	2.475	2.475	0.000	No
V23	2.471	2.471	0.000	No
V25	2.473	2.473	0.000	No
V27	2.471	2.471	0.000	No
L11	2.473	2.474	0.001	Yes
L13	2.475	2.494	0.019	Yes
L15	2.474	2.475	0.001	Yes
L17	2.473	2.476	0.003	Yes
L19	2.473	2.474	0.001	Yes
L21	2.473	2.581	0.108	Yes
L23	2.473	2.480	0.007	Yes
L25	2.476	2.482	0.006	Yes
L27	2.473	2.577	0.104	Yes

All "V" series units (blue) did not display visual leaks and likewise no change in mass was present. Units from the "L" series (red) all failed the visual inspection and presented a detectable increase in mass. Note that although all of the units displayed here are within 0.005 g of 2.472 g, however, due to leaks being as small as 0.001 g each unit needs to be tested against the pre-test weight instead of a baseline.

Using a milligram balance to measure mass increase from water seepage meets all current testing metric needs. Being able to detect additional mass from a water droplet measuring 1 mm has a 100% success rate over repeated tests on over 100 test samples. The initial results generating false positive results was completely eliminated with proper attention to air pressure draining. The end result is a testing metric with a perfect pass-fail detection.

4 Proposed Testing Procedure

Testing would be accomplished by a milligram balance, a single YuMi robot, and multiple submersion-vacuum stations. Because the YuMi is free to multitask there would be multiple units in staggered testing stages. Also, because the test would take place prior to the D-Fend being attached to the housing submersion would be utilized to cover the membrane with water.

4.1 Measuring the Mass of Leaked Water

A milligram balance to measure possible mass change from water seepage proved to be an effective method to reliably detect defective units. With an accuracy of 0.001 mg as little as 0.001 cm^3 of water can be detected. Since that is often the difference between a pass or fail there is no margin for error and draining water from the exterior of the unit has utmost importance.

Although this testing process requires before and after weighing, these steps require only a few seconds and do not alter the takt time since they take place while other units are being tested. The ability of the milligram balance to communicate with software allows measurement data to be compared automatically in the manner desired for this application. [13.]

Software integration will also be vital in calibration testing and error detection and handling. Since this phase of the project was focused on the testing process and metric those aspects have not yet been explored.

With no room for error the balance must be enclosed. Opening and closing of the draft shield may need to be automated independently. It is possible that it could be added to the tasks YuMi performs while placing and removing units. Having an automatic system for the shield to open would save time.

Another step that may need to be addressed is the state of units as they enter the testing phase of assembly. It is vital that the units be clean of debris prior to the first weight measurement. Therefore, depending on the environmental conditions it may be necessary to include cleaning, likely with compressed air, prior to testing.

4.2 YuMi

The dual armed YuMi robot is put to full use with both arms operating simultaneously.

