Drift Tubes Quality Assurance and Quality Control

Draft 4

Hints for Discussions and Decisions
To be used internally in the QC Group

The Drift Tube Chambers Quality Control Group

June 11, 1999

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Abstract

In this note we describe the set of measurements and tests for the Quality Assurance and the Quality Control of the CMS DT Muon Chambers. This document is subject to change and will be regularly updated.

Contents

1 Introduction

This document gives a detailed description of all steps of Quality Assurance and Quality Control during the assembly of the Drift Tube (DT) Muon Chamber.

Only the tests to be organized in the *DT production sites* are considered here. These include the Quality Assurance procedures on the material delivered by industry which follow the technical specifications described in the "Invitation to Tender" documents.

The final tests to be performed on the chambers prior to installation in the CMS wheels will instead appear in a separate document.

Both the descriptions of the *quality assurance tests* on the material received from industry and of the *quality control tests* during the drift chambers assembly are associated to flow-charts which define the sequence of the operations during the production.

Many of the tests described in this note were developed during the construction of several DT prototypes.

In the following the *general characteristics* of the tests and the *specifications* of the measurements are described. Local QC procedures may differ from one production site to another, but they will always ensure the agreed quality of the product and monitor the failure rates.

At present all the tests described in this note are considered *mandatory*. This is for safety considerations at the beginning of the production. Some of the QC tests may be omitted or replaced as more experience is gained during production.

2 General Considerations on Quality Control and on Quality Assurance

Components for the chamber assembly will be manufactured at the following production sites:

- Al-plates are preassembled in DUBNA (Russia)
- I-beams are preassembled in Bologna (Italy) and DUBNA (Russia)
- Wires are quality controlled in Aachen (Germany)
- electronics boards are assembled in IHEP (Bejing.).

Drift chambers will be assembled at the following production sites:

- Aachen (Germany),
- Madrid (Spain),
- Padova (Italy)

- Torino (Italy).

The assembly of all CMS Muon DT chambers will span over four year time period and can be summarized in the following main steps: the external suppliers provide the *part production sites* of raw materials and then the pre-assembled parts, together with other components coming from industry, are submitted to the *chamber production sites.*

All chamber production sites will use identical components such as: Al-plates, I-beams, wires, strips, endplugs, SL enclosures and all the other mechanical and electronic components. Regarding the chamber design all parameters in the drawings are agreed upon centrally.

The production tools and the QC test stands may not be the same in all production centers but the measured parameters will be entered in a common database.

The Quality Control tests can be divided into two principal parts:

- Quality control tests on *raw materials* and on *pre-assembled parts*; these tests are performed on Wires, Al-plates, I-beams and Mylar/Al-strips, and on the Al-plates and I-beams assembled with the electrodes.
- Quality control tests during chamber assembly; these tests are performed during the Super Layer (SL) assembly, when the SL is finished and when the chamber is assembled.

Each test has to satisfy pass/fail criteria which are specified in the following sections.

During the DT chambers assembly all the material coming from industry will be inspected on a sample basis for each production batch. Failures of these tests will be monitored and will trigger further testing to establish the integrity of the corresponding batch and the compliance of the manufacturer with the QC tests specified in the contract. Faulty material is definitively discarded and might be send back to the supplier.

The pre-assembled components which fail the QC test are instead temporarily discarded. If the failure rate will be low these parts will be repaired at a later time, without disturbing the production flow.

If a QC test during chamber production fails, the problem is instead cured as soon as possible and the QC test is repeated.

In general quality control tests may be divided in *local tests*, performed *only* in the part production centers or in the chamber production centers, and *central tests* performed at the production center and at CERN before the installation in CMS. These are the tests which concern the full chamber already mechanically closed, but there are items, like the wire tension measurement, which may be necessary to check after the chamber shipping.

The chamber assembly and quality tests during production are performed in a temperature controlled clean room. The temperature should be monitored at least every hour. The minimum temperature of the production site must be 18^oC, this to ensure the right epoxy/hardener mixing during glue curing. A nominal working temperature should be defined and shold be mantained within $\pm 2^o C$. The air must be kept as clean as possible using clean clothes and shoes and filtering the air. A reasonable goal is the class M6. The atmospheric pressure must be measured and recorded during quality tests on Super Layers. The umidity should be measured during H.V. tests, the current limits are referred to umidity lower than 70%.

Table 1: Environment variables to be controlled

Variable	Bonds	Freedom level
Temperature	$T > 17\ ^oC$	Mandatory
Temperature	$\Delta T \pm 2\ ^oC$	Suggested
Air cleanliness	Class = M6	Suggested
Atmospheric pressure	Measured	Mandatory
Humidity	Measured	Suggested

3 Recording and Archiving of the Data

All items used during the assembly of the DT chamber will be identified by an *id* number or a *batch* number which corresponds to a computer readable *bar code*.

Some items require also a text-code identifier for easier reading by the operator.

All production sites use the same *Data Base* to store the flow of material during chambers production and to store Quality Tests results. It is a *distributed* Data Base and it is based on Objectivity.

3.1 Barcode

The barcode to mark the bare components and the produced objects has the following structure:

3	51	XX	XX	XXX	XXXXX	X
CMS	BMU	Prod. Centers	Products	Specifics	Serial Number	Check digit

The first three numbers come from a CERN standard assignment. The rest of the barcode is intended to be a numeric code. The suggested code is the Interleaved 2 of 5 (I 2/5). It allows a variable length and a high density (16 characters in a label 22.4 mm long). One limitation of the code is that it requires to use an even number of digits (check digit included).

