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Electrode Strip Deposition for the CMS Barrel Drift Tube System

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Abstract

The full production ideation, design, setup, and realization of the Electrode Strip Deposition for the entire construction of the CMS Barrel Drift Tube System are described in detail.

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1 Introduction

The construction of a large area detector needs, when compared with prototypes and small detectors, a careful engineering of the tools used for the production which should be efficient, robust, safe, easily maintainable, and user friendly. Moreover it is very important that quality control and database storage of the parts produced are carefully designed to guarantee overall quality and traceability of each item. The Barrel Drift Tubes Detector [1] is made of 250 chambers, distributed on 4 layers and 5 wheels. Each chamber is built with 3 Super Layers (SL, only 2 SL in the external layer 4), each SL made of 4 sensitive layers. The area of each layer ranges from 5.2 to 10 m^2, and the total coverage area of the Barrel DT System is $\sim$1800 m^2.
The basic element of sensitive layers is the cell, as shown in Figure 1.

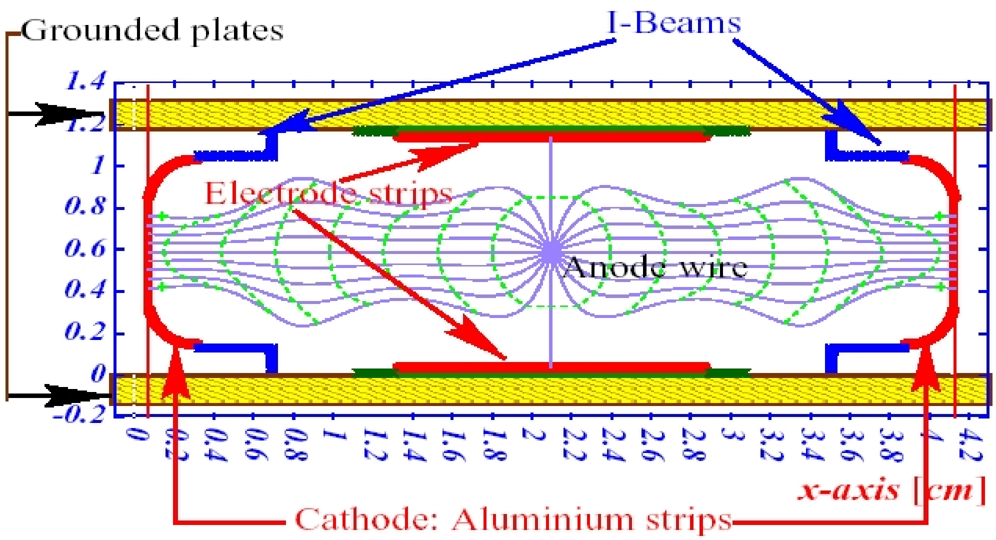

Figure 1: The elementary cell of the Barrel DT System. In the picture one can see the structural 1.5mm thick aluminium plates, the anode wire, the cathode I beams and the strips which shape the drift field, respectively at nominal voltages of +3600V, -1200V, +1800V.

The gas volume, filled with 85%Ar+15%CO_2 mixture, is confined between 2 aluminium plates, 1.5mm thick, spaced by 11.5mm thick I-beams which are structural elements (glued on both sides on the aluminium plates). I-beams are used to separate the cells and are the mechanical support of a 100μm thick mylar tape on which it is glued a 50μm thick aluminium tape, the latter being the cathode of the drift volume. Field strips are placed both on the top and the bottom of the aluminium plates, just above and below the anode wire. As for the cathode electrodes, the aluminium strip, 50μm thick, 16mm wide, is glued on top of a 100μm thick, 23mm wide mylar strip, which is finally glued on the aluminium plate. The strip pitch is 42mm and each strip has to be positioned with $\pm$0.2mm accuracy.
As previously mentioned, the Barrel DT chambers are grouped in 4 main types, differing mainly in the azimuthal length, which grows as function of the radial distance. Each chamber type is assembled in a different production site, RWTH-Aachen for MB1 chambers, CIEMAT-Madrid for MB2, INFN-Legnaro for MB3 and INFN-Torino for MB4. Moreover, Bologna University and INFN are responsible for the production of the cathodes, the mass production being carried on in IHEP-Protvino for the whole collaboration and Torino University and INFN are responsible for the preparation of the aluminium plates and the deposition of the field electrode strips for the whole system, the latter being done in JINR-Dubna.
The technical preparation and logistics organization for cutting $\sim$3600 plates subdivided in 72 different plate models, the deposition of $\sim$900 km of aluminium and mylar strips, the validation of strip deposition both optically and with HV test and the delivery to the production sites, will be described in detail in this note.

2 Aluminium Plates modelling

All the aluminium plates needed for the full production ($\sim$100 tons) are manufactured by Pechiney Rhenalu, Issoire (France). All plates are made of aluminium alloy EN.AW 5005, temper H44, and are delivered in two standard sizes (2550x5300mm and 2550x4150mm) with coating on both faces, chemical conversion with alodine to skim and improve the surface grip for gluing. A surface analysis with an electron microscope scan has shown O, Al, P, and Cr (P and Cr are due to the Alodine surface chemical conversion) plus occasional contributions of Ca and S on scratches produced during plate rolling-mill. The overall quality of the delivered plates is in accordance with the contract technical specifications, although 20% of the material has been rejected either because the plate arc was larger than 5mm/m as, defined in the contract, or because condensation produced inside the box during transportation had dissolved the surface chemical conversion developing large oxidation spots on the plate surfaces. All the aluminium plates used for the production of the full barrel DT system have been cut in Torino (except 15 plates for the first MB2 chamber, cut in CIEMAT-Madrid). For this activity a table x-y plotter with gantry and ancillary tools has been designed and built by INFN-Torino. Tools were designed having in mind the following important needs:

- ease of operations. Each operation, including the alignment of large plates on the cutting table, requires only one person;
- unambiguous mechanism for the choice of the plate to cut and automatic recording of the cut plate in the local database. Fully automatized cutting procedure (22 plate models in terms of dimensions);
- strict safety criteria used in all phases of the plate handling and cutting;
- tolerances on sides are $\pm$0.5mm and $\pm$1mm on diagonals (corresponding to a relative error of $\pm 10^{-4}$).

This tool is shown in Figure 2.

