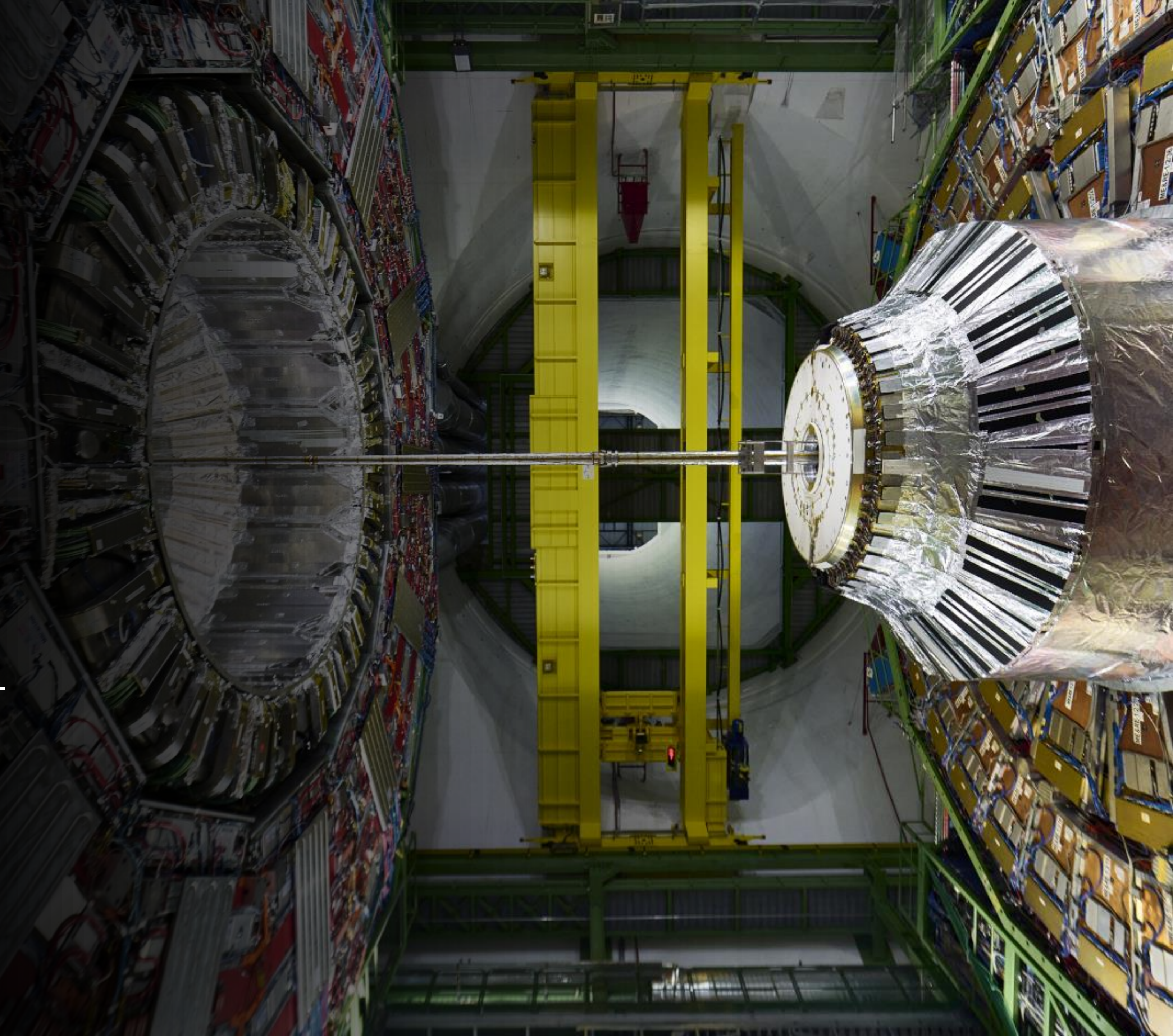
Fiber Bragg Grating

Fiber Optic Sensors Measuring Strain & Temperature Changes at the CMS's Central Beam Pipe



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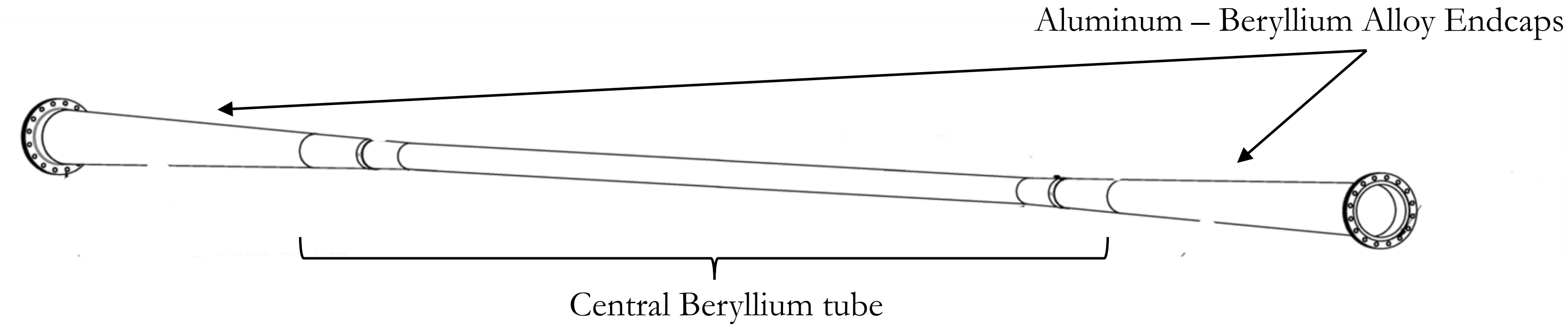
CMS's Beam Pipe

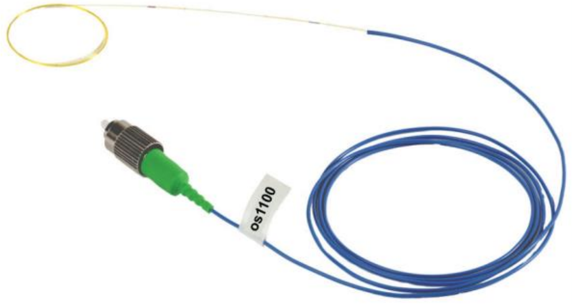
Characteristics:
- central 3-meter long gossamer Beryllium tube
- 1.5-meter long Aluminium - Beryllium Alloy endcaps
- Diameter of 4.5 cm with 0.8 mm thickness

Subjected Conditions:
- Ultra-high Vacuum of 10^{-13} atm
- 40 MHz proton-proton collisions
- High levels of radiation 10^{5} - 10^{6} Gy
- Large Magnetic Field 3.8 T



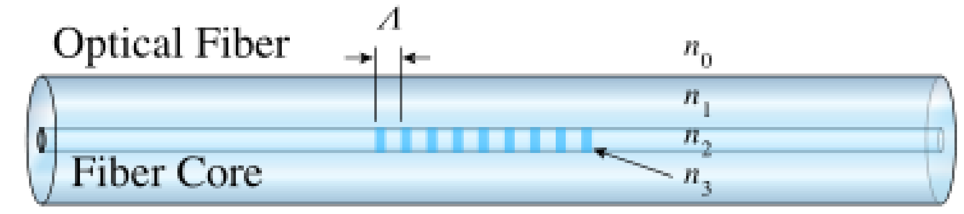
Working Principle of FBGs

The basic notion relies on periodically modulating and varying the refractive index in the core element of the optical sensor.



