Reconditioning of the SL-BOCLE and BOCLE Instruments

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Abstract

In the year 2012 the tribology group of the University of Pretoria received lubricity testing instruments from Sasol as donations. They were:

- Scuffing-Load-Ball-On-Cylinder-Lubricity-Evaluator (SL-BOCLE)
- Ball-On-Cylinder-Lubricity-Evaluator (BOCLE)

The instruments were first commissioned upon arrival in the Tribology laboratory in 2012 because they were not in good working conditions. However, after a series of renovations in the Tribology laboratory over a space of 5 years, the instruments have fallen out of use. They have become redundant and several parts and wiring are lost or no longer functional.

In 2017's CML 732 project much work was done to reinstate both machines into good working conditions. Several repair works have been done on both machines. And communication to the Opto 22 network has been established. Data logging and control was successfully done using Simulink and a good knowledge of the operating mechanism of these machines was obtained.

What remains is the acquisition of a ring mandrel assembly for the SL-BOCLE.

Keywords: BOCLE, scuffing, friction, wear, Opto 22

Contents

1. Introduction

The Ball-On-Cylinder Lubricity Evaluator (BOCLE) is modelled after the Furey tester which was developed to study metallic contact and friction between sliding lubricated surfaces (Evans, 1988: 5). InterAv Incorporation first designed and produced a commercial unit of the BOCLE to test for wear and the SL-BOCLE (developed slightly later) to test for the load carrying capacity of aviation fuels. They were particularly designed for the US Air Force.

Sasol has owned a copy of these instruments for several years and upon acquisition of a newer model, the old models were donated to the University of Pretoria. Upon arrival, these instruments were commissioned in the Tribology laboratory, as they were not in proper working conditions. The lab used them secondly to the SRV machine and the HFRR to perform lubricity tests on samples. However, the Tribology lab has undergone several renovations over the past five (5) years and several wiring systems and connections to the BOCLES's have been taken down, damaged and even some machine parts lost.

In 2017's CML 732 project, the objective is to

1. Recondition the machines
2. Establish communication with the Opto 22 network
3. Establish data logging and control using Simulink/LabVIEW
4. Obtain a good knowledge on the operating mechanism of the machines
5. Recollect and gather all the important literature about the instruments

Several software packages and hardware were used to achieve the set objectives.

2. Theory

2.1. Fundamental operating principles of the BOCLEs

Lubricity is one of the few fuel properties that may be degraded by certain refining processes. A great amount of effort has been expended in research and development of low-lubricity fuels and test method development since the early 1960’s. The Ball-On-Cylinder Lubricity Evaluator has emerged as a test tool to provide a quantitative value to fuel lubricity (Evans, 1988: 3).

The BOCLE schematic presented in Figure 1a comprises of a non-rotating 12.7mm diameter test ball (A) which is held in a vertically mounted holder (B) and forced against the highest point on the outer surface of a 44.5mm test cylinder/ring (C). The test ball and cylinder are placed inside a rectangular basin/reservoir (D) which contains 45-50mL of lubricant sample. The cylinder is mounted axially to a horizontal shaft (E) which goes through the sides of the basin’s upper detachable housing and is connected to a variable speed motor. The entire setup rests on a metallic base (F).

Figure 1 and 2 shows a schematic diagram of the Ball-On-Cylinder configuration.

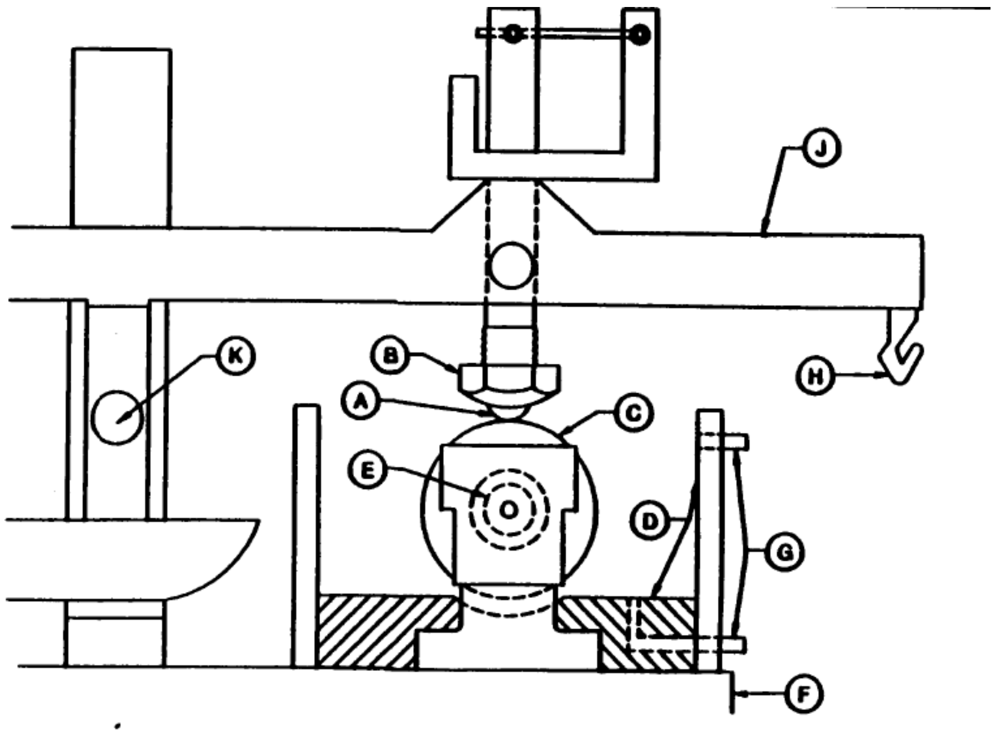


Figure 1: Ball-On-Cylinder configuration (adapted from CRC (1988))

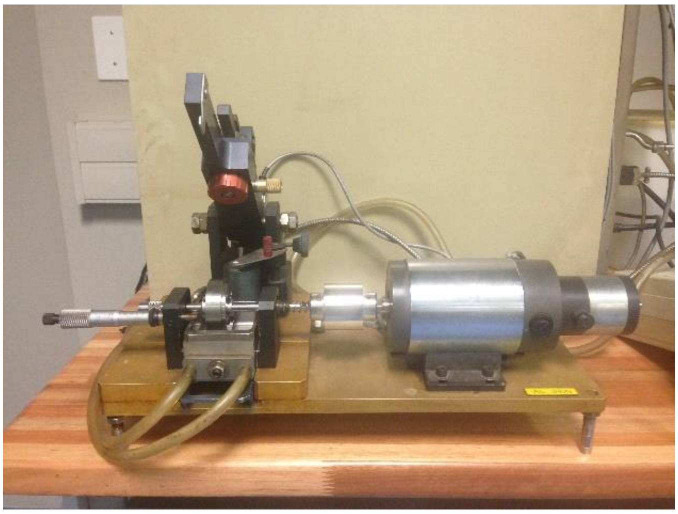


Figure 2: Ball-On-Cylinder configuration (Actual photograph taken at the Tribology lab)

2.2. Instruments test methods

The SL-BOCLE and BOCLE both work on the principle of a stationary ball pressed against a rotating ring. The rotating ring is positioned in the basin which is filled with the lubricant/fuel whose lubricity is investigated. The test cylinder is rotated at a fixed speed and receives a momentary exposure to the test fluid upon each revolution.

The coefficient of friction between the ball and cylinder is determined by Equation 1

$$\mu = \frac{F}{N} \tag{1}$$

where F represents the frictional force needed to overcome friction and, N is the load. The subsequent sections elaborates the testing method of each instrument.

