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The LHCb Inner Tracker Module Production Steps and Quality Assurance

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Abstract

This note describes the various production steps for the LHCb Inner Tracker silicon modules. We quickly sketch where the various items are produced and mention their acceptance criteria where applicable. A detailed description is given of the various production and testing steps of the silicon detector modules in Lausanne and at CERN.

<u>*Disclaimer:*</u> *Despite the publication date, this is an old note with old calculations done in 2004. I apologize for the late publishing.*

1 Introduction

The "Inner Tracker" is part of the LHCb tracking system [1, 2]. There are three tracking stations located behind the bending magnet. The "Inner Tracker" covers the part closest to the beam-pipe with silicon micro-strip detectors where particle densities are high, while the outer region of the these tracking stations are covered by the "Outer Tracker" which is designed as a straw tube tracker.

An Inner Tracker station consists of 4 individual detector boxes, which are arranged around the beam-pipe. Boxes on top and below the beam-pipe are equipped with modules consisting of a single silicon sensor with 11cm readout strip length. Modules with two silicon sensor bonded together to form 22cm long readout strips are employed in the boxes to the left and the right side of the beam pipe. There are 4 detection layers per station. A total of 336 detector modules are needed for the Inner Tracker.

The assembly of the LHCb Inner Tracker modules is performed by groups from the "Universidad de Santiago de Compostela" and the "Ecole Polytechnique Fédérale de Lausanne". The work is split between two production sites where the mechanical production will take place in Lausanne, while the bonding and testing is done at the CERN site.

The modules are assembled from the read-out hybrids including the pitch-adapter, the silicon sensor(s) which are both glued on the carbon-fibre support structure and connected via wire bonding. The silicon sensors are delivered from Hamamatsu to Zürich, where they are tested for acceptance according to their specifications [6] before being shipped to Lausanne. The read-out hybrids are produced and tested under the responsibility of the MPI-Heidelberg.

This note first specifies the various module components, including a summary of the test performed before the delivery to Lausanne. Then the steps of the ladder assembly are listed in section 3, together with the quality tests for the different production steps. A detailed description of the basis electrical module tests designed to find open, shorted and channels with pinholes is given in the appendix.

2 The module components

This section describes briefly the different components of the module production and their individual acceptance test. For the sensors and hybrids that are under the responsibility of Zürich and Heidelberg, respectively the following should be regarded only as a brief summary.

2.1 Silicon Sensors

2.1.1 Sensor tests in Zürich

The sensors are tested in Zürich for acceptance [7] before being delivered to Lausanne. In summary the tests include:

- visual inspection
- I-V and C-V curves
- individual strip test and long term bias test on 10% of the sensors

2.1.2 Sensor tests in Lausanne

After the arrival of the sensors in Lausanne, no repetitions of the test performed already in Zürich are done. We perform only a quick visual inspection for obvious transport damage.

2.2 Readout hybrid and pitch-adapter

The readout hybrids with the Beetle readout chips [3] are produced under the responsibility of the MPI-Heidelberg. The pitch-adapter is glued directly on the Kapton hybrid by the company which performs the loading of the hybrid with the electrical components, RHe Microsystems [4]. The pitch-adapter is cut out of the ceramic piece with a precision of $\pm 25 \mu$m for each edge. The edges of the pitch-adapter are used to position of the whole hybrid on the carbon fibre module support. For the gluing of the hybrid the CF-support is placed in a jig which allows to hold the pitch-adapter in a well defined position w.r.t. the reference alignment holes on the mini-balcolny. The read-out chips are positioned w.r.t. the pitch-adapter such that the bond-pads on the read-out chip are aligned in x and y with the bond-pads on the pitch-adapter within $\pm 25 \mu$m. The distance between the bond-pads with the minimal bonding-length is adjusted to 1.5 mm.

2.2.1 Tests in Heidelberg

All hybrids undergo a first test at the assembly company, using a test setup provided by the MPI-Heidelberg. After delivery of the hybrids to Heidelberg, they undergo a temperature cycling and a 96h burn-in.

2.2.2 Hybrid tests in Lausanne

No specific tests in addition to what has been done in Heidelberg are foreseen in Lausanne. We perform a fast check of the hybrid for transport damage testing the principal functioning of the configuration and operation of the read-out chips, using the same test equipment provided by the MPI-Heidelberg as also used at the production company. Afterwards a careful visual inspection of the hybrid is done, focusing on possible damage of bond wires and damages of the pitchadapter. The visual inspection of the pitch-adapter particulary focues the bond pads and on scratches etc. in the fine-pitch region, where later repair would be impossible

2.3 Carbon Fibre support

2.3.1 Mini-Balcony

The mini-balconies are produced by the Atelier Mécanique Di Chiara [5] As the two sides need to be exactly parallel to ensure a correct positioning of the ladder. Therefore the mini-balconies are milled on each side, rather than simply produced from an aluminium sheet. The planarity of the mini-balconies is individually veryfied using a calliper gauge, accepting all hybrids where thickness variations are less than 30 μm.

2.3.2 CF-sandwich

The carbon fibre support (CF-support) is delivered from Composite Design Echandens [10]. It is a CF - Airex R82 foam sandwich [8], including the aluminium mini-balcony and the Kapton-coating which insulates the CF-side where the silicon sensors are placed. The mini-balcony is glued using a heat conductive silver glue (Tra-Duct 2902) After arrival from the company they have to be tested for:

- cutting precision: The ladders need to be cut to a precision considerably better than 0.5mm. The space between the sensor edge and the CF-edge is 1mm. As at the cutting edge, no HV-insulation can be guaranteed, a cutting precision of +-200 μm of the CF-support has been agreed on with the company[1].
- flatness: before measuring the flatness and HV-stability of the CF-support sandwich the holes for the alignment pins are drilled into the mini-balcony in the EPFL-workshop.
  The flatness of the CF-sandwich and the mini-balcony is then measured using a laser distance meter. This test is performed with the ladder fixed via the mini-balcony onto a standard support. A precision for the flatness of the support of 200 μm has been agreed on with the company. For the test including the mini-balcony, 500 μm maximum deviation at the tip of the ladder is allowed.
- HV-insulation: An insulation test up to 1000 V is done over the whole surface where later on the sensors will be placed. We get the CF-sheets coated with Kapton before they are further fabricated into the sandwich ladders for an acceptance test. After this initial test, the final CF-support sandwich is also specified to withstand the 1000 V. This guarantees that the insulation layer has not been damaged during the sandwich production. This test is performed using an aluminium block which has the same width and is about 6mm longer than the silicon sensors. This block is visually positioned on the CF-support where the actual silicon sensor will be placed. CF-supports that do not withstand the test at 1000 V are repaired using Epoxy for additional insulation. The test is repeated after the repair work.

3 Ladder Assembly

3.1 Production steps in Lausanne

- inspection of cutting edges of the CF-frame as described above
- drilling of positioning holes and fixation holes in the mini-balcony on the CNC milling machine at the EPFL-workshop. The position of these drillings is chosen centrally w.r.t. the side edges of the CF-support. Like this possible width variations of the CF-support are equally distributed on both sides of the sensors. The positioning is done using an occular attached to the milling head of the CNC machine,

[1] These specification proved unrealistic, and were actually relaxed at the same time when the CF-support width was increased from an original 79mm to 80mm, which allowd for wider margin. No fixed numbers however were put down.

recording the edge coordinates of the CF-support. During this procedure the width of the CF-support is controlled[2]

- smoothing (sandpaper) and glue coating of the edges of the CF-frame as a means of avoiding carbon fibre and foam "dust" or filaments sticking out of the support edges.
- HV-insulation test.
- test of planarity/flatness
- functionality test + visual inspection of the hybrid before gluing
- hybrid gluing: The hybrid with the pitch-adapter is glued to the CF-support using normal Araldite (loaded with micro-ballons to adjust the viscosity) applied by the gluing robot. Only underneath each Beetle chip a small amount of conductive silver glue is used that provides ground connection and thermal contact of the readout chips to the mini balcony. The positioning of the hybrid is done using the pitch-adapter fitting in a positioning jig.
- check resistivity of GND-VDDA and GND-VDDD to spot possible shorting of hybrids via the conductive glue. This test is done immediately, i.e. before the glue is cured. This allows for repair work in case such shorting should happen.
- functionality test of the hybrid after gluing
- visual inspection of the pitch-adapter (for possible damage/glue traces etc)
- pairing of sensors with similar depletion voltage in case of 2 sensor modules
- quick visual inspection of the sensors
- sensor gluing: The sensors are glued using silicone glue (Dr. Neumann NEE-001-weiss) applied using the gluing robot. Two traces of glue are applied per sensor, placed underneath the bonding pads. The sensors are placed on the CF-support using a vacuum transfer tool [9]. The sensors have previously been positioned against alignment pins on the positioning jig from where they are picked up with the vacuum transfer tool with a teflon surface. The sensors are lying on the backplane when being positioned. The vacuum tool attaches to the strip side of the sensors. In addition to thorough cleaning of the sensors using a ion-air gun, a fresh piece of clean-room paper is placed between the transfer tool and the sensor for further protection.

  The CF-support is fixed during this gluing procedure on a jig by means of the alignment pins.
- visual inspection of the sensors after gluing

After the curing of the glue, the modules are mounted in our transport boxes and brought to CERN.

3.1.1 Production steps at CERN

The main production steps performed at CERN are the bonding of the modules, HV-tests, electrical readout tests and metrology.

Bonding and HV-tests:

- visual inspection for possible transport damage and thorough checking of the bond pads.
- a few test bonds are placed in the "centre of the pitch-adapter" on the wide strips. These bonds are pulled as a test of the bond parameters, which are adjusted if necessary.
- bonding hybrid to pitch-adapter (row by row) with visual inspection

[2]Basically none of the CF-supports had a width smaller than the specified 80mm. Wider supports up to 80.5mm were finally accepted for the production.

- bonding 1st sensor bias connection
- I-V measurement
- bonding 2nd sensor bias connection (for 2 sensor ladders)
- I-V measurement (for 2 sensor ladders)
- bonding pitch-adapter to sensor
- bonding 1st sensor to 2nd sensor (for 2 sensor ladders)
- I-V measurement

For the module burn-in and readout tests, the modules (up to 6 at a time) are placed in a temperature cycling box. This box allows to make temperature cycles between $-5^\circ C$ and $+40^\circ C$ in about $1\frac{1}{2}$ hours. During the whole time of the temperature cycling, the 500 V bias voltage is applied to the sensors. A readout of the module is performed at 5 different temperatures ($-5^\circ C$,$0^\circ C$,$10^\circ C$,$20^\circ C$,$40^\circ C$). The readout hybrid is powered only for the actual time of the data taking while it is switched off during the cooling and warming up periods. This is necessary as the cooling power is not sufficient to cool down the box within a reasonable time while the hybrids are powered. This however does not pose a problem, as each hybrid already had passed a 96h burn-in period at Heidelberg before.

The various steps are:

- I-V measurement before burn-in
- temp-cycling (30 cycles between $-5^\circ C$ and $+50^\circ C$) with one data taking from the hybrid per cycle at varying temperatures of: $-5^\circ C$, $0^\circ C$, $10^\circ C$, $20^\circ C$ or $40^\circ C$. One data taking includes:
  - pedestal (noise) measurement
  - pulse-shape scan performed with an internal test-pulse signal injected to all Beetle channels at the same time
  - test-pulse scan at the peak of the pulse-shape with only every 8th -channel being having injected the test-pulse charge at a time. This test aims to find open and shorted channels (see also appendix A).
- pinhole test. The pinhole test consists of taking pedestal data without sensor bias and a 25W light bulb shining (infrared-)light onto the sensors. The induced photo current saturates the Beetle preamplifier in case of pinholes which then results in very low noise signal for the respective readout channel.
- I-V measurement after burn-in

All I-V measurements are done at ambient room temperature and humidity which is typically about $20^\circ C$ and some 40% relative humidity. If the I-V measurement has been done at slightly elevated temperatures, we note the temperature and perform afterwards a temperature correction of the recorded leakage current.

The leakage current during the temperature cycling is also recorded at intervals of about 5 min. However the resolution of the CAEN HV-supply used for biasing the modules during the temperature cycling has a minimal resolution of 100 nA only and does not seem to give very precise and reliable measurements for very low current readings.

The electrical tests are made with nominal Beetle settings (see Beetle Manual [3]). A more detailed description of these tests is given in the appendix A.

- Metrology: At any time, before or after bonding or electrical readout test, a metrology measurement of the (long) ladder modules is performed using a microscope and an x-y table. The z-coordinate is also recorded using the focusing of the microscope and a readout attached to the z-axis of the microscope.

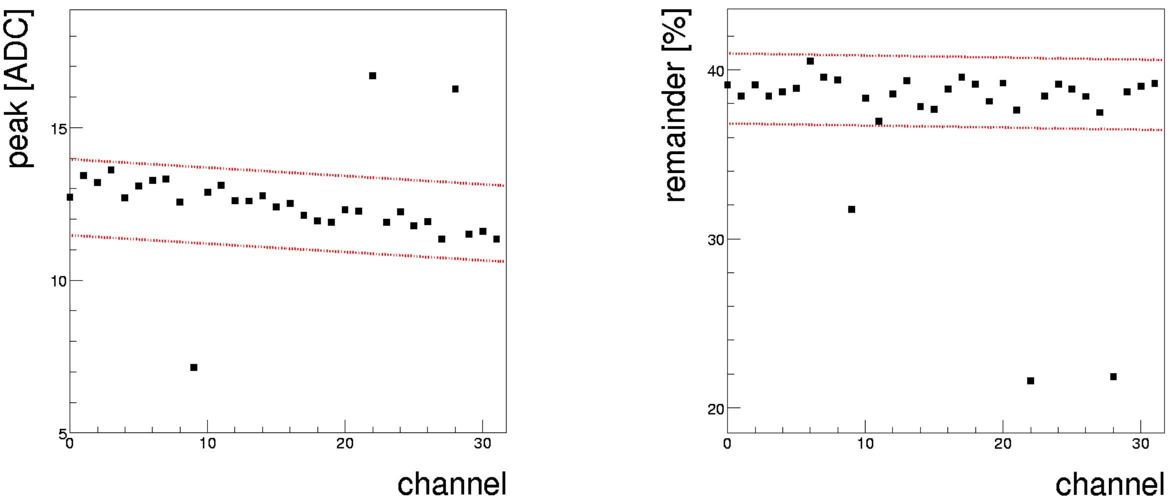

Figure 1: The result of the peak hight test (left) and the remainder test (right). The dashed lines indicate three standard deviations to a linear fit after discarding the defects. Every fourth channel is plotted due to the four-fold test-pulse pattern of the Beetle1.2 chip. The outliers mark candidates for broken or shorted bonds. For two channels with a broken bond between the middle and the first sensor, the pulse height is higher than the average. For a shorted channel the pulse height is smaller due to the increased load capacitance. Shorts and broken bonds appear as having a smaller remainder than the average (right).

A Electrical module tests

An efficient detection scheme of potential defects on the ladders is important for the quality assurance during the production. The test procedure forseen for the production has been verified on a test-beam module, equipped with 3 sensors. On this module artifical defects were introduced by removing bonds, creating shorted channels and shorting the DC with the AC pads on the sensor to simulate a pinhole. [3]

The electrical module tests rely to a large extend on the internal test-pulse provided by the Beetle readout chip in order to detect defects occurring during the production (in particularly the bonding process). This test-pulse allows in an efficient and reliable way to detect shorted and open channels as they cause a change in the load capacitance and thus affect the response of the Beetle read-out chip [11].

A.1 Peak-height and remainder tests

Pulse-shape scans were performed with the internally generated test pulses of the Beetle. Defects are identified as channels whose pulse height lies more than three standard deviations outside the general distribution of the other channels. An example is shown in figure 1 (left). A linear fit is used to allow for an overall linear trend over the different read-out channels. Channels with broken bonds have less capacitance which increases the gain in the amplifier. Shorted channels appear to have a lower peak height, due to the increase of the capacitance. This makes it easy to identify these two defects. Additional information can be gained from the shaping time. The distribution of the ration between the signal and its remainder 25 ns after the peak time is shown in figure 1 (right). This is however not done in during module production as it did not seem necessary.

[3]these tests were later on repeated in the finale temperature cycling box using a real module which also had natural shorted and open channels as well as artificial pinholes (and probably a real one, too).

References

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