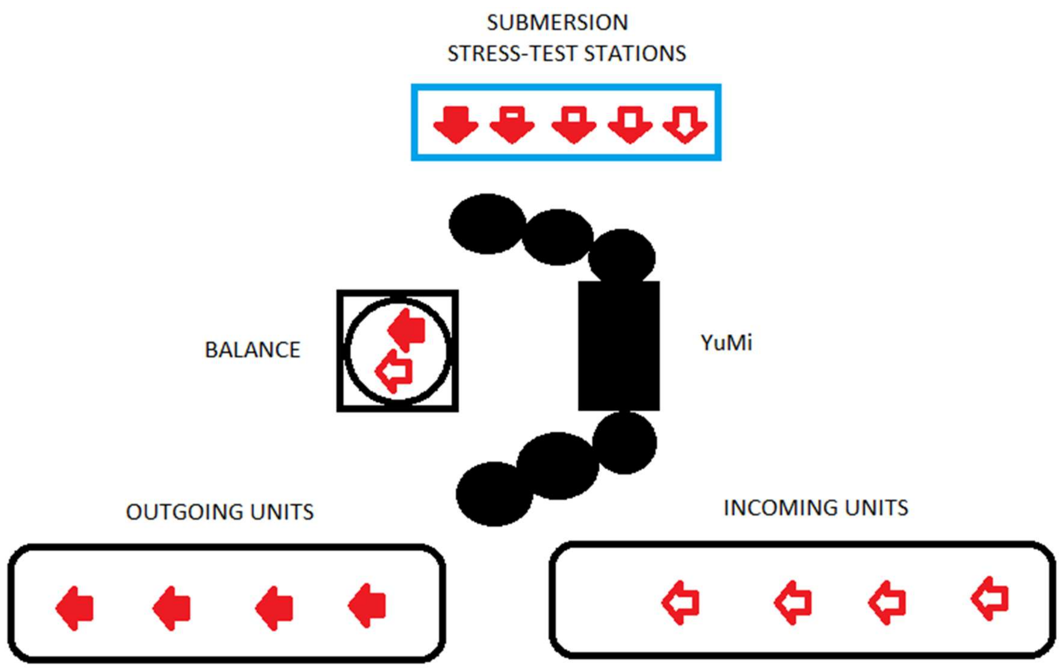

Figure 6. Technical illustration of testing station.

The first arm begins the testing process by grasping a new incoming unit and moving it onto the balance for a pre-test weight. The weight is recorded by the testing program and the second arm takes the new unit for water submersion and vacuum seal testing.

The automated submersion-vacuum station docks with the D-Fend and submerges the DUT in to distilled water. The testing stations will need utilize its own regulated vacuum system to maintain adequate testing levels. In-house positive air pressure source to perform the blow-draining the unit will be adequate.

After the stress test and the exterior of the unit is drained the second arm will be responsible for returning it to the balance for the post-test weight. The first arm will remove the unit and forward it to be mated with a housing at the next assembly phase or discard it depending on the result of the test.

Since YuMi is able to perform these tasks simultaneously the full procedure is more compressed. Each time an arm moves to the balance it will place the held unit there and then take the unit that has just completed being weighed to its next station. When the first arm goes to pick up a unit that has completed submersion it will bring a new unit. Similarly, when the second arm goes to pick up the new unit to be submerged it will be taking a unit that has just finished post-test draining. The balance will weigh the delivered units after the previous unit is removed and the draft shield is closed.

4.3 Submersion Stress Test

The stress test is fully redesigned as well. The test will be automated so that YuMi is free to be dedicated to sorting and moving units. This includes a gripping mechanism and method to place the DUT under water to cover the membrane, and automated valves to control the vacuum and compressed air.

4.3.1 Clamp

The most common source of leaks found during testing were due to a poor seal between the DUT and the testing system. The D-Fend Pro housing is designed to mate with a respiratory module. The unit is pushed into springs loaded flanges and held in place firmly by a clip (reference figure 1 and 2). In current testing respiratory module front housing is used to perform that task. Without that housing another solution is needed to ensure a proper seal and hold the DUT.

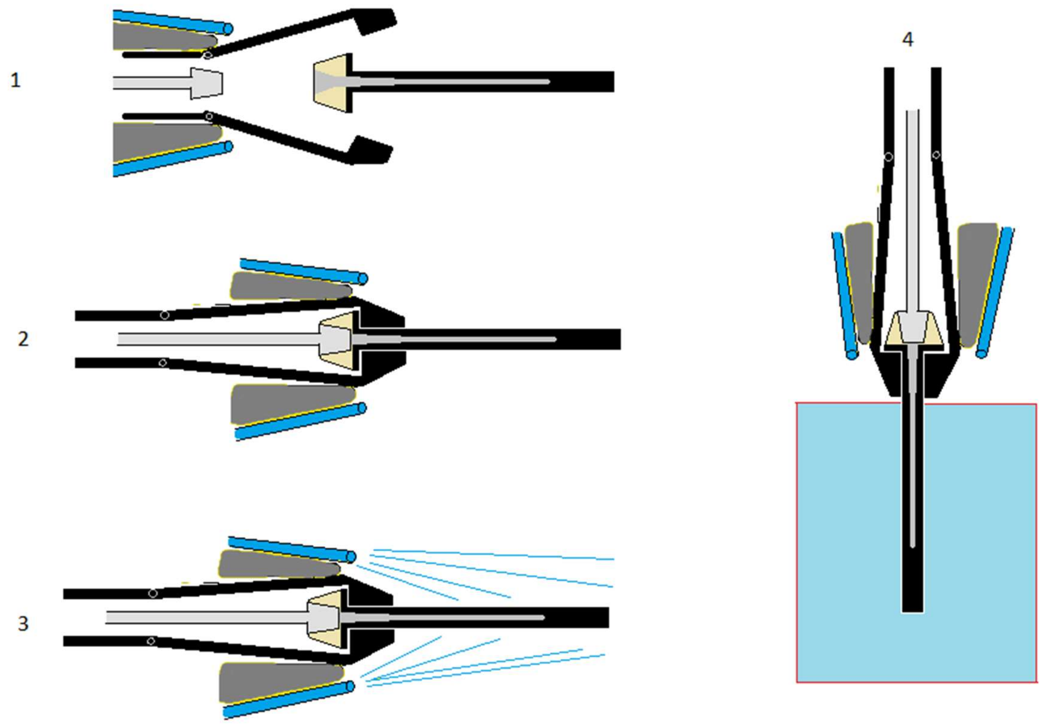

Figure 7. Clamp and Air-Jet Technical Illustrations.

