Available on CMS information server

CMS NOTE 2004/010

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

June 10, 2004

Silicon Tracker Module Assembly at UCSB

A.A. Affolder, K. Affolder, A. Allen, S. Burke, D. Callahan, C. Campagnari, D. Hale, J.R. Incandela, S. Kyre, D.D. Staszak, J. Stoner, R.J. Taylor, D. White

Department of Physics,University of California, Santa Barbara, CA 93106, USA

Abstract

This note details the infrastructure deployed and developed at the University of California at Santa Barbara (UCSB) to handle the construction of CMS Silicon Tracker modules for the outer barrel and endcap. Capacity has been developed to assemble and wirebond 15 modules per day and in addition to wirebond 30 hybrids. Early results and experiences of production are also given. In the £rst substantial module build, 5.3% of 150 modules were slightly outside of the mechanical speci£cations. Based on the data obtained during that build, it was possible to introduce correction factors which resulted in the 58 subsequent modules constructed being all within speci£cations. For module bonding a very low introduced failure rate of only 0.005% is observed. A higher corresponding rate for hybrid bonding of 0.022%, is attributable to one particular batch of problematic hybrids.

1 Introduction

This note is intended to provide details on the mechanical assembly of CMS silicon tracker modules [1] at UCSB. UCSB and Fermilab are jointly responsible for the assembly of all of the $\sim$5500 Tracker Outer Barrel (TOB) modules, and UCSB has also developed capacity for Tracker End Cap (TEC) Ring 5 and 6 modules, and will assemble up to 2000. In all, six different types of modules (3 TOB and 3 TEC) will be built at UCSB, with the distinction being in the total number of channels and whether the sensors are positioned for axial or stereo track measurements. All these types of module are made up of a carbon £bre support frame, a front-end electronics hybrid containing four or six 128-channel analogue pipeline readout chips (APV) [2] readout chips and two silicon strip sensors, each of which is approximately 10 cm by 10 cm in area. In addition to this, approximately one third of the total number of hybrids in the Tracker will be wirebonded at UCSB. Alongside these assembly activities a large amount of electronic testing work is also ongoing, details of which are given in a separate note [3].

All of the assembly work takes place in a class 10,000 clean room that was recently built for this project. The major pieces of equipment are: an Aerotech AGS 10000 Cartesian gantry positioning system [4], on which module assembly takes place; an OGP measuring microscope [5] to provide an independent post-assembly survey of the modules; and two Kulicke and Soffa aluminium wedge wirebonders [6, 7].

The rest of this note provides full details of the equipment and procedures for module assembly, particularly focusing on the numerous hardware and software improvements which have been implemented by UCSB physicists and engineers. These have not only increased the rate of the assembly process, but also its accuracy, reliability and level of automation. Observations based on our experience of module production to date are also included.

2 Automated Module Assembly (Gantry)

Prior to this construction effort, silicon detector modules have been assembled by hand. Given the scale of the present task – some 20,000 modules in the entire Silicon Tracker – it is clear that the manual techniques would not result in suf£cient throughput and that a signi£cant level of automation was required. The gantry system was originally conceived and developed by the CMS Tracker group at CERN [8]. A picture of the UCSB gantry, which is used to assemble three modules at a time, is shown in Fig. 1. The Aerotech AGS 10000 [4] provides motion in four coordinates (three linear and one rotational) over a 75 cm x 75 cm working area. The motors are controlled by a dedicated processor running on a PC card, along with a software interface program which runs on the PC itself.

Figure 1: The gantry

A CCD camera is mounted on the z axis. The camera's output is fed to a National Instruments frame grabber card installed in the PC, where LabView based pattern recognition software is used to accurately locate £ducial markers on the various module components and communicate their positions to the Aerotech software.

A vacuum system is used both to pick and place the module components and to hold them in place before and after assembly. The vacuum is distributed from the pump via a system of reservoirs and commercial electrovalves and sensors, which was designed and built by collaborators in Bari.

A custom-designed tool support head is mounted on the ϕ (rotational) axis, which itself is mounted on the z axis. It is supplied with vacuum which enables it to pick up the tools used to move the sensors and hybrids, as well as the syringes used to dispense glue onto the frames. A contact switch is mounted inside the head which is used to determine when contact is made with a component or with the assembly surface. The glue syringes operate by means of an air pressure system which is regulated using Festo [9] valves. When not in use, the tools are stored in a rack at the back of the gantry.

The vacuum and air pressure valves and sensors are controlled by a custom digital IO interface box which is connected to the TTL level channels provided on the Aerotech PC card.