Under nominal and ambient conditions this wavelength is constant and can be referred to as the Bragg Wavelength $\boldsymbol{\lambda}_B$

$$\lambda_B = 2n_{eff}\Lambda$$



As the FBGs get subjected to temperature and strain changes the wavelength changes and using the following mathematical model:

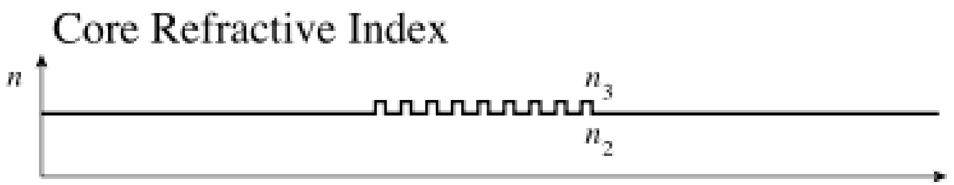
$$\frac{\Delta\lambda}{\lambda_B} = \underbrace{(1 - P_e)\in}_{\text{Strain measure}} + \underbrace{[(1 - P_e)\alpha + \xi]\Delta T}_{\text{Temperature measure}}$$

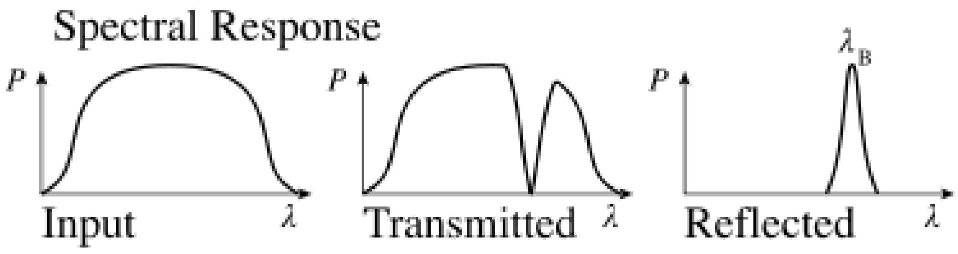
P_e: photoelastic constant

ϵ: strain

α: coefficient of thermal expandability

ξ: coefficient of thermo-optics

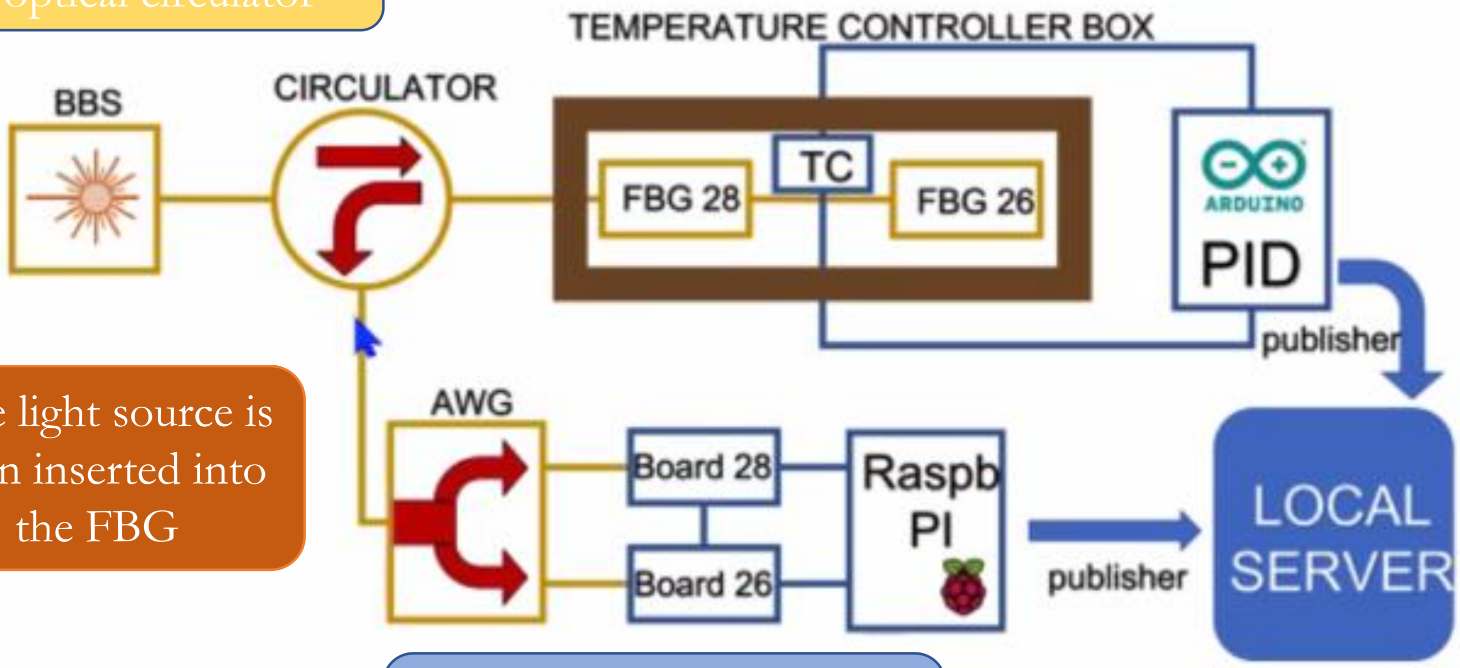




FBG Interrogation System Implemented to test and Calibrate different FBGs

A broadband source of light is fed into an optical circulator

The light source is then inserted into the FBG



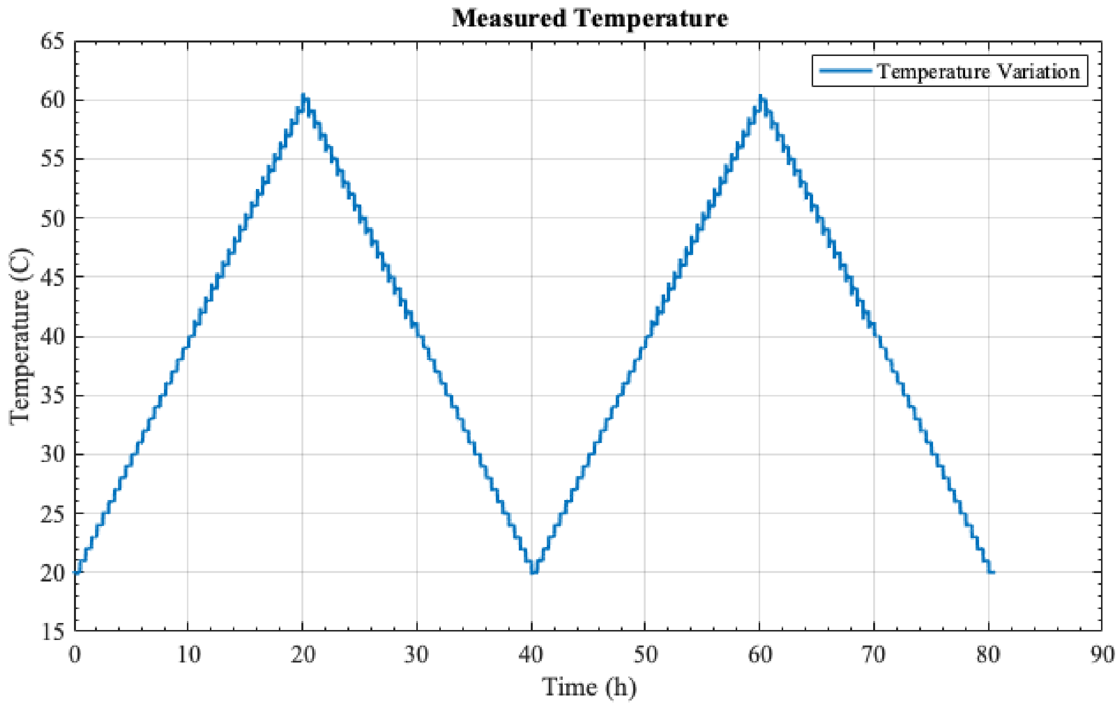
Temperature and current measurements are then uploaded on a local server