2.2.1. BOCLE

The BOCLE is specifically a wear test instrument. The wear scar generated on the test ball after a test is used as a measure of the fluid's lubricating properties. A theoretical equation (Equation 2) developed by the Coordination Research Council (CRC) in Atlanta-Georgia is sometimes used to validate the wear scar diameter (d_S) on the ball after the test is performed. This is because of the sensitive nature of the BOCLEs tests to contamination.

The relationship between the major and minor diameters (d_{mjr} and d_{mnr}) are used as the criterion for reviewing the test result. Results from the BOCLEs tests falling outside the envelope of values calculated from Equation 2 may be considered suspect to contamination, and the wear scar remeasured or test repeated (InterAV, 1988: 15).

$$d_{ws} = \frac{d_{mjr} + d_{mnr}}{2} \qquad\qquad d_{mjr} = 1.133(d_{mnr}) \qquad (2)$$

where d_{ws} is the wear scar diameter on the ball and d_{mjr}, d_{mnr} are the major and minor diameters obtained from the test.

2.2.2. SL-BOCLE

The SL-BOCLE is a scuffing load or a load carrying capacity test instrument. The test performed examines the specific load at which the friction coefficient (μ) in the fuel exceeds 0.175. That specific load is termed as the failure load and is used to measure the lubricity behaviour of the fuel.

Figure 3 shows how scuffing occurs. The scuffing wear graph in Figure 3 exceeds 0.175 after roughly 8 seconds whiles the mild wear is generally below 0.1.

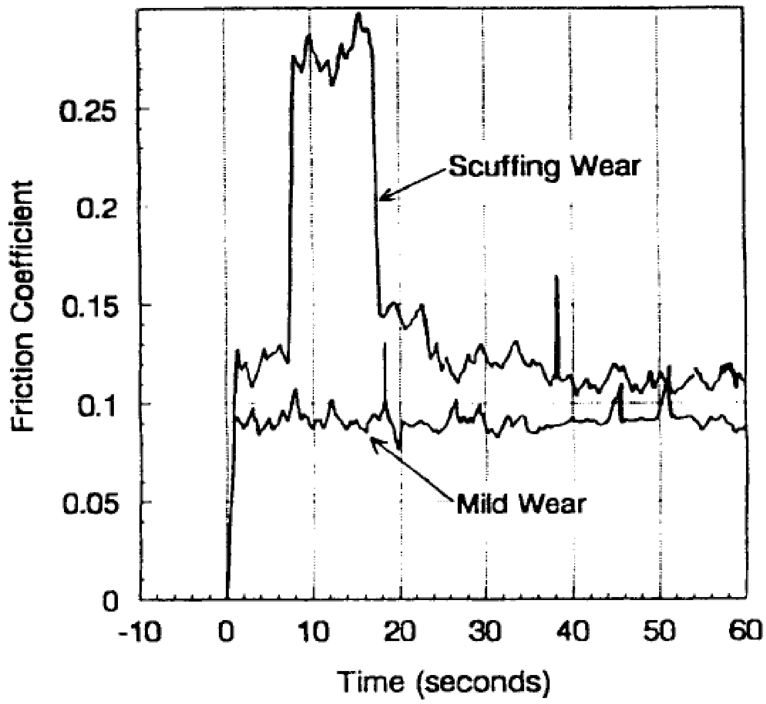


Figure 2: Scuffing load test (ASTM, 1999: 6)

In performing a scuffing load test, a test load sequence suggested by the U.S Army is deemed creditable for quickly identifying the failure load for a given fuel sample. The schematic is presented in Figure 4. The procedure follows that one moves from the left to right when selecting load. 2800g is the starting load (furthest left), if scuffing is observed at that load then one must select the next lower load to the right (follow the upward arrow).

If no scuffing is observed however, select the next higher load to the right (follow the downward arrow). This technique is continued till a value to the nearest 100g is known. However, if a higher level of accuracy is desired smaller test load can be used as well.

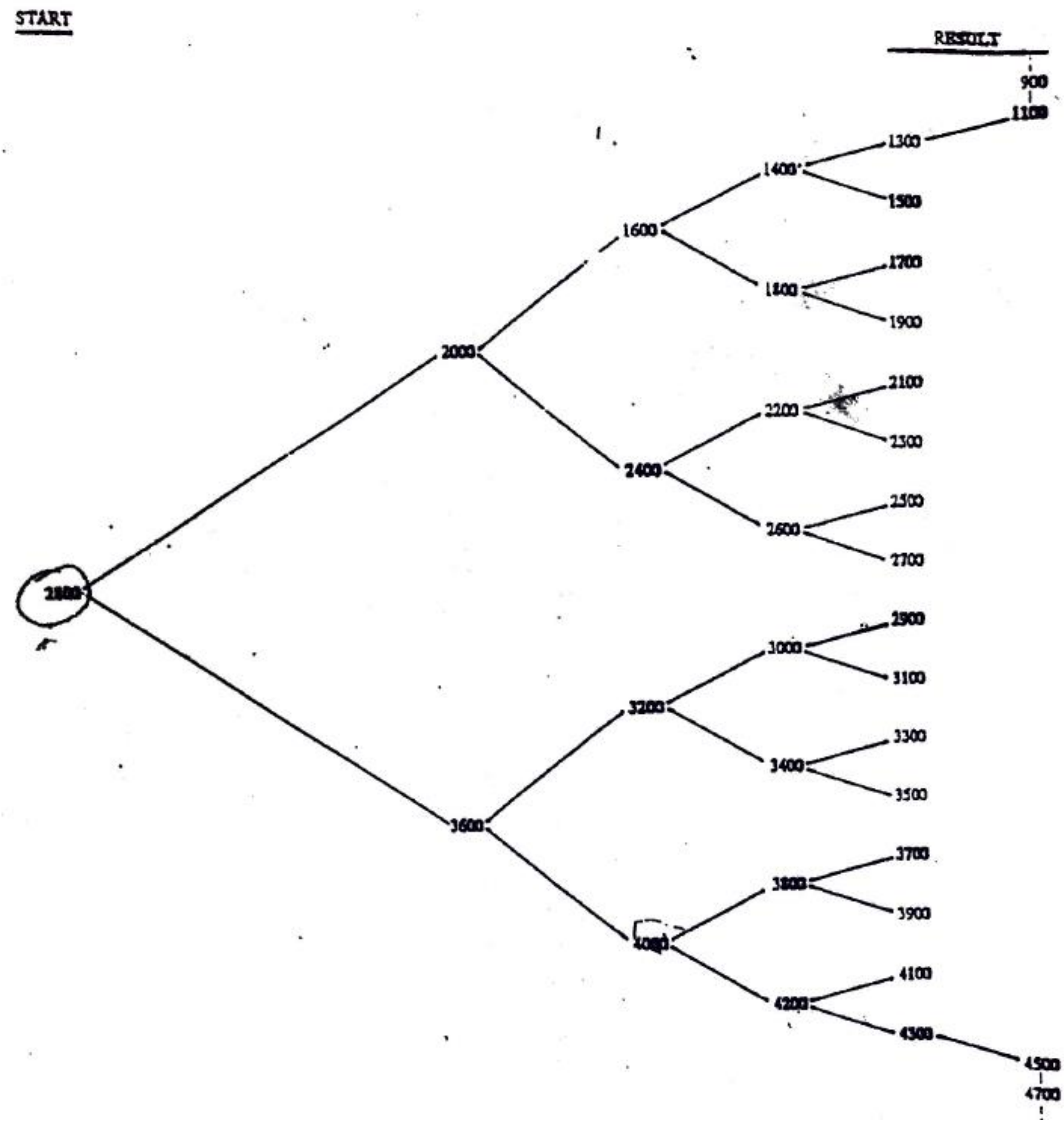


Figure 3: Recommended load sequence (in grams) for the SL-BOCLE (U.S. Army, 1994: 11)

2.2.3. Specifications for test methods on the BOCLE and SL-BOCLE

The operating conditions and specifications for the apparatus used in performing tests on the BOCLE and SL-BOCLE are detailed in Table 1.