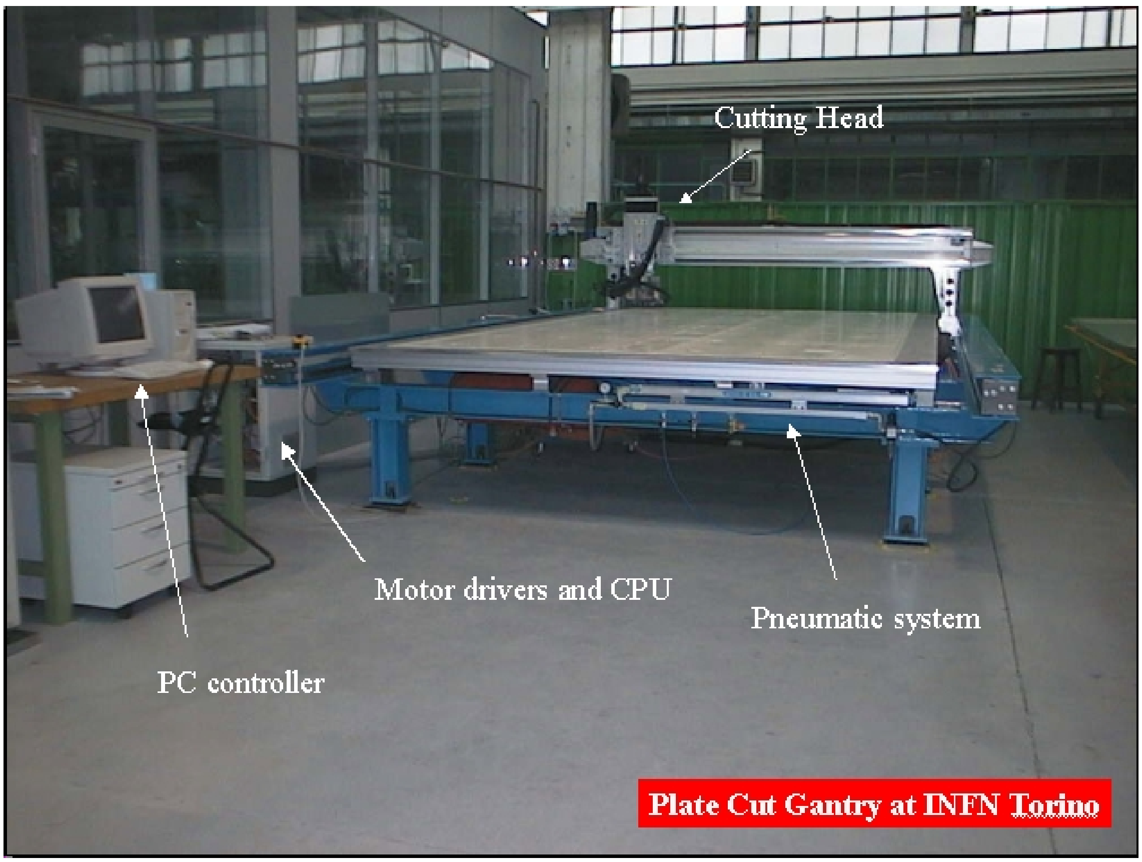

Figure 2: The Aluminium Plates Cutting Table in INFN-Torino

The overall dimensions of the table surface are 6000 x 3500 mm^2. The *y* axis moves perpendicularly to the long side (*x* axis), and it is driven by two 380V synchronous motors controlled in coordinated motion (see Figure 3 for motors characteristics). With a maximum motor speed of 2500 rpm, and a motor reducer x10, each axis can reach a maximum linear speed of 3 m/s. Motor position is monitored by rotational encoders, and the positioning precision has been measured with an external laser interferometer to be better than 300μm. The gantry consists of a chariot which moves along the *y* axis, holding the tool which is used for cutting the plate (cutting head), with a vertical

8 MKD071

8.1 Technical Data

Description	Symbol	Unit	MKD071B-035		
Cooling mode – Motor overtemperature			Natural 60K	Natural 100K	Surface 60K /100K
Electric parameters					
Characteristic motor speed	n_K	min^{-1}	2500		
Continous torque at standstill	M_{dN}	Nm	8,0	9,0	12,0
Continous current at standstill	I_{dN}	A	6,3	7,4	9,5
Peak current	I_{max}	A	28,3		
Torque constant at 20°C [1]	K_m	Nm/A	1,38		
Voltage constant at 20°C	K_{Eieff}	$V/1000min^{-1}$	125		
Winding resistance at 20°C	R_{12}	Ω	4,57		
Winding inductace	L_{12}	mH	23		
Number of pole pairs	p		4		
Rated data [2]					
Rated speed	n_N	min^{-1}	2500	2500	2500
Rated torque	M_N	Nm	5,2	7,5	10,2
Rated current	I_N	A	2,9	4,4	5,7
Rated power	P_N	kW	1,6	2,5	3,4
Rated voltage	U_N	V	333	349	366
Rated frequency	f_N	Hz	167	167	167
Mechanical parameters					
Rotor inertia	J_M	kgm^2	$8{,}7 \times 10^{-4}$		
Theoretical maximum torque	M_{max}	Nm	32		
Minimum strand cross-section [4]	S	mm^2	1	1	1
Thermal time constant	T_{th}	min	45	45	20
Maximum speed	n_{max}	min^{-1}	6000		
Motor mass [3] [5]	m	kg	8,8		
Perm. storage and transport temp.	T_L	°C	-20 to +80		
Permissible ambient temperature [6]	T_{um}	°C	0 to +40		
Max. setup height [6]	h	m	1000 above NN		
Protection category [7]			IP65		
Insulation class (according to DIN VDE 0530 Part 1)			F		
Housing coat			Prime coat black in a/w RAL 9005		

[1]) K_m is to be used for calculations with crest values (I_{dN}, I_{max}). For calculations with root-mean-square values (rated data), the torque constant K_m must be multiplied by a factor of $\sqrt{2}$.
[2]) Values determined according to EN 60034-1. Current and voltage specified as root-mean-square values.
[3]) Use the declared value in bracket for motors holding brake.
[4]) Applicable to REXROTH INDRAMAT cables. Rated according to VDE0298-4 (1992) and installation type B2 according to EN 60204-1 (1993) at an ambient temperature of 40 °C.
[5]) Without blower unit.
[6]) If the limits specified are exceeded, the performance data must be reduced if necessary. For reduction factors, refer to the chapter entitled "Environmental Conditions".
[7]) Provided the power and encoder cables are mounted properly

Fig. 8-1: Technical data MKD071B-035

DOK-MOTOR*-MKD*******-PR06-EN-P Rexroth Indramat

Figure 3: Technical Data of MKD071 Motors

moving axis (z-axis). The maximum moving speed of x and y axes is 3 m/s. All motors are controlled by a group of drivers (ECODRIVE03 by Rexroth-Indramat) interconnected with an optical link (SERCOS bus) to a local CPU (CLC) and two input-output register boards (DEA, 32 inputs, 24 outputs). Connection with the PC controller is achieved through the serial port. This system (Rexroth-Indramat) is extremely flexible and can be used for the full control of all the operations made with the gantry. Firmware, which is driver resident, allows the storing of all motor parameters and the full characterization of the motor performance. The logic sequence of movements and controls is set up with software which runs on the CLC. The language used for the programming is *Visualmotion*, a motor control dedicated language full customized by Indramat for their products. Through *Visualmotion* it is possible to integrate in the same software both motor control and monitoring, and full control of the tool handled by the gantry via I/O register boards (DEA). The cutting tool, a circular saw mounted on a thrust block with three possible orientations (0^o, 90^o, 270^o, see Figure 4), is mounted on the chariot through a vertical (z) movement which allows the retraction of the saw, when needed, in a safe position.