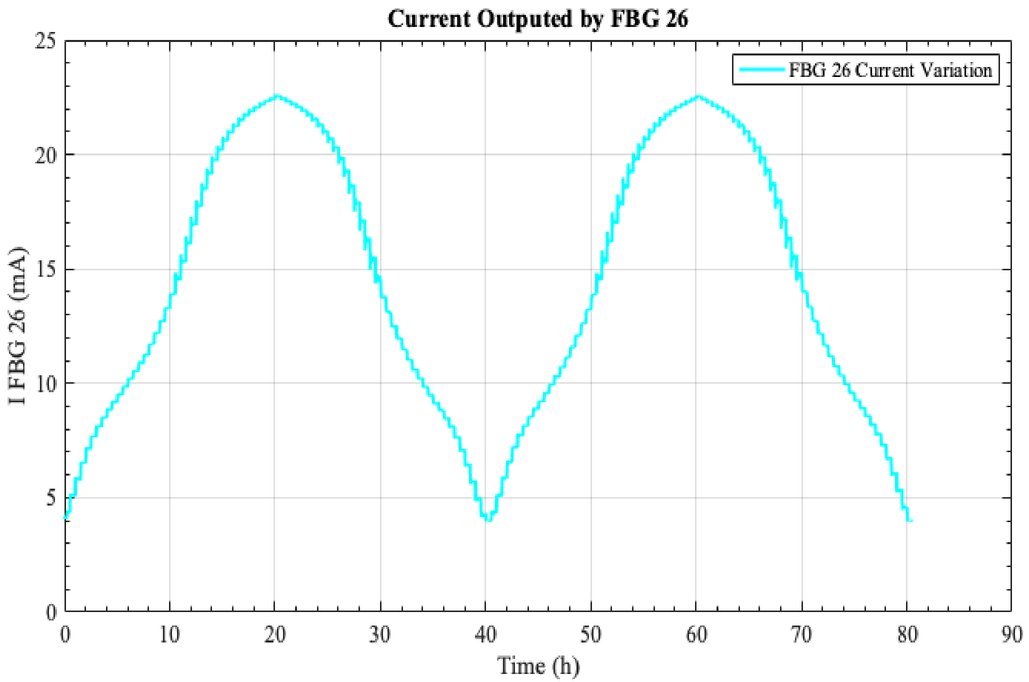
A photodetector is employed to the Arrayed Waveguide

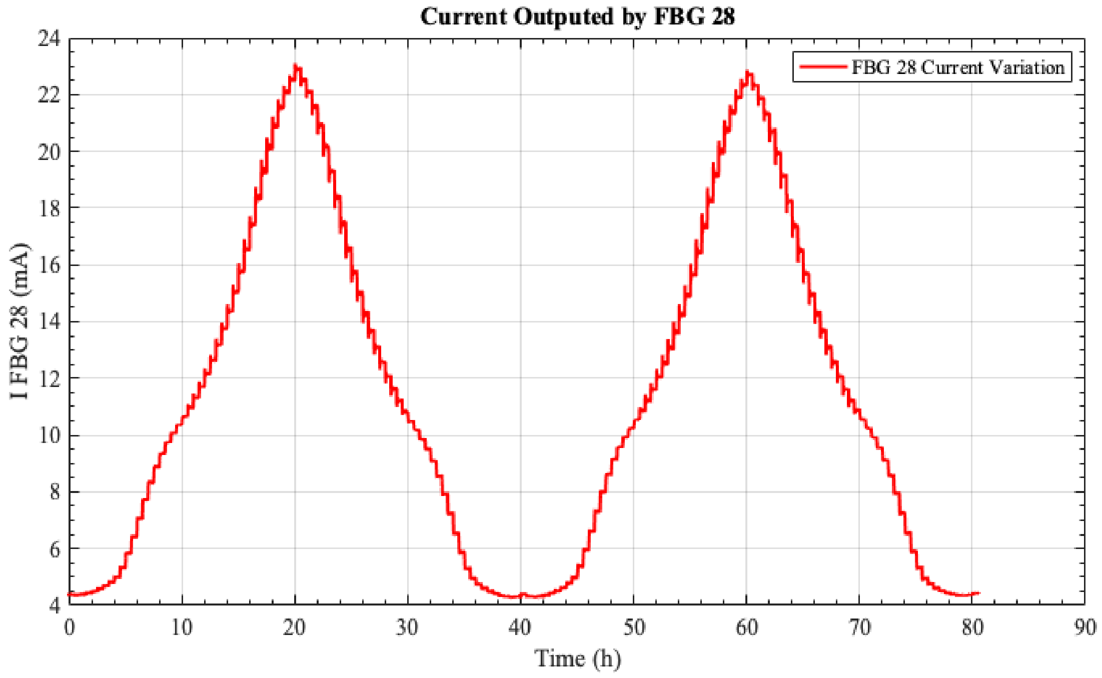
FBG Calibration Test

To construct a model between the measured Temperature and the output current by the photodetector:

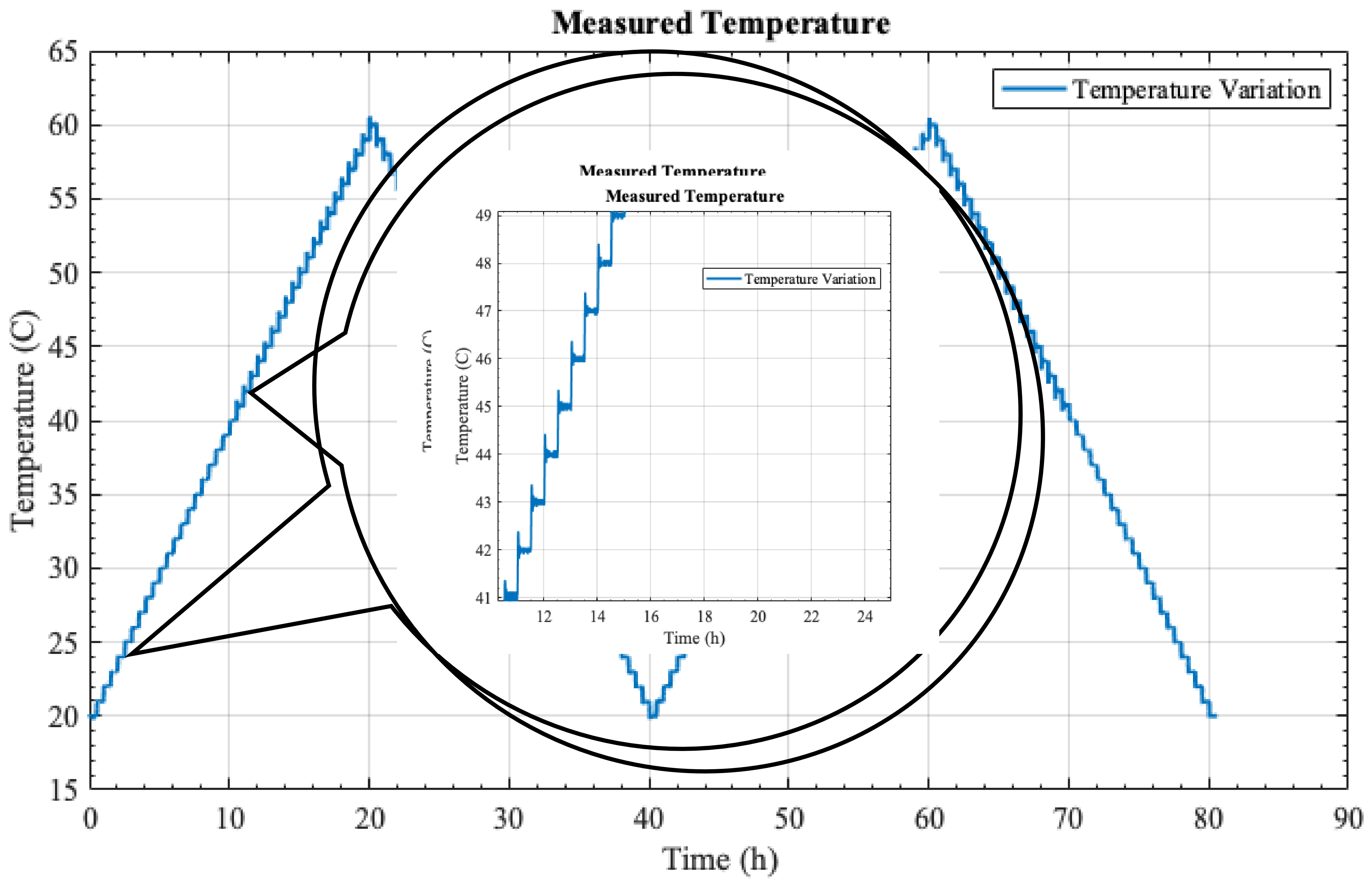
- Starting from 20 °C, the temperature was increased by 1 °C every 30 mins.
- The system overloads at 60 °C and goes back to 20 °C twice
- The measured temperature and the current outputed by each FBG were recorded in a SQLite table.