3.1.1 Production centers

There are 9 production centers: 4 for the chamber assembly and 5 for the chamber components. The list of the centers with their code and their task is described in Table 3.

3.1.2 Products

The list of the products to be tagged with a bar code label is described in Table 2 with their code and their identification requirement. ID indicates that each individual item was given a label with an identification number which in the case of the "chamber" must persist for the duration of the experiment. Batch indicates that the corresponding items are assigned a "batch number" which identifies their production period. In this case boxes are identified with bar code labels rather than the individual items.

3.1.3 Specific code

Some objects need an additional specific code. A single object code has been allocated to the Al-plates but there are 5 different Al-plates inside one SL. Moreover different chambers (MB1/PHI, MB1/Z, MB2/PHI, etc.) have Al-plates and I-beams with different dimensions. Using a bar code portable reader is possible to decode and display the specific type of the object. This code will help technicians to pick up the right object and will avoid errors in the chamber construction by implementing an automatic check. The list of the specific codes is described in Table 4.

4 Quality Assurance on Raw Material

The following materials are supplied by industry and are subjected to Quality Assurance tests in the *Part Production Sites* or in the *Chamber Production Sites*.

- Al-plates
- I-beam profiles
- Al-strips
- Mylar strips
- Wire spools
- Honeycomb panels
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Qualification criteria about the commercial and technical aspects are described in details in the Market Survey Documents relative to each item. Here a review on the technical specifications of the materials, the supplier obligations and the Quality Assurance tests is given.

4.1 Aluminium Plates

4.1.1 Technical Specifications

The technical specifications for the material supply are given in the following:

- The aluminium alloy is 5005 in its metallurgic state H32;
- Plate thickness is 1.5 mm nominal (tolerance ± 0.13 mm);
- Tolerance on plate length +5/-0 mm;
- Tolerance on plate diagonal 5 mm;
- Tolerance on plate planarity: maximum arc 4 mm/m on lenght, maximum arrow 5 mm/m on width.

4.1.2 Supplier Obligations

The supplier obligations are:

- The plates will be delivered cleaned and treated with a skim bath at the end of the rolling mill, as suited for industrial surface treatment for structural glueing, but with the requirement that the surface electrical resistivity is not increased by the chemical bath.
- Each plate will be protected with paper foils on both sides.
- Chemical analysis of the casting will be performed.
- Geometrical dimensions and tolerances of the plates will be statistically checked.
- A statistical ($\sim 10\%$) visual inspection of plates surfaces will be performed.

4.1.3 Quality Assurance

The Quality Assurance plan at the *AL-plates production site* foresees the following steps:

- The QC documentation provided by the manufacturer for each production batch will be controlled to certify that the contractual standards were met in the production.
- A visual inspection of the Al plates will be performed to ensure that they were not damaged during transportation, storage and handling.

4.2 I-beams

4.2.1 Technical Specifications

The technical specifications for the extruded profiles are:

- The aluminium alloy is AIMgSi 6060 T5 ;
- The cross-section area used to identify the extrusion bores should not exceed $0.06mm^2$;
- The straightness and torsion of the I-beam should be better than 50 % of the DIN17615 requirement;
- The I-beams must be smooth and free of defects;

4.2.2 Supplier Obligations

The supplier obligations are:

- it will analyze the chemical and mechanical properties of castings and billets;
- it will perform ultrasonic tests of billets;
- it will perform statistical control of geometric tolerances and of the straightness of the extruded profiles;
- it will perform full dimensional and visual control of at least 10 % of the finished I-beams for each batch with certificates;
- The I-beams will be enclosed in a plastic bag inside the box with a dehumidifier bag. Different batches are packed in separate identifiable boxes.

4.2.3 Quality Assurance

The Quality Assurance plan at the *I-beams production site* foresees the following steps:

- The QC documentation provided by the manufacturer for each production batch will be controlled to certify that the contractual standards were met in the production.
- A visual inspection of the I-beams will be performed to ensure that they were not damaged during transportation, storage and handling.
  Under visual inspection the I-beams should appear to be straight and without any sign of damage.
  The thickness of the I-beams and other crucial parameters will be measured on a random basis for each batch of delivered I-beams and for each extrusion bore.
  The results of these measurements will be entered in the *DataBase*.

4.3 Honeycomb

4.3.1 Technical Specifications

The technical specifications for the material supply are given in the following.

The panels are composed by:

- honeycomb: inch cells , aluminum 3003-0028N
- skins: aluminum 5754 H 257, 1.5 mm thick
- lateral profiles: extruded aluminum 6060 provided by CMS-DT group

The lateral profiles must be glued to the top and bottom skins with structural adhesive. They must also be glued to the honeycomb with foaming adhesives.

The tolerances are (for definition of Lenght, Thickness and Width):

- L: 2 mm
- T: 0.5 mm
- W: 2 mm
- flatness: ¡ 0.5 mm on overall panel
- Difference between 2 diagonals of the same skin: ¡ 3 mm

The skins must be clean, with no marks, dents, kinks, handling marks etc.

4.3.2 Supplier Obligations

The supplier obligations are:

- Panels are to be delivered fully cleaned and degreased of any contaminants, e.g. oil, dirt, metal chips, metal dust etc. They are intended to be used without any further cleaning at the production sites.
- A control of geometrical tolerances (L, W and diagonals) and a visual control of all panels have to be performed.