Table 1: Specification for test methods (U.S. Army, 1994: 3)

Parameter	SL-BOCLE (ASTM D6078, 1998: 1-9)	BOCLE (ASTM D5001-90a, 1995: 1-6)
Type of fuel evaluated	Diesel	Aviation
Test ring	SAE 8720 steel Rockwell C HRC 58 - 62 Surface roughness 0.04 - 0.15	SAE 8720 steel Rockwell C HRC 58 - 62 Surface finish 0.56 - 0.71
Test ball	AISI No. E-52100 Diameter 12.7 mm HRC 64 - 66 5 - 10 EP finish	AISI No. E-52100 Diameter 12.7 mm HRC 64 - 66 5 - 10 EP finish

Aeration pre-treatment of fuel (at Humidity and Temperature specified)	0.5 L/min through fuel 3.3 L/min over fuel 15 min	0.5 L/min through fuel 3.3 L/min over fuel 15 min
Fuel volume (mL)	50 ± 1	50 ± 1
Humidity (%)	50 ± 1	10 ±0.2
Temperature (°C)	25 ± 1	25 ± 1
Aeration (mL/min)	3.8	3.8
Applied load (g)	500 (break in) 500 to 5000 (incremental)	1000 (500 weight)
Rotation speed (rpm)	525 ± 1	240 ± 1
Duration	30 s (break in) 60 s (test)	30 ± 0.1 min
Lubricity evaluated by	Load carrying ability. Smallest load for $\mu >= 0.175$	Average wear scar size Wear scar shape and appearance

Several changes to the instrument and repair works had to be done on both BOCLEs to recondition them. Hardware and software modifications were needed to bring both instruments up to standard. The subsequent section elaborates several changes that were made.

3. Work done on hardware

3.1. SL-BOCLE and BOCLE

At the start of the project I accessed the working conditions of both instruments and noticed that the friction measurement line had been severed in both BOCLEs. The cable that links the friction display unit to the circuit needed to be rewired to enable friction measurement and this was done.

Another important thing was because the instrument stood idle and unused for several years many parts have fallen apart or experienced rust. Example, the arm lift actuator knob on the BOCLE was broken, and upon inspection it was detected that the nut was damaged (rusted) and needed replacement. A new nut was installed to make the knob functional again. The line used to control the motor speed on the BOCLE had also been removed, the BOCLE wiring diagram was used as a guide for correcting this problem.

On the SL-BOCLE, the wires measuring the motor speed (line 556) and that used to control the speed (line 557) was out of place. They were rewired back to the motor speed display and motor DC supply respectively.

Another crucial problem was; tremendous difficulty was observed when identifying signals inside the machines because the wires were lumped together using cable ties. All the wires in both machines were appropriately labelled and this made working on the instruments less strenuous.

One more factor was the instruments had accumulated dust over the years and required intense cleaning. Additionally, the water in the bubble assembly of the humidifier was murky/dirty and had to be changed. Various cleaning detergents were used on both instruments to restore them back to a neat condition.

3.2. Opto 22 and Junction box

The wiring diagram for the wiring inside the junction box for both BOCLEs was found in the BOCLEs red file in the library section of the Tribology lab. It had already been drawn by Mr. Jacques Langenhoven who worked on the instruments in 2012 when they first arrived.

The same wiring diagram was used to lay the wiring again for both instruments in a new/unused junction box. But additional 12AWG and 10AWG DIN rail terminals (2.5mm^2) and fuses were added to the junction box as the terminals in the box were not enough. I found the wires and the trunking he used in one of the boxes in the lab. And those were reused for the project so there was no need to purchase wires for this section.

In the Opto box setup there were two wiring ports already created on the box and the BOCLEs were connected through those ports. The wires in the trunking from the BOCLEs junction box were connected to fourteen (14) 12AWG DIN rail terminals inside the Opto box. This was again connected to another fourteen (14) DIN rail terminals before final connection to the SNAP modules were done.

3.3. SNAP Modules and Ethernet

The SNAP modules used in this project were mostly recovered from the ones used back in 2012. But it was observed that one of the SNAP AITM (±150mV) modules was no longer working and needed to be replaced. A SNAP AITM (±150mV) module was borrowed from the Process Control Laboratory to this effect.

Again the SNAP AOV (0 - 10V) module that was used back in 2012 was now been used to connect the humidifier instrument in the lab and was no longer available. I contacted Mr. Mike Harrison from OPTO 22 to send me a quote for this module. The Quote is available in the Appendix C.

The connection to the Ethernet was done via Opto 4. The IP address is 137.215.117.266.

4. Work done on software

4.1. Simulink

The Simulink model was originally developed in 2012. And since much of the program worked accurately, very little changes were made. I changed the sampling time from -1 (inherited) to one minute. This prevents excessive data points from being generated during a run.

The interface (program) however for the SL-BOCLE and the BOCLE are quite similar. In both cases the output/measured values are on the right whereas the inputs are on the left. The following are inputs that are required from the user:

- Temperature setpoint
- Motor speed setpoint
- Motor on/off

- Heating/Cooling

The Heating/Cooling function on the program is used to control temperature. The allowable difference between the setpoint and measurement is adjusted by a switch which uses a “bigger than” criteria. The Simulink model for the machines is presented in Figure 5.

The “Signal conditioning” subnet mask is presented in Figure 6 for the SL-BOCLE and Figure 7 for the BOCLE. What it contains are the calibration constants, noise filters and the signal transformations.

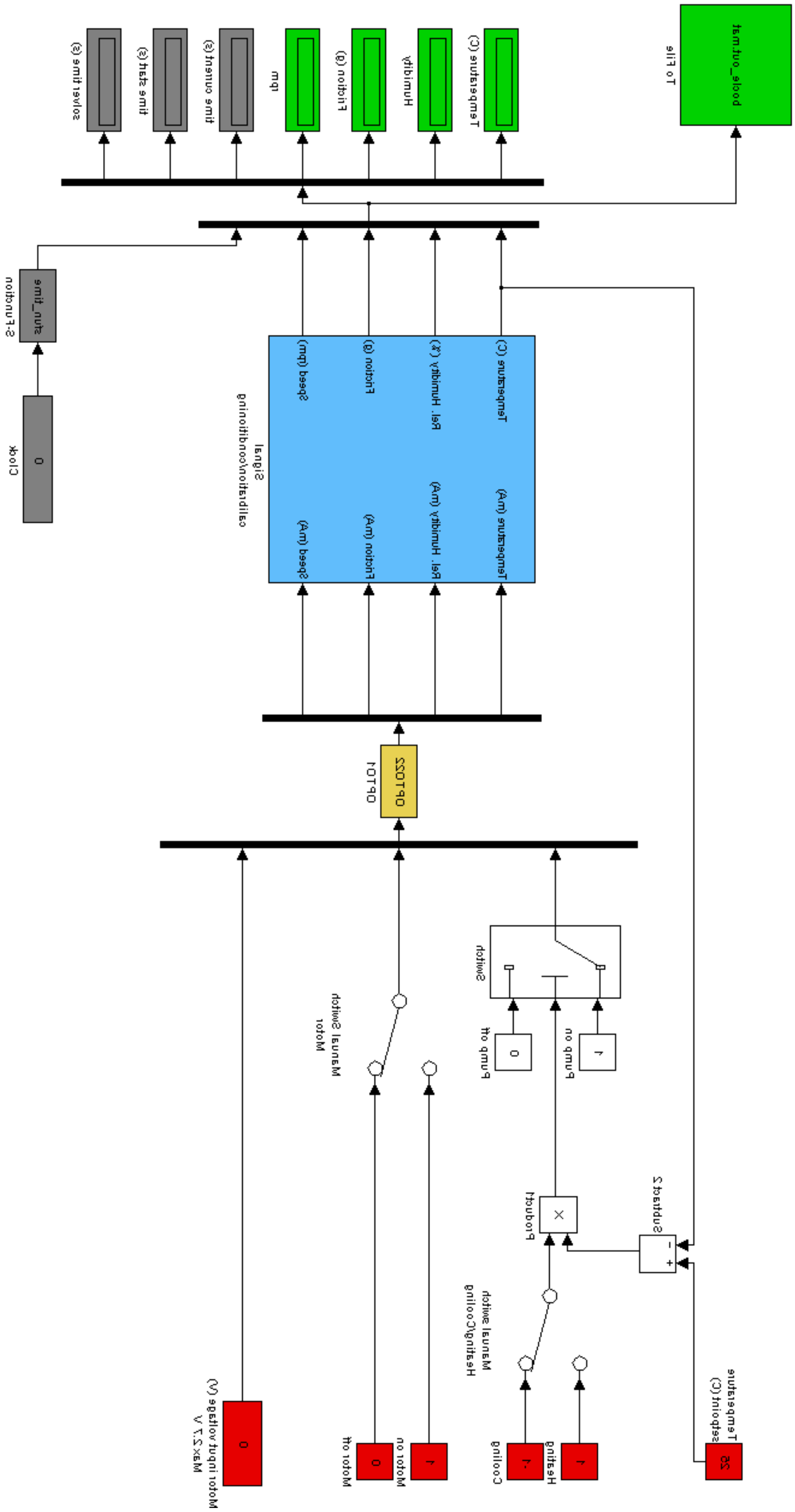


Figure 4: Simulink program

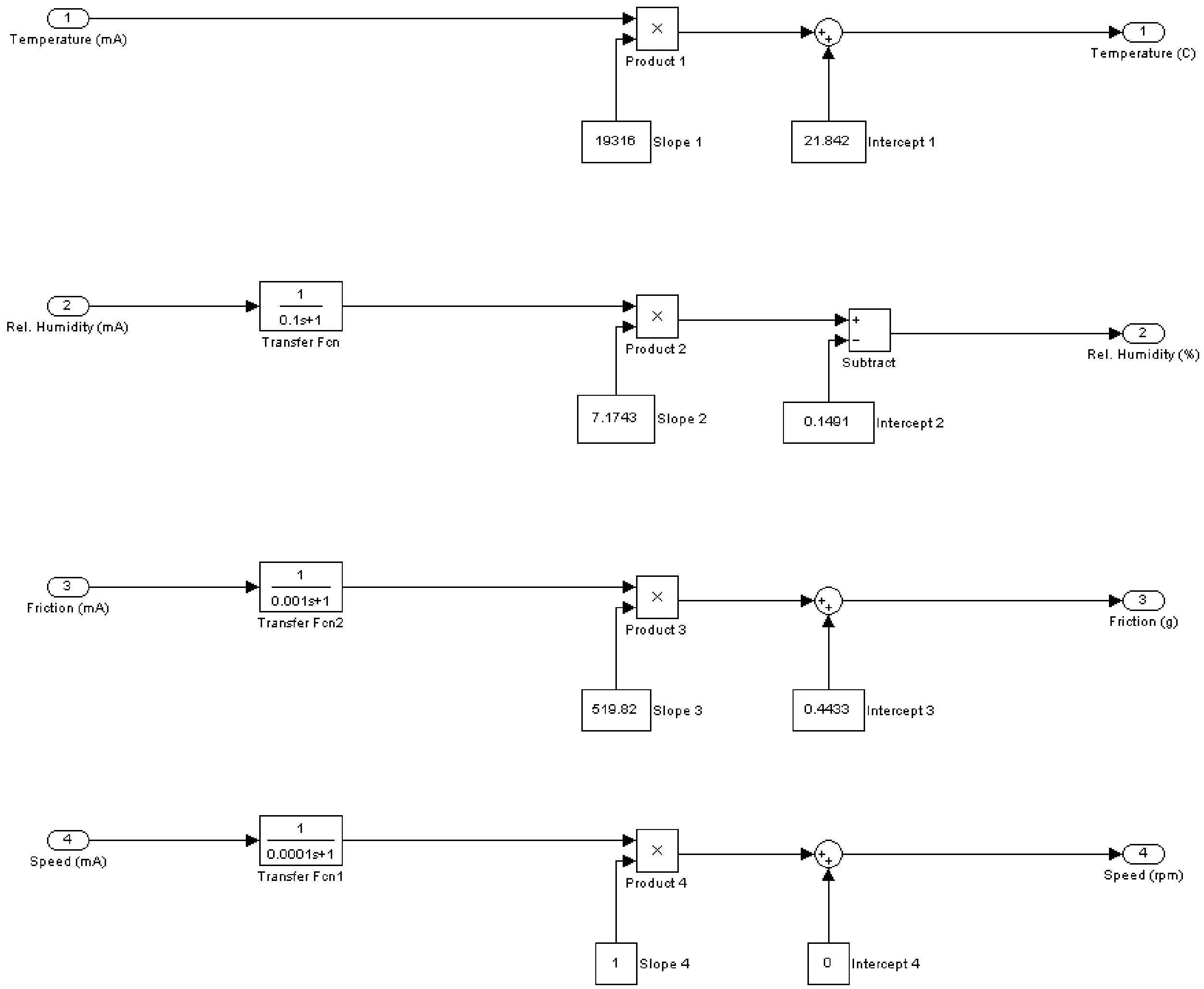


Figure 5: Signal conditioning subnet mask for the SL-BOCLE instrument

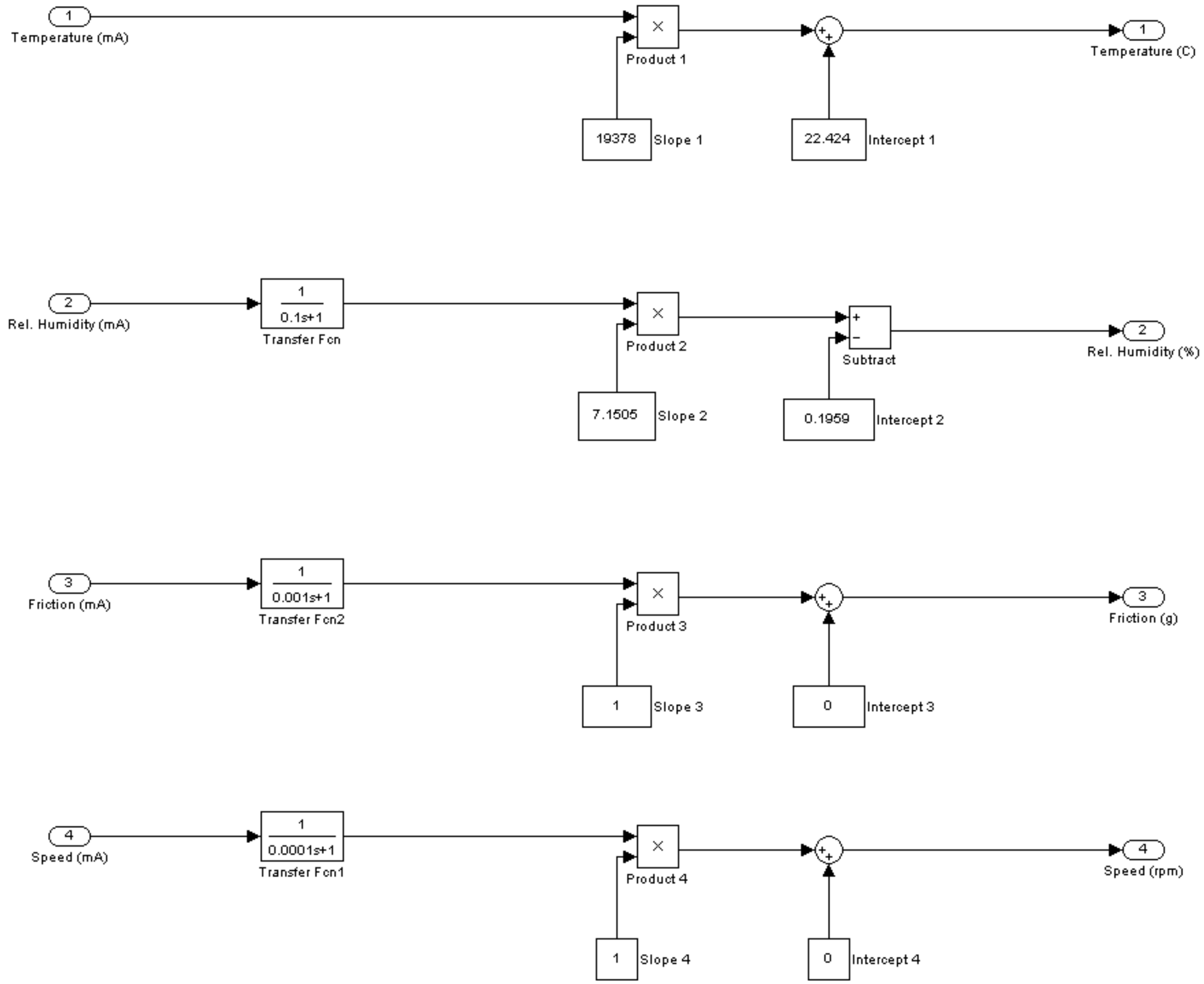


Figure 6: Signal conditioning subnet mask for the BOCLE instrument

5. Control and logging of data

The logging of data using Simulink is achieved by SNAP modules which are connected to the rack with a ''brain'' unit which transfers information to the network using TCP/IP. The wiring and connection details of the SNAP modules to the OPTO system is presented in Table 2.

Table 2: Wiring and SNAP modules connection details to Opto system

Wiring no.	Signal Information	SNAP Module	Opto point no. (rack)
BOCLE			
331 / 441	Friction measurement	AIMA (± 20 mA)	32
332 / 442	Humidity measurement	AIMA (± 20 mA)	33
333 / 443	Temperature measurement	AITM (± 150 mV)	25
334 / 444	Temperature control	ODC5-I Digital output	28
335 / 445	Motor on/off	ODC5-I Digital output	29
336 / 446	Motor speed measurement	AIMA (± 20 mA)	36
337 / 447	Motor speed control	AOV (0-10V)	21
SL-BOCLE			
551 / 661	Friction measurement	AIMA (± 20 mA)	0
552 / 662	Humidity measurement	AIMA (± 20 mA)	1
553 / 663	Temperature measurement	AITM (± 150 mV)	24
554 / 664	Temperature control	ODC5-I Digital output	17
555 / 665	Motor on/off	ODC5-I Digital output	16
556 / 666	Motor speed measurement	AIMA (± 20 mA)	10
557 / 667	Motor speed control	AOV (0-10V)	20

5.1. Humidity measurement

The signal transformation for humidity measurement is detailed in Table 3. A graphical display of humidity measurement on Simulink is shown in Figure 8 and 9.

Table 3: Signal transformation for humidity measurement

Instrument	Wiring line	Output Voltage	Resistance (Min)	Input to Opto module
SL-BOCLE	552/662	0-10	500	0-20mA
BOCLE	332/442	0-10	500	0-20mA

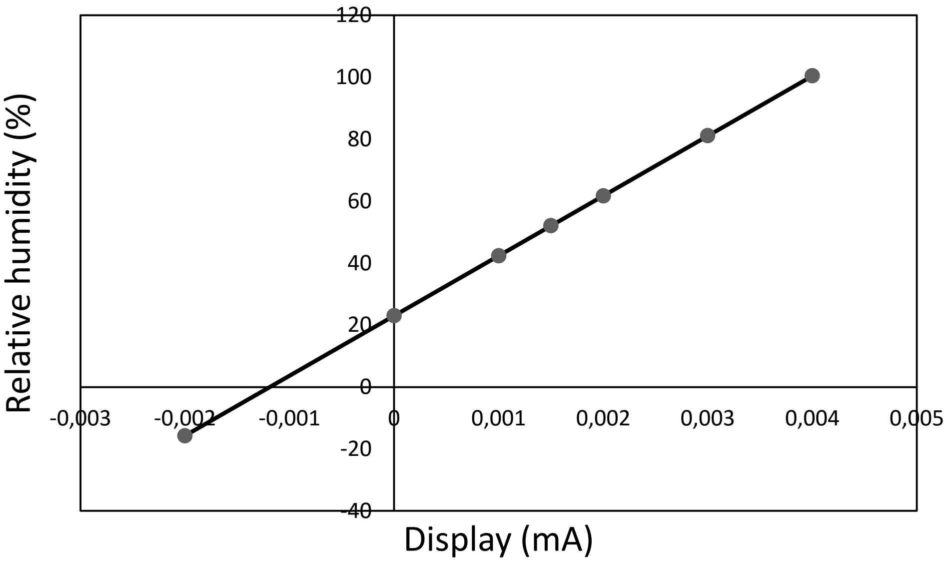


Figure 7: Simulink signal calibration for humidity on BOCLE

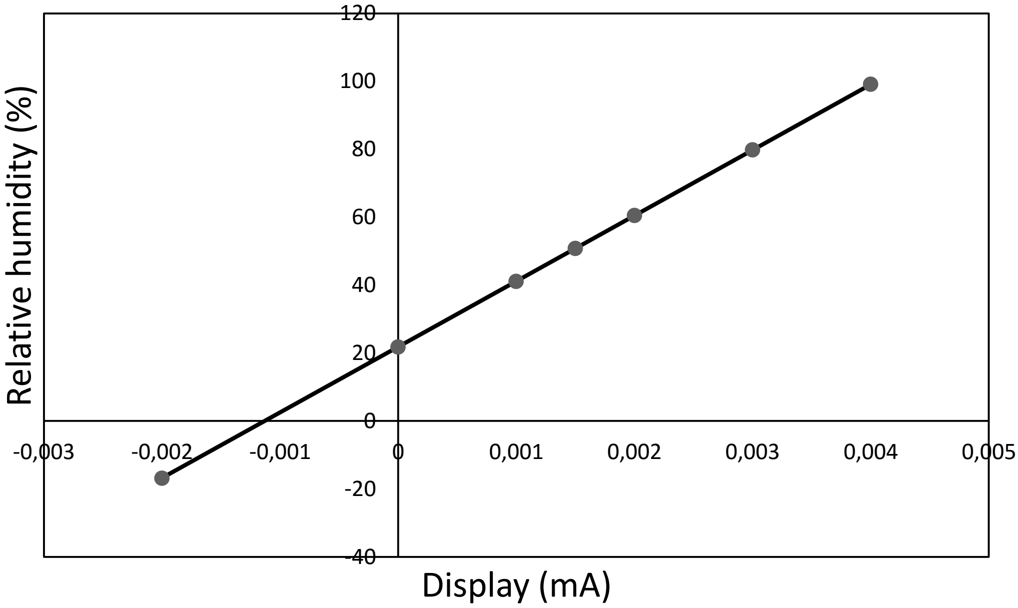


Figure 8: Simulink signal calibration for humidity on SL-BOCLE

5.2. Frictional force measurement

Frictional force measurement and signal transformation details is presented in Table 4. Calibration of friction measurement for the BOCLE is presented in Figure 10. However, friction measurement for the SL-BOCLE is not shown as the ring and mandrel assembly was not found. That part of the instrument is missing/lost.

Instrument	Wiring line	Output Voltage	Resistance (Min)	Input to Opto module
SL-BOCLE	551/661	0-4	±200	0-20mA
BOCLE	331/441	0-1	±50	0-20mA

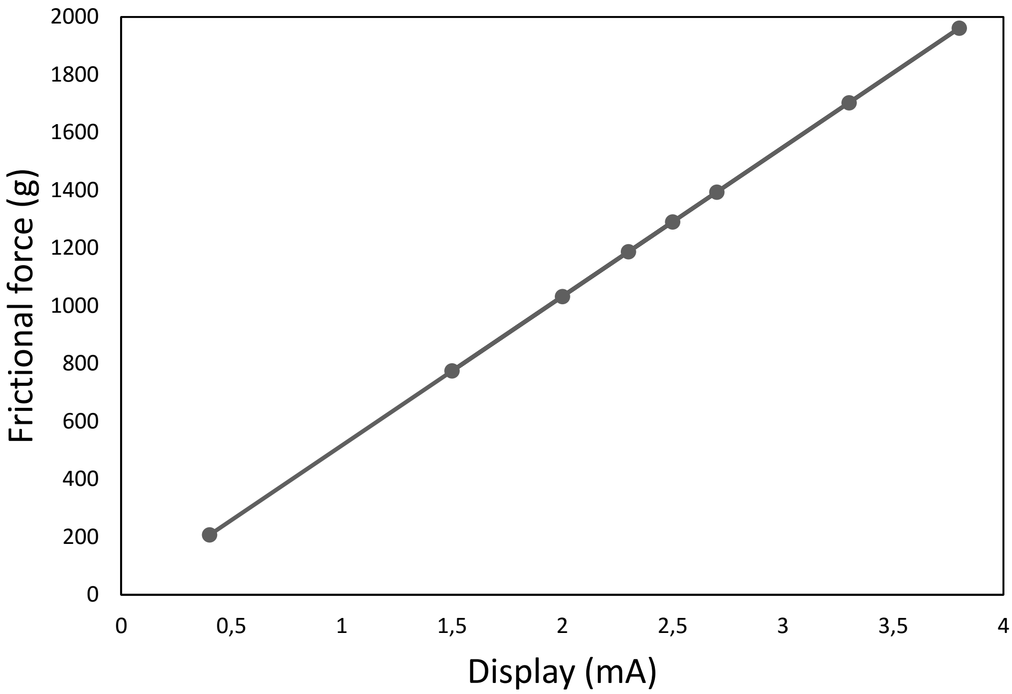


Figure 9: Frictional force signal calibration

6. Wiring network

The wiring network designed in 2012 was reverse engineered to connect both instruments to the junction box and Opto box. The changes made to the original diagram from Sasol was also maintained in 2017's version.

The original author being Jacques Langenhoven redesigned the internal wiring diagram of the instruments (available in the Appendix B) and the wiring diagram which is presented in Figure 11 and 12.

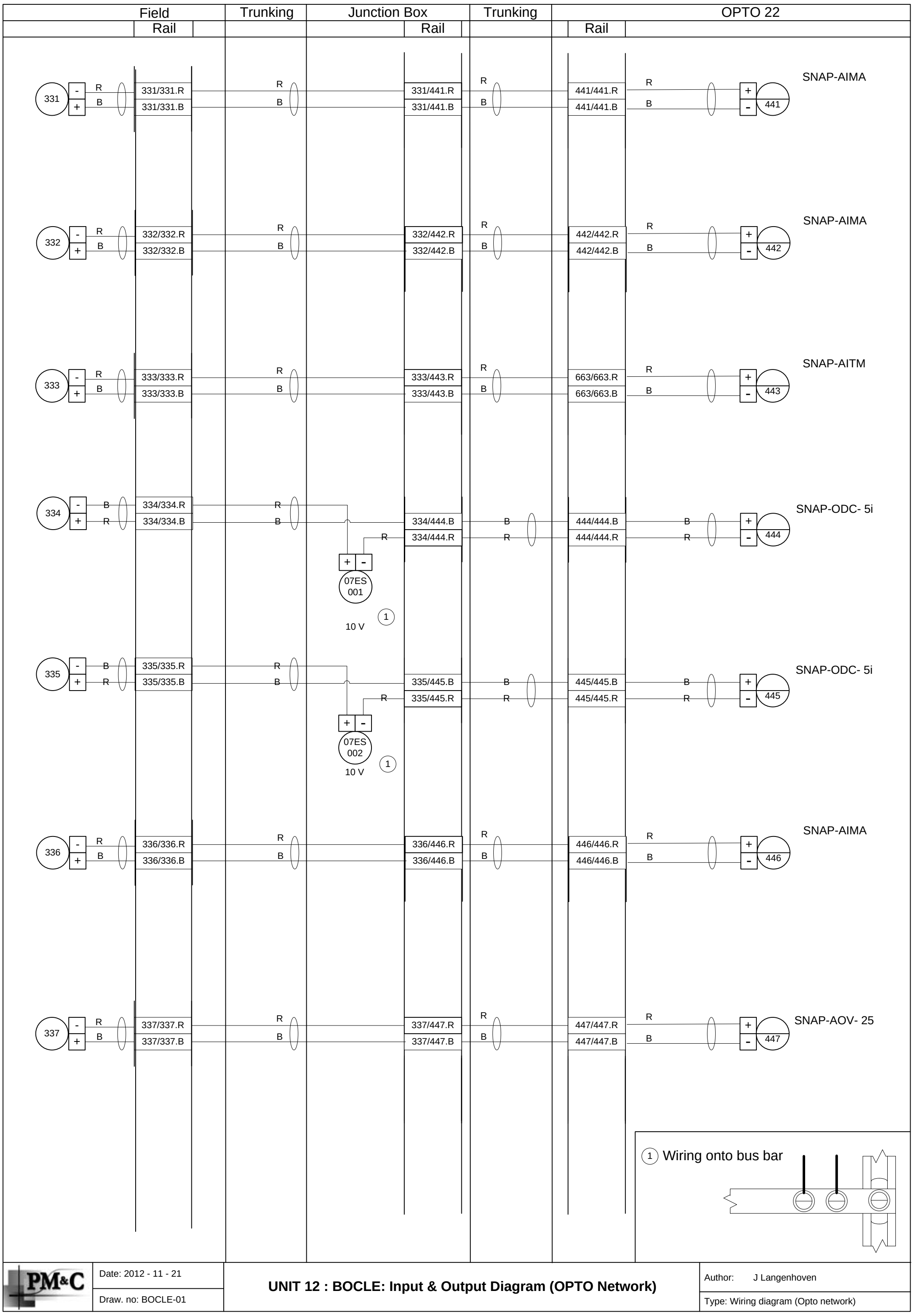


Figure 10: BOCLE Opto wiring diagram

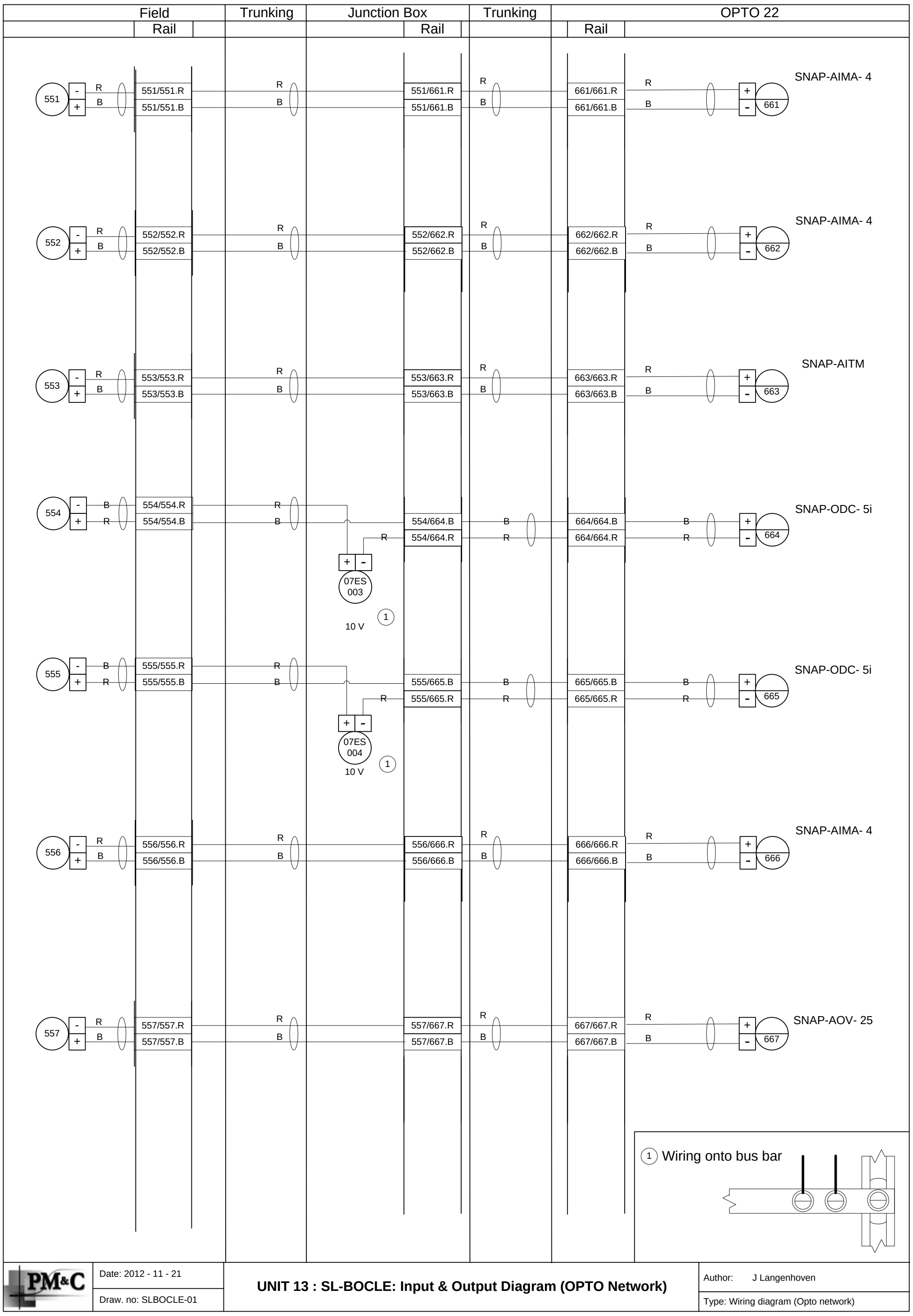


Figure 11: SL-BOCLE wiring diagram

Conclusions and Recommendations

In general, a level of success was attained for both instruments, but more on the BOCLE than the SL-BOCLE. Data logging was successful in both instruments using Simulink. However the SL-BOCLE needs a ring mandrel and a new dryer assembly. Both machines require new pumps as temperature control was difficult.

It is recommended that routine maintenance and calibration should be exercised.

References

American Society for Testing and Materials (ASTM) (1999) " Standard test method for evaluating lubricity of diesel fuels by the Scuffing Load Ball-On-Cylinder Lubricity Evaluator", USA.

Evans, B (1988) “Aviation Fuel Lubricity Evaluation” CRC Aviation Group report to the Defence Document Center, Alexandria, Virginia

InterAV (*sa* a) "Friction force measurement capability for BOCLE machine", San Antonio, Texas, USA.

Tribology laboratory (2012) “T12 & T13 BOCLE, SL-BOCLE” University of Pretoria, Hatfield, South Africa

U.S. Army (1994) “The U.S. army scuffing load wear test”, San Antonio, Texas

Appendix A

Start up and shut down guidelines

Pre-tasks:

- Adjust the unit legs till the motor drive unit, fuel bath and friction unit are all levelled.
- Perform the cleaning process as outlined in the ASTM standards.
- Lay the cleaned specimens and equipment in the desiccator.
- Ensure the load arm is level.

Pre-checks:

- Ensure that the water tubes are dry and the fuel bath contains no liquid
- Verify that all tube connections are correctly connected and properly sealed:
  - Connections between the BOCLE/SL-BOCLE and air delivery line.
  - Connection between the BOCLE/SL-BOCLE and the drive/fuel bath/friction unit.
- Quickly ensure that the motor drive unit, pump, and thermocouple are plugged in on the left hand side of the machine.
- Check that the humidifier in the BOCLE/SL-BOCLE is in good working condition. That is, the water column still has clean water and the drying agent is still orange in colour.
- The water level in the circulation tank must be sufficiently above the submersible water pump.

Start up:

- Switch on/plug in the power to the OPTO brain if it is not on yet.
- Switch on/plug in the junction box power supply if not yet on.
- Switch on the BOCLE/SL-BOCLE unit using the physical switch on the left hand corner (red light on).
- Switch the arm lift actuator to the up position using the physical switch on the unit.
- Switch on the external friction force indicator.
- Make sure a copy of the previous experimental run is saved. You do NOT want to overwrite someone else’s work.

- Open the simulink model. Ensure all inputs are correct for the ASTM standards.
- Check the lab temperature with any thermometer and determine if heating or cooling will be required. Switch this in the simulink model.
- Ensure the motor drive is OFF.
- Connect the bath to the water tubes.
- Place the thermocouple in the orifice on the left hand side of the fuel bath.
- Start the simulation.
- Check that all output readings are realistic.
- The red hood should not be placed over the bath at this time.
- Open the air inlet valve if not open to a pressure of 100 kPa and ensure that the overall flow rate is 3.8 L/min. The humidity should stabilize at the required value since the valves are left in that position. If not adjust it with the wet and dry air flow rate whilst maintain the overall flow rate.
- Wait for the humidity to stabilize.
- Connect the ring and ball according to the ASTM standards.
- Transfer a 50 ± mL sample to the bath and wait for temperature to be within 25 ± 1 °C. This will take less than a minute.
- Attach the red hood over the bath securing it in place with the available clip.
- Set the pre-treatment timer to 15 min with the flow through the fuel set to 0.5 L/min of the total flow. The alarm will sound, flip the switch next to the flow meter. This will stop when the timer runs out and return the flow to 3.8 L/min over the fuel. Flip the switch back to stop the timer.
- The test respective test method can now be carried out. See ASTM standards.

Shut down:

- When a test is completed do not stop the simulation before switching the motor to the off position (simulink) and checking that the water pump is off.
- Stop the simulation.
- Switch the arm lift actuator to the up position and do the recording of the wear scar characteristics (if a wear test is done).
- Switch off the main power switch (red light off). A solenoid valve will close off the air supply for you.

- Make a copy off the Matlab output file “bocle_out” or “slbocle_out” somewhere to prevent it being overwritten by the next user. Export your data.
- Close the simulation.
- Switch off the junction box power supply as well as the OPTO brain if no one else is using them.
- Clean all test specimens and the bath according to ASTM standards.

Note the following:

- The timer above the pressure regulator is useful during tests and is independently connected from other processes.
- The load arm can be locked mechanically in the up position using the blue handle pin. It therefore doesn’t really require air pressure from the switch.

Maintenance guidelines: BOCLE/SL-BOCLE unit checks

- When cleaning any part first ensure all power to the unit is off.
- Drying crystals: Be aware of which colour pairs are being used e.g. dry/wet = orange/green or blue/pink. Crystals are available from Merck when they turn colour.
- Distilled water should be replaced regularly.
- Water circulation tanks should be cleaned if contaminated or dirty.
- The inside of the machine should be cleaned at least once a year since dust makes its way in through the fan opening and other small holes.
- Check if (wet air + dry air) = (total air flow). If not locate leak.
- The humidity transmitter has a 0.5 A fuse if faulty.

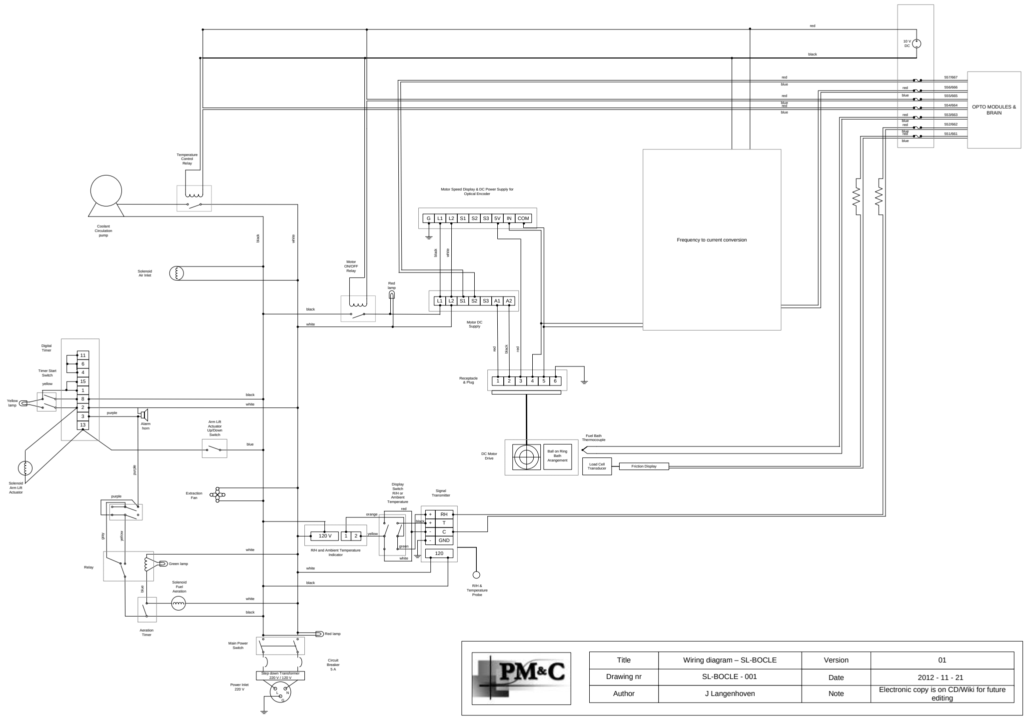
Note: The contact details of the manufactures of the BOCLE/SL-BOCLE instruments are as follows (In case one wants to order for more balls and rings):

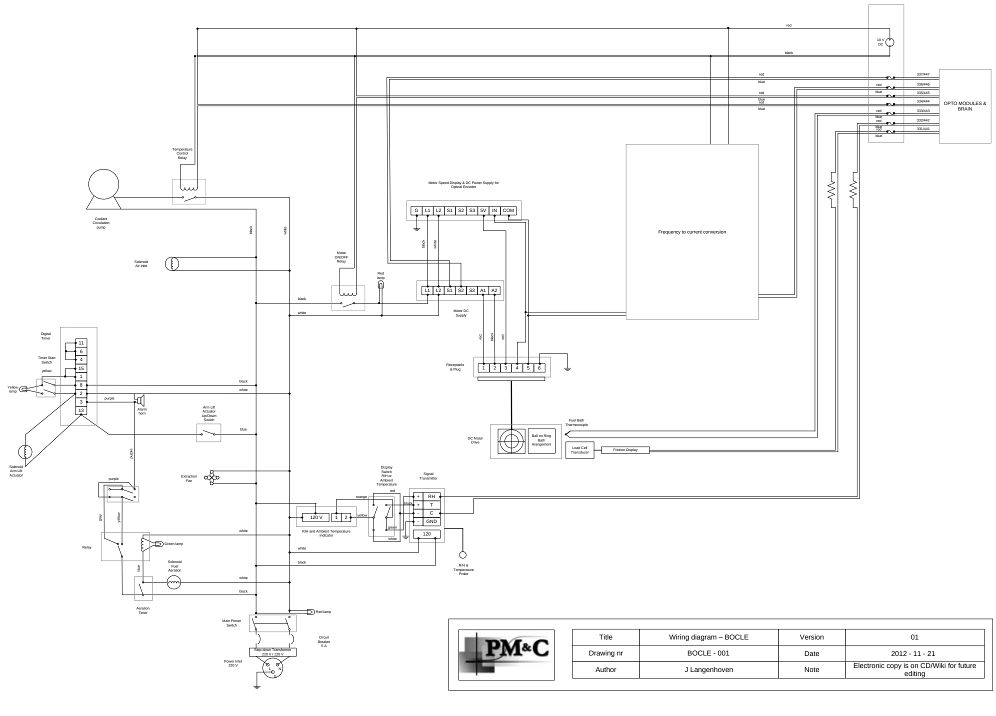
Manufacturer:
InterAV inc.
San Antonio, Texas, USA
Interavinc@hotmail.com
210-344-2785

Supplier:
ExpotechUSA
USA
sales@expotechusa.com
www.expotechusa.com

Appendix B

Internal wiring diagram for SL-BOCLE and BOCLE respectively.





Appendix C

Quotation for modules from OPTO 22

OPTO
Controls (Pty) Ltd

P.O. Box 766
Bromhof
2154
Tel: 011-792-5232
Fax: 011-792-1987
Cell: 082-958-1700
E-mail: mike@opto.co.za
Web: www.opto.co.za

University Of Pretoria
Department Of Chemical Engineering
Pretoria

11 September 2017

Attention: Mr. Andrew Osei Sakyi

Re: Opto 22 SNAP Modules Quotation:

Dear Andrew

As requested, please see the quotation for the modules as per your e-mail request.

Please note that I have listed individual prices that will allow you to select the quantities required for your project.

One: SNAP-AIMA 2-channel 4 to 20mA analogue input model.

Price Each (Ex VAT): ***R 4 485.00***

One: SNAP-AIV 2-channel 0 to 10VDC analogue input model.

Price Each (Ex VAT): ***R 4 485.00***

One: SNAP-ODC5-I 4-channel Isolated 5 to 60VDC digital output model.

Price Each (Ex VAT): ***R 875.00***

Yours truly

Mike Harrison
"Opto Controls (Pty) Ltd"

1

Directors: M. L. Harrison (Sales & Marketing)
Co Reg No: 2000/017990/07

TERMS AND CONDITIONS OF SALE.

VALIDITY:	This quotation is valid for a period of 30 days from date hereof.
DELIVERY:	Should not exceed 4 to 6 weeks from placement of your official order and receipt of deposit.
PAYMENT:	Strictly 30days from date of invoice.
RATE OF EXCHANGE:	All prices quoted are based on the following rate of exchange: US $ 1.00 = SA R 13.00. Any major fluctuations in the above rate will be for your account.
VAT:	All prices quoted exclude VAT.
WARRANTY:	All new goods carry a One-Year factory warranty against any defect parts caused through normal wear and tear. Any damage caused through neglect or acts of God will not be covered. **Please Note:** All Opto 22 SNAP I/O modules carry a lifetime warranty.

Our standard terms and conditions of sale apply and are available on request.

Directors: M. L. Harrison (Sales & Marketing)
Co Reg No: 2000/017990/07