Curve Analysis



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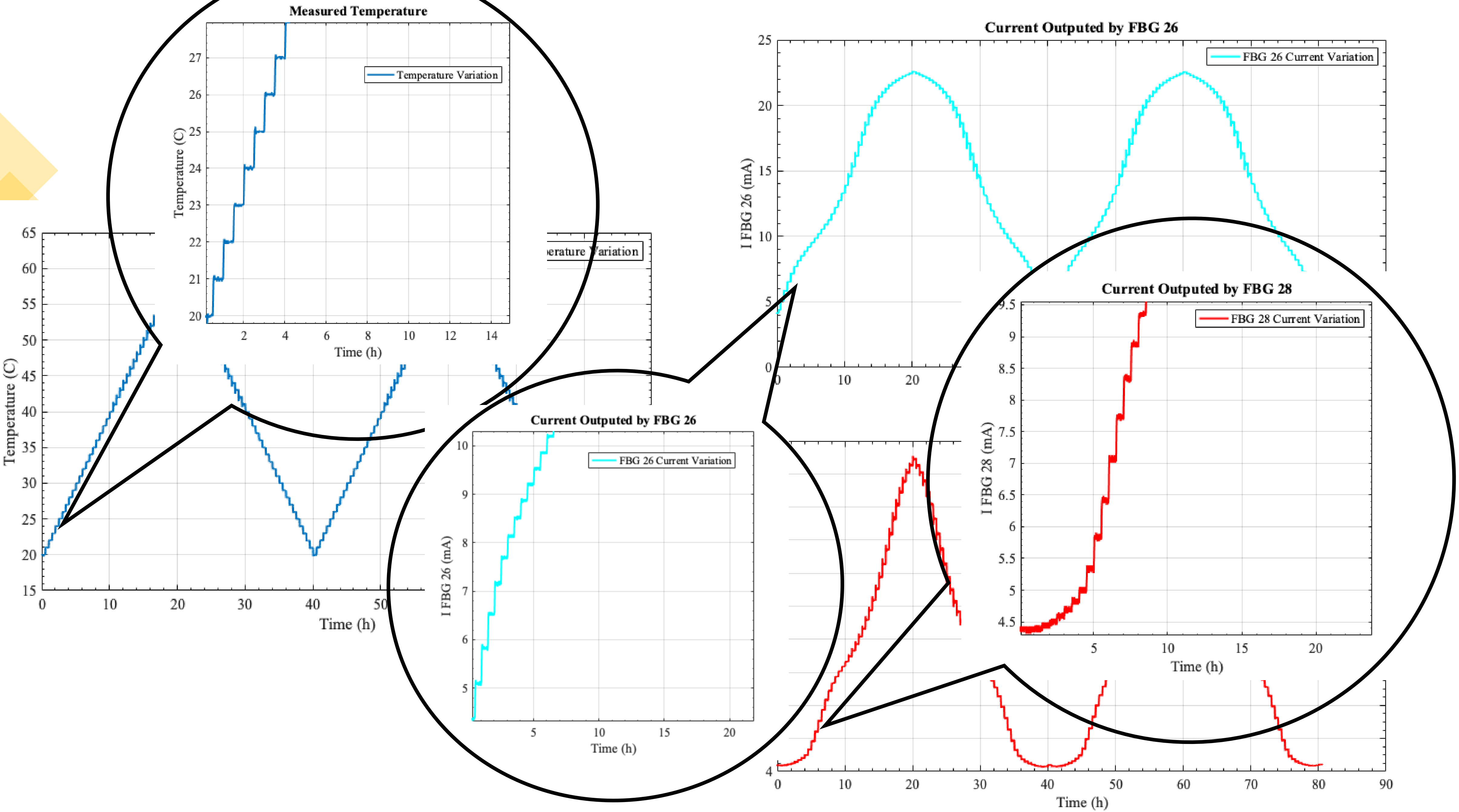
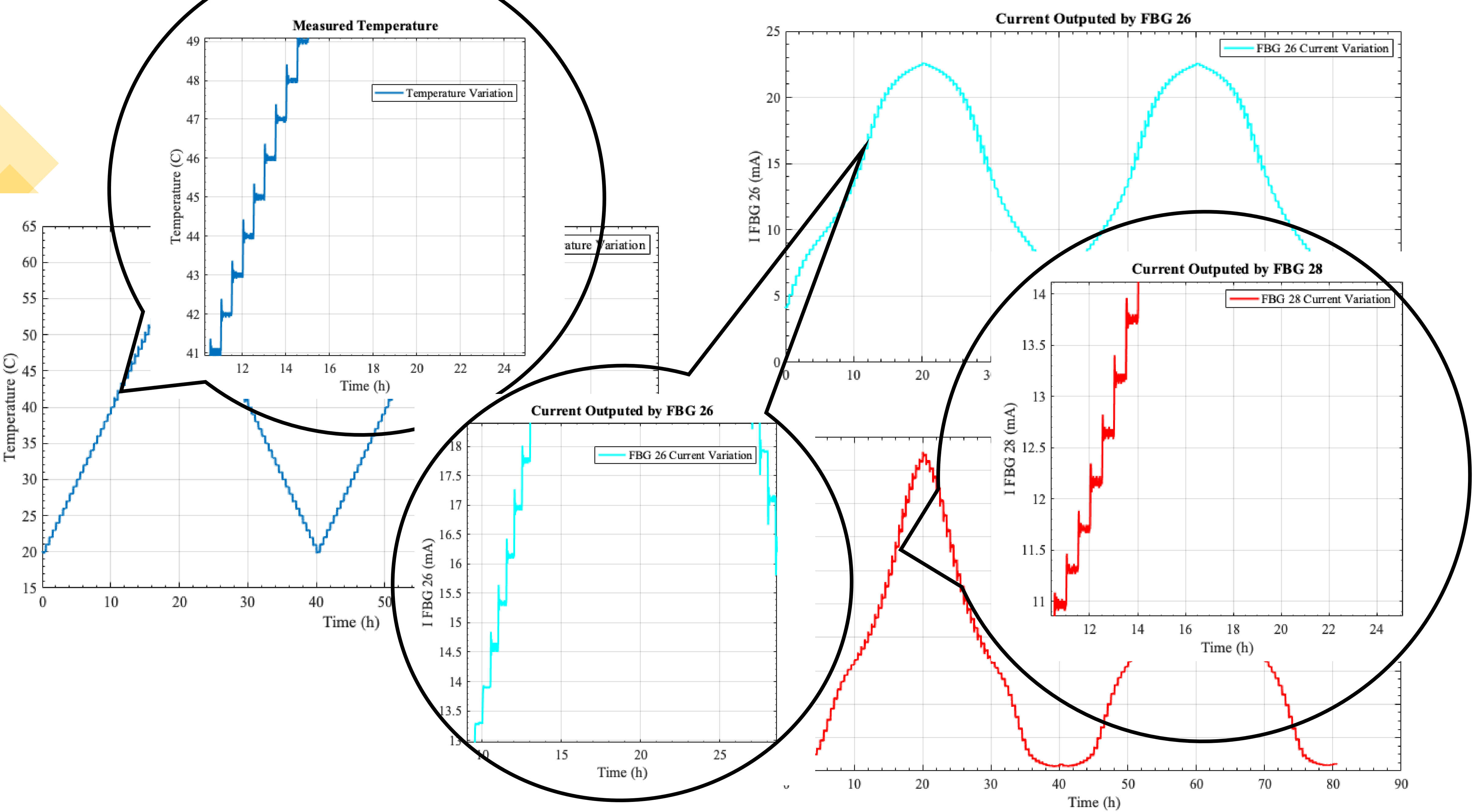
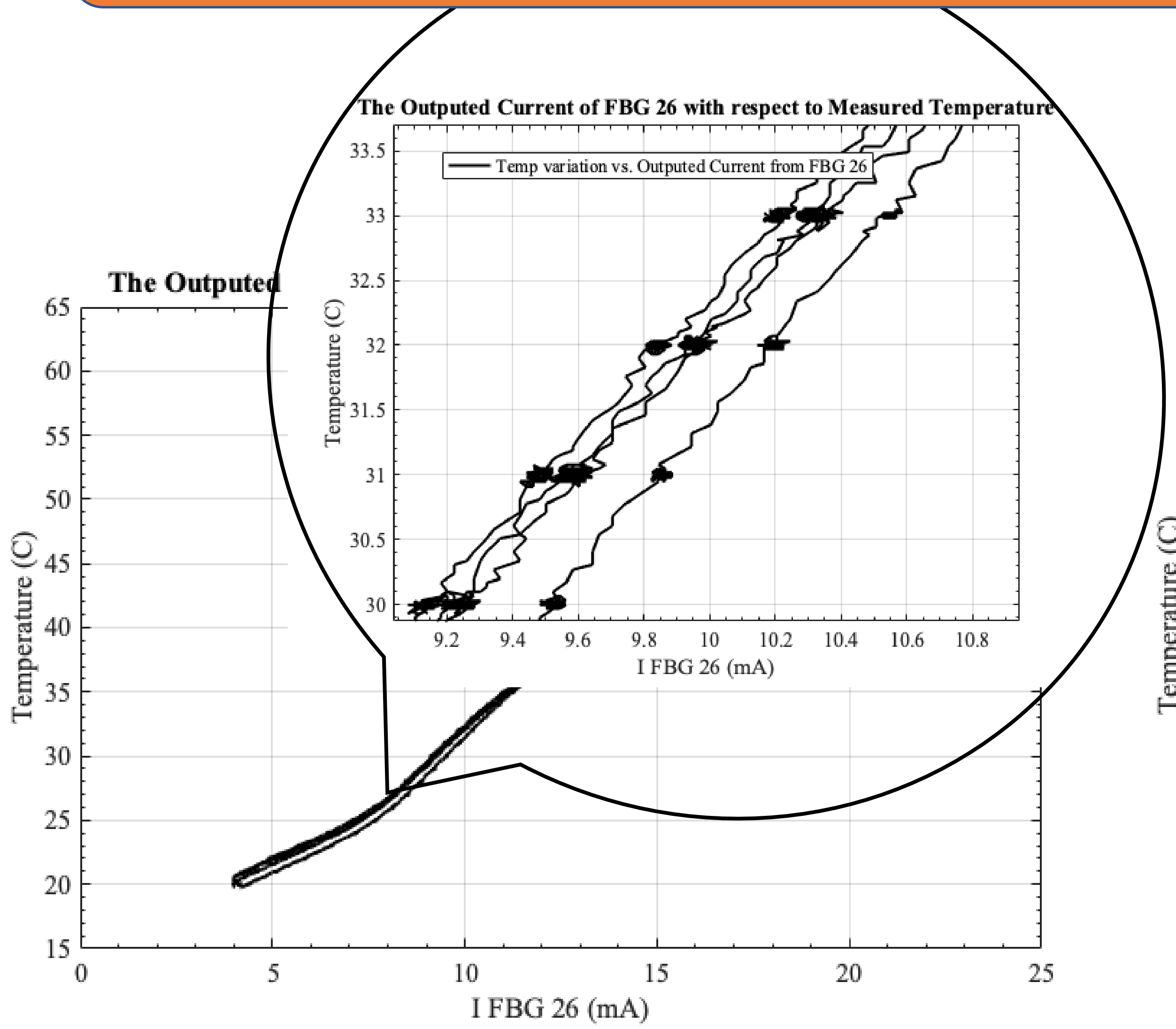
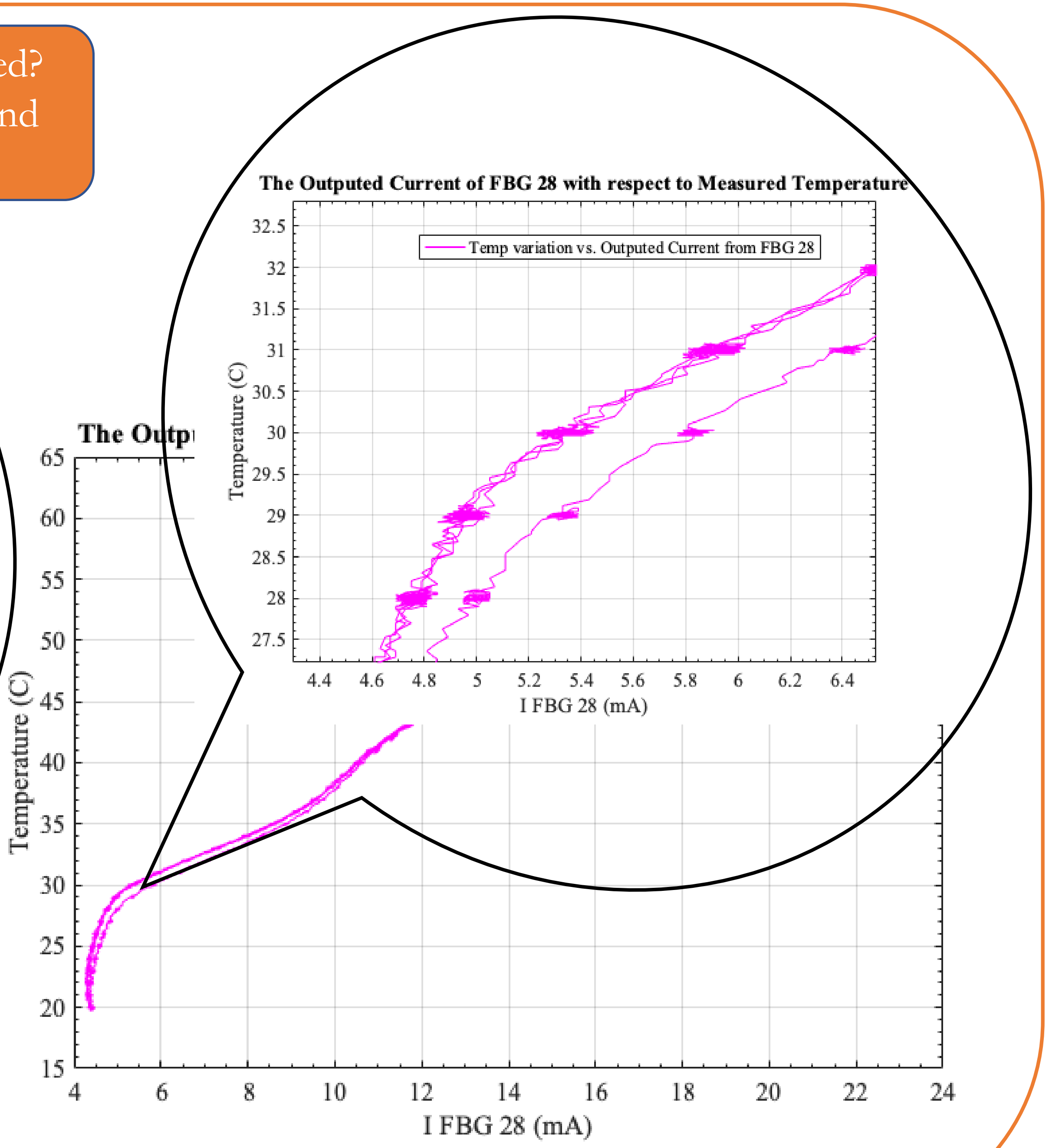


Curve Analysis



Why Should the overshoot and the undershoot be addressed?
The graph plotting the correlation between Temperature and Outputted Current will thus look like this

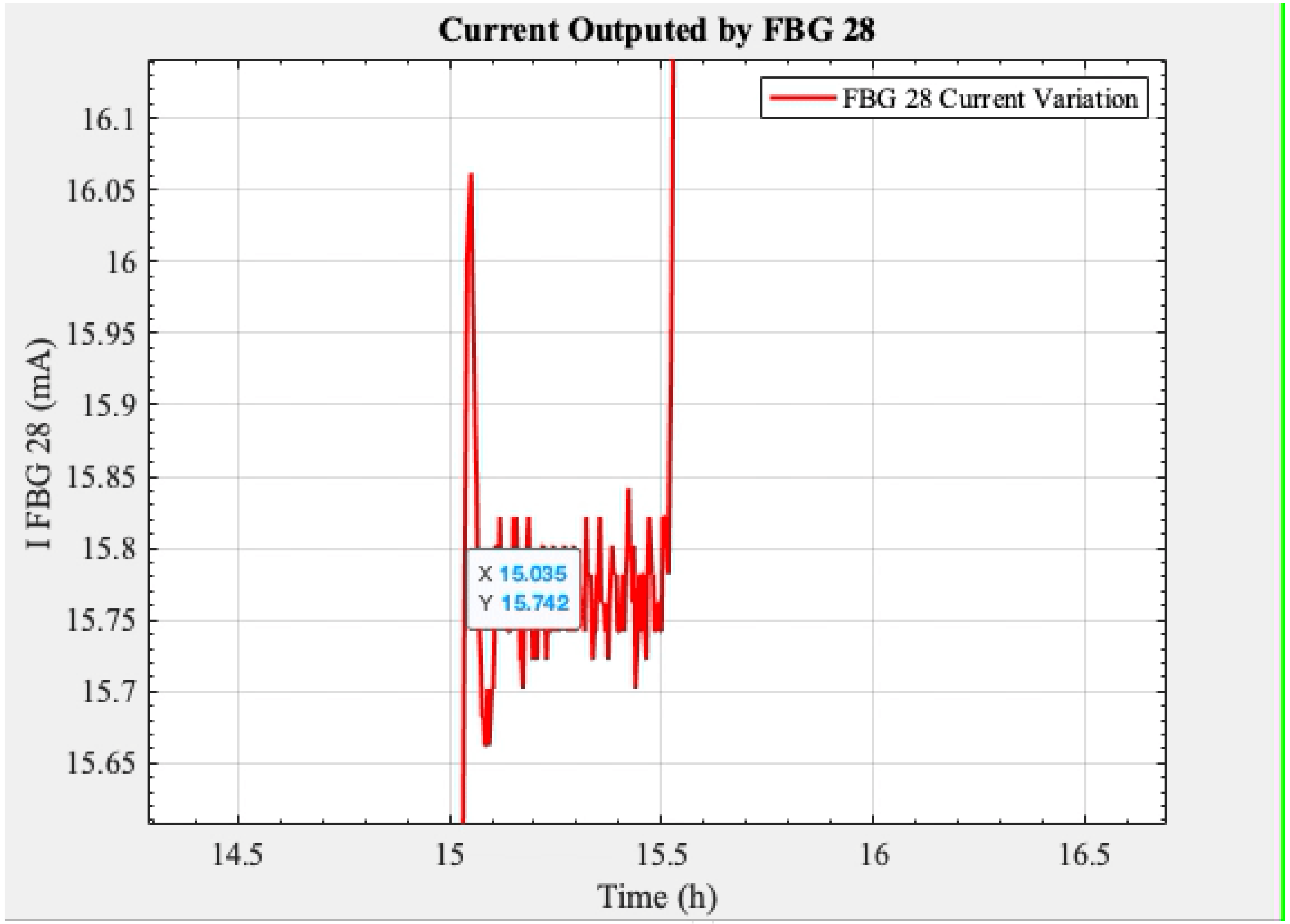




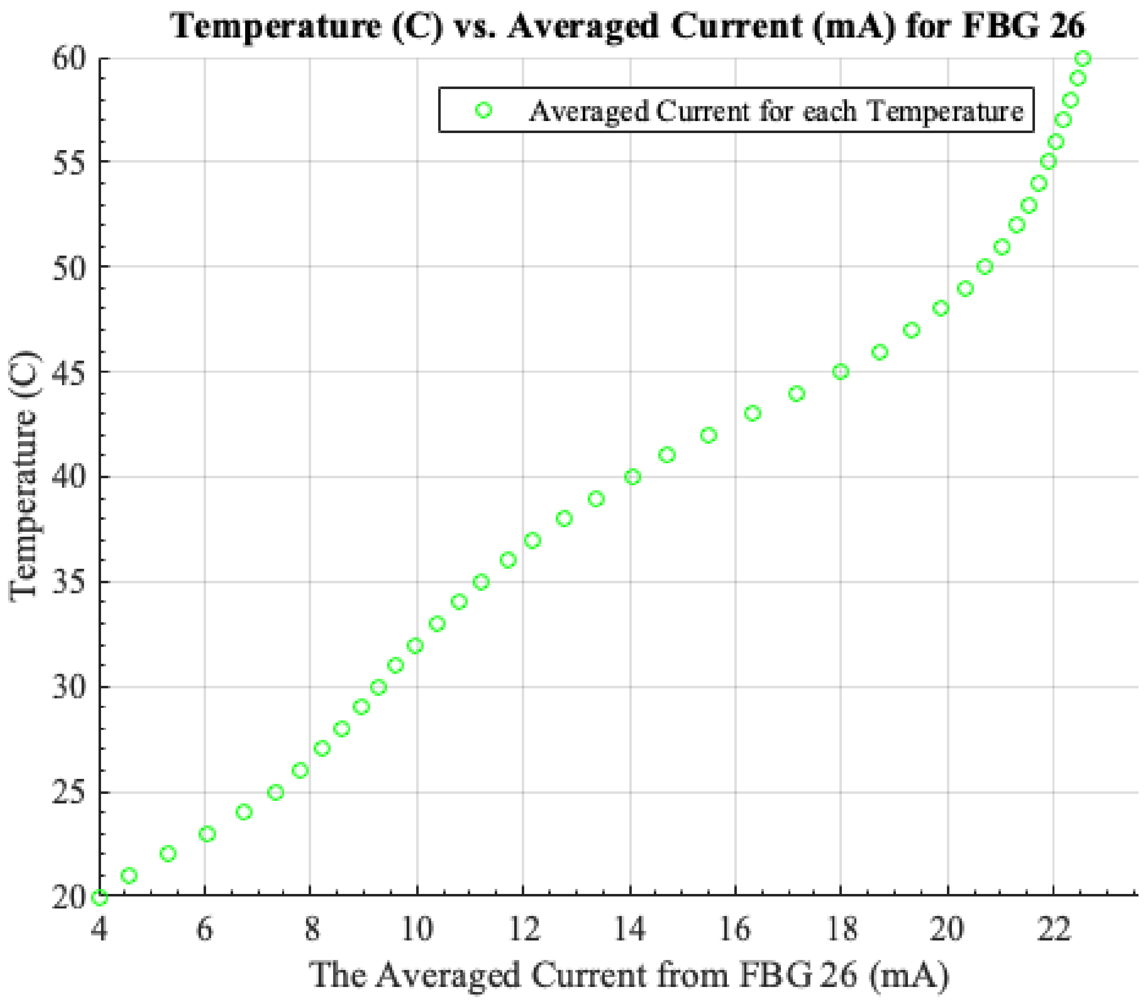
Discretizing the Data

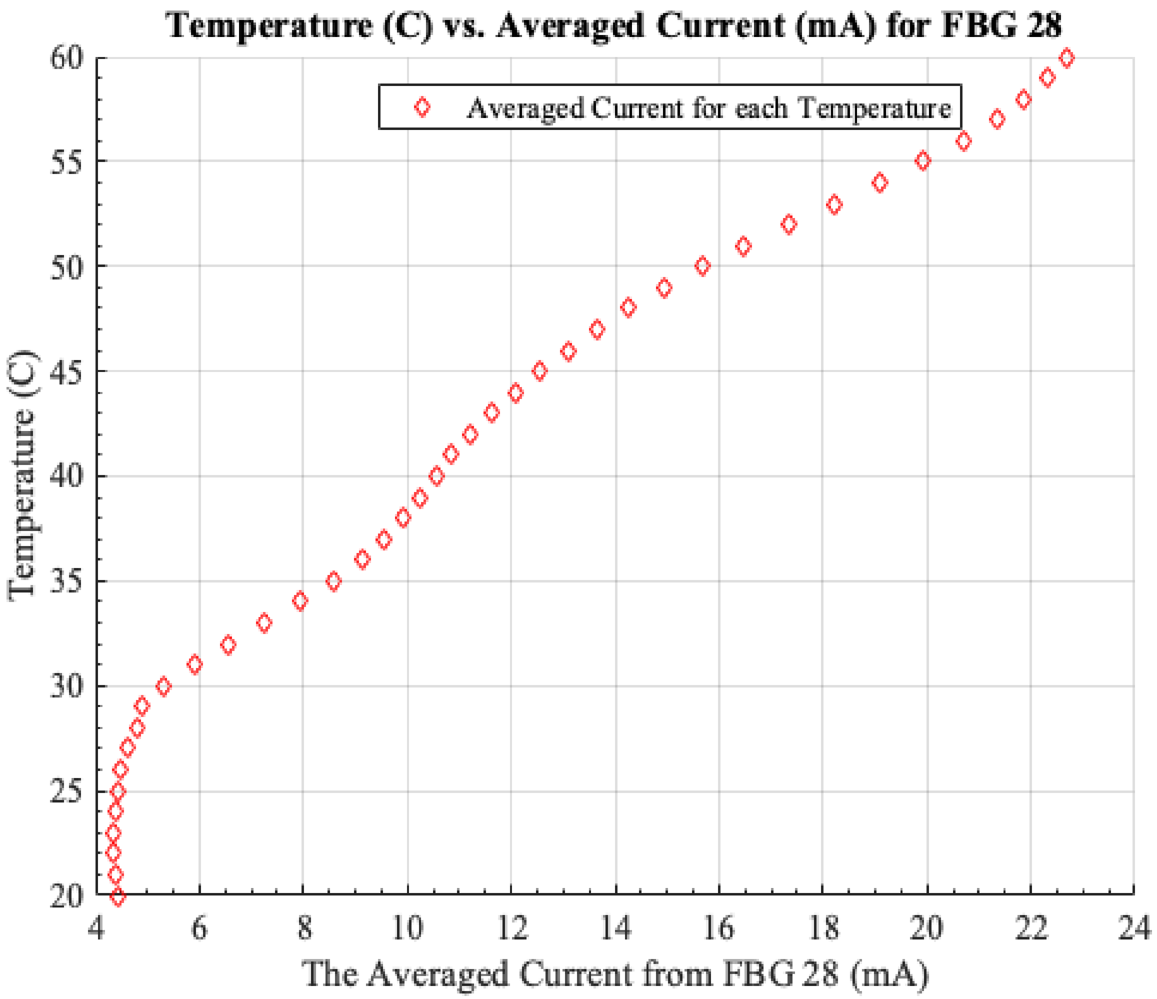
A MATLAB code was constructed to do the following:

- For each temperature, scan for a plateau, with a 1% difference between two data values
- Average the current for each of the 4 cycles
- Associate each temperature with a discrete current output.



