Software development for production of the ATLAS inner tracker

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Abstract

The flatness measurement plays an important role in the process of testing the components of the ITk detector, especially the core. The project is focused on measuring the local flatness of each module of the petal core and the global flatness of the whole petal core. Final script may be afterwards implemented into the ITk Production Database.

Contents

1 Introduction

This report summarises the work I have done during my summer student program at DESY. The project was mainly focused on the Quality tests that need to be done when uploading the components of the inner tracker to the Production Database which is a tool used for tracing every single object that comes to the process of building the new inner tracker.

2 Theory

2.1 Inner Tracker

Inner tracker is the innermost part of the ATLAS detector. ITk will be the new inner tracker of ATLAS for the high-luminosity LHC that is going to be built in the future. The layout of the detector is shown in Figure 1. It is basically divided into two parts. Around the interaction point is the barrel region and in the forward directions there are two end-caps. Both of these structure constitute of so called local supports. Local supports may take the form of the stave cores in the barrel region or the petal cores in the end-caps. These supports are composed of a module with silicon readout electronics. The composition of the petal cores which where mostly discussed in the project is shown in Figure 2.

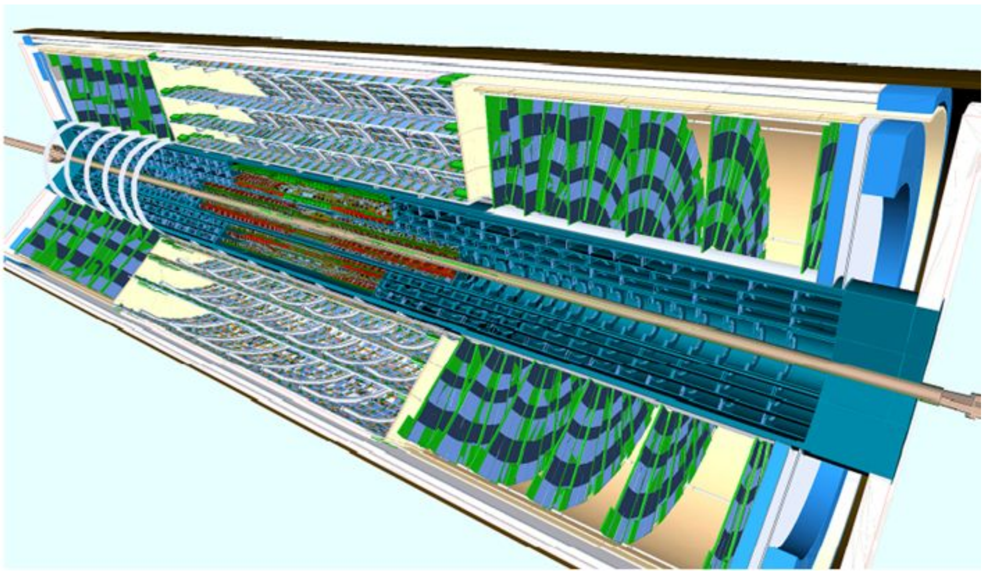

Figure 1: The layout of the ATLAS inner tracker. [1]

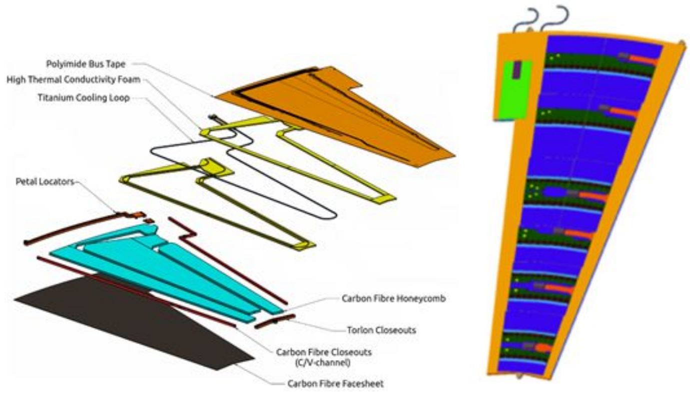

Figure 2: The structure of a petal core. [2]

2.2 Quality Control Tests

Before the local supports and other components of the inner tracker are combined they need to be tested. There is a great variety of different testing methods. In Figure 3 a brief summary of these tests for the local structure components of the inner tracker may be seen.

Component	Tests
Co-cured facing	Thickness. Tape measurements identical to those described for a bus-tape. Modulus tests on facing coupons. Resistance measurements on co-cured copper strips.
Carbon-fibre honeycomb	Thickness. Crush strength. Density.
Pipes	Pressure tests 200 bar. Helium leak tests.
Carbon-foam	Density. Electrical conductivity. Thermal conductivity.
C-channels	Thickness and dimensional measurements.
Peek closeouts	Thickness.
Graphite/epoxy	Two molded dog bone sample coupons per stave/petal. Full electrical and thermal testing of one sample for a fraction of the cores (1 in 5 cores or 1 in 10 cores). Other sample will remain a traveler with stave/petal for later testing if needed.

Figure 3: List of suggested quality tests on local structure components of the ATLAS inner tracker. [1]

The main focus of this work was on the flatness measurement [1]. It is a scanning technique used to measure the deviations on the surface of the sample so in our case on the surface of the petal core. Measurements are performed by Smartscope [3] which is an extra-large capacity multisensor dimensional measuring system. It offers very accurate positioning. The scanning head uses a focusing method to determine the relative distance of a measured point by identifying the focal plane with the measured point. Therefore the sample doesn't have to be touched and consequently the risk of a damage is reduced. The image of Smartscope and a typical result of a measurement may be found in Figure 4.

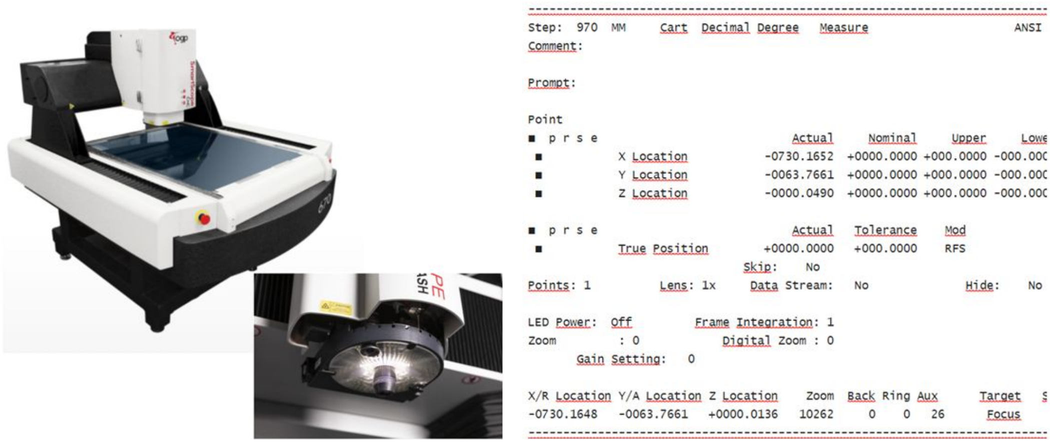

Figure 4: The layout of Smartscope used for flatness measurements [3] and a typical result of a measurement.

2.3 Calculation of flatness

The most interesting question is how to calculate the flatness from the z coordinates of the measured points on the surface of a petal core. In our work the Least Squares Reference Plane (LSPL) method [4] was. The idea of this method lies in finding the reference plane and subsequently calculating the deviations of the measured points relative to the plane.

The procedure may be described in following steps [5]. Let us note the coordinates of each point measured with Smartscope as X_i,Y_i and Z_i. Then a new coordinate system is defined as follows:

$$\bar{X} = \frac{\sum X_i}{n} \quad \bar{Y} = \frac{\sum Y_i}{n} \quad \bar{Z} = \frac{\sum Z_i}{n} \tag{1}$$

where n is a number of measured points in total and $O(\bar{X}, \bar{Y}, \bar{Z})$ would then be the origin of the new coordinate system. Coordinates of each measured point in the new coordinate system are then:

$$x_i = X_i - \bar{X} \quad y_i = Y_i - \bar{Y} \quad z_i = Z_i - \bar{Z} \tag{2}$$

Next step is calculating the parameters of a least squares reference plane passing thhrough the point O. These can be calculated as:

$$\hat{\mathbf{a}} = \frac{\sum y_i^2 \cdot \sum z_i x_i - \sum x_i y_i \cdot \sum z_i y_i}{\sum x_i^2 \cdot \sum y_i^2 - \left(\sum x_i y_i\right)^2} \tag{3}$$

$$\hat{\mathbf{b}} = \frac{\sum x_i^2 \cdot \sum z_i y_i - \sum x_i y_i \cdot \sum z_i x_i}{\sum x_i^2 \cdot \sum y_i^2 - \left(\sum x_i y_i\right)^2} \tag{4}$$

Using these 2 parameters one can describe the reference plane as $z = \hat{\mathbf{a}}x + \hat{\mathbf{b}}y$.
Finally the deviation of each measured point from the reference plane is given by:

$$e_i = \frac{z_i - \hat{\mathbf{a}}x_i - \hat{\mathbf{b}}y_i}{\sqrt{\hat{\mathbf{a}}^2 + \hat{\mathbf{b}}^2 + 1}} \tag{5}$$

This gives us an idea of how the deviation of each point may be calculated using the least squares reference plane method. However often it is important to know the local flatness of a certain region or a global flatness of the whole measured surface. In that case the total flatness E is calculated as:

$$E = |e^+_{max}| + |e^-_{max}| \tag{6}$$

where e^+_{max} is a maximum positive deviation and e^-_{max} a maximum negative deviation in the considered region.

2.4 Production Database

Production Database [6] is a centralized web application used for tracking the geographic location and utilisation of all parts during the construction of the ITk. All the results of Quality Control Tests as well as raw data are uploaded to the database so that the information about each step of the process is concentrated in one place and that every single detail, damage or wrong functionality is recorded.

3 Results

The main goal of the project was to prepare a script capable of working with the data obtained in a flatness measurement performed by Smartscope and subsequently calculating the local flatness of each module of the stave or petal core as well as the global flatness of a sample. The final part of the project was dedicated to uploading the raw data as well as the test results to the Production Database.
The scripts presented on the following pages were all written in Python 3 using Jupyter Notebook platform.

3.1 Flatness measurement

In the beginning it was important to prepare a script that would be able to load the data previously obtained in measuring the flatness of a stave or petal core. In our case the work was done using only one test file. Generally measurements are done on both sides of the core which are then referred to as front and back side. An example of the real surface of the petal core measured from both sides is shown in Figure 5. Specifically the test file represented the flatness measurement of a petal core. It contained approximately 1000 measured points distributed all over the surface of a petal core.

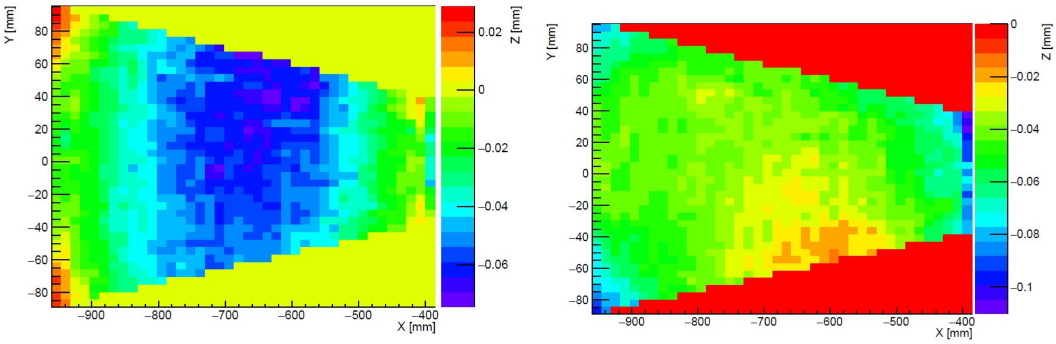

Figure 5: The surface of a petal core measured from front side and back side by Smartscope.

Afterwards a scheme visualising the petal core layout divided into 9 different modules was prepared and was plotted into the same graph with the measured data as shown in the Figure 6 (in this case only their x and y coordinates).

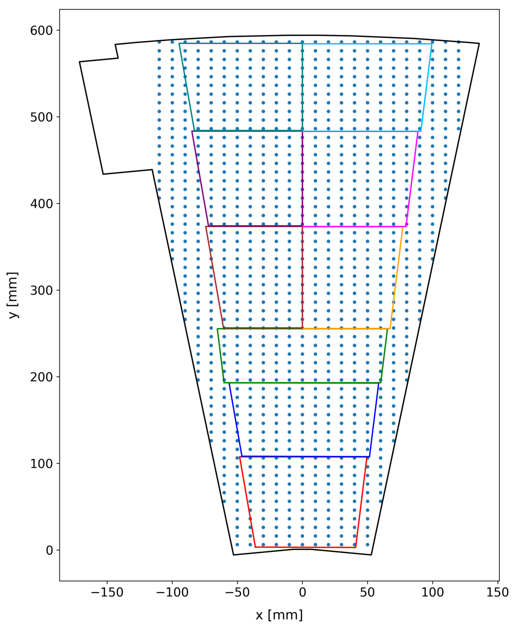

Figure 6: Points measured in a flatness test compared with the layout of a petal core.

Using this comparison it was possible to define the borders of the modules and divide the measured data into the subsets representing each of the 9 modules. For illustration the different subsets were plotted in 3D now including the measured z coordinates in order to be able to observe the surface of each module. An example of such 3D plot is shown in the Figure 7.