4.3.3 Quality Assurance

The Quality Assurance plan at the *Chamber production site* foresees the following steps:

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4.4 Wire

4.4.1 Technical Specifications

The technical specifications for the material supply are given in the following:

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4.4.2 Supplier Obligations

The supplier obligations are:

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4.4.3 Quality Assurance

In the following the Quality Assurance tests on wire spools are described. All the spools necessary for the whole chamber production are received and tested in Aachen (Germany).

A *batch bar code* is assigned to *each spool of wire* as it arrives from industry.

The Quality Assurance of raw wire batch comprises the following tests:

- Magnetic properties of the wire
- Wire elasticity
- Wire strength

A simple visual inspection of the wire will be performed with an optical microscope to check the quality of the wire surface.

To test of the magnetic properties of the wire the equipment from a solid-state institute will be used. The wire should be non-magnetic. A goldplated *Nicotin* wire by Microfil industry (50 μm in diameter) has been tested and has shown a magnetic susceptibility of the order of $5{\cdot}10^{-3}$ which is acceptable.

This test has to be performed on each spool of wire since the magnetic property may depend on the production process.

To test the wire elasticity some manual equipment exists for measurement of the wire's Young's Module. A computerized version is also considered. This measurement can also be performed during the assembly of the wire with the crimping blocks with the help of the wire crimping tool and the single channel wire tension meter.

The wire's strength is characterized by the wire's rupture point which can be measured with two methods:

1. maximum wire tension: this can be done with the same manual equipment used for measuring Young's Module (see above);
2. maximum elongation: this can be done with the wire crimping tool. The machine's software foresees this point.

Note that the second method can be used at every production site as well, to check batches in use and especially, for larger spools, to check the end of the spooled wire, which is unaccessible beforehand.

The quantitative measurements of wire elasticity are driven by the nominal tension of 3 N. The elongation has to be linear (about 9 mm/m at 300g) and far enough from the rupture limit (about 4.7 N). The acceptable range for these parameters is around $\pm 5\%$.

If a spool fails one of these tests, it should not be used.

4.5 Mylar and Al Strips

4.5.1 Technical Specifications

The technical specifications for the material supply are given in the following:

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4.5.2 Supplier Obligations

The supplier obligations are:

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4.5.3 Quality Assurance

The Quality Assurance plan at the production site foresees the following steps:

- the tape width should be within $\pm 200\mu$m of the nominal value
- the cut surface should be free of excess glue
- the cut surface of the Al tape should be free of dents or other imperfections.

4.6 High Voltage Boards

4.6.1 Technical Specifications

The technical specifications for the material supply are given in the following:

The HVB is a 8 layers printed circuit board 305 mm long (L) by 36 mm wide (W) by 3.5 mm thick (T) made of FR4 material. Each one of the 6 inner layers must be 0.5 mm thick; the 2 outer layers must be 0.2 mm thick. The tolerances are:

- L : 0.5 mm
- W: + 1 mm, - 0 mm
- T : 0.1 mm
- C : 0.1 mm
- Flatness : 0.5 mm

Particular care is requested in the cleanliness of the fabrication process and in the centering of the printed area with respect to PCB borders.

The boards will be operated in high voltage conditions. Layers 3 and 4 will be tested to -3kV, layers 2 and 5 to +3kV, layers 1 and 6 to +5kV, simultaneously with respect to the diffused ground of the layers. The two outermost layers 0 and 8 have no paths and are meant for insulation. Non metallized vias are marked (*).

A HVB will feed the three high voltages (+/- 2kV, +4kV) to 8 consecutive cells of one plane, on two adjacent planes. Each board will lodge 4 groups of hybridized resistors, 6 HV blocking capacitors, 18 pins for input/output connections of high voltages, and 16 wires providing for connections to the chamber anode electrodes; components will reside on both sides of the PCB.

4.6.2 Supplier Obligations

The supplier obligations are:

Production runs shall be clearly identified and traceability ensured. The boards must be delivered fully tested for short circuits and interruptions.

High Voltage test at the above specified values will be performed by the supplier with a dedicated Test-Jig. Boards not passing this test shall not be accepted.

4.6.3 Quality Assurance

The Quality Assurance plan at the *HV production site* foresees the following steps:

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5 Quality Control on Pre-assembled Components

In this section a detailed description of all the tests to be performed at the part production sites is given. In Table 5,Table 6 and Table 7 the principal numbers for the following quality control tests are summarized.

5.1 Aluminium Plates

Aluminium plates are a component of the DT chambers which will be pre-assembled in the JINR production center.

The raw components to be delivered at this production center are:

- Al plates
- Mylar and Al tapes which constitute the electrodes.

Each box of material arriving from industry will have QC papers as specified in the contract which, in all cases, will include the production period. This information will be entered in a *DataBase* and will be associated with a *bar code* label (*batch number*) which will be attached to the corresponding box.

The main phases of the plate production are:

- cutting the plates to the required dimensions
- cleaning the plates
- electrode deposition
- HV test.

These operations, which will be carried out in parallel in three different working areas, require frequent access to the *DataBase* for monitoring the work flow and for data storage and retrieval. A user friendly *DataBase*, or a suitable interface, will be provided in order to minimize the interference with the production work.

Calibration of the dedicated tools used for cutting, and depositing the electrodes will be performed *every day* to certify their functionality.

5.1.1 QC on AL-Plate geometry

with tolerances.

- Thickness
- Lenght, width
- Diagonals

5.1.2 QC of Electrode Deposition

Each plate will be identified by a *bar code* and a visual identifier after cutting, cleaning and visual inspection.

The *bar code* will be entered automatically in the *DataBase* when the plate is still on the cutting table.