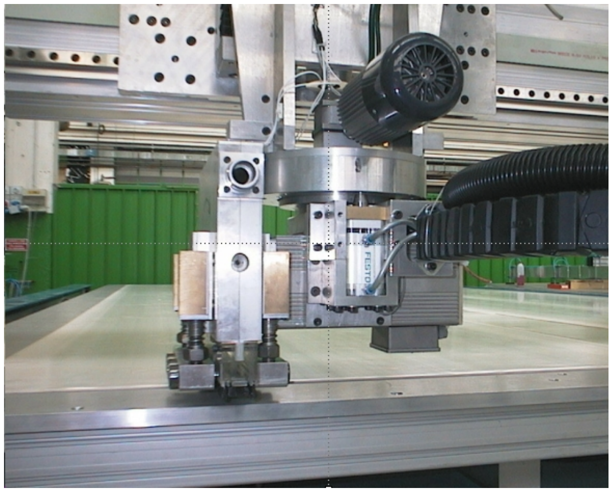

Figure 4: Details of the cutting tool

The motor which controls the saw orientation is the fifth axis of the system. The saw revolution speed is 6000rpm (the electromotor mandrel is the sixth controlled axis of the system) which allows a cutting speed of 100 mm/s. Complete swarf removal is obtained with an exhaust fan which is placed outside the working area. The blade is cooled during cutting with a high pressure stream of isopropyl alcohol vapors. The GUI to control the cutting sequence is written in Visual Basic and is resident on a PC connected to the CLC via the serial port. The sequence of operations (performed by a single operator) is the following:

- align and place the raw plate on the cutting table;
- from the main form of the program initialize the program. This option moves all axes to home position (zero of the machine);
- the operator chooses the plate model which has to be cut from an option menu (in total 72 different plate models) and starts the cutting procedure;
- out of the raw plate, one or two plates are extracted, depending on the desired model, by cutting along the four sides. When the cutting is finished the gantry returns automatically to the parking position;
- on request of the operator the program prints an adhesive label with the bar code which fully identifies the plate (model and serial number) and places it on a corner of the plate. The produced plate code is automatically stored in the local production database;
- the operator deburs all sides of the plate and places it in the transport box.

Plates are handled horizontally and kept flat with a frame, suspended by a crane, which supports 24 vacuum suction cups to hold the plate. An average production rate for normal working hours is $\sim$18 plates/day, which corresponds to more than 1 chamber/day.

3 Field Electrode Strip Deposition

This part of the production has been conceived and organized from the very beginning as a collaboration of INFN-Torino and JINR-Dubna. INFN-Torino designed and constructed the production tools and made a preproduction of 10% of the full lot in Torino, not only with the purpose of providing material for the production sites to start chamber assembly, but also to perform a full debugging of all hardware and software components of the production line and to train JINR engineers who joined the preproduction efforts in Torino. In July-August 2001 the Torino Strip Production line was completely disassembled, packed and sent to JINR-Dubna for full reassembly to continue the production. The tasks of JINR-Dubna , as agreed in a contract between JINR and CERN, are the full reorganization of the premises allocated to this production, the full production of all plates, and the maintenance in operation of all tools. INFN-Torino keeps responsibility of the production for all aspects concerning the schedule and the repair/improvements and complete provisioning required during the full production period. For these reasons all tools of the production line have been designed keeping in mind the following basic criteria:

- all tools should be designed to allow a production rate of plates for 1 Super Layer/day (8 plates/day = 10 surfaces/day). This is the rate necessary to allow all productions sites to build 2 chambers/month;
- electrode strips should be positioned with a tolerance of $\pm$ 0.5mm and the position of each strip should be monitored and recorded;
- all parts of the production line should be easy to assemble and transportable;
- management of the production should be simple and as much as possible error-free;
- control software should be very robust and user-friendly to be easily operated by quickly trainable operators;
- all relevant steps of the production should be documented and recorded in a local database.

The production line can be subdivided in two main objects: the strip deposition tool, and the HV test stand.

3.1 The Strip Deposition Tool

The aluminium and mylar strip deposition gantry is a *x-y* plotter, 5000x4000mm, designed and constructed as a clone of the gantry for plate cutting described in Section 2. The most substantial difference is in the position encoder used in the motor positioning loop. Indramat motor drivers are designed to be operated using either the motor internal rotational encoder, or an external encoder. An external optical encoder (System *Heidenhain Lida 187C*) is installed in this gantry, both for *x* and *y* coordinates. This arrangement has three main advantages with respect to rotational encoders:

- higher precision ($\pm 20\mu$m);
- direct measurement of the position on an optical bar (independent of the motion transmission system);
- quick and precise zeroing procedure, switch independent. The homing procedure can occur in any place of the machine since it uses coded reference marks on the optical bar rather than a switch.

The absolute positioning error of each axis has been measured with a laser interferometer, and found to be compatible with technical specifications of the linear encoders for all axes ($\pm 20\mu$m, see Figure 5). Linearity of all axes has been measured with the same external system to be better than 100μm. The table surface is made of 20mm thick anodized ALCOA plates (see Figure 6). The surface is machined with small holes connected to a vacuum circuit which is used to fix and keep flat the aluminium plate on the table during strip deposition. This circuit is subdivided to cover different areas on the table and to account for the varying sizes of the plates to be worked (see Section 1). Precision locating holes on the ALCOA table surface are present to place the plate reference blocks (two along *y* axis and one along *x* axis). Reference block shapes and positions change as function of the plate model, and are chosen according to Super Layer assembly convention [2].

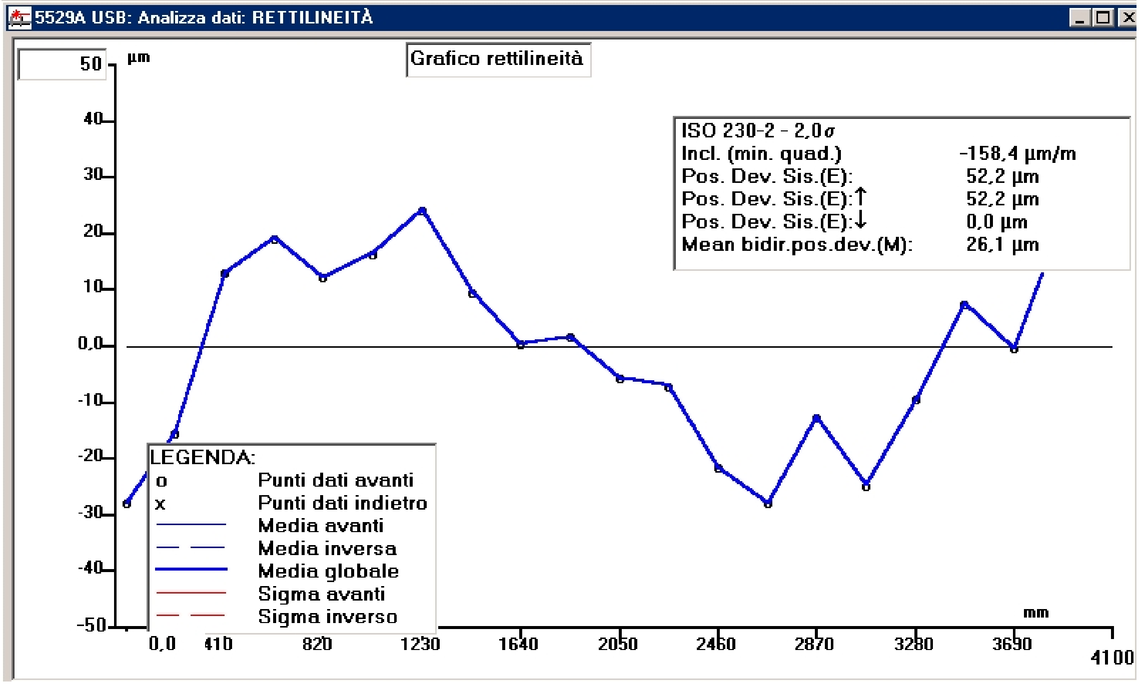

Figure 5: Residual distribution of absolute coordinate as function of the position along the axis measured with the interferometer.

Figure 6: The Aluminium and Mylar Strip Deposition Table

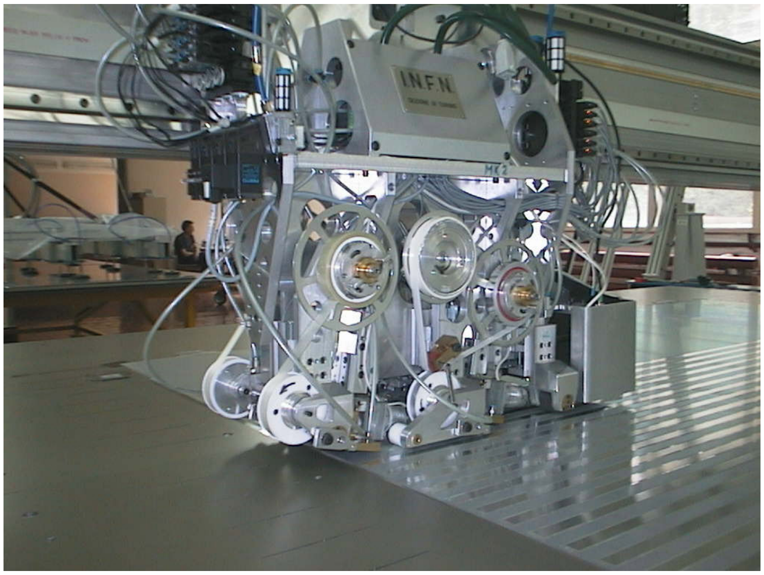

Figure 7: The Electrode Strip Deposition Head

3.1.1 Electrode Strip Deposition Head

The *x-y* gantry shown in Figure 6 operates the Electrode Strip Deposition Head (ESDH), the mechanical unit which places and cuts on the aluminium plate a 16mm wide 0.05mm thick aluminium tape on top of a 23mm wide, 0.1mm thick mylar tape. Both tapes have adhesive on one side (liner protected in the case of the aluminium tape).
The ESDH (see Figure 7) lays down in one operation two mylar and two aluminium tapes. The choice of two tapes deposited in a single run was done both because this halves the overall strip deposition time and because two tape rolls per type are needed to complete the largest plate surface, thus minimizing dead time due to roll exchange operations. The two tapes which are placed in parallel are 4 pitches apart (168mm). All vertical movements (four tapes and two tail rolls) are driven by a pneumatic system, whilst the four cutters consist of of rotating blades powered by four small electric motors. Compressed air is also used to keep tapes in position after cutting (Venturi valve), and to push the cut tape tail on the plate surface. All pneumatic valves which control the ESDH are controlled through the DEA input-output registers, by the CLC, the CPU where the full table control software is resident (see Section 3.2 for details). The sequence of operations for the deposition of each strip is described in Figure 8.

The tail of the ESDH hosts two CCD cameras (aligned respectively with the left and right strip deposition systems) which have three functions:

- monitor table calibration reference mark (absolute machine zero);
- monitor plate corners (check correct plate alignment on table before strip deposition);
- monitor strip position.

Details on the management of CCD images are in Section 3.2.

3.2 Controls and Operation

The software developed to control ESDH movements and operations is organized in different levels. All driver and motor parameters are stored in the ECODRIVE03 firmware. The program which controls all movements and ESDH operations in the strip deposition cycle (*Strip-Program.str*) is written in *Visualmotion* language and it is resident in the CLC CPU. This program is linked to other two programs. One is PC resident, it is written in Visual Basic (*Strip.vbp*), and communicates with *Strip-Program.str* both via a DDE server on the serial port and through a *National Instruments* PCI6527 board. This program is hierarchically the highest level of software control, provides the GUI component of the system (controls and handshakes with *Strip-Program.str*), it communicates through the serial port with the bar code reader, and it writes all relevant information after strip deposition on a file (*traveller*). The other program is written in DELPHI, it is PC resident, it communicates with *Strip-Program.str* via

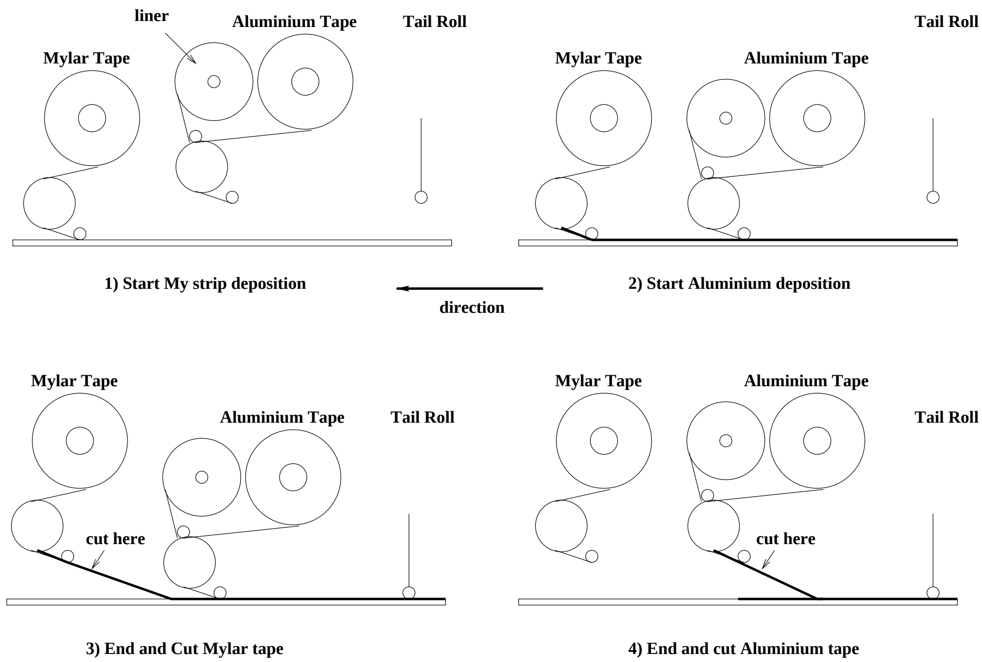

Figure 8: Strip deposition sequence:1) The ESDH is moved at strip start and mylar rolls are lowered; 2) The ESDH is advanced by 25cm and the Aluminium rolls are lowered; 3) the ESDH is moved to strip end depositing the strip on the plate. Toward the end the Mylar rolls are raised; 4) the ESDH is moved by 25cm and Al rolls are raised. Tail roll is kept low down to the very end of the strip. During strip deposition the ESDH is moved at a speed of 560mm/s, whereas during normal displacement the speed is 1.3m/s.

the PCI6527, connected with the CLC via the DEA, and it has the double function of acquiring data images with the CCD cameras (*Acquisition.pas*), and analyzing and archiving processed images (*Analysis.pas*). A diagram of the software and hardware architecture of the system is shown in Figure 9; a description of the software is in the following sections.

3.2.1 Strip-Program.str

The Strip Deposition Program, written in *Visualmotion* is built in two main parts. The first part of the program executes the zero machine search (homing procedure). During this procedure, the two axes are moved ($\sim$ 100mm) to allow determination of the gantry coordinates (using the external optical encoders). This procedure is always performed when the program is started. The second part of the program is made of a collection of all routines used to perform different tasks. Each task can be executes independently by the GUI Program through the operator selection (see 3.2.3). The options available to the operator are the following:

1. Table absolute calibration: this task is started once/day. It brings the ESDH cameras (**L**eft and **R**ight) on top of an image whose position is known, and compares actual with known position (see Figure 10). This check is important to verify that the camera measuring offset is stable and known.

2. Perform measurement of plate geometry: as soon as the plate is positioned on the table the operator starts the program by simply reading the bar code placed on the plate corner (as described in Section 2). The ESDH is moved to the corners of the plate in order to check with the cameras that the plate corners are in the correct positions (plate properly aligned) and to monitor the overall dimensions and squaring of the plate. See Figure 11 for the description of the measurement.

3. Start normal strip deposition: it is started when the plate is ready to be stripped. Number, length of strips to be deposited, and position of the first strip are automatically determined and passed to the program by simply reading the bar code placed on the plate corner (as described in Section 2).

4. Pause, stop, restart and cut tapes: the operator can interrupt at any time strip deposition (for instance when mylar and/or aluminium tapes have to be changed). The position of the last deposited strips is always in memory and strip deposition can be recovered from the point where it was interrupted.

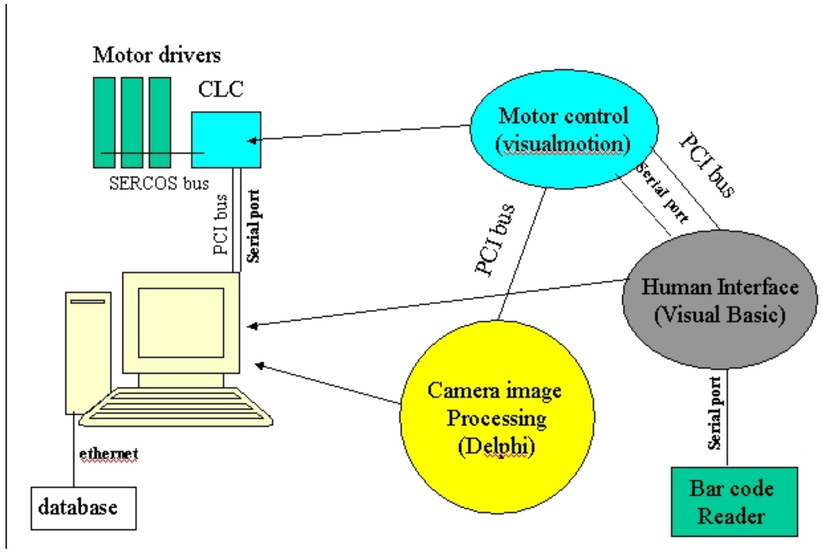

Figure 9: Strip Deposition Software

5. Change single strip; when strip deposition is finished it can happen that a single strip has to be replaced (either it is outside position tolerances, either it has a surface damage, or it failed HV test).

6. Go to x-y: this task is foreseen for the simple purpose of sending the ESDH to any operator defined *x-y* position.

7. Perform measurement of strip positions: with this task the operator can perform a scan of all strips by moving the ESDH on top of each strip and by acquiring images with the two cameras (see details in Section 3.2.2).

All option parameters and execution commands are controlled by the *Strip.vbp* program (see Section 3.2.3).

3.2.2 Acquisition.pas and Analysis.pas

The program *Acquisition.pas* is a fast acquisition program written in DELPHI and running on the PC, which communicates with the CLC based *Strip-Deposition.str* program via a digital I/O PCI board (PCI6527 National board), connected on the CLC side, to the DEA input/output registers. Through the I/O bits it is possible to handshake the PC *Acquisition.pas* program with the CLC *Strip-Deposition.str* program so that images belonging to each deposited strip, can be saved on-line for later analysis during strip deposition (the cameras are placed on the tail of the ESDH). The maximum acquisition rate is 25 images/s which guarantees the possibility to fully map each single strip. In background, during strip deposition, also the program *Analisys.pas* is run. This program analyze each single image by filtering and enhance contrast in order to distinguish the mylar and aluminium tape edges. Once the edges are found, the corner positions are stored and the original image is deleted. An example of a reconstructed image is shown in Figure 12. The same programs are used to acquire and analyze images of the plate corners (which are determined as the intersection of the two edge fitted lines), and the position calibration image. The camera resolution, as shown in Figure 10, is 48μm for the *x* coordinate, and 96μm for the *y* coordinate. Strip positions, plotted as residual *absolute measured strip position - nominal* distribution are shown in Figure 13. Each point is averaged over $\sim$50 images of the same strips at different *y* values, the spread of the edge fitted values being better than the camera resolution. The position spread gets worse at the end of the strips, where the aluminium gets a characteristic s-shape with respect to mylar (which being stiffer remains straight) but still inside tolerances.

3.2.3 Strip.vbp

This program, as described in Section 3.2, is started and used by the operator for all operation controls. It is hierarchically the top level control and communicates with all the processes described in Section 3.2.1 and Section 3.2.2. The program main panel is shown in Figure 14. Bar Code Number and Plate Name, number of strips, strip length, and position of first and last strip are automatically loaded by reading the bar code on the plate with the bar code reader. Once this operation is done the operator can *Initialize* (perform homing procedure) and start any of the options 2-6 described in Section 3.2.1 (see *Step 3* in Figure 14). The last step, after strip deposition and Fast HV

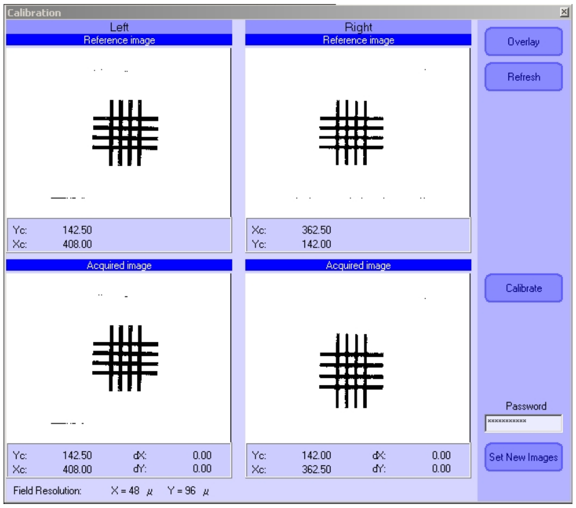

Figure 10: Residual distribution of acquired-reference image position (dx and dy measured in camera pixels. 1 x-pixel=48μm, 1 y-pixel=96μm).

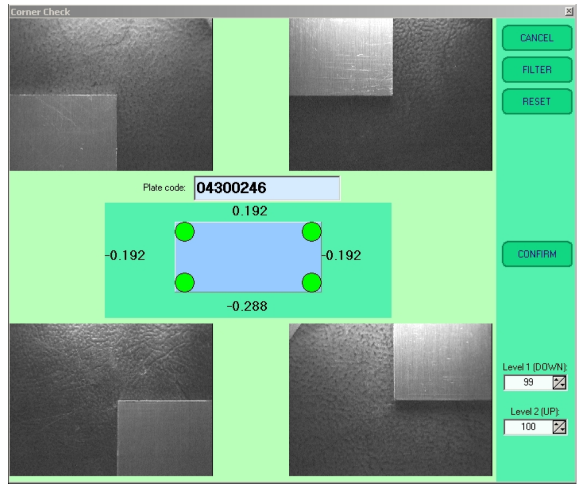

Figure 11: Plate corners check. The ESDH is moved above the four corners, the CCD image is acquired and analyzed by the programs described in Section 3.2.2. The program checks the corner position and compares it with the nominal ones. The four numbers in figure, are the residuals of the plate sides in mm. The green dots indicate that the image was acquired successfully and the residual are within tolerance.

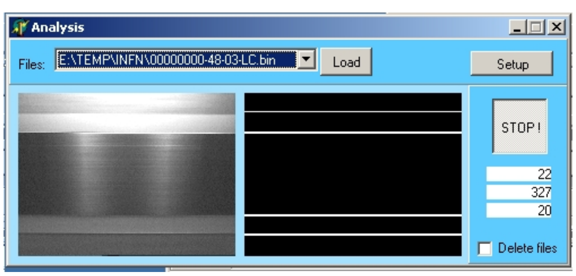

Figure 12: Acquired image (left) and reconstructed lines of tape edges (right)

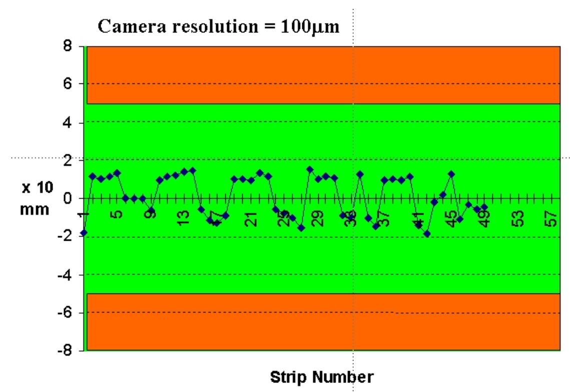

Figure 13: Residual distribution of *absolute measured strip position - nominal*. The relative offset of $\sim$150μm with a multiplicity of 4 strips is due to the relative left-right tape roll distance in the ESDH. One pixel = 0.96μm.