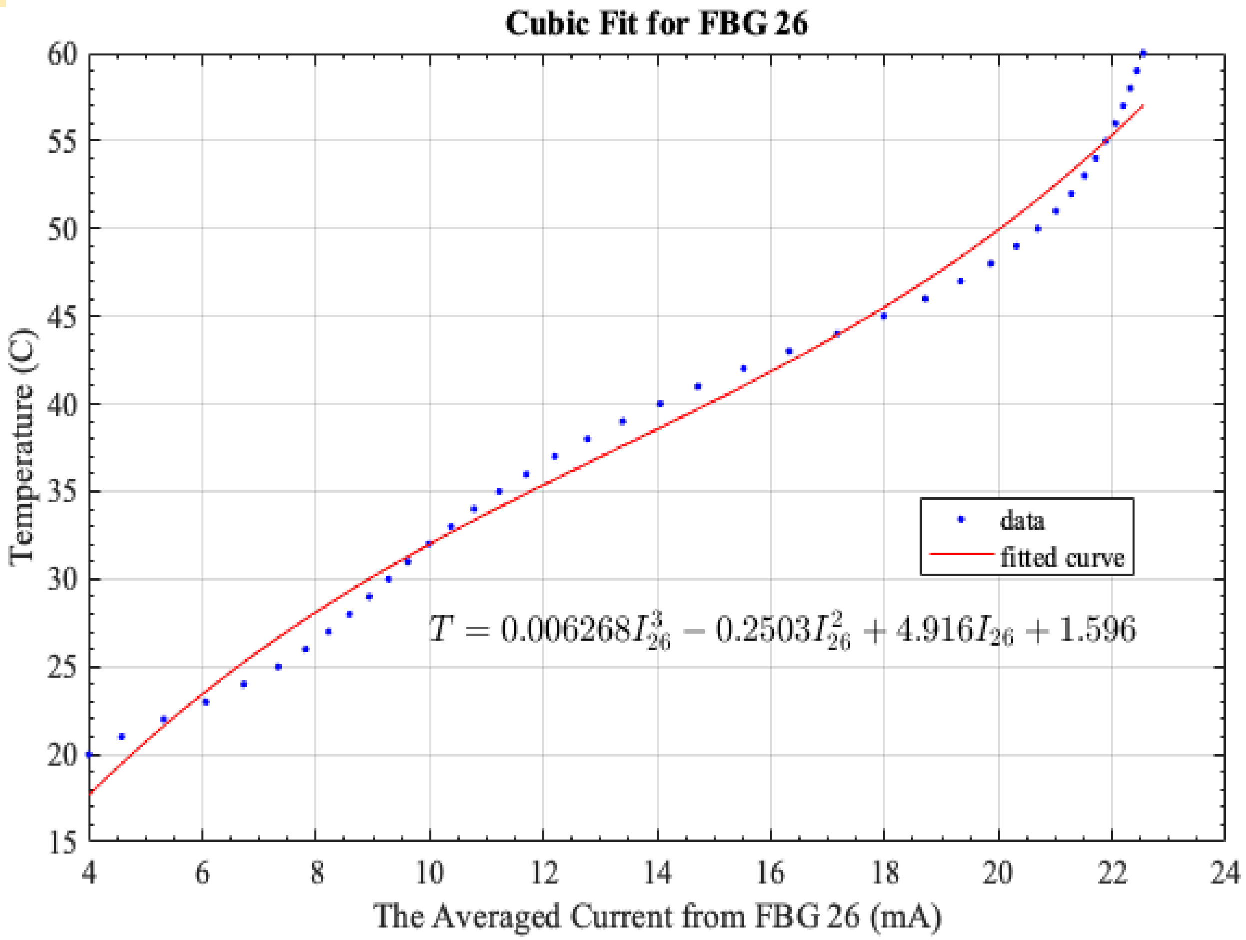
This allows us to alter the graphs to a more amicable and “fittable” shape

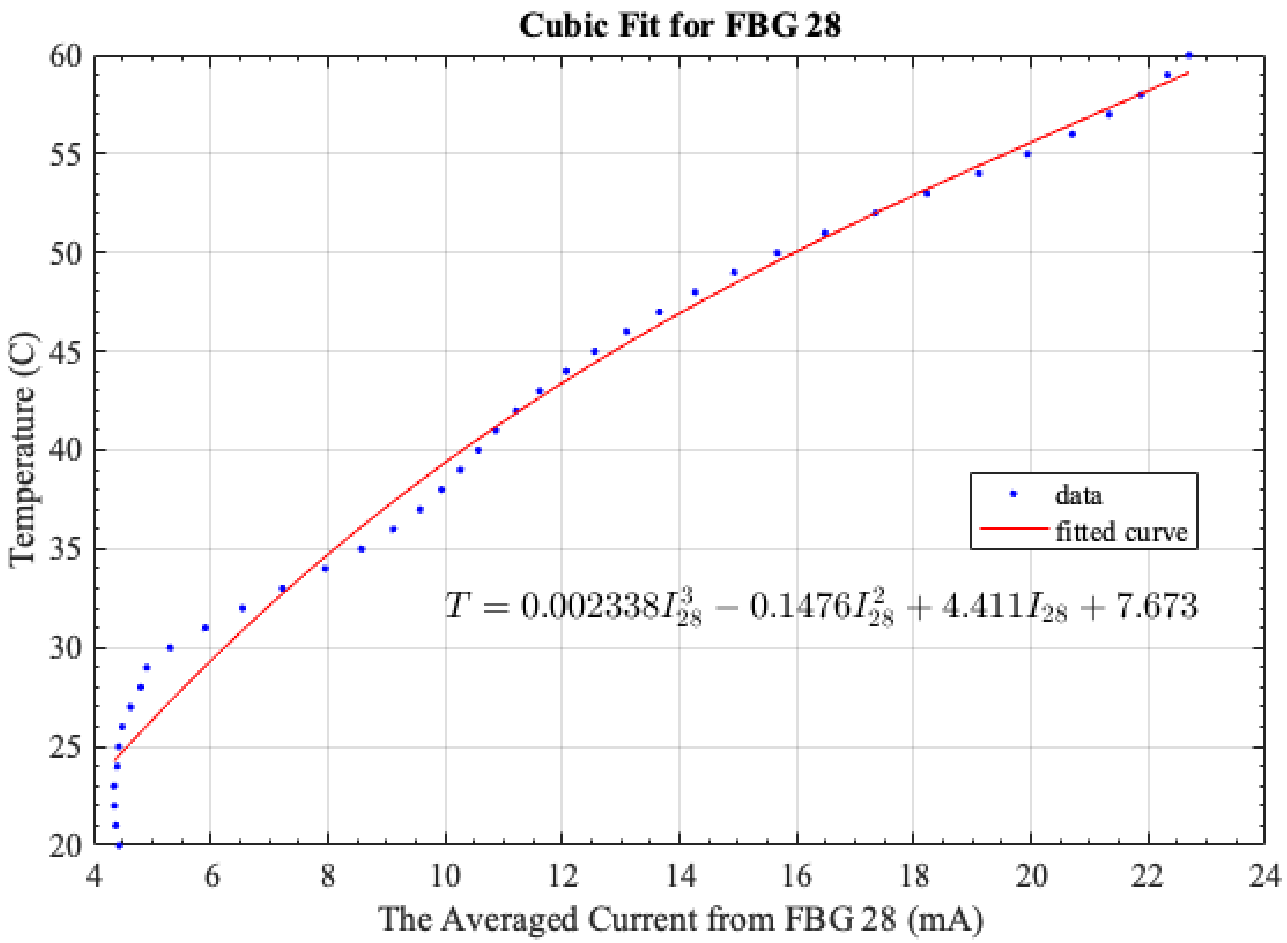




Finally, a fitting can be constructing

- Both linear and cubic fits are viable for this model
  - For the linear fitting, some data must be excluded where the system overloads
- Whilst for the cubic fitting, the entire data is taken into account





Testing the efficacy of the linear and cubic models of both FBG 26 and 28 in final Calibration test at 40°C

Plotted measures:

- Temperature Measured
- FBG 26 Linear Model
- FBG 28 Linear Model
- FBG 26 Cubic Model
- FBG 28 Cubic Model
- FBG 28 Fifth Degree Fit