The main steps of the electrode deposition are:

- move the plate on strip deposition table
- align the plate on the table; precision of $\pm xxx\mu$m guaranteed by positioning pins
- retrieve the type of plate using the *bar code* from the *DataBase*
- attach the Mylar and Aluminium tapes with a PC controlled movable head
- QC of tapes and centering of the Al tape with a CCD camera during the deposition of the tapes. In case of failures the strips will be substituted
- move the plate to a service table and perform a visual inspection of the strips.

After completion of this phase a code will be entered in the *DataBase* to indicate that the plate is ready for HV test.

5.1.3 HV test

The finished Al plates will be moved to a rack which can contain up to eight plates. The HV test will be done simultaneously for the electrodes deposited on both sides of the plate with custom made multi-contact bars.

The HV test comprises the following steps:

- retrieve the plate type from the *DataBase* using the *bar code*
- ramp-up the HV to 4000 V under computer control
- monitor the current with a granularity of 10 strips for 10 minutes
- measure the humidity pressure and temperature inside the HV rack
- compare currents drawn with reference value at the same ambient conditions.

If the test was successful, i.e. all currents within tolerances from reference value, the following information will be stored in the *DataBase* :

- current drawn by each group of strips

- humidity pressure and temperature inside the HV rack
- number of trials before a successful HV test
- ID of strips which had to be repaired and type of repair

If the HV test fails the faulty strips will be identified for repair which typically will require the substitution of the Al tape or of both the aluminum and mylar tapes.

5.2 I-beams

I-beams are a component of the DT chambers which will be pre-assembled in a separate production center at IHEP Protvino.

The raw components to be delivered at this production center are:

- Aluminum extrusions (I-beams)
- Mylar and Al tapes which constitute the electrodes.

Each box of material arriving from industry will have QC papers as specified in the contract which, in all cases, will include the production period. This information will be entered in a data base and will be associated with a *bar code* label (*batch number*) which will be attached to the corresponding box.

The main phases of the I-beam production are:

- cut I-beam to nominal size with $\pm 200\mu m$ tolerance
- de-burr and smooth cut surfaces
- wash with cleaning mixture (water and special detergent)
- rinse with demineralized water
- dry the I-beams in a clean (dust free) environment
- attach mylar and aluminum tapes
- HV test of finished I-beams.

During all production phases the *batch number* of the used raw materials will be entered in the *DataBase*.

A *bar code* label (*batch number*) will be assigned to each box of finished I-beams, typically 2000.

The packing order of the I-beams inside the box will index to sub-*batch numbers* corresponding to the daily production, ~ 300 finished I-beams.

Calibration of the dedicated tools used for cutting the I-beams and depositing the electrodes will be performed *every day* to certify their functionality.

5.2.1 Electrode Deposition Procedure

The mylar and Al tapes will be attached to the I-beams in a clean, dust free, area with temperature control ($15 - 28°$C).
This production phase consists of the following steps:

- attach the mylar tape to the I-beams one side
- precision cut of the mylar tape
- attach the electrode (Al tape) to the I-beams one side
- cut and finish the electrode ends
- repeat for the other side of the I-beams

During the electrode attachment procedure, up to 40 I-beams are positioned flash against reference blocks, on a precision machined plate (dish).

The production cycle begins with the dish loaded with bare I-beams on a service table (C1).

The dish (D1) is moved with a small overhead crane to the XY-plotter (A) and positioned with precision reference pins.

The mylar is then precision cut (-0 + 200μm from the I-beam ends) with semiautomatic tools positioned at the two extremities of the XY-plotter. The mylar distribution tool (*head*) is replaced with the aluminum distribution *head* .

The aluminum tape is attached automatically to the I-beams.

The dish D1 is then moved to a service table (C2) for the precision cut of the electrode and the dish D2, is moved from C1 to the XY-plotter.

While the mylar and aluminum tapes are being attached to the I-beams on dish D2, the electrode is precision cut to the nominal value (5mm $\pm 200\mu$m from I-beam edge) on the I-beams in D1 and the I-beams are turned to the second side.

In the next step, dish D2 is moved to C1 and dish D1 is moved on the XY-plotter.

The most critical parameter in this procedure is the alignment of the tape distribution *head* with respect to the I-beams. This will be checked automatically for each dish by positioning the *head* on a reference mark mounted on the dish itself.

Bookkeeping is a very difficult task in the case of the I-beams since it is not realistic to identify them individually. The strategy adopted is to associate the I-beams with the dish used during the electrode deposition and the sequence of the dish during the daily production (sub-*batch numbers*). This correspondence will be entered in the *DataBase* and will be maintained in the packing order of the finished I-beams in the shipping boxes.

5.2.2 QC of Finished I-beams

This production phase comprises the following steps:

- visual inspection of the electrode surface and centering in the I-beam profile.
- measurement on a random basis of the distance of the mylar and electrode edges from the edge of the I-beam
- HV test in air:
  - ramp-up the HV to -4600 V under computer control
  - monitor the current with a granularity of 10 I-beams, both sides, for 10 minutes
  - measure the humidity pressure and temperature inside the HV rack
  - compare currents drawn with reference value at the same ambient conditions
  - identify and disconnect faulty I-beams for repair; typically the Al tape or both Al and mylar tapes will be replaced
  - bookkeeping of number and types of failures for feed-back to the manufacturing level.
- HV test in Ar:CO_2:
  - insert the I-beams which passed the HV test in a gas tight box
  - pump-out the air from the tank and fill with Ar:CO_2 (85:15) mixture
  - after a given level of oxygen contamination (500ppm) is reached, the I-beams should:
    - reach -2200 V without discharges
    - maintain -2100 V overnight;
      the current drawn will be monitored with a granularity of 20 I-beams and compared with reference values.
  - the I-beams which fail this test will be visually inspected and the centering of the mylar and Al tapes will be measured to determine the nature of the failure. These I-beams will then be set aside for repair or will be tested again.

– a bookkeeping of the number and types of failures will be kept for feed-back to the manufacturing level.

I-beams passing the QC tests will be stored in the shipping crates which will be identified by a *bar code* and a visual label. The packing order in the shipping crates will be stored in the *dataBase* and will reflect the dish sequence used during the electrode deposition phase.

5.3 High Voltage Boards and Capacitor Boards

High Voltage boards are a component of the DT chambers which will be pre-assembled in the IHEP-Bejing production center.

5.3.1 HVB mounting specifications

HV pins and GND contacts should be mounted by use of the appropriate jigs and oriented as in the artwork sketch.

HV Capacitors should be oriented as in the artwork sketch.

HV hybrid resistors soldered to PCB pads by means of appropriately short wires and positioned precisely with respect to pads.

Wire connections assembled as shown in the HV Interconnection drawing.

All soldering points should be carefully executed so to avoid spikes.

To clean soldering residuals, mounted boards should be washed with the appropriate solvent to be specified.

All soldering points on one face should be isolated with the proper amount of 3M-DP 190 epoxy glue and left $\sim$ 4 hours to cure, then the opposite face should be treated and left $\sim$ 12 hours to cure at ambient temperature. Epoxy glue should be stored as specified by the fabricant.

Mounted boards should be stored in a dry ambient for at least 24 hours before test and should be always handled with gloves.

5.3.2 HVC mounting specifications

Guidance pins and GND contacts should be mounted by use of the appropriate jigs.

HV Capacitors should be oriented as in the reference specimen. Wire connections assembled as shown in the HV Interconnection drawing.

All soldering points should be carefully executed so to avoid spikes. To clean soldering residuals, mounted boards should be washed with the appropriate solvent to be specified. All soldering points of capacitors on the HV face should be isolated with the proper amount of 3M-DP 190 epoxy glue, as in the reference specimen, and left $\sim$ 12 hours to cure at ambient temperature. Epoxy glue should be stored as specified by the fabricant.

Mounted boards should be stored in a dry ambient for at least 24 hours before test and should be always handled with gloves.

5.3.3 HVB and HVC Boards Quality Control Tests

Test Jigs are built for Quality Control tests of the HV boards. The jigs will automatically disconnect and record faulty boards, record currents and maintain the book-keeping of the whole test.

A quick entry HV test at +5kV, +/-3kV should be made on groups (16 to 32) of arriving PCBs with the appropriate jig (a few minutes in air), to check them for discharges or leakage (actual storage time in dry ambient before test, HVs, test duration and accepted rate of decrease of leakage currents are to be optimised experimentally)

Mounted boards should be inserted in the appropriate Test Jig in groups (16 to 32) The appropriate HVs (+/-2.4kV,+4.5kV for HVB and +4.5kV for HVC) applied and relative currents checked to be in the range of a few tens of nA for the lot of boards under test

In case no board shows undue currents or discharges, the Test Jig should be closed and the gas flow started (85%Ar - 15% CO2); "bad" boards should be set apart for further inspection.

The test starts as soon as the O2 content reaches a value below 300ppm: all currents should be monitored to be $\sim$ 20 nA for at least 4 hours; in case of a discharge or of higher currents, the faulty board shall be excluded by HV and set apart for further inspection

5.4 Front End Boards

Front End boards are a component of the DT chambers which will be pre-assembled in the XXXX production center.

5.4.1 Front End boards mounting specifications

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5.4.2 Front End Quality Control Tests

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6 Quality Tests during SL Assembly

A rack of wires of correct length and crimped with the crimping blocks on both sides should be prepared before starting the SuperLayer assembly procedure.

The crimping blocks should pass a visual inspection and be indentified with a *batch bar code*.

A check of the crimping tool is performed *every day* to ensure that the wires will meet the later QC.

All the tests described in this section should be implemented in each chamber production site and shold be done on the precision assembly table *before* each layer is closed.

At the beginning of the assembly the SL is assigned an ID *bar code* which is recorded in the DataBase. This allows the DataBase to identify the object during the full assembly period.

6.1 Wires Position

This measurement is made, for each layer of the superlayer, before closing the layer with the aluminium plate corresponding to the next layer. The wires are therefore visible from the top.

A tolerance in the wire position below 500 μm is required to maintain full efficiency of the trigger. The offline momentum reconstruction requires an accuracy of less then 100 μm for the segment reconstruction with 8 points. The precision required to the measurement is therefore less then 100 μm, the pass/fail criterion is set for a deviation above 500 μm.

A CCD camera, installed in the head of the main bridge of the coordinatograph, and connected to a PC, is used for this purpose.

A simple program controls the movement of the CCD camera which proceeds in steps corresponding to the nominal wire positions (42 mm pitch, as given by the cell nominal dimensions). In each of the steps, a CCD picture is taken. The time needed to cover all wires in a layer is of the order of two minutes. The measurement is done at both wire ends (HV and FE side).

The position of the CCD camera itself, in each of the steps, is given by the encoder readout of the coordinatograph, which has a resolution of 5 μm.

The position of the wire itself is given by the position of the CCD camera plus the wire image displacement. Since the wire image is clean in the CCD picture, the displacement can be very easily obtained by a simple center of gravity method.

With the optics used, the pixel size is about 7 microns, and the resolution of the reconstructed wire displacement is less than 15 microns. Each measured wire position is recorded into the database.

This procedure must be calibrated in order to control systematic errors. At the level of precision which is needed in these measurements it is important for example to take into account temperature effects.

The calibration of the measuring system is also very important.

In some production site the calibration is performed using a laser interferometer system, in others using a reference bar. Independently from the used system it is required a daily calibration of the measuring machine.

Details on the wire position tool and calibration procedure may be found in the following *Document on Tools and Instruments* (ref.).

6.2 Wires Tension

The tension of all the wires is measured directly after they are placed in the layer. The measurement must be done on an open layer with a custom made instrument, the *Multi Channel Tension Meter*. This operation is computer assisted; it is performed simultaneously on 16 channels (2 or 4 groups of wires for a full layer) and requires less than 5 minutes.

Later, some single wires should be checked on a sampling basis, for example after transport or after a long time of storage. These single wire tests are done manually with the Single Channel Tension Meter. The SCTM can be used at any stage of the production or on finished chambers. No software is needed and the measured values must be entered into a computer by hand.

Both the MCTM and the SCTM measure the wire tension to better than 0.1%. In both cases the tension has to deviate less than 10% from the nominal value of 3N. This tolerance is determined by the maximum displacement from the nominal position of the endcaps (2 mm) along the wire lenght. At the nominal tension a 2 m long wire becomes $\Delta L = 20mm$ longer, the maximum displacement represents the 10 % of ΔL.

Details on the working principles of the Tension Meters may be found in the following *Document on Tools and Instruments* (ref.).

6.3 Strips and I-beam Positions

The same CCD camera system described to measure the position of the wires is used to test the position of the first strip and the first I-beam on the HV side and on the FE side of each open layer. These are the I-beam and the strip which are next to reference marks.

These four measurements represent a check that the Al-plate is correctly positioned on the precision table.

Both objects must be positioned in the SuperLayer within 500 μm in order not to affect the drift velocity.

Each position is recorded into the *DataBase*.

The rest of the strips are measured to be in the correct position during the Al-plates assembly directly by the tool which deposit them; the position of the I-beams, on the other hand, is guaranteed by the design precision of the I-beam table.

6.4 Corner Blocks Position

Before the last Al-plate is glued to close the Super Layer, the corner blocks and side enclosures are attached and the the position of the external faces of the corner blocks is measured with respect to the closest wire.

The measurement is done with the same CCD camera setup described in the previous section and the accuracy should be better than 100μm.

These measurements are recorded into the *DataBase*, they will be the Reference Frame of the SL.

Later they will be used, together with alignment data, for offline reconstruction and for linking the portions of tracks inside the Track Finder of the muon regional trigger.

6.5 Electrical connections of I-beams

Each I-beam has to be controlled to be properly grounded. This is obtained inserting some conductive glue at the I-beams extremities and checking the contacts with a tester when the I-beam tool is removed from the assembly table.

7 Quality Tests on Super Layer

Super Layers need to be tested before the chamber assembling. A quality control procedure and a set of threshold values for each tests have to be defined. There are three foundemental tests to be performed: strips electrical contacts, high voltage behaviour and gas tightness. Two tests are needed for high voltage behaviour and gas tightness : a fast test to fix macroscopic problems and a more refined test to certify the SL quality.

A summary of the main quality control tests to be performed on each Super Layer is given in Table 8.

7.1 Strip Electrical Contacts

The SL is removed from the production table and the strip capacity is measured for every cell. Two identical strips are connected in parallel. The measured capacity should be $\sim 6.7\ nF/\text{m}$ for 17 mm wide strips.

Measuring half of this value would indicate that one of the two strip contacts is missing and the SL should be repaired.

This measurement is not required to be recorded.

The same test has to be performed on the cathode strips of the I-beams. The measured capacity has to be $\sim 4.7\ nF/\text{m}$ for 12 mm wide strips.

Both the capacities have been calculated with a $e_r = 2.22$ and a $100\mu\text{m}$ Mylar thickness.

7.2 First High Voltage Test

The first high voltage (HV) test is performed in air (i.e. the SL has the gas enclosures not mounted). The segmentation is supposed to be 32 connection (or lower) every HV channel. The nominal high voltage setting at the sea level is: $V_c = -1500\ V$, $V_s = 1900\ V$, $V_w = 3700\ V$. The steps to perform the test are indicated in the following:

- mount the HV and front-end boards;
- ramp up the HV to the nominal value with a ramp of 20 V/s;
- stay at nominal value for 30 min checking for discharges;

- check that the current in every HV channel is lower than 100 nA with tendency to decrease;
- inform the responsible of the production site about the test result.
- record the currents into the *DataBase*

7.3 First Test on Gas Tightness

The SL is closed with the front and back gas eclosure and is flushed with standard gas mixture (85% Ar, 15% CO_2) operated at 1 atm.

The following steps describe the test:

- connect the SL with a manometer with at least 0.5 $mbar$ resolution;
- give to the SL 10 $mbar$ overpressure (using a safety valve with $p_{over} = 20$ $mbar$);
- measure every 5 min p_{over} and p_{atm};
- after 30 min the overpressure must be at least 8 $mbar$ (excluding effects from p_{atm});
- when test is negative solve the problem and repeat;

7.4 Second Test on Gas Tightness

When the SL has passed succesfully the first gas test a second and more precise test has to be performed to measure the oxygen concentration in the SL. For this test we use an Oxygen analyzer which has a resolution of ??.

The following steps describe the test:

- flush the chamber with high flow (more than 10 volume change/day);
- after 4-5 volume changes O_2 concentration should be of the order of *per mille*;
- when O_2 concentration is below 500 ppm turn down gas flow to 1 volume change/day;
- after few hours O_2 concentration should stay steadly below 500 ppm;
- if the test failed fix the problem and repeat.

7.5 Second High Voltage test

When the first HV test is passed and the gas tightness of the SL is proved a second HV test (with low O_2 concentration) must be performed.

- when O_2 concentration is lower than 500 ppm ramp up HV to the nominal values and record into the Data Base the currents every 5 min for 1 day (6 hours);

- condition for 4-5 days, i.e. ramping up and down H.V. every 2 hours, and monitoring currents;
- for every ramp up the current in all the channels must be lower than 100 nA after 30 min;
- inform the responsible of the production site about the test result.

7.6 Super Layer Thickness

The SuperLayer thickness measurement is necessary for the BTI which relies on a parameter that is the distance between the wires across the planes. The averaged value from this measurement represents this parameter and it has to be within a tolerance of $\pm 500\mu$m.

From the mechanical point of view we need a much more stringent limit of $\pm 200\mu$m.

The measure is done manually with a caliber.

7.7 Rates - Same as Draft 1

When the SL is certified with respect to the HV and gas tightness, a test on cosmic ray count rate is performed.

For this purpose the FE boards have to be mounted and a mini-DAQ system has to be organized. This include mainly the use of scalers connected to a computer to record the rate.

The cosmic count rate per unit cell length is recorded every X sec. into the *DataBase*.

When the test is passed?

If the test fails the corresponding cell is disconnected.

8 Quality Tests when the Chamber is assembled - same as Draft 1

The three (or two in case of MB4 chambers) Super Layers which form the muon chamber have passed all tests foreseen on HV, gas and count rate, and they have HV and FE boards mounted.

They are glued together with the Honeycomb and the lateral C-shapes on the chamber assembly table.

Three main QC tests are foreseen when the chamber is assembled: two mechanical tests and a cosmic ray test.

8.1 Mechanical Tests on Chamber

The measure of the relative position of the Super Layers is an input parameter for TRACO system.

The upper and the lower phi Super Layers must be aligned within 500 mu. This is due to the assumption of the TRACO design, however if a chamber results to be outside this value an offline correction may be applied.

This measure is performed with a precision of 100 μm and a tolerance of 1 mm/500 μm tilt . These values are recorded into the *DataBase*.

Which instrument/tool ?

The thickness of the chamber must be measured with 1 mm tolerance. The TRACO allows a distance between the phi quadruplets centres to vary within ± 13 mm.

More stringent requirements are coming from mechanics in order to be able to mount the chamber. A tolerance of 1 mm is finally accepted.

Which instrument/tool ?

8.2 Cosmic ray test

We foresee to run each chamber for an extended period of one week in a cosmic ray muon test stand.

The aim of the cosmic ray test is to verify mainly the chamber operation stability and the noise level. One experimental setup to test cosmic rays is present in each production site.

Definition of the trigger.

A precise list of the measurements we want to perform with this test is still to be defined. It is clear that it would be too lengthy to measure all the drift tubes characteristics with an analysis similar to the one done for test beam data. On the other hand we must ensure the correct functioning of each cell in the chamber before shipping that to CERN.

It is fundamental therefore to indentify some key quantities that can be measured in each production site in a reasonable amount of time. One of them is certainly the distribution of the TDC times, another is a first estimate of the noise.

In case a cell does not follow the foreseen distributions, it will be disconnected.

After the chamber has passed these tests, it is ready to be shipped to CERN, where some quality checks may be repeated to verify that the chamber has survived the transport.

The time necessary to collect enough data cannot goes much beyond the 10 days, in order not to accumulate too many finished chambers in each production site. The exact time of the cosmic ray test however is still a matter of decision. We can also organize the test stand in order to place more than one chamber at a time, the experience with the first produced chambers will indicate us the best configuration.

In the following we report, as an example, the measurements of these two quantities which we have performed with test beam data on our last prototype chamber MB96 (ref.).

8.2.1 TDC spectra

Fig.1 shows a typical TDC spectrum of one drift tube as observed in test beam data on the MB96 chamber. The output signal has been stretched to a width of about 350 *nsec*, which correspond to the maximum drift time. The drift times have been collected by multi-hit TDC boards using a range of 4 μsec.

To give quantitative parameters which allow to set a pass/fail criterion we can fit the distribution to an analytic function.

Figure 1: Comments.

8.2.2 Noise level

Fig.2 shows the distribution of noise rate for MB96 cells. The random noise rate has been calculated taking some runs with a random trigger and 32 μsec of window time.

A limit may be set on this distribution in order to define a pass/fail criterion.

9 Hardware required for Quality Tests

The existing and planned quality control equipment at the *part production sites* and at the *chamber production sites* is summarized in Table 9.

A crude cost estimate and the site to be contacted for more information is also given.

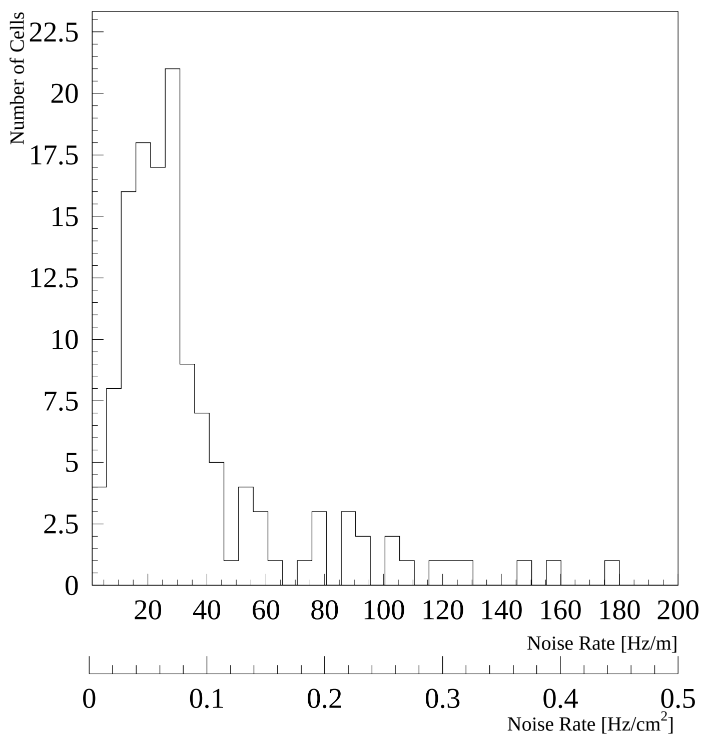

Figure 2: Noise rate distribution for MB96 drift tubes.

References

Table 2: The list of the products

Object	Code	Tagging
Chamber	1	ID
Super Layer	2	ID
Honeycomb	3	ID
C-frames (F/B)	4	ID
C-frames (L/R)	5	ID
Al plate	6	ID
I-beams	7	Batch
End plugs (big)	8	Batch
End plugs (small)	9	Batch
SL enclosure (front)	10	ID
SL enclosure (back)	11	ID
SL enclosure (side)	12	ID
Gas distribution	13	ID
Ref. blocks	14	Batch
H.V. connectors	15	Batch
F.E. connectors	16	Batch
H.V. board	17	ID
F.E. board (preampl.)	18	ID
F.E. board (decoupl.)	19	ID
Rack	20	ID
Wire rolls	21	Batch
Crimping blocks	22	Batch
I-beam contacts	23	Batch
Strip contacts	24	Batch
Mylar rolls (I-beam)	25	Batch
Al rolls (I-beam)	26	Batch
Mylar rolls (strip)	27	Batch
Al rolls (strip)	28	Batch
PCB (H.V. board)	29	Batch
Capacitors (H.V. board)	30	Batch
Hybrids (H.V. board)	31	Batch
PCB (F.E. board)	32	Batch
Capacitors (F.E. board)	33	Batch
MAD chips (F.E. board)	34	Batch

Table 3: The list of the production centers

Prod. Center	Code	Task
Aachen - RWTH III	1	Chamber assembling
Legnaro - LNL	2	Chamber assembling
Madrid - Ciemat	3	Chamber assembling
Torino - Sez. INFN	4	Chamber assembling
Bologna - Sez. INFN	5	I-beams preassembling
Protvino-IHEP	6	I-beams assembling
Dubna - JINR	7	Al-plates assembling
Beijing - IHEP	8	H.V. cards assembling
XXXX	9	F.E. cards assembling

Table 4: The list of the specific codes

Code	Specific
000	None
XX1	Al plate N. 1
XX2	Al plate N. 2
XX3	Al plate N.3
XX4	Al plate N.4
XX5	Al plate N.5
X1X	Object related to PHI chambers
X2X	Object related to Z chambers
1XX	Object related to MB1 (1-12) chambers
2XX	Object related to MB2 (1-12) chambers
3XX	Object related to MB3 (1-12) chambers
4XX	Object related to MB4 (1,2,3,5,6,7) chambers
5XX	Object related to MB4 (4a,4b) chambers
6XX	Object related to MB4 (10a,10b) chambers
7XX	Object related to MB4 (9,11) chambers
8XX	Object related to MB4 (8,12) chambers

Table 5: Quality Control tests on Al-Plates, precision and tolerance of the measurements

Test	Precision	Tolerance
Aluminium Plates		
Dimension		
Thickness		
Strip position		
High Voltage		

Table 6: Quality Control tests on I-beams, precision and tolerance of the measurements

Test	Precision	Tolerance
I-beams		
Thickness		
Strip position		
High Voltage		

Table 7: Quality Control tests on Wire, precision and tolerance of the measurements

Test	Precision	Tolerance
Wires		
Elasticity		$\pm$ 5 % of 300 gr
Rupture limit		$\pm$ 5 % of 300 gr
Magnetic properties		

Table 8: Quality Control tests on Super Layer, precision and tolerance of the measurements

Test	Precision	Tolerance
Super Layer		
I-beam position	100 μm	$\pm 500 \mu$m
Strip position	100 μm	$\pm 500 \mu$m
Wire position	100 μm	$\pm 500 \mu$m
Wire tension	0.1 % of 300 gr	1 % of 300 gr
Ref. block position	100 μm	200 μm
HV test	20 nA	less then 100 nA
Gas leak rate		500 ppm
Thickness	caliber	200 μm
Rates		

Table 9: Hardware required in the production sites for QC

Test	Hardware	Cost	Info Site
Infrastructure			
Bar Code Reader+Writer	TEC (Torino)	5 kSFr	Torino
Enviroment monitors			
PC + OS		4 kSFr	
Bare Components QC			
High Voltage(Al-plates)	CAEN 527	40 kSFr	
Super Layer QC			
Wire Position			Madrid/Padova
Wire Tension	Aachen system		Aachen
Gas system			Padova
High Voltage on SL	CAEN 527		
Big caliber			
Chamber QC			
Cosmic ray stand			