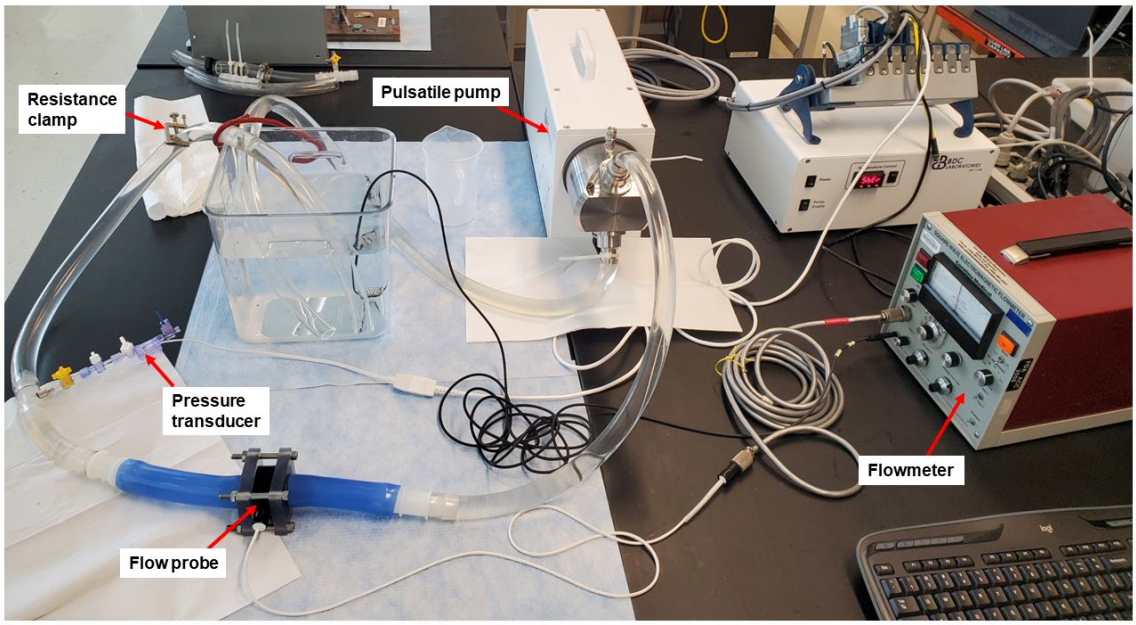
## Filter Frequency Response Characterization

*Note: The test fluid used is blood analog fluid (BAF). Please prepare the BAF by following detailed instructions outlined in the document, 'Preparation of Blood Analog Fluid (BAF)'. For preliminary or feasibility testing, De-ionized (DI) water may be used in place of BAF as the test fluid. While all test protocols in this document are written for BAF, they are also directly applicable to DI water, when used as the test fluid.*

1. Connect the simplified flow loop per the diagram shown below.
   *Note: The diagram below shows representative samples of 1 pressure transducer and 1 flow probe. The flow loop may be modified to incorporate 3 pressure transducers and 2 flow probes to achieve simultaneous sensor characterization, if needed.*




Available pressure transducers and amplifier:
Three (left ventricle (LV), left atrium (LA), and aorta (Ao)) pressure transducers [Utah Medical Products Inc., Midvale, Utah] connected to the pressure amplifier module [Bus 21097, ViVitro Labs, Inc., Victoria, BC, Canada].

Available flow sensors and flowmeter modules:

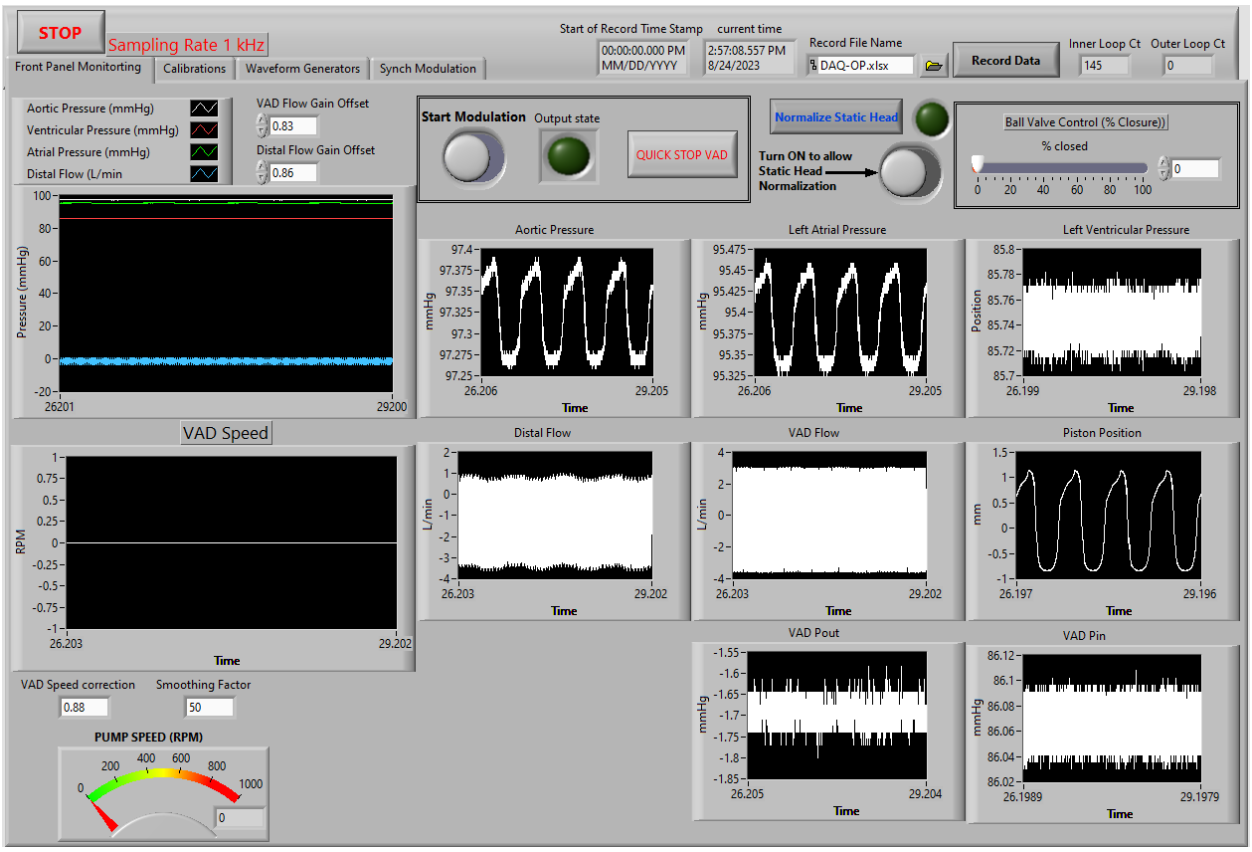
| **Flowmeter** | **Flow sensor** |
|---|---|
| T402 (dual channel), Transonic Systems, Inc., Ithaca, NY | ME-25PXN, ME-11PXL, ME-16PXL |
| FM501, Carolina Medical Electronics, East Bend, NC | EP688 (size 88 mm cir) |

*Note: Since the EP688 flow probe requires a conductive fluid, sodium chloride (NaCl) would need to be mixed with DI water, when used as the test fluid.*

2. Make the appropriate electrical connections:
   a. Connect the flow sensor/pressure transducer to the corresponding flowmeter/pressure amplifier module.
   b. Connect the pulsatile pump [PD-1100, BDC Laboratories, Wheat Ridge, CO] per its user manual.
   c. Connect the output channels on the flowmeter/pressure amplifier module to the channels on the analog input (AI) module [NI-9205, National Instruments, Austin, TX] of the data acquisition system [cDAQ-9174, National Instruments, Austin, TX] per the table below.

| **Instrument Channel** | **AI Channel on cDAQ-9174** |
|---|---|
| Pressure transducer amplifier – Aorta (Ao) pressure channel | AI 1, NI-9205 |
| Pressure transducer amplifier – Left ventricle (LV) pressure channel | AI 2, NI-9205 |
| Pressure transducer amplifier – Left Atrium (LA) pressure channel | AI 3, NI-9205 |
| T402 output channel | AI 4, NI-9205 |
| FM501 output channel | AI 5, NI-9205 |