The components brie¤y described above are common to all seven gantry systems in operation in the US and Europe, and for full details the reader is referred to a very detailed description given in a previous note [8]. The remaining gantry components not mentioned above have been manufactured at UCSB, mostly with signi£cant modi£cations to the original designs. The rationale behind most of the modi£cations was to make the parts easier to construct and more robust, particularly bearing in mind the many different types of module which will be constructed on the UCSB gantry and the high throughput required.

The bracket used to mount the ϕ axis (Fig. 2) was remade when it was discovered that the original Aerotech piece did not provide orthogonality between the ϕ and z axes.

Figure 2: The bracket upon which the ϕ motor, pick-up head and camera are mounted.

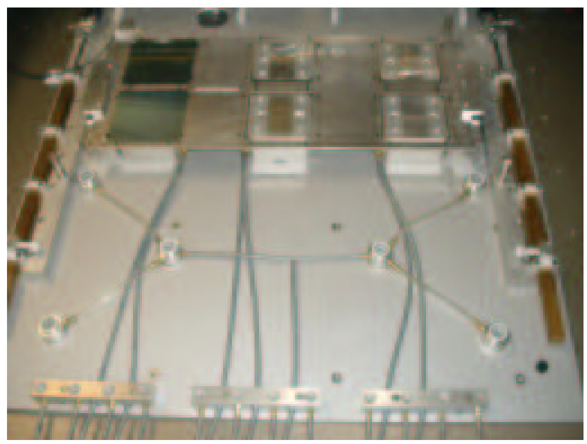

Figure 3: The gantry baseplate, showing a sensor supply plate and the mounting for the assembly plate.

A sensor supply plate is shown in place on the gantry in Fig. 3. A number of these plates have been fabricated so that whilst one is being used on the gantry, another can be loaded with sensors for the next set of modules. A small vacuum handling tool was purchased (Cleanroom-VS VAC from Virtual Industries [10]) so that the sensors can be loaded without being directly touched. Small pins position the sensors on the plate. When it is placed in position on the gantry, as de£ned by two locating pins, each sensor sits on an aluminium block which is bolted to the base plate. Great care was taken to ensure that in this way the sensors lie ¤at in the gantry x–y plane. The tops of the blocks are partially covered with te¤on tape to provide a smooth non-abrasive surface for the sensors to be vacuum clamped against. Four commercially available silicone vacuum cups, embedded in the blocks, provide the vacuum clamping. In this way, a sensor can be held £rmly in place from the time at which its position is surveyed using the pattern recognition system until it is picked up to be moved into position on a module.

The support posts for the assembly plate are shown in position on the base plate in Fig. 3. The te¤on heads of the posts were machined ¤at and parallel to within 25 microns in the gantry coordinate system by using the gantry itself to hold the milling tool. The assembly plate is held in place on the gantry by means of vacuum supplied through the support heads and two air pressure activated pistons, one on either side of the plate.

The design for the assembly plate itself is almost entirely new. The original CERN design was a three piece laminated plate with many custom parts. It was decided that this design was too dif£cult to build and maintain and that it also led to greater challenges in meeting the required accuracy. The UCSB design uses a single aluminium plate to which all other components are attached. In addition, all vacuum fittings and check valves are commercially available parts. These changes make it possible to modify the plates to correct problems without necessitating a major rebuild. The components are also very easily replicated, simplifying the construction of the numerous plates that will be required for use during the full production period. The underside of an assembly plate is shown in Fig. 4. The six feet are machined flat and parallel to within 25 microns. Vacuum is supplied to the plate via twelve vacuum cups on the gantry base plate that mate with the vacuum transfer blocks along the front edge of the assembly plate. The upper side of an assembly plate is shown in Fig. 5. All of the module components sit upon teflon blocks, which have been machined flat to within 25 microns with respect to the feet underneath. Underneath each sensor pad, vacuum channels and an o-ring groove have been machined into the assembly plate. In one corner of the plate a screw connector allows the connection of a separate vacuum line so that the plate can be removed from the gantry for overnight glue curing. One-way valves ensure that vacuum to the components is maintained during the switchover to the curing station vacuum.

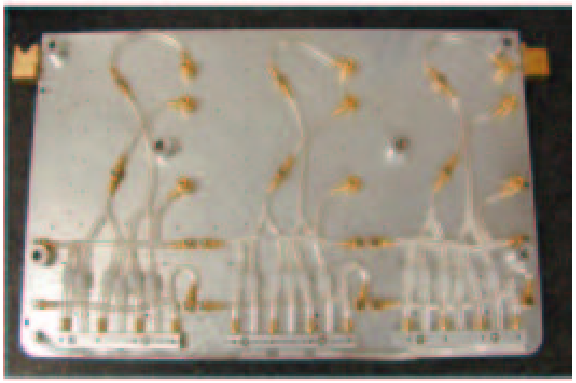

Figure 4: The underside of a TOB assembly plate.

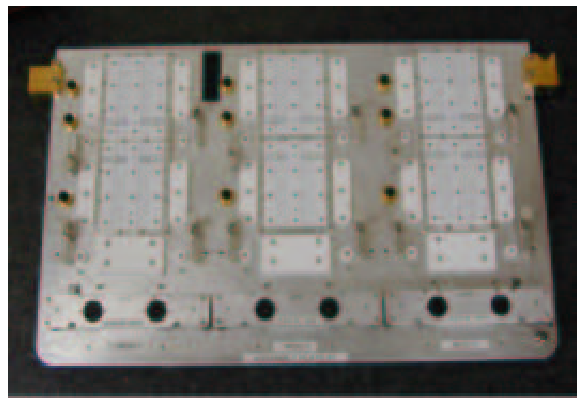

Figure 5: The upper side of a TOB assembly plate.

Figures 4 and 5 show an assembly plate for TOB $r - \phi$ modules. Further plates have been designed for the other types of modules: TOB stereo, TEC Ring 5 (axial and stereo) and TEC Ring 6 (axial only). The designs have a lot in common; indeed, many of the components are identical. The TEC plates required modifications to take account of the wedge shaped sensors, and different supply plates are also required. For the stereo module assembly plates, a design was adopted whereby the frames and hybrids are rotated on the plate whereas the sensors are placed in exactly the same positions as on the axial plates. The reasoning behind this decisions is that, with the sensor alignment being the most critical placement parameter, it is best to avoid large sensor rotations during assembly. This also means that, for sensors, the rotation axis is only used in the calibrated region. The hybrids are also rotated in the supply position so that only small rotational corrections are required when moving them into position on the frames. A picture of a TOB stereo assembly plate is shown in Fig. 6. The nominal rotation of the sensors is 100 mrad with respect to the precision location pins. Figure 7 shows a TEC R6 assembly plate with an assembled TEC module thereupon. In total, 19 plates of the various types have been built, giving great flexibility to adapt to the production needs at any given time.

The tools used for picking up sensors and hybrids are shown in Fig. 8. Each tool uses a stainless steel welded bellows to provide an even spring force whilst eliminating unwanted rotational movement. A precision machined shaft and bore with two internal o-rings guarantees repeatable vertical movement. The great care taken to ensure that all surfaces are flat and parallel leads to very repeatable component placement results. The hybrid tool works in conjunction with a bridge (Fig. 9), which when held down by vacuum applies downward pressure on the hybrid (which in contrast to the sensors cannot have vacuum directly applied when in place on the carbon fibre frame). The design allows vacuum from the pick-up tool to be passed through to the hybrid. For the syringe holding tools, the CERN designs have been retained. The gantry is used to dispense the adhesives for the sensors (Dow Corning 3140) and hybrids (GE Silicones RTV12). Due to the small amount required and its high viscosity, it was decided that it would be simpler to manually apply the silver epoxy (TRA-DUCT 2902 from TRA-CON) used to make the bias connection between the frame and the backplane of the sensor.

A major task after initially setting up the gantry was to carry out a calibration of the x–y plane, using a calibration

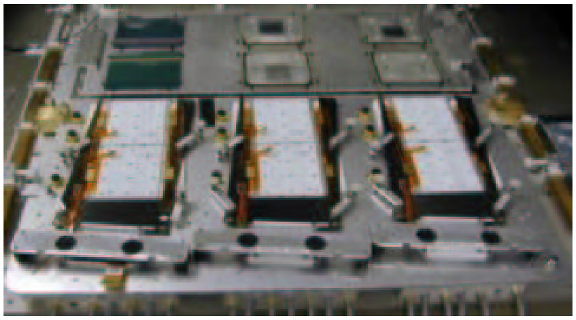

Figure 6: TOB stereo assembly plate.

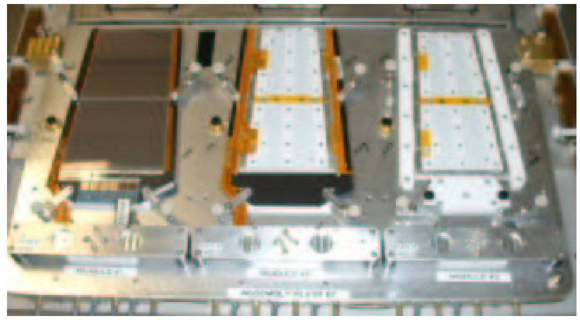

Figure 7: TEC assembly plate.

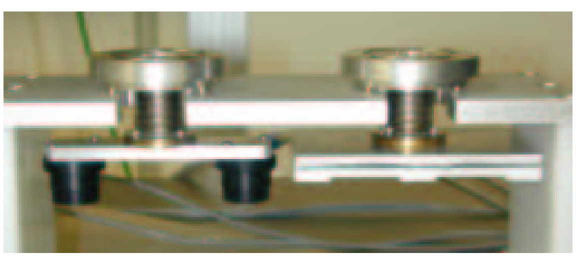

Figure 8: Photo of the hybrid (left) and sensor (right) pick-up tools on the gantry tool rack.

Figure 9: Photo of the bridge used in picking up the hybrid.

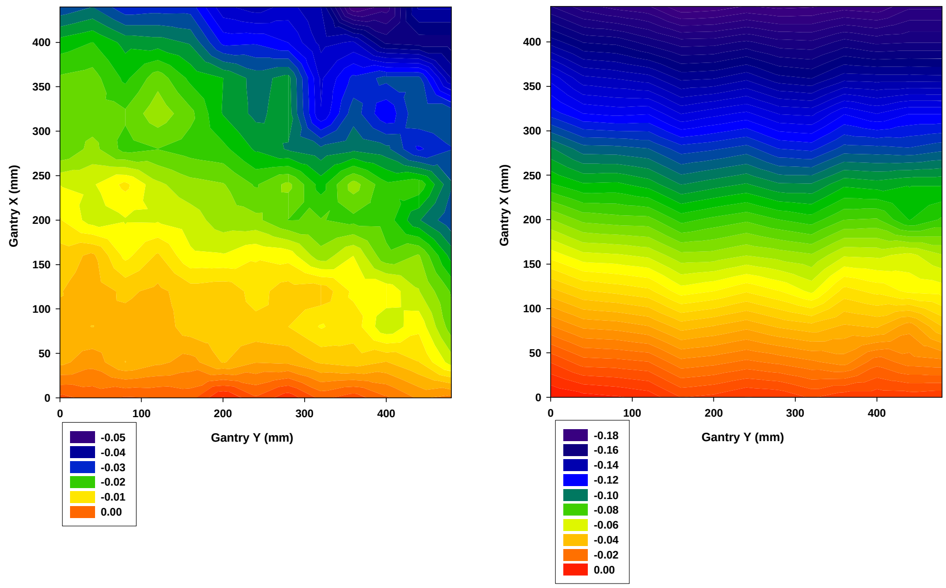

Figure 10: The precision (in colour) before calibration of the gantry x (left) and y (right) axes in the gantry $x - y$ plane. The scales are given in units of mm.

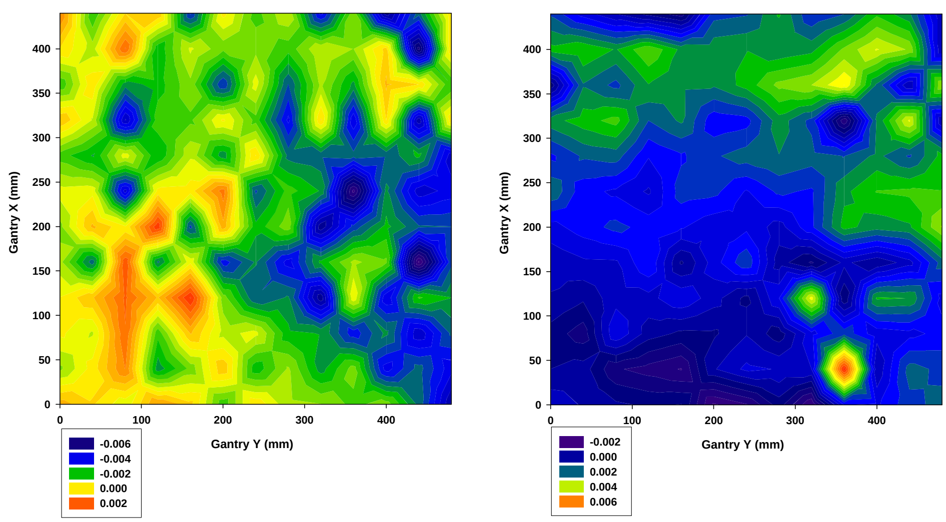

Figure 11: The precision (in colour) after calibration of the gantry x (left) and y (right) axes in the gantry $x - y$ plane. The scales are given in units of mm. Note the very different scales with respect to the uncalibrated precisions.

plate provided by CMS collaborators in Catania, Italy. This glass plate has a rectangular grid of markers which can be measured using the gantry's pattern recognition system. The measured coordinates are compared to measurements of the plate on the OGP (precision $\sim$1 micron) and a correction £le produced. Before the calibration was applied deviations of up to 200 microns were observed (Fig. 10). On re-measuring the plate with the calibration £le active it was shown that an absolute precision of $< 6\ \mu m$ is achieved as seen in Fig. 11.

In addition, it was necessary to derive a correction to the rotation of the pick-up head. Uncorrected, the rotation exhibited an error which varied sinusoidally as a function of rotation angle θ. A function of the form

$$a\,\theta + b\cos\left(c\,\theta + d\right) - b\cos d \tag{1}$$

was £tted to the data within the range of (small) angles through which corrections need to be applied to align the module components as seen in Fig. 12. This £t is then applied as a correction, which strongly reduces the systematic error on the rotation (Fig. 13).

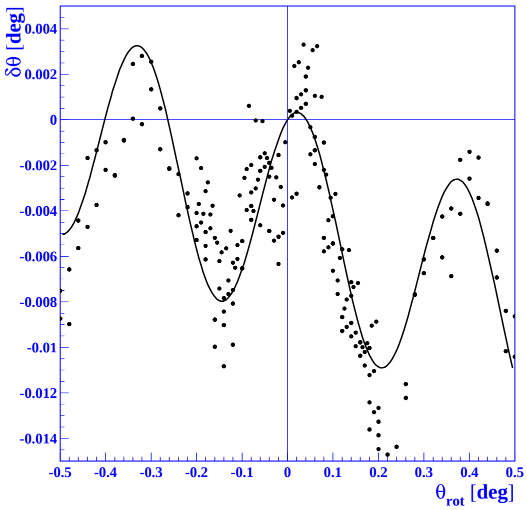

Figure 12: Before calibration, the gantry head rotation shows a sinusoidally varying error as a function of rotation angle.

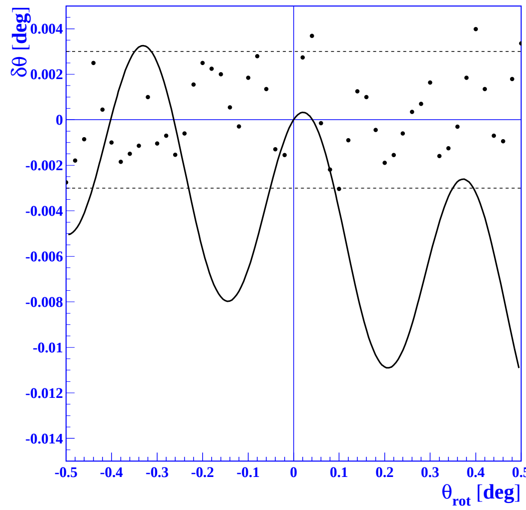

Figure 13: The calibrated ϕ axis shows only small deviations from the ideal, which are uncorrelated with the rotation angle.

The entire gantry system is connected to emergency power. Furthermore, all gantry electrical systems and vacuum pumps are connected to uninterruptible power supplies which will keep the systems running during the 15–30 seconds it takes for the emergency power to come on. This also includes the vacuum pumps that supply the assembly plates while they are curing over night. This will avoid potential damage to modules stemming from brief or long term power outages.

The module assembly program was originally written at CERN and has not been radically changed. The general outline and details on the software environment can be found in Ref. [8]. However, many incremental improvements have been made. For example, a routine was written to calculate the positions of the pins from measurements of two £ducial markers (actually corners of sensors) which are glued to each assembly plate, the relationship between the markers and the pins having been measured on the OGP. Previously, it had been necessary to measure three separate points on each pin (which are too large to be measured using the pattern recognition) – a very time consuming process. Because the assembly plates are made of aluminium, which has a signi£cant thermal expansion coef£cient, the temperature stability in the clean room (± 1 °C) is critical to the success of this approach.

A further important step was the validation of the 'recovery' routines which allow a module assembly run to be completed in the event of problems which require the program to be stopped. An example of this could be if the vacuum to an individual part were lost prior to it being moved. In this case the program can be resumed from the exact point at which the problem occurred, with previously entered data retained, and the assembly run completed.

Numerous minor changes have been made to make the software compatible with the speci£c geometry of our gantry and £xtures, and to make it as user-friendly as possible. More signi£cant changes were required to extend the software to enable assembly of stereo and TEC modules. After module assembly, the program carries out a survey of the £nal positions of the components. This information is then written to a £le in the XML format for upload to the central CMS Tracker database in Lyon, as well as to a more legible text £le. The results £les are automatically backed up and uploaded to the database each night.

Following the completion of an assembly run, which takes about 30 minutes from start to £nish, the assembly plate of completed modules is removed and placed in a curing cabinet (Fig. 14). Originally, it was envisioned that curing would take place at a slightly elevated temperature of about 25 °C, to assist in the curing of the silver epoxy. However, it quickly became apparent that this would lead to the sensors becoming noticeably displaced during curing, as the aluminium assembly plate expanded. It was thus determined that curing should take place at room temperature, which is in any case 22–23 °C in the clean room.

Figure 14: The cabinet used to store the modules during glue curing.

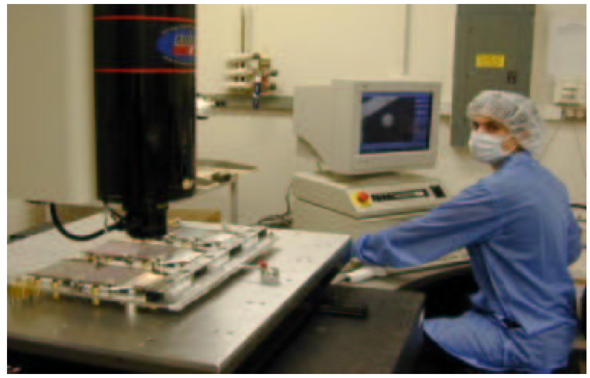

Figure 15: The OGP measuring microscope measuring a plate of assembled modules.

3 OGP Measuring Microscope

The OGP (Optical Gauge Products) Avant 600 ZIP measuring microscope [5] is shown in Fig. 15. It is PC controlled using the manufacturer's proprietary software and incorporates a pattern recognition system which, along with high-magni£cation optics, leads to an accuracy of $\sim$1 micron. As well as being used in the initial calibration of the gantry, as described above, it will be used on an ongoing basis to survey the modules after glue curing. Originally, the plan was for this survey to be performed on the gantry itself. The motivation for switching this task to the OGP is that it is not only much quicker and more accurate, but also means that the gantry is available for module assembly for the full working day. In addition it facilitates careful monitoring of the calibration of the gantry on an ongoing basis and feeds back small correction factors in the gantry module assembly program to improve the precision of the assembled modules.

A £xture was designed and manufactured which sits upon the movable platform of the OGP and clamps the gantry assembly plates in place. The plates are therefore removed from the curing cabinet and fastened in position with the modules still in place (although the vacuum is removed at this point). The OGP has then been programmed to measure the positions of the module (sensor and pitch adaptor) £ducials with respect to the assembly plate £ducials. The measured coordinates are exported into Excel, where a macro transforms them into the module coordinate system (de£ned by the precision pins to which the frames are af£xed during assembly) making use of stored relationships between the positions of the pins and those of the assembly plate £ducials. The £nal output is a text £le for each module, which is parsed the following night to create a £le in the correct format for upload to the Tracker database. The whole process is almost entirely automated and each plate of modules can be measured in well under £ve minutes.

Following this stage, the modules are removed from the assembly plate and placed into individual module carrier plates. The aluminium carrier plates for all types of modules were designed at UCSB and incorporate four plastic spring clips, dowel pins which address holes in the carbon £bre frame and strain relief clamps for the kapton tails. The plates contain further holes which are used to af£x the plate to, for example, the wirebonding £xtures or the testing stations. The modules can thus remain on the carrier plates right up to the point at which they are installed in rods.

4 Wirebonding

Two Kulicke & Soffa wirebonders, one model 8060 [6] and one model 8090 [7], ful£ll the bonding needs of the project. They are shown in Fig. 16. The essential difference between the two is in the bonding area that can be covered. The smaller 8060 is therefore only suitable for the task of bonding hybrids (i.e. making the bonds between the APV readout chips and the pitch adaptor) whereas the 8090 can be used for either hybrids or modules. Either 512 or 768 wirebonds, plus four bias bonds, are needed to fully bond a hybrid. A module requires double this number since bonds need to be made both between the pitch adaptor and the near sensor as well as between the two sensors. Programs have been written for all types of modules and hybrids which exploit the full pattern recognition capabilities of the K&S machines. These programs fully bond the entire module or hybrid, leading

Figure 16: The K&S 8090 (left) and 8060 (right) wirebonders.

to bonding times of approximately 5 minutes for both modules and hybrids. Including set-up time and entering information into the Tracker database, a module can be bonded in about 15 minutes and a hybrid in less than 10.

Fixtures for all types of modules have been designed and built at UCSB. These aluminium vacuum £xtures with te¤on pads hold the modules for wirebonding, providing stable, rigid support under the bondpads (Fig. 17). Hybrids are held using aluminium plates with two plastic clips and strain relief clamps for the tail. The wirebond stage uses a cam to clamp the hybrid plate to the height adjustable stage. The hybrids remain in the plates for testing and storage and variants have been produced for all different hybrid types.

In addition, a DAGE model 3000 pull tester [11] (Fig. 18) is used to develop optimal bonding parameters and for quality control of bond strengths thereafter. A number of microscopes are available for detailed inspection of bonds and for repairs.

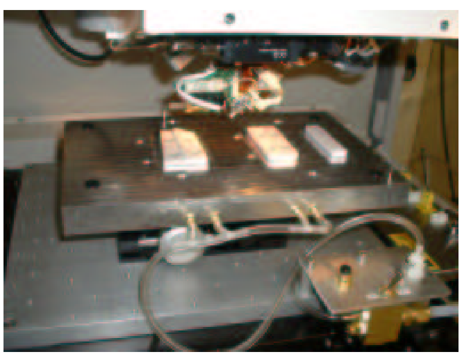

Figure 17: A module wirebonding £xture on the stage of the 8090.

Figure 18: The DAGE model 3000 wirebond pull tester.

5 Module Reinforcement

Upon shipping a number of early TOB modules from the US to CERN, a common pattern of wirebond breakages quickly emerged, with the central 100–200 wirebonds between the PA and the near sensor being weakened or broken during transport (Fig. 19). The hypothesis emerged that the problem stemmed from the fact that the sensors, which have a width of about 10 cm and are glued to the frames only along their edges, had freedom to ¤ex with fairly large amplitudes in between the supports if perturbed during transport. The pitch adaptor, on the other hand, is much stiffer and better supported, so would not be expected to bend nearly as much as the sensors. The difference in the amplitudes of vibrations between the two could account for the observed damage.

A simple solution was developed and tested whereby lines of Sylgard 186, a silicone elastomer manufactured by Dow Corning, were added to the back of modules between the two sensors and between the pitch adaptor and near sensor. With this reinforcement, a packaged module was found to survive a 1 m drop test without any damage. The same test on an unmodi£ed control module resulted in damage to every single wirebond. A more rigorous evaluation was carried out in Germany using a vibration table. In those tests, the unmodi£ed module broke in a 3.4g random vibration test, whereas the reinforced module showed no breakages even after a 6.8g test [12]. This series of tests also demonstrated that the two-sensor TEC modules had the same vulnerability to breakages.

Module thermal pro£le tests at UCSB and CERN, as well as £nite element analyses (FEA) at CERN showed that adding the glue lines increases the temperature of the sensor near the hybrid by less than 0.3 °C, which is within acceptable limits. In addition, tests of the mechanical bowing of the module during the temperature changes expected in detector operation were performed in Germany. These tests, as well as FEAs performed in Germany and at CERN, all showed that adding the glue lines did not adversely affect the mechanical properties of the module. In fact, these studies demonstrated that the additional glue reduced the amplitude of thermally induced physical distortions of the module by a factor of four. Accordingly, this solution has been adopted and the reinforcement will be applied to all TOB modules prior to mounting them on rods. A slightly different solution has been implemented for TEC modules whereby two ceramic strips are glued to the backs of the modules, in the same locations, during assembly by the gantry.

In order to apply the glue lines to the TOB modules in a consistent manner that can keep up with the peak production rate, a Fisnar I&J 2300 Bench Robot [13] is used (Fig. 20). This apparatus has a working area of 30 cm x 32 cm and uses a volumetric twin pack dispenser, which automatically mixes the Sylgard as it is applied.

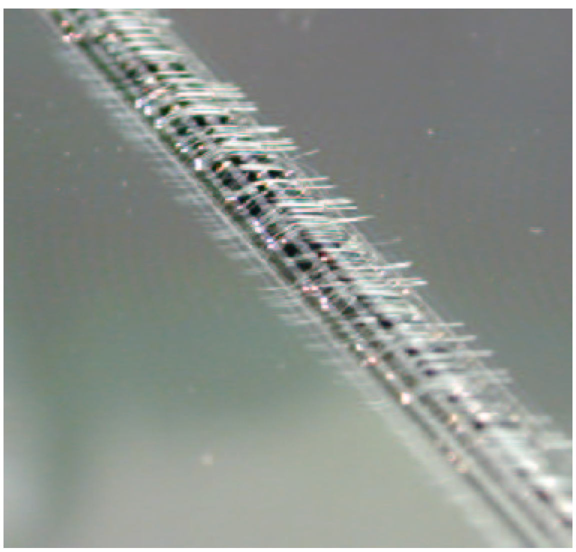

Figure 19: Broken wirebonds between sensors following module transport.

Figure 20: The Fisnar bench robot used for the application to the modules of reinforcement glue.

6 Production Results

6.1 Mechanical Assembly

At the time of writing (April 2004) a total of 287 modules have been assembled at UCSB since the £rst module was produced in March 2003. A breakdown of the different types built is shown in Table 1. According to the schedule, the peak production rate will be 15 modules per day, corresponding to £ve assembly plates of three modules. Early this year, this rate was sustained for ten days as a test of the production centre capacity.

Module assembly is generally handled by a two person team. Typically, one person will operate the gantry or OGP while the other prepares for the next run. This involves picking out and visually inspecting the components, which – particularly in the case of sensors – are sorted and paired according to an algorithm [14] which uses information

Table 1: Numbers of different types of modules built as of April 2004.

Module Type	# built
TOB Axial 4-APV	224
TOB Axial 6-APV	30
TOB Stereo	6
TEC Ring 6	27

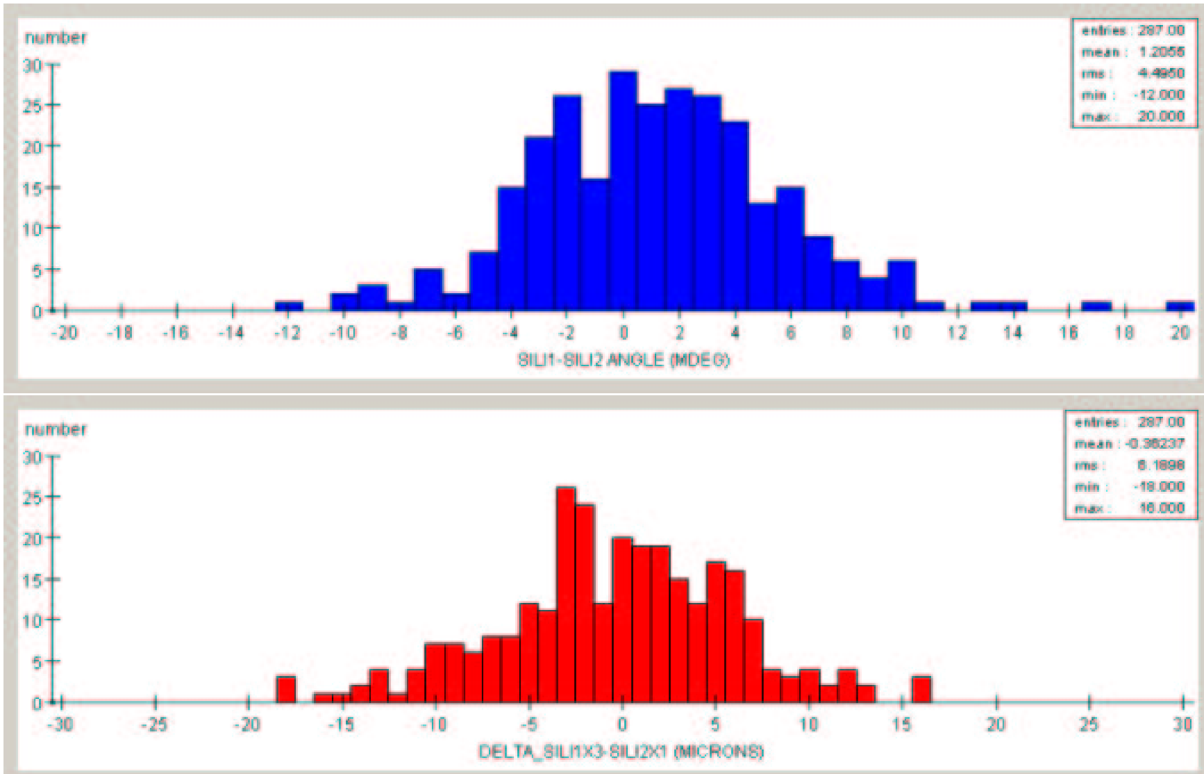

Figure 21: Results on the alignment of the sensors for all modules built at UCSB. Top: Angle between sensors. Bottom: Δx between sensors.

obtained from the Tracker database concerning their electrical properties. The component's IDs then need to be associated in the database with that of the module. It is also necessary to prepare the glues, whose properties mean that new preparations are required for each run. It was found that, on a problem-free day, all 15 modules can be assembled and the previous day's surveyed within six working hours. This leaves a comfortable buffer at the end of the working day to absorb any glitches that may occur during the assembly process.

With regard to the component placement accuracy, the most critical parameters concern the mutual alignment of the two sensors. Figure 21 shows the angles between the sensors and the strip offsets for all the modules built to date. The hybrid placement is less critical, with the only real requirements being that it is within mechanical limits and can be wirebonded. The angle of the hybrid with respect to the silicon is shown in Fig. 22. The ultimate aim is for this to be less that 30 mdeg. However, no problems were encountered with bonding any of these modules.

The speci£cations for the sensor placement call for the strips to be aligned to 30 microns or less and for the angles of the sensors to be less than 10 mdeg., both with respect to the frame and to each other. The sensors are also required to be positioned on the frames to an absolute accuracy of less than 30(50) microns in $x(y)$. In total 12 modules have been ¤agged as being outside the assembly accuracy speci£cations. Of these, two are the second and third modules made (back in April 2003). It was these modules that led to the discovery that curing at elevated temperatures produced large shifts in the sensor positions. Of the others, eight out of the ten were ¤agged due to a large angle between the sensors. Six of these came during the recