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by Alex Williams

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1. System Investigation

The CIM system comprises the following control loops:

TC541 – Level control of water in tank B1

TC511 – Temperature control of water in tank B1

TC535 – Flow control of water into tank B1

TC531 – Flow control of water into tanks

Substation 1

Each control loop is made up of different sensors and components.

There are two limit switches (LS543 and LS542) within loop TC541 ensuring the level of the water in the tank is within the correct range. The low-level switch interlocks with the heating element, preventing it from starting if the lower limit hasn't been achieved. The upper-limit switch turns off the pump, indicating the tank is full. This is a safety feature to stop the tank overflowing, protecting the system and any workers present. Level controller LC541 and level transmitter LT541 are also present in this loop, as well as the drain solenoid valve V500. The pump/amplifier LY541 controls the water flow.

Within control loop TC511, is the temperature control of the system. This produces a CV which is fed into a relay using PWM to control the heater. The water temperature being monitored in this loop is affected by cold water being added to the system from solenoid valves V515 and V516 in addition to the pump and cooling fan.

TC 535 and 531 deal with the flow of water, with TC535 controlling the flow to tank B1. TC535 is made up of flow controller FC535 that produces a CV to feed amplifier LY541. It has a PV supplied from FT535.

Substation 2

Substation two supplies the recirculated water back within the system. The DC pump, pumps the collected water from the bottom tank back to the top tank in readiness to feed the system. Both tanks have a level transmitter with the loop having a flow transmitter included.

The sensor's technical data is provided in Table 1.

Table 1: Sensors Characteristics

Citation

Component Type	Sensor Model	Range	Accuracy	Static Sensitivity	Other Properties
Pressure Sensor	GE Druck LPM5380	0-5 bar	0.1	3.00015 volts per bar	18-30VDC 0-10VDC output
Temperature Sensor	PT100 RTD	-20°C/ +100°C	0.125	0.13 mA per °C	
Temperature signal controller	Conlab RTT2	Operating Temperature: -20 to 70°C	0.05	0.019 mA per °C	Output Current: 4-20 mA
Level Sensor	Endress and Hauser PMC133	400 bar	0.5	25 mA per bar	Input 2.5-30VDC 4-20mA output
Flow Sensor	RS PRO Radial Flow Turbine Flow Meter	0.25 – 6.5 L/min	0.4	0.03mV per L	

2. Research

Industry 4.0 is now referred to as the modern standard because production is rapidly changing with automation. Marr advises it “represents the fourth revolution that has occurred in manufacturing.” (2018). It combines computers with automation, thereby enhancing and improving efficiency in manufacturing, including cyber-physical systems, the Internet and cloud computing (Nseabasi, et al., 2020). Figure 1 shows the industrial revolutions stages.

Correctly cited

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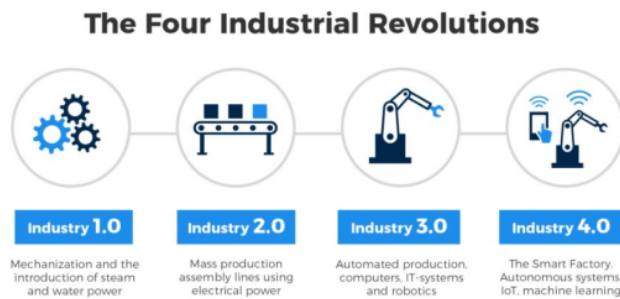


Figure 1: The Four Industrial Revolutions (Spectral Engines GmbH, 2018)

Correctly cited

Industry 4.0 is heading towards data driven engineering. All data gathered and processed by machines helps manufacturers with efficiency, planned maintenance and addresses issues with the system, in addition to machine learning. Figure 2 shows how machines and factories with different smart sensors and collected data can interface together in a smart factory.

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Figure 2: Material sensing in Industry 4.0 (Spectral Engines GmbH, 2018)

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Spectral Engines (2018) say that it deploys real-time information from the measurement objects to an automation database and uses it in automated control decisions, eg in a system measuring temperature. Here, the data being transmitted can be monitored in real time on an HMI screen. Therefore, an engineer can view the temperature and how the machine is reacting accordingly, with real time decisions being made specifically on this data.

A big development in industry 4.0 is I/O links. Sensors can be out in the field, even in harsh environments and remotely send signals back to the PLC over I/O link. It is an open-source, communication protocol using serial point-to-point communication for connecting sensors and actuators to an automation system (Phoenix Contact, n.d.). The different level of I/O link is shown in Figure 3.

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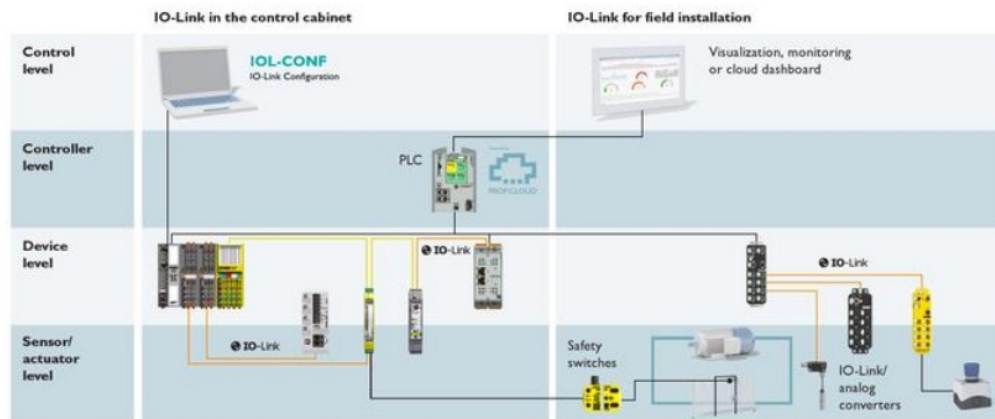


Figure 3: Levels in the IO-Link system (Phoenix Contact, n.d.)

Sensors in industry 4.0 (often considered to be ‘smart sensors’), are getting smarter and self-aware. According to Shea (2019) “a smart sensor has three major components: a sensor that captures data from an environment; a microprocessor, which computes on the output of the sensor via programming; and communications capabilities that enable the sensor to communicate the microprocessor's output for action.” These sensors can also record environmental data such as run time which helps with PPM’s and scheduled maintenance.

The CIM system could be upgraded with sensors that are industry 4.0 compatible. An ultrasonic level probe could be used to replace both the low and high-level limit switches in the tank, eg using the Siemens SITRANS Series Ultrasonic Level Probe. On review of the operating manual, it indicates this can also be configured to measure level, volume or flow.

Siemens SITRANS Series, Ultrasonic Level Probe

RS Stock No.: 493-7186 | Mfr. Part No.: 7ML5221-1BB11 | Brand: Siemens



Figure 4: Siemens SITRANS Series, Ultrasonic Level Probe (RS Components, n.d.)

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The flow sensor can be replaced with the Turck FS+ flow sensor, shown in Figure 5.

Simplified mounting and start-up

The FS+ product series offers a variety of helpful features that make installation, connection and start-up as efficient and simple as possible.

Since the sensor housing can be freely rotated by 340°, the display and the electrical connection can be easily adjusted after the sensor has been installed

The modular mechanical concept with a large range of adapters allows flexible adaptation to almost any process

Since the sensors also measure the media temperature, fewer components are required for a single application



The innovative Delta Flow monitoring ensures systematic safety when teaching in the sensor

The user can adjust the switching point conveniently and quickly using the Quick Teach function

Output signals are automatically detected making it easy to connect the device to the controller environment

The sensor operates within the specified parameters, regardless of how the probe tip is orientated in the medium



Figure 5: Turck FS+ flow sensor (Turck, n.d.)

The Temperature sensor in Figure 6 with display TN2511, could replace the temperature sensor. Figure 7 shows its specification.



Figure 6: Temperature sensor with display TN2511 (ifm electronic ltd., n.d.)

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Product characteristics	
Number of inputs and outputs	Number of digital outputs: 1; Number of analogue outputs: 1
Measuring range	-50...150 °C -58...302 °F
Process connection	threaded connection M18 x 1,5 internal thread
Installation length EL [mm]	45
Application	
Special feature	Gold-plated contacts
Measuring element	1 x Pt 1000; (to DIN EN 60751, class A)
Media	liquids and gases
Pressure rating [bar]	300
Minimum installation depth [mm]	12
Electrical data	
Operating voltage [V]	18...32 DC; (*supply class 2" to cULus)
Current consumption [mA]	< 50
Protection class	III
Reverse polarity protection	yes
Power-on delay time [s]	1
Integrated watchdog	yes

Figure 7: Temperature sensor with display TN2511 data (ifm electronic Ltd., n.d.)

These 3 sensors have I/O link capability allowing for:

- Efficient remote monitoring and extraction of information
- Adjustment of system parameters
- Notification of faults for diagnostic purposes

Integrating sensors with I/O link into the CIM system will help align it with latest standards in industry 4.0, improving its efficiency and accuracy.

3. Environmental, Sustainable Development, Commercial Risk and Code of Practice

The CIM system can be split into self-sufficient parts. All rinsing chambers drain into a collect and cleaning tank. These have the capability of collecting the drained water which gets recirculated, saving the need for fresh water or a continuous mains supply. Consequently, it's environmentally friendly and cost effective.

Commercial risk must be considered when producing a new similar system. If purchasing or exporting machines, they should be CE marked, demonstrating the manufacturer has checked these products meet EU safety, health and environmental requirements and indicates compliance with EU legislation (GOV.UK, 2020). Correctly cited

Likewise, when producing a new system for a customer, it's the manufacture's responsibility to;

- complete a conformity assessment
- create and supply the technical file
- issue the EC Declaration of Conformity
- place CE marking on a product

(GOV.UK, 2020) Correctly cited

Codes of practice must be followed when installing machines and calibrating analogue sensors. All work should be completed to latest industry standards e.g. ensuring all electrical wiring meets BS7671:2018 - 'Requirements for Electrical Installations, IET Wiring Regulations'. Whilst not statutory, it sets standards for electrical installations (such as providing fail-safe interlocks), enabling compliance with Health and Safety and other UK legislation. Non-compliance with these standards could result in prosecution should accidents occur.

Sensor calibration ensures that the instrumentation functions accurately, maintains reliability and is traceable to National Standards. ISO 17025 UKAS accreditation is the international standard for these calibrations (Simpson, 2013). Correctly cited

4. Calibration of Pressure Sensor

The pressure sensor (GE Druck LPM5380) was tested by monitoring the increasing then decreasing pressure in the system. Voltage readings were taken at every half bar and the results recorded onto a spreadsheet.

Firstly, the pressure was set to zero bar and the voltage reading was taken. From the data sheet, at 0 Bar pressure the sensor should be giving an output voltage of 0V. This was the reading showing. However, there is a terminal on the pressure sensor that can be adjusted accordingly until the output is 0V as and when required.

By calculating the gradient of the curve, the linear values can be calculated, giving a baseline to the expected result. Consequently, its rising and falling linear errors can be determined, showing the accuracy of the sensor compared to its expected reading. Figure 8 shows the voltage reading against the increase and fall in pressure. The grey line displays the expected linear correlation of the sensor. The blue and orange lines identify the rising and falling reading with the gap between them the non-linear errors. This shows the linear error is increasing as the pressure gets greater, demonstrating the sensor needs calibrating. The full set of results are in Table 2, Appendix 1. The sensor can be calibrated in a similar way, setting the output to zero volts when the pressure is at zero bar. The gain terminal can be adjusted to match the required output as per the sensor's data sheet.

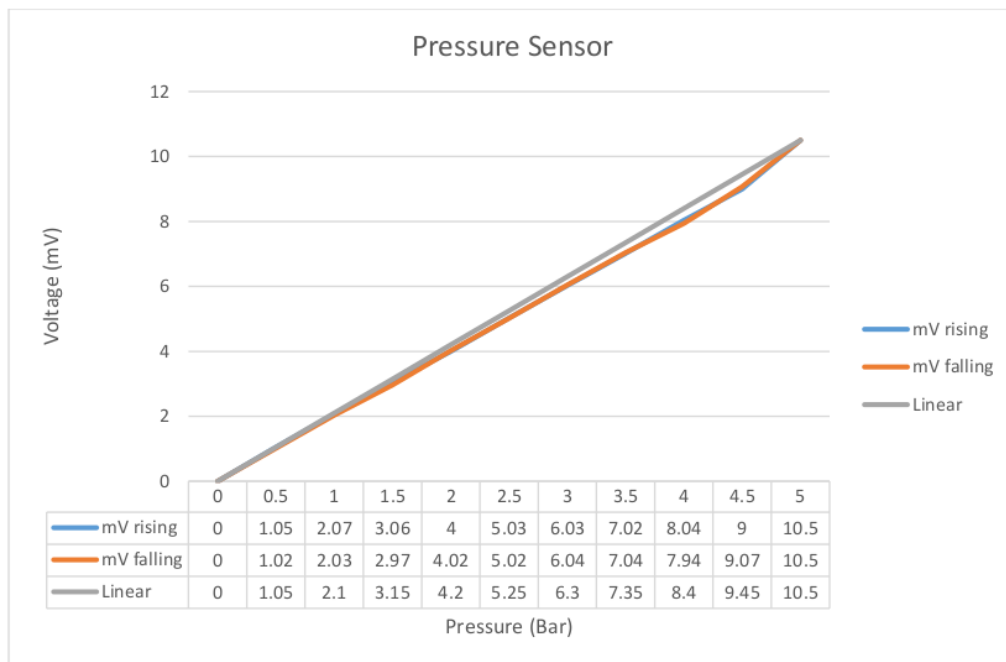


Figure 8: Pressure sensor graph

5. Calibration of Temperature Sensor

The temperature sensor measures the tanks' temperature. The test was undertaken by starting the temperature at 0°C and increasing up to 100 °C by 10°C increments. At each stage, the current was monitored for the rising and falling temperature and completed using a calibration device, (see Figure 9).



Figure 9: Fluke 726 Multi-Function Calibrator (RS Components UK, n.d.)

The calibration meter gives an output into the sensor whilst an ammeter was connected to it to read the current. The initial results were incorrect as they had a high number of anomalies with a higher temperature coming in at a lower amperage than expected. Based on results from other groups, the sensor required some fine adjustments. On the temperature sensor, the zero setting was altered similarly to the pressure sensor. The test was repeated and the result recorded. As with the pressure sensor, the results are expected to be linear so a higher current will be present at higher temperatures. The full results are in Table 3 of Appendix 1, with the results graph shown in Figure 10 below. Upon analysis, it is clear that the calibration was successful as the rising and falling temperatures match its linear expectation leading to no non-linear errors proving the success of the calibration.

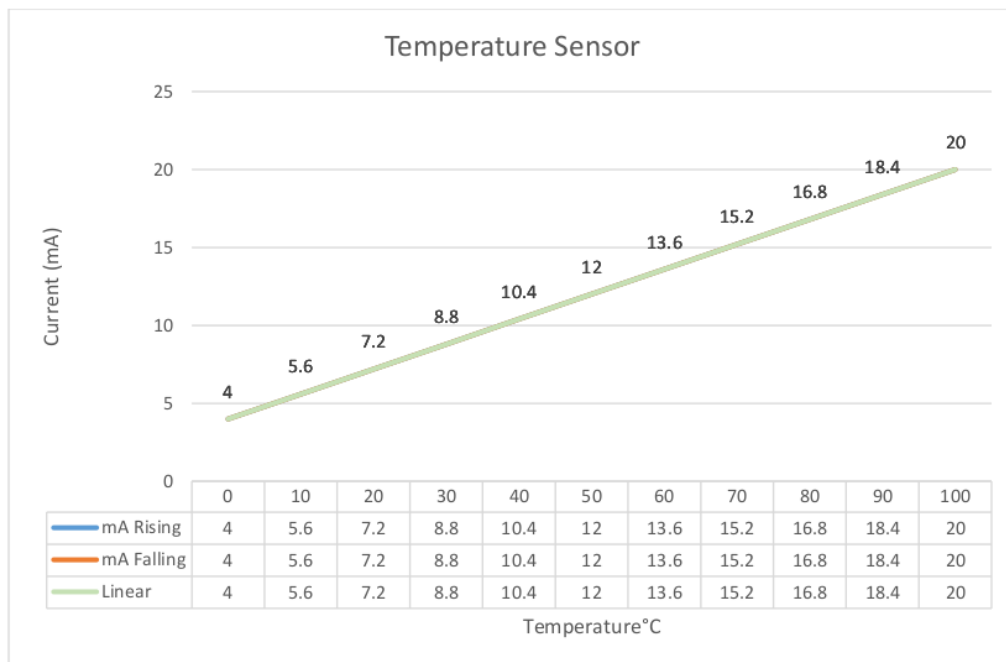


Figure 10: Temperature sensor graph

6. Calibration of Level Sensor

The level sensor measures the level in the tank's system. This test was undertaken by filling the tank in cubic meter increments up to 23cm then draining back down in the same increments. At each stage the current was manually monitored and recorded. Due to tank limitations, the lowest reading started at 7cm. The filling process was controlled on the HMI via the DC pump and compared against the fill gauge. This can lead to small discrepancies due to human error. The draining was completed using a manual drain valve so the same discrepancies could potentially be seen. As the sensor runs with an offset from 4 to 20mA, the equation $y = mx + c$ was used to calculate the linear values of the sensor as in theory, it should have a linear correlation between the level and the current.

$$m = \frac{\Delta y}{\Delta x} = \frac{12.7-6.2}{23-7} = \frac{6.5}{16}$$

$$y = mx + c$$

$$12.7 = \frac{6.5}{16} \times 23 + c$$

$$C = 12.7 - 9.343 = 3.357$$

$$y = 0.406x + 3.357$$

When all linear values were calculated, the non-linear errors could be determined to establish the sensor's accuracy and what calibration is required, (see Table 4, Appendix 1). The results were subsequently put into a graph (Figure 11) for visual representation to identify trends and any potential errors. Upon analysis, there is a greater non-linear error on the decreasing level but this could be due to the manual operation of the drain valve. The hysteresis error is fairly consistent throughout, ranging from 0.1 to 0.3mA. Only one reading had the hysteresis error of 0.3 suggesting this could be human error as it also had the biggest non-linear error. Due to the manual operation, an average should be taken over three tests to obtain more accurate data on which to base the calibration. The average data can then be analysed to determine the required calibration adjustment.

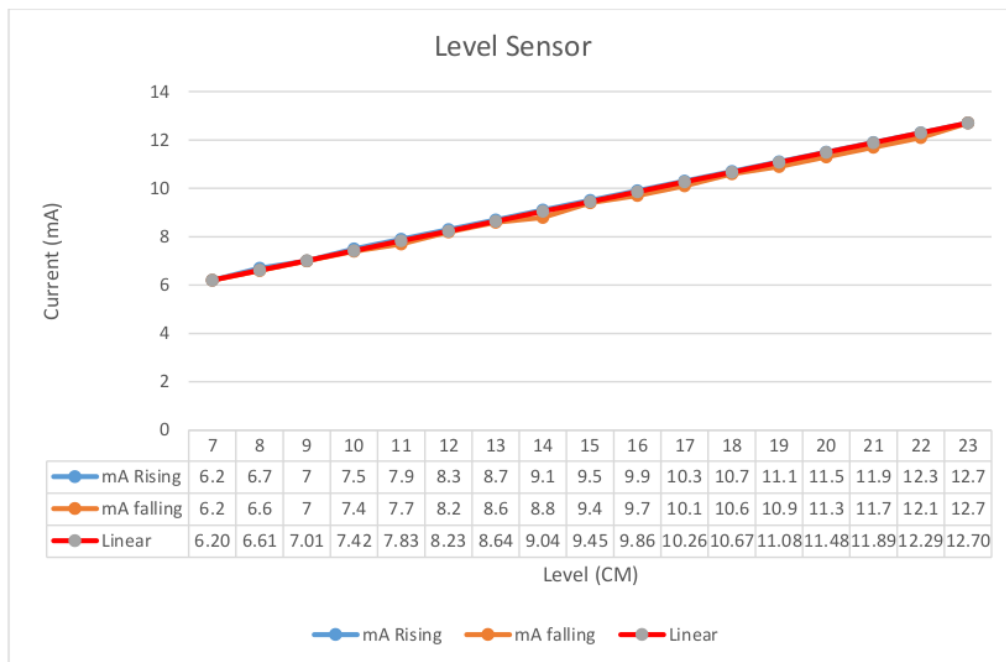
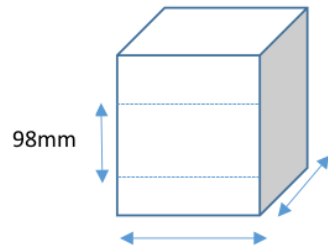


Figure 11: Level sensor graph

7. Calibration of Flow Sensor

This sensor measures flow rate as the turbine is being spun by the flow of water. The pulse is then scaled in PLC to give a digital reading of the flow rate in litres per minute (LPM). To test the sensor's accuracy, the flow rate was set to the tested LPM value and the time taken to fill the tank was recorded.

The first stage was to calculate the volume of the tank.



$$Volume(L) = 0.138 \times 0.14 \times 0.098 \times 1000 = 1.89L$$

The test was carried out at 0.4, 0.7, 1.0, 1.2 and 1.5 LPM. The time taken was converted into minutes and then to LPM. The results are in Table 5, Appendix 1. The practical results were then compared against the set values to determine the sensor's accuracy. Figure 12 shows the calculated LPM against the expected LPM, demonstrating the sensor requires calibration.

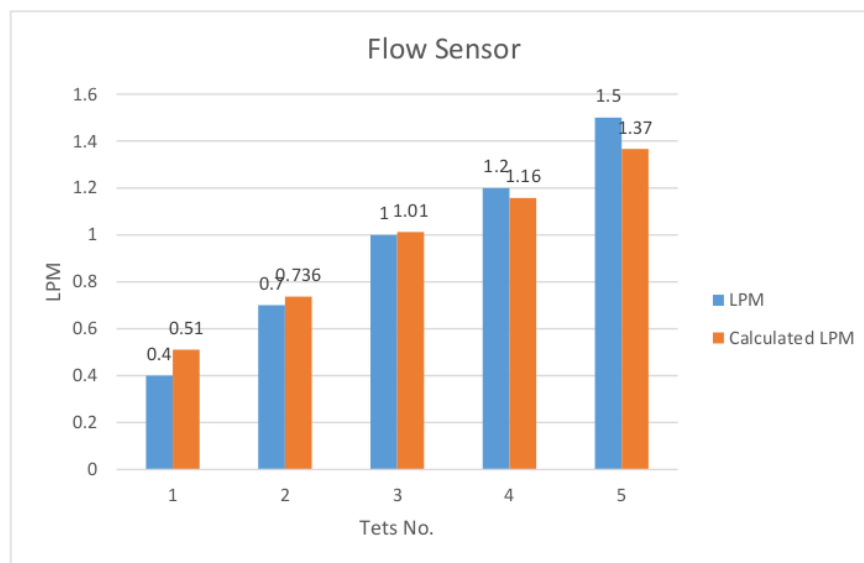


Figure 12: Flow sensor graph

8. Design Adaptation for Maintenance and Reliability

The local station HMI screen, identified HMI 133 didn't have any visual representation of the system, making it nearly impossible for any calibration, adjustment or monitoring to be undertaken at the local station. Consequently, three HMI screens were developed to rectify this which were; TC511 Temperature Control, LC541 Level Control and FC535 Flow Control.

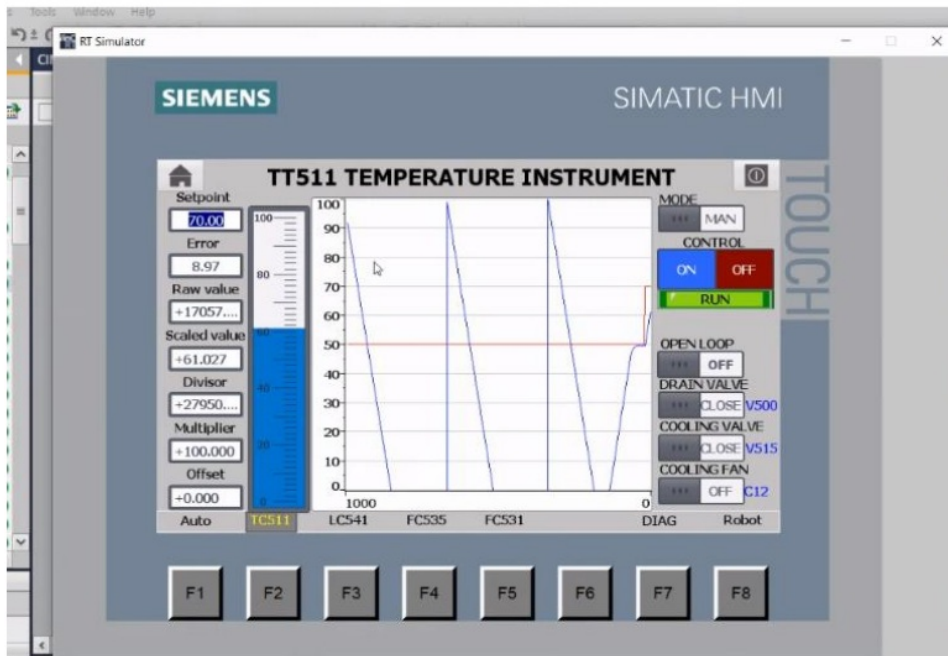


Figure 13: TT511 Temperature instrument

Figure 13 shows the HMI screen for temperature control. The left-hand side shows the values used in the calculation, including the multiplier, divider, offset, scaled value etc. This allows the engineer to change the values used to help calibrate the machine. The raw and scaled value can be monitored from the HMI without going into the programme or back to the main HMI. A visual graph is also displayed showing a live reading with the red line representing the set point which can be adjusted on the HMI, with a level indicator to show the rise in temperature.