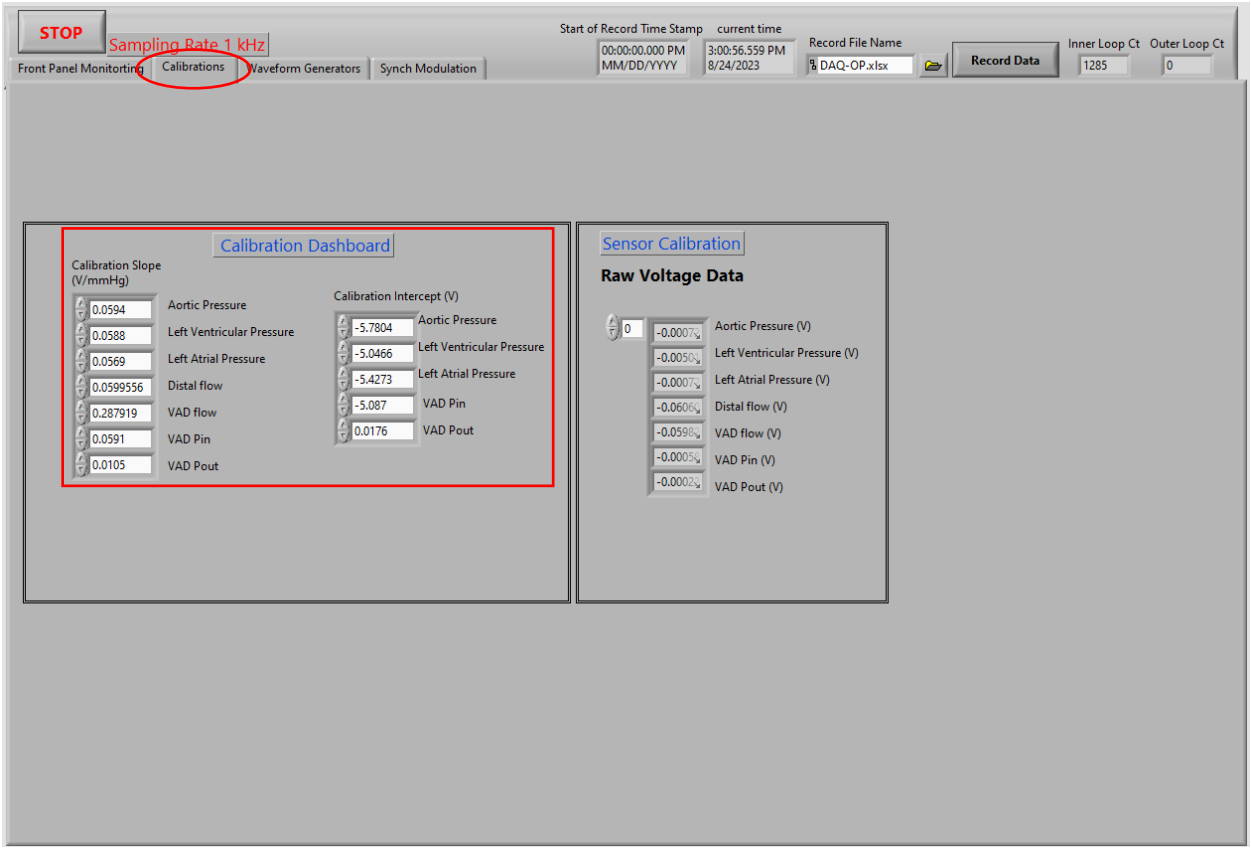
   d. Connect the cDAQ data cable to the mock circulatory loop (MCL) laptop.
   *Note: The pulsatile pump [PD-1100, BDC Laboratories, Wheat Ridge, CO] is controlled using its own desktop computer while the MCL laptop and data acquisition system is used to monitor and acquire data from pressure transducers and flow probes/sensors.*
   *Note: As an alternative to the MCL laptop and data acquisition, the pulsatile pump's [PD-1100, BDC Laboratories, Wheat Ridge, CO] data monitoring and acquisition capabilities can be used which allows for 1 pressure transducer and 1 flow probe at any instant of time. Please refer to the PD-1100 user manual.*
3. Power ON all equipment.
4. Open and Run the LabVIEW VI (or Virtual Instrument) that executes the custom MCL software (snapshot graphical user interface (GUI) shown below).



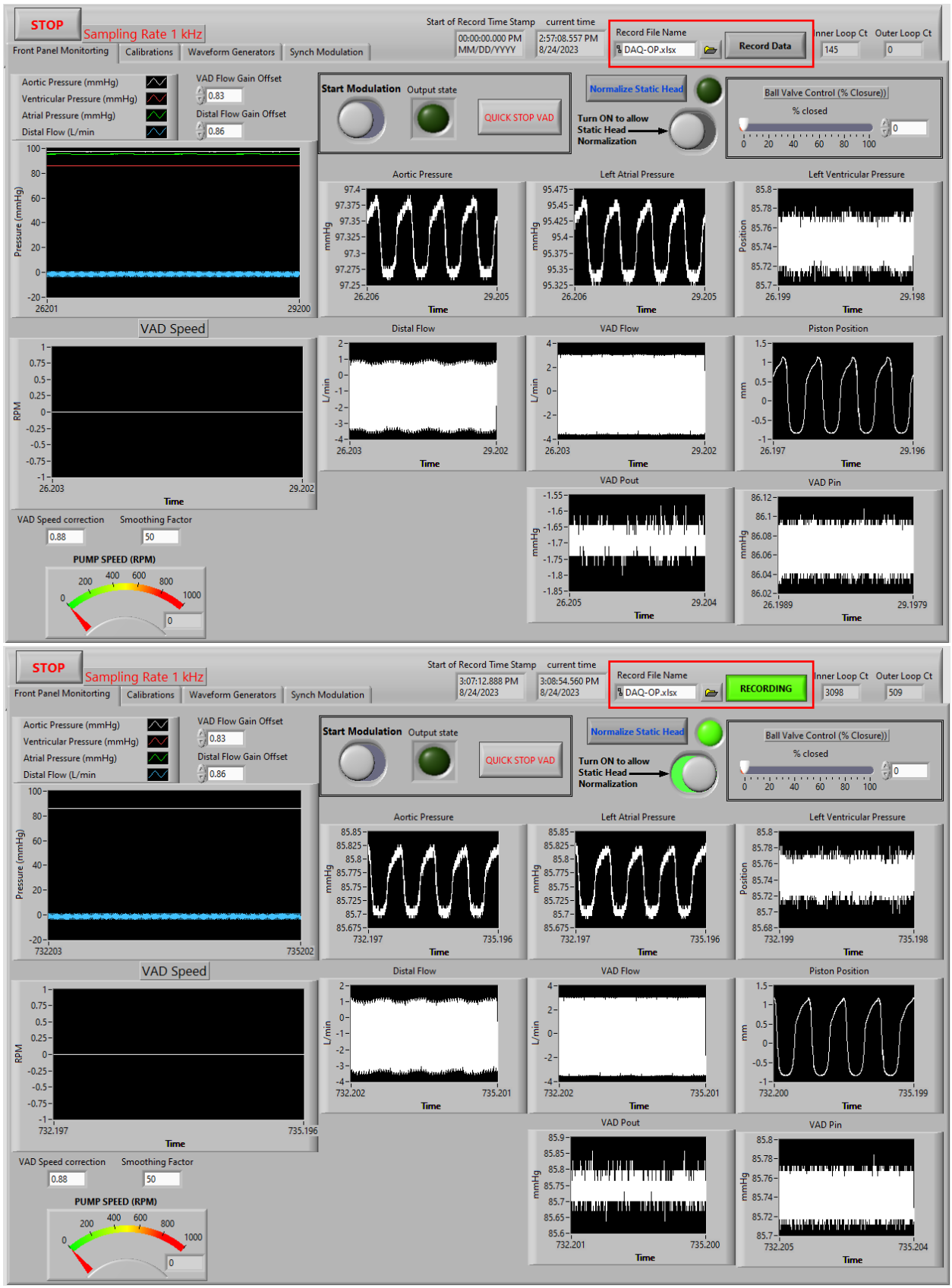

5. Apply the sensor/transducer Calibration Slope and Calibration Intercept such that the MCL software displays the pressure in mmHg and flow rate in L/min. Please refer to the documents, '[Pressure Transducer Calibration]' and '[Flow Sensor Calibration]'.