Illustrations 1 and 2 show the clamp open and closed. The clamps close around the DUT and pull it back into the vacuum port to ensure a secure connection. Since the system already utilizes both positive and negative air pressure, compressed air could easily be used. On the right the DUT in held in place during submersion just past the membrane openings. Finally, on the bottom integrated air-jets are used to drain the water from the exterior to complete prepare the unit for post testing measurement and the next phase in assembly.

4.3.2 Pneumatics

Four (4) valves are automatically operated to control the air pressure within the testing system.

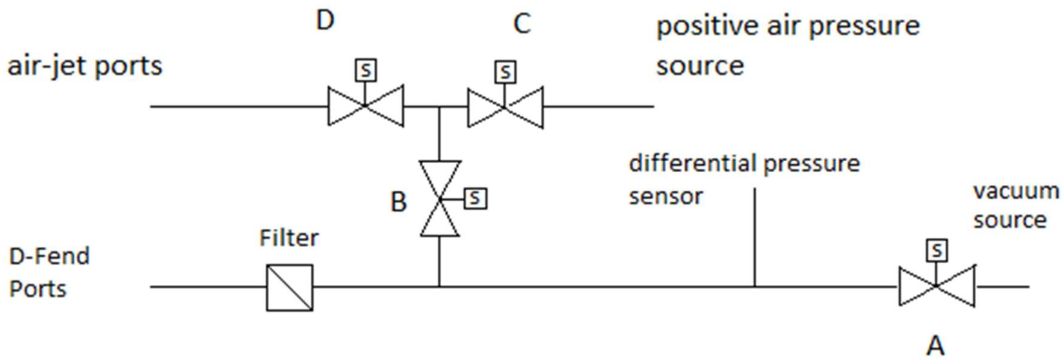

Figure 8. Pneumatic Circuit of the Testing System.

A filter to ensure water does not enter the testing system is positioned near the D-Fend ports. Since water entering the system would cause the filter to clog the positive air pressure is used to purge the system for the next test.

Table 2: Table of Valve States.

State:	A	B	C	D
First state. All closed	0	0	0	0
Second state. Vacuum test	1	0	0	0
Third state. Vent and re-pressurize	0	1	0	1
Fourth state. Air drain DUT exterior	0	0	1	1
Fifth state. Purge testing system	0	1	1	0

Table 2 shows the cycle the system goes through. The testing system begins at rest. Once the DUT is attached and submerged, the vacuum source will open and the test will begin. After the test is completed the system will re-pressurize using the air-jet ports as vents. Then the exterior draining of the unit will occur. Finally, after the DUT has been removed by the YuMi, the positive air pressure will be used to purge the system in case an extreme leak resulted in water entering the system. If necessary, the differential pressure sensor could also be protected with a fifth valve. That valve would be placed between the sensor and the ‘T’ to the main line and would function with an input of ~C.

5 Conclusions

GE Healthcare Finland is designing a new, fully automated, assembly line. This project was undertaken to automate testing part of that production line. In this thesis testing methods were explored and developed in order to implement automated product testing of the D-Fend Pro and Pro+ water traps. Current testing methods were also modified to be performed by an ABB YuMi robot while maintaining product quality compliance.

The primary focus of the project encompassed creating a new testing metric. This involved researching possible solutions and in many cases experimenting with ideas that were generated while exploring the behavior of different testing methods.

Ultimately measuring change in mass proved to be the only solution that reliably detected all visible leaks. This solution has a very low margin for error however that risk has been mitigated by proper water draining of the exterior to ensure that the only possible change in mass is a result of seepage inside the chambers.

There were other requirements beyond the competency of the automated testing metric. The testing process had to be developed in such a way that it could be automated and when needed performed by the YuMi robot. As such, possible designs have been proposed. The testing area and method in which YuMi can operate were added to the project at a late stage.

The new testing metric and automated process proposal have been submitted to GE Healthcare Finland.

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