On the engineer's screen, it has the capability of changing the operating mode from manual to automatic and the option to open or close the bypass valve, drain valve and operate other elements of the loop. This saves time by not having to keep going to the main HMI for every adjustment and reading.

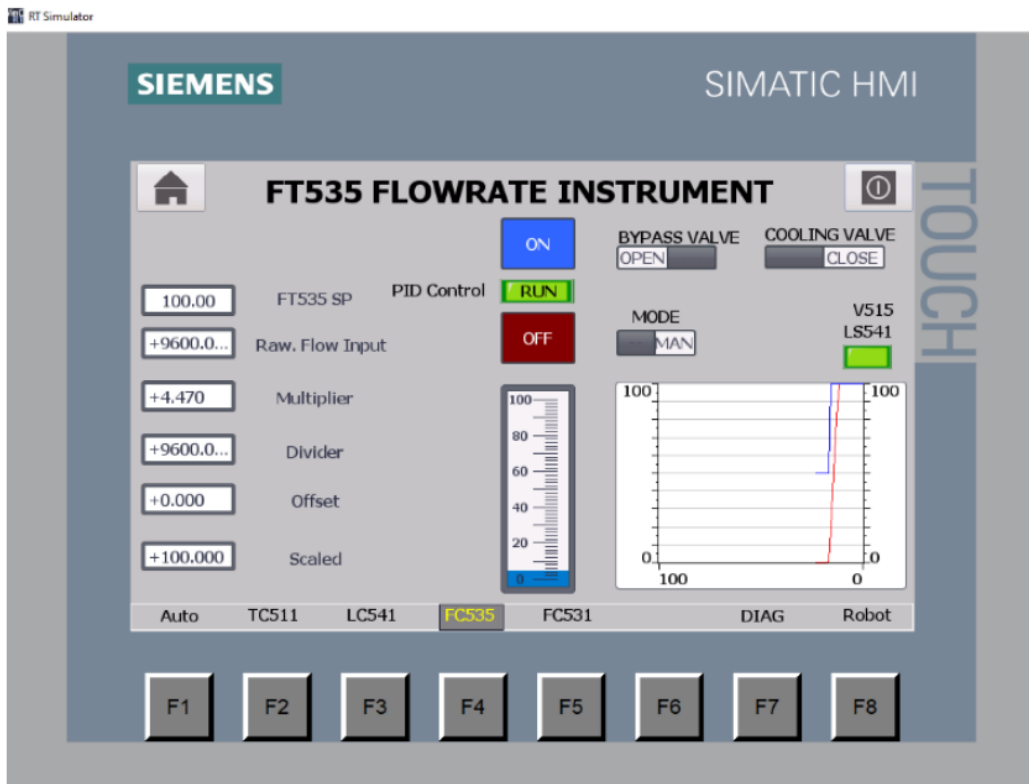


Figure 14: FT535 Flowrate instrument

Figure 14 shows the screen for the flow-rate instrument. The design is similar and user friendly to use. It has the same variables that can be adjusted by the engineer on the left-hand side, in addition to the scaled and raw values. Furthermore, it has the option to open/close the bypass valve and switch between manual and automatic mode. This screen also allows control of the cooling valve and allows the engineer to turn on/off the PID control. This is backed up by the graph and level for visual representation of the flow-rate.

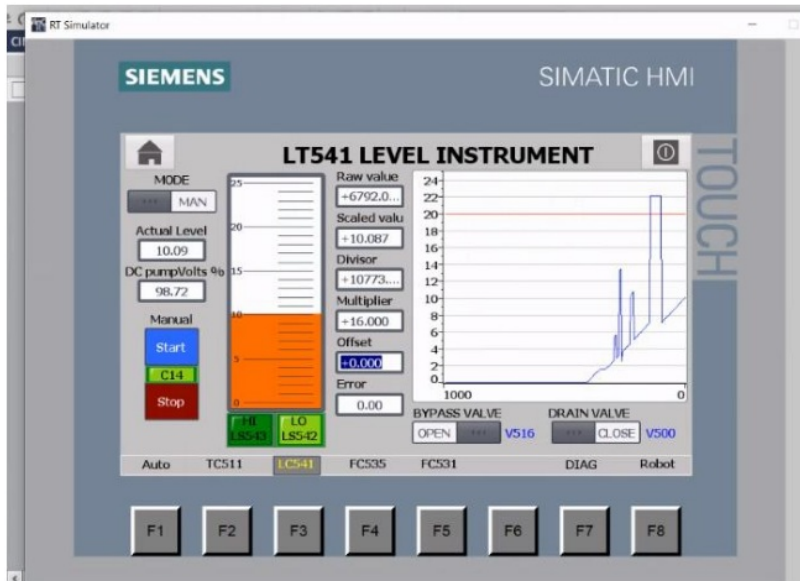


Figure 15: LT541 Level instrument

Figure 15 shows the HMI screen for the level instrument. The same options are displayed for continuity across screens. It allows the engineer to change variables for the PID loop and displays the raw and scaled values. This is a good visual indicator. It also has the same set of controls where the bypass valve can be operated in addition to the operating mode (manual or automatic) and the on/off control of the PID loop. The low-level sensor turns on at 10cm. Once reached, the heating element will be allowed due to the safety interlock in the code. The pump will stop when the high-level sensor is at 20cm.