   *Note: The MCL software has been developed with the goal of evaluating ventricular assist devices (VADs) within the MCL, which is the reason for the nomenclatures, 'Distal flow' and 'VAD flow'. The MCL is designed to incorporate a maximum of 2 flow sensors at any given time of testing. Thus, in the absence of a VAD connected to the MCL, the 'VAD flow' AI channel is used to record cardiac output (CO) using the EP688 flow probe. 'Distal flow' represents the aortic (Ao) or systemic flow recorded by the ME-25PXN flow sensor.*

   *Note: Please ensure that the VAD Flow Gain Offset and Distal Flow Gain Offset (in the Front Panel Monitoring tab) are set to 0.00.*




6. Run the pulsatile pump [PD-1100, BDC Laboratories, Wheat Ridge, CO] per its user manual using its accompanying software [Statys® PD, BDC Laboratories, Wheat Ridge, CO]. Use the following Flow Controller > Pump Control settings: Rate: 110 BPM, Target Flow: 3.5 LPM, Profile: 35% Systole.
7. Start to close the resistance valve till the peak pressure is under 300 mmHg and the flow rate is ~2.8 L/min – 3 L/min. A pressure pulse reading of ~ 0/250 mmHg is acceptable.
8. Set the lowest low pass filter /pulsatile frequency response setting on the flowmeter/pressure amplifier module.
9. Using the MCL software, record ~ 10 seconds of data by selecting Record Data (Note: A green illuminated Recording tab will appear when the software is recording data). Select an appropriate file name and path under Record file Name to save the Excel (.xlsx) data file. At the end of 10 seconds, select the green illuminated Recording tab to stop recording. Please refer to the snapshots below.


STOP
Sampling Rate 1 kHz
Front Panel Monitoring
Calibrations
Waveform Generators
Synch Modulation
Start of Record Time Stamp
current time
00:00:00.000 PM
MM/DD/YYYY
2:57:08.557 PM
8/24/2023
Record File Name
DAQ-OP.xlsx
Record Data
Inner Loop Ct
Outer Loop Ct
145
0
Aortic Pressure (mmHg)
Ventricular Pressure (mmHg)
Atrial Pressure (mmHg)
Distal Flow (L/min
VAD Flow Gain Offset
0.83
Distal Flow Gain Offset
0.86
Start Modulation
Output state
QUICK STOP VAD
Normalize Static Head
Turn ON to allow
Static Head
Normalization
Ball Valve Control (% Closure))
% closed
Pressure (mmHg)
Aortic Pressure
Left Atrial Pressure
Left Ventricular Pressure
mmHg
Position
Time
VAD Speed
RPM
Distal Flow
VAD Flow
Piston Position
L/min
mm
VAD Pout
VAD Pin
VAD Speed correction
0.88
Smoothing Factor
50
PUMP SPEED (RPM)
STOP
Sampling Rate 1 kHz
Front Panel Monitoring
Calibrations
Waveform Generators
Synch Modulation
Start of Record Time Stamp
current time
3:07:12.888 PM
8/24/2023
3:08:54.560 PM
8/24/2023
Record File Name
DAQ-OP.xlsx
RECORDING
Inner Loop Ct
Outer Loop Ct
3098
509
Aortic Pressure (mmHg)
Ventricular Pressure (mmHg)
Atrial Pressure (mmHg)
Distal Flow (L/min
VAD Flow Gain Offset
0.83
Distal Flow Gain Offset
0.86
Start Modulation
Output state
QUICK STOP VAD
Normalize Static Head
Turn ON to allow
Static Head
Normalization
Ball Valve Control (% Closure))
% closed
Pressure (mmHg)
Aortic Pressure
Left Atrial Pressure
Left Ventricular Pressure
mmHg
Position
Time
VAD Speed
RPM
Distal Flow
VAD Flow
Piston Position
L/min
mm
VAD Pout
VAD Pin
VAD Speed correction
0.88
Smoothing Factor
50
PUMP SPEED (RPM)

10. Repeat step 10 at all other low pass filter/pulsatile frequency response settings.
11. Plot flow rate/pressure *vs.* time over one beat cycle for all the low pass filter/pulsatile frequency response settings. Record the date of filter frequency response characterization.