Vacuum Chamber Control Procedure

## Control strategy: PID

**Automated Tuning (Ziegler-Nichols Method)**

* Set  K\_i  and  K\_d  to 0
* Increase  K\_p  until the system oscillates consistently (find the critical gain,  K\_u)
* Measure the oscillation period ( T\_u ).
* Use these values to set the PID gains:
* K\_p = 0.6 ⋅ K\_u
* K\_i = 2 ⋅ K\_p / T\_u
* K\_d = K\_p ⋅ T\_u / 8

**5. Test the Controller**

* Apply a step change in target pressure and observe the system response
* Adjust gains iteratively to minimise overshoot, oscillations, and steady-state error

**6. Fine-Tuning with System Behaviour**

* the response is too slow, increase  K\_p  and  K\_i
* If overshooting occurs, decrease  K\_p  or increase  K\_d
* If oscillations persist, reduce  K\_i  or increase  K\_d

## Nonlinearity:

The system will have a nonlinear response; as pressure in the chamber approaches the operational limits of the pump, it will become less effective.

**Methods (linearisation):**

* Gain scheduling
* Pressure dependant scaling

**Methods (Feedforward):**

* Accurately predicting the pump speed required based on target pressure and current pressure. Combining this with feedback from PID to refine control.

**Methods (Nonlinear PID gains):**

* Adjust PID gains based on the error magnitude or rate of change.

## Modelling the system:

**Pumping rate (Pa/s):**

* Pump out air at maximum speed and log the pressure rate
* Create a model of **pumping rate** as a function of pressure

**Leak rate (Pa/s):**

* Take pressure to max operating vacuum and log the **leak rate** as it goes back up to atmospheric pressure
* Create a model of **leak rate** as a function of pressure

**Chamber pressure rate (Pa/s):**

* Subtract the **leak rate** model from the **pumping rate** model, this will produce **chamber pressure rate** model as a function of pressure.

**Gain scheduling:**

* Divide the Pressure Range into bins
* For each pressure bin, select an operating point P\_0 (the midpoint of the bin)
* Tune PID gains for each bin
* Develop a model to interpolate between gain values based on pressure

**Linearising pump control:**

**PWM to motor speed:**

**Automated calibration procedure:**