The screens were tested in TIA portal simulation mode whilst viewing a shared screen on Google meet due to college closure under the COVID-19 restrictions.

9. Conclusions and Recommendations

The CIM system comprises loops TC541, TC511, TC535 and TC531. The sensors used in these two sub-systems can be upgraded with ones that are industry 4.0 compatible. Calibrating the different sensors gave a better understanding of the testing procedures and how to analyse the results to determine and improve their accuracy.

Maintenance of the system becomes easier with I/O link and upgraded sensors since the system can be monitored and adjustments made to the settings remotely. By using error detections of the IO-Link devices, it determines the cause of problems easily and quickly. Another opportunity to improve, is replacing both limit switches for an ultrasonic sensor for the level, so the one sensor can pick up both limits. On a new system, this could be more beneficial as it can save on inputs and cable runs.

Grocer's apostrophe

With added HMI's, the engineer can now make adjustments at the local HMI screens without going back to the master screen for every adjustment, saving time and money. Most companies are now progressing towards industry 4.0. It's therefore important to upgrade systems or at least have new machines or systems designed to 4.0 standard due to the many benefits it brings in data collection and transmission.

10. Team Working

Team working was vital throughout the tasks. During the testing and calibration of the sensors, a team of four was created, namely -the author of this report, Evan Thomas, Ethan Joel and Joshua Williams. During this stage, we all considered each other's safety and adhered to local COVID-19 regulations, including wearing face masks and washing/sanitising hands. During the test, the author of the report was responsible for input/operating the instruments, including operating the DC pump on the HMI for the level sensor, increasing the pressure for the pressure sensor etc. Ethan's role was to read the measuring devices (ammeter, voltmeter, stopwatch etc.) whilst Joshua recorded the results and distributed them amongst the team for independent analysis and investigation. Evan was in charge of software development.

As a group, regular discussions took place where ideas were shared and collaborated. Once ideas were discussed and a plan chosen, Evan was responsible for putting the ideas into the software and onto the HMI. Due to coronavirus restrictions, this was often done over google meet where his screen could be shared, so ideas could be continually inputted in addition to continuous feedback for development. Evidence of this can be seen in Appendix 1, Figure 16.

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12. Appendix 1

Pressure (Bar)	mV rising	mV falling	Linear	Non linear error rising	Non linear error falling	Hysteresis error (mV)
0	0	0	0	0	0	0
0.5	1.05	1.02	1.05	0	-0.03	0.03
1	2.07	2.03	2.1	-0.03	-0.07	0.04
1.5	3.06	2.97	3.15	-0.09	-0.18	0.09
2	4	4.02	4.2	-0.2	-0.18	-0.02
2.5	5.03	5.02	5.25	-0.22	-0.23	0.01
3	6.03	6.04	6.3	-0.27	-0.26	-0.01
3.5	7.02	7.04	7.35	-0.33	-0.31	-0.02
4	8.04	7.94	8.4	-0.36	-0.46	0.1
4.5	9	9.07	9.45	-0.45	-0.38	-0.07
5	10.5	10.5	10.5	0	0	0

Table 2: Pressure sensor results

Temperature	mA Rising	mA Falling	Linear	Non linear error rising	Non linear error falling	Hysteresis error (mV)
0	4	4	4	0	0	0
10	5.6	5.6	5.6	0	0	0
20	7.2	7.2	7.2	0	0	0
30	8.8	8.8	8.8	0	0	0
40	10.4	10.4	10.4	0	0	0
50	12	12	12	0	0	0
60	13.6	13.6	13.6	0	0	0
70	15.2	15.2	15.2	0	0	0
80	16.8	16.8	16.8	0	0	0
90	18.4	18.4	18.4	0	0	0
100	20	20	20	0	0	0

Table 3: Temperature sensor results

CM	mA Rising	mA falling	Linear Calculation	Linear	Non linear error rising	Non linear error falling	Hysteresis error (mA)
7	6.2	6.2	$=(6.5/16)*B2+3.357$	6.20	0.00	0.00	0.00
8	6.7	6.6	$=(6.5/16)*B3+3.357$	6.61	0.09	-0.01	0.10
9	7	7	$=(6.5/16)*B4+3.357$	7.01	-0.01	-0.01	0.00
10	7.5	7.4	$=(6.5/16)*B5+3.357$	7.42	0.08	-0.02	0.10
11	7.9	7.7	$=(6.5/16)*B6+3.357$	7.83	0.07	-0.13	0.20
12	8.3	8.2	$=(6.5/16)*B7+3.357$	8.23	0.07	-0.03	0.10
13	8.7	8.6	$=(6.5/16)*B8+3.357$	8.64	0.06	-0.04	0.10
14	9.1	8.8	$=(6.5/16)*B9+3.357$	9.04	0.06	-0.24	0.30
15	9.5	9.4	$=(6.5/16)*B10+3.357$	9.45	0.05	-0.05	0.10
16	9.9	9.7	$=(6.5/16)*B11+3.357$	9.86	0.04	-0.16	0.20
17	10.3	10.1	$=(6.5/16)*B12+3.357$	10.26	0.04	-0.16	0.20
18	10.7	10.6	$=(6.5/16)*B13+3.357$	10.67	0.03	-0.07	0.10
19	11.1	10.9	$=(6.5/16)*B14+3.357$	11.08	0.02	-0.18	0.20
20	11.5	11.3	$=(6.5/16)*B15+3.357$	11.48	0.02	-0.18	0.20
21	11.9	11.7	$=(6.5/16)*B16+3.357$	11.89	0.01	-0.19	0.20
22	12.3	12.1	$=(6.5/16)*B17+3.357$	12.29	0.01	-0.19	0.20
23	12.7	12.7	$=(6.5/16)*B18+3.357$	12.70	0.00	0.00	0.00

Table 4: Level sensor results

	A	B	C	D	E	F
1	LPM	Time (s)	Time (Minutes)	Calculated LPM	Calculated LPM	Error
2	0.4	222	3.70	$=1.89/C2$	0.51	-0.11
3	0.7	154	2.57	$=1.89/C3$	0.736	-0.04
4	1	112	1.87	$=1.89/C4$	1.01	-0.01
5	1.2	98	1.63	$=1.89/C5$	1.16	0.04
6	1.5	83	1.38	$=1.89/C6$	1.37	0.13

Table 5: Flow sensor results

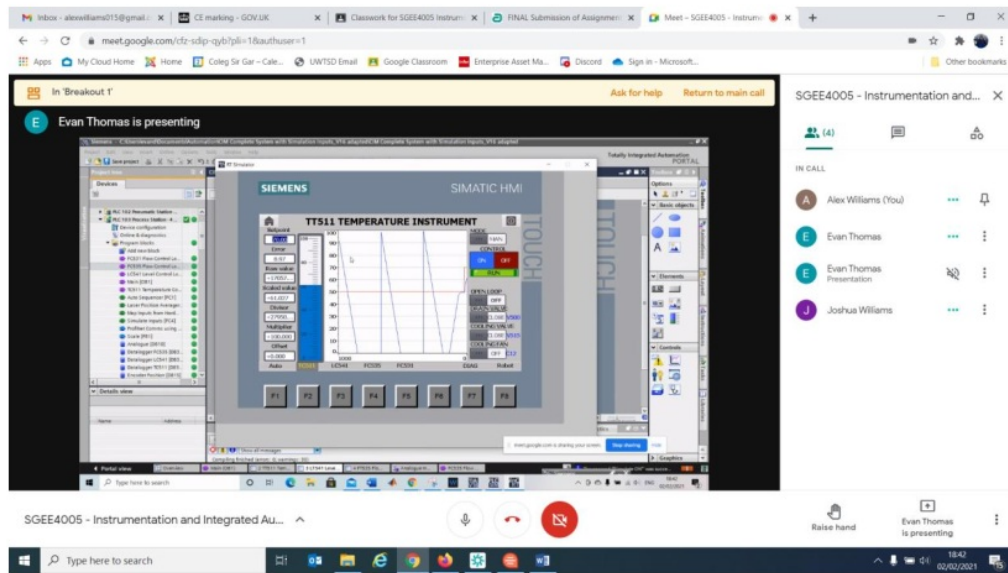


Figure 16: Team working on Google Meet

1909751

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

82/100

PAGE 1

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

QM

Citation Needed

Cite Source:

Please use the link below to find links to information regarding specific citation styles:

http://www.plagiarism.org/plag_article_citation_styles.html

PAGE 6

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Good formatting of paragraph through full justification and 1.5 line

spacing

PAGE 7

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

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Correctly cited

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PAGE 8

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Citation method conforms to Harvard standard, well done.

PAGE 9

PAGE 10

QM

Datasheet - DO NOT include these, read, digest, quote and cite them as a source

PAGE 11

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Correctly cited

Citation method conforms to Harvard standard, well done.

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Correctly cited

Citation method conforms to Harvard standard, well done.

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QM

Grocer's apostrophe

If you meant this as a plural word, don't use an apostrophe. This also applies to acronyms and initialisms such as PLCs

PAGE 23

PAGE 24

QM

Good range of sources

You have demonstrated reading from a good range of sources shown by your list below

QM

Correct method of listing.

You have listed your sources correctly according to the Harvard method.

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GRADING FORM: NEW CSG-RUBRIC

1. ENGAGEMENT WITH LITERATURE

-  Exceptional engagement with an extensive range of relevant and credible literature. High-level referencing skills consistently applied. Avoid including datasheets in the main report. (17/20)

17

2. KNOWLEDGE AND UNDERSTANDING

-  Excellent knowledge and understanding of the basic underlying concepts and principles of the subject (16/20)

16

3. COGNITIVE AND INTELLECTUAL

-  Excellent evaluation of the underlying concepts and principles. Can interpret qualitative and quantitative data accurately and with some insight. Excellent ability to devise arguments using evidence and make appropriate and valid judgements. (16/20)

16

4. PRACTICAL APPLICATION

An advanced application of a range of taught, basic



methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Excellent evidence of different approaches to problem-solving in particular contexts and proposes appropriate solutions (16/20)

16

5. TRANSFERABLE SKILLS



Work is accurate, exceptionally coherent, very fluent and presented well. Can work effectively independently and/or as part of a team, with an exceptional contribution to group activities. Demonstrates exceptional skills for employment requiring the exercise of some personal responsibility with an appetite for further development (17/20)
Word count appears to have been exceeded since there are not that many words in the appendix and Turnit-in shows 4132 Penalty will applied next time.

17