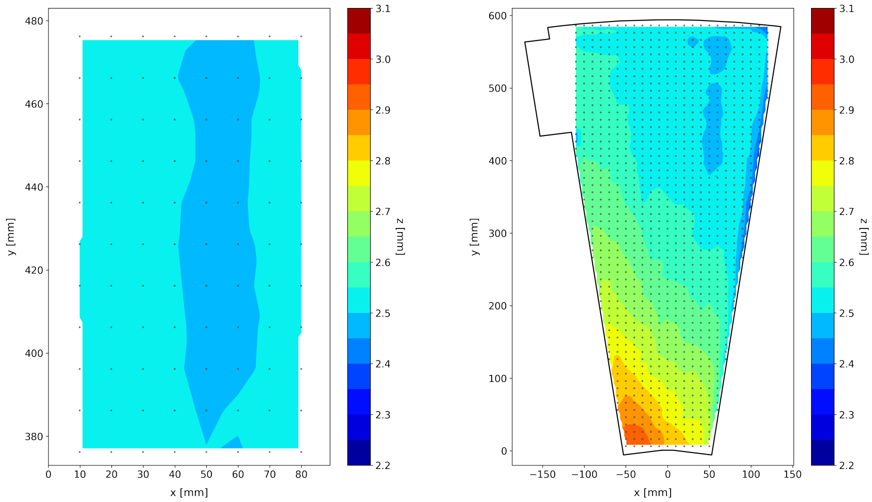

Figure 7: The surface of a module compared with the surface of the complete petal obtained from the test file.

3.2 Flatness calculation

In the next step the local flatness of each module was calculated using the process described in the Section 2. In Figure 8 a piece of code used for calculation is shown. The global flatness was calculated in the same manner only using the full measured dataset. The resulting values of local flatness of the modules and the global flatness for our test file is shown in the Table 1.

```python
def LocalFlatness(df_in):
    sumR = df_in.sum(axis=0)
    df_R = df_in - sumR/len(df_in)
    dfRxy = df_R.x*df_R.y
    sumRxy = dfRxy.sum(axis=0)
    dfRxz = df_R.x*df_R.z
    sumRxz = dfRxz.sum(axis=0)
    dfRyz = df_R.y*df_R.z
    sumRyz = dfRyz.sum(axis=0)
    dfRx2 = df_R.x*df_R.x
    sumRx2 = dfRx2.sum(axis=0)
    dfRy2 = df_R.y*df_R.y
    sumRy2 = dfRy2.sum(axis=0)
    A = (sumRy2*sumRxz - sumRxy*sumRyz)/(sumRx2*sumRy2 - sumRxy*sumRxy)
    B = (sumRx2*sumRyz - sumRxy*sumRxz)/(sumRx2*sumRy2 - sumRxy*sumRxy)
    dfRdev = (df_R.z - A*df_R.x - B*df_R.y)/math.sqrt(A*A+B*B+1)
    flatness = dfRdev.max(axis=0)-dfRdev.min(axis=0)
    return flatness
```

Figure 8: Part of the script where the Local Flatness is calculated.

Table 1: The local flatness of each module of the petal core and its global flatness calculated for the test file.

Module	Flatness [μm]
R0	76.0
R1	49.3
R2	54.4
R3S0	32.3
R3S1	46.9
R4S0	81.3
R4S1	56.1
R5S0	96.1
R5S1	53.0
Global	360.2

3.3 Results upload

In the end the raw data and the results needed to be uploaded to the Production Database. For that task a JSON file supported by database was created and filled with the raw data as well as the calculated local flatness of each module and the global flatness of the whole petal core. This file was then uploaded to the Production Database and assigned to a dummy core component created for our purposes.

4 Conclusions

The goals of the project were successfully accomplished. A script written in Python 3 was prepared. In near future it will help to calculate the Local Flatness of each module of the petal core as well as its Global Flatness. The measurements on Smartscope will have to be adjusted in the way that the orientation of a grid of measured points is the same as in the basic layout. Also the process would be much easier in the end if the measured points were divided into 9 modules already during the flatness measurement on Smartscope. Finally creating the JSON file useful for uploading the raw data as well as the calculated Local and Global Flatness values is also part of the script which again simplifies and accelerates the performance of the Quality Control Tests.

References

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[4] Jan-Hendrik Arling, *Detection and Identification of Electrons and Photons*, 2020

[5] Flatness fundamentals: https://remotelab.fe.up.pt/planesa/assets/Flatness_fundamentals.pdf

[6] ITk Production Database: https://desycloud.desy.de/index.php/s/D2NESCFyZFGs9Eg?path=%2FReferences%2FITkProductionDatabase#pdfviewer