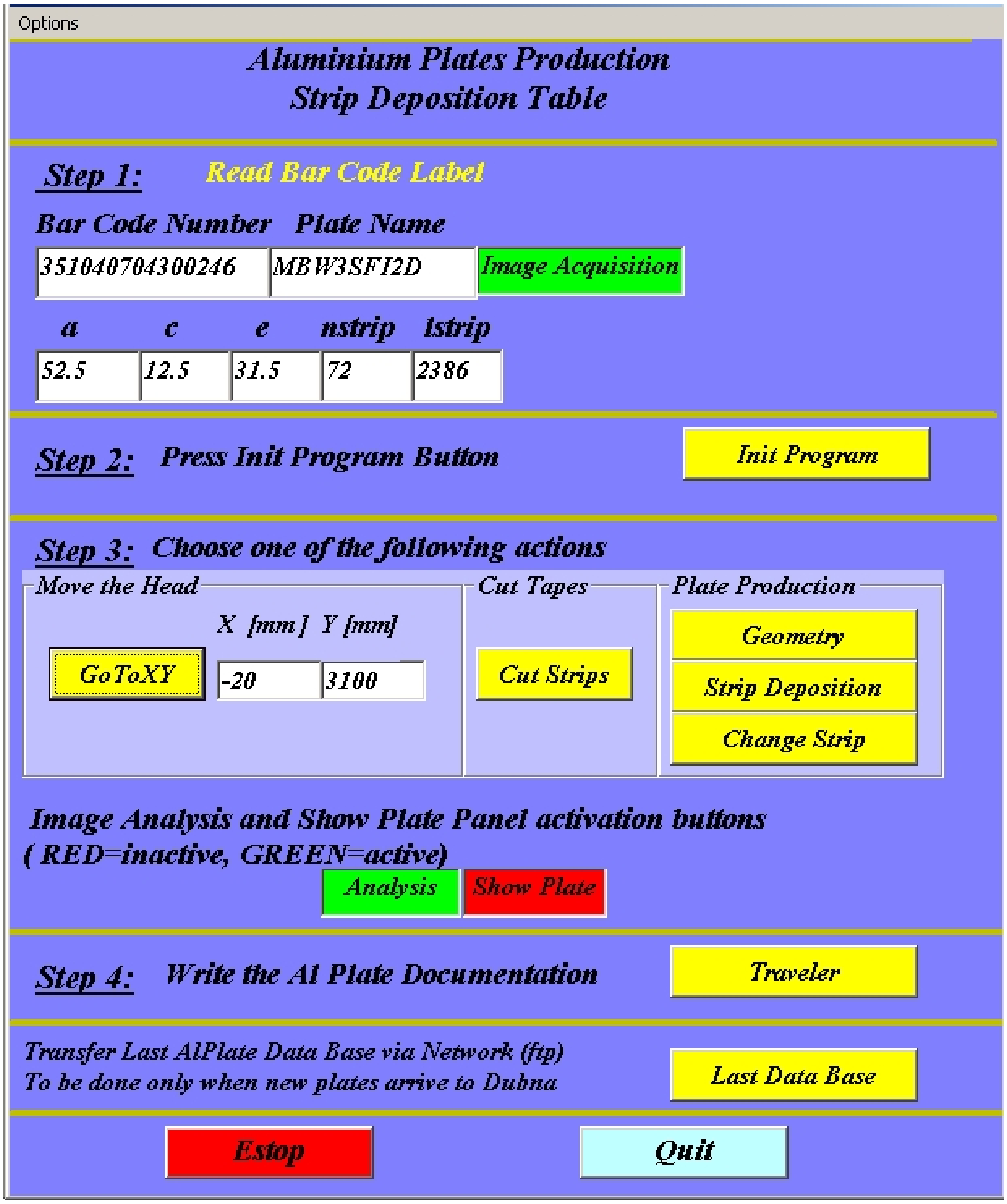

Figure 14: *Strip* program main panel.

Test (see Section 3.3), is to write the *traveler*, a file which contains information on that plate, as the operator name, temperature and humidity, problems encountered both during strip deposition and HV test, number of exchanged strips and reason of substitution.

3.3 HV Test Stand

Electrode strip quality control is completed, after dimensional check with the CCD camera, by the High Voltage test [3]. The aim of the HV test is to identify strips which are not properly insulated by monitoring the currents after the strip voltage is raised to high values.

HV test is performed on each plate surface in two steps:

1. a fast test to +4200 V, immediately after strip deposition.
2. a standard test to +4000 V on a special dedicated test stand.

The fast test is done immediately after the strip deposition with a test probe, a 4.2 m long bar with 96 pins, all connected to one HV channel. This test lasts 30 seconds and it is declared passed if the total current is below 50 nA*(number of connected strip) within this time window and no discharge is observed. Most of the insulations problems (mainly due to small holes in the mylar caused by residual thin scratches in the aluminium plate) are identified by the fast test, and the bad strips are replaced immediately without having to realign the plate on the table.

Once the HV test has been passed, the plate is moved to another table, where a dedicated tool is used to measure the currents simultaneously on the upper and the lower surface of the plate. The tool consists of two bars equipped with contact pins which can be positioned on the strips of both the plate surfaces. In this test, groups of strips (from 1 up to 4) are connected to each HV channel. The voltage is ramped up to +4000 V and the currents are monitored for 30 min; the test fails if the current from one HV channel is greater than 50 nA*(number of connected strips) for more than 120 s. In addition to these tests, one plate per day is kept at +4000 V overnight in order to monitor the current stability over a long time (about 10 hrs). The distribution of the mean currents per strip measured during the long test runs is shown in Figure 15. The mean current drawn by the strips that passed the HV test is less than 20 nA; the small tail to higher values is related to dust that occasionally could deposit on the strips, producing an increase of the current, often recovered after a short time.

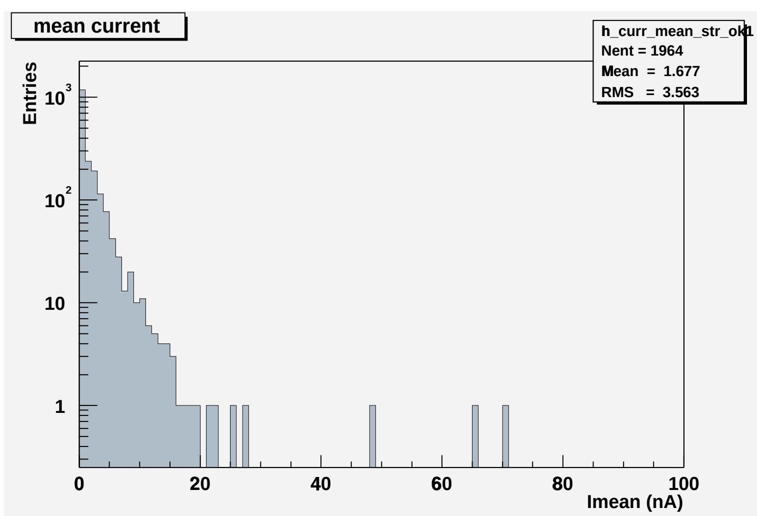

Figure 15: Mean current per strip measured on strips that passed the HV test

The HV power supply consists of a CAEN SY527 mainframe equipped with voltage distributor modules (CAEN module A832), each containing 12 output channels with a resolution in the current measurement of 20 nA. Small current offsets are periodically measured in order to correct for them.

The HV power supply is remotely controlled by a PC with a dedicated monitoring program, written in Visual C++. A graphical interface allows the operator to choose the type of test (fast, standard, long), to record the plate bar code, to select the connected HV channels, and to start the test. The software manages all the possible exceptions before and during the test (open contacts, short circuits, over-currents, discharges), it ramps up the HV channels, it monitors the currents once the nominal voltage is reached and it ramps down the voltages at the end of the test. During and after the test, the status of each channel, the histograms with voltages and currents as a function of time, and the result of the test are shown. For each plate all this information is written to files.

In case of test failure, the graphical panel shows the HV channel the problem comes from, the operator identifies the bad strip, replaces it and the test is repeated.

The rate of rejected strips per plate, after the HV, test is 0.22%. Strips identified by the HV test typically present local defects in the gluing of the mylar or aluminium tapes (about 30% of the cases) or a wrong positioning of the aluminium or mylar strips at the edges (70% of the cases).

3.4 Production at JINR

Before the installation of the production line in the JINR laboratories, the premises which had been reserved for CMS, have been completely restored by JINR personnel in order to accomplish CMS production requirements on the cleanliness, temperature and humidity controls of the work environment, the logistic distribution of the rooms, and the performance of the crane (fast and smooth movements to allow proper plate handling and alignment on the table).
On the 29 September 2001 the electrode strip production line, after a preproduction of 300 plates done in Torino was sent to Dubna. The production line, fully disassembled and packed in 21 boxes, had a total weight of 15 tons. Installation in Dubna, with technical support both from Torino and JINR, started on 20 September, after complete custom clearance, and was fully completed on 20 October (see Figure 16). Calibration of all moving

Figure 16: The Electrode Strip Production Line assembled in JINR-Dubna

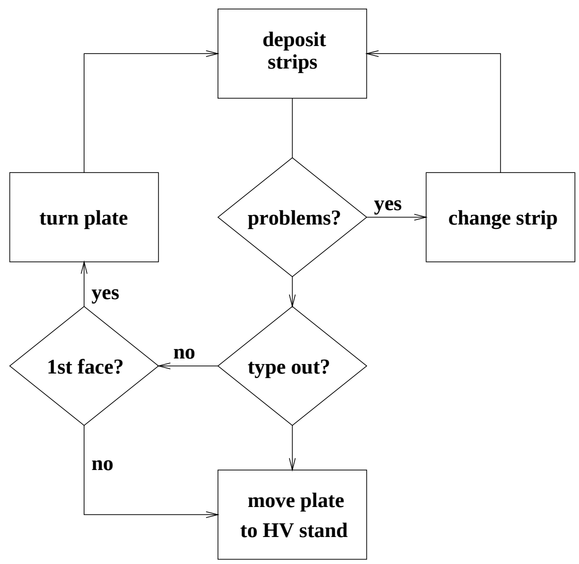

Figure 17: The Strip Deposition Operation Flow

parts was done in 7 days and in on October 29 production started. Electrode Strip Production is carried on by three experienced technicians, two mechanical and one electronic engineers, coordinated by a supervisor and supported by an external mechanical engineer and a software engineer for special dedicated assistance. A person from the administration department is dedicated to the organization of all transports and the related custom formalities.

3.5 Sequence of operations

Aluminium Plates are delivered to JINR from Torino in boxes which hold plates for 2-5 chambers. As a first step the box is opened and all plates are placed on a service table. Each plate surface is then carefully sanded in order to remove all scratches. Scratches are potentially dangerous since the tiny pointed shavings which are always on the tail of a scratch can penetrate in the mylar tape and short the aluminium electrode to the aluminium plate

(which is grounded). After sandpapering, the plate surface is cleaned with isopropyl alcohol. The plate is now ready to be placed on the strip deposition table. Before placing each plate on the table, the table surface is brushed with isopropyl alcohol. The operator reads the plate surface code bar with the bar code reader, after starting the *Strip.vbp* program (see Section 3.2.3). This automatically loads all plate parameters in the *Strip-deposition.str* program (Section 3.2.1) and instructs the operator on how to place the plate on the table (depending on plate models the operator must use different reference blocks in different table positions). After plate alignment on the table, the table vacuum system is activated and the plate sticks to table surface. The operator can then start the *check geometry* procedure where the plate position and dimensions are checked. Immediately after strip deposition can start. The flow chart of the operation sequences is shown in Figure 17. Since 3/5 plates have strips on both sides, in this case the plate must be turned upside down and reworked.
Before removing the plate from the strip deposition table, the HV fast test is performed (see Section 3.3), and in case a bad strip is found, it is immediately replaced. When the plate is finished and HV fast-tested, the plate is moved to the HV test stand and the *traveller* file is written by the operator. The procedure used by the operator in the HV test has been described in details in Section 3.3.
Special care is set in the packaging of the plates after strip deposition. Each plate is separated from the neighbour plates with a thin polyethylene foil. The full stack of plates is finally vacuum packed in a closed thick (0.1mm) polyethylene envelope, and boxed in its original shipping box, ready to be transported to the production sites.
All transportations from JINR to the production sites are scheduled once per year and organized by JINR personnel.

3.6 Production performance

As described in Section 3.4 the production started in JINR on 29 October 2001, and was terminated on 17 June 2005. JINR and Torino personnel worked closely in the last two months of 2001 in order to complete recommissioning of the full production after reassembly, and to train the JINR personnel involved. The profile of the integrated production is shown in Figure 18. The rate of $\sim$8 surfaces/day, which corresponds to the amount of plates needed to build one SL, was approached on February 2002 and kept constant for the full period of 3.5 years, as required in the agreement between JINR and CMS. Three main breaks occurred during the full production. The first occurred in June 2002, when the gantry was stuck due to a misalignment of the two motors driving the bridge in the homing phase. This error was fixed within 2 days with an intervention of JINR personnel assisted remotely by Torino experts. The second and third breaks had the same origin, a stuck motoreductor respectively on the left (a broken gear) and right (an oil leak) motor of the bridge. In both cases (October 2004 and March 2005) it was necessary to replace them and make an hardware intervention with Torino experts assisted by JINR experts, with a maximum loss of 20 working days per interruption (almost entirely due to the time needed to order and send the spare part). Apart from these interruptions, the full production was absolutely steady with the normal assistance and ordinary maintenance of all the mechanical parts and the routine calibrations of the measuring devices.
At the present time the production line has been deactivated, but it is ready to be immediately operated in case of need, in the JINR laboratories.

3.7 Acknowledgments

We would like to thank Marcos Cerrada and the CIEMAT group for having provided us with the prototype strip dispenser head and for very friendly collaboration with our group on the development of the ideas of the new tool.
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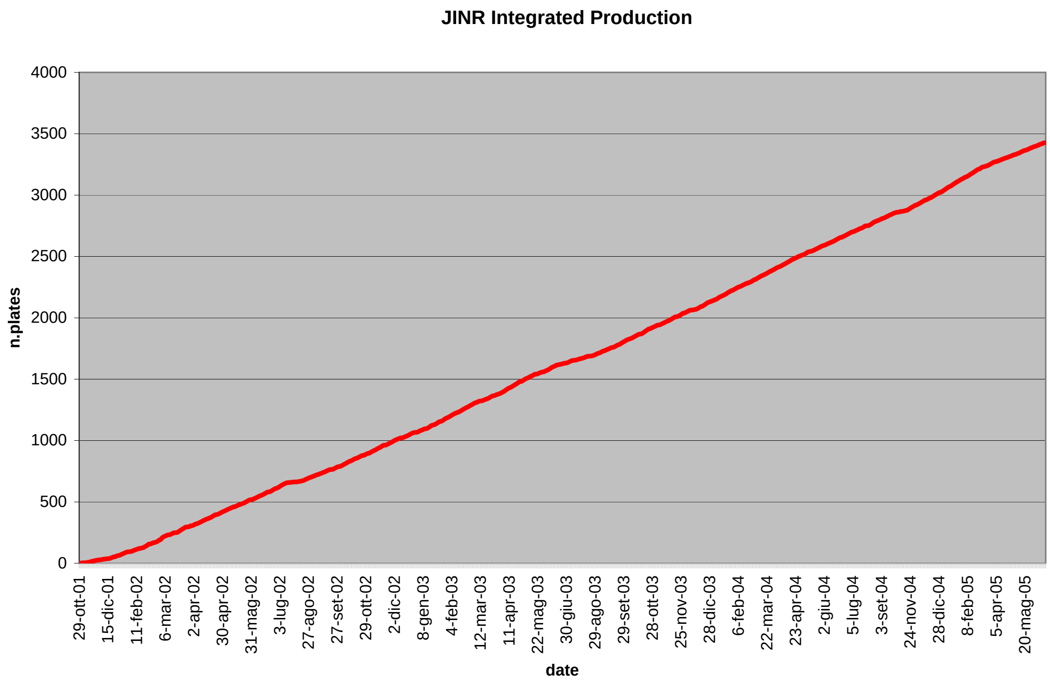

Figure 18: Integrated Electrode Strip production in JINR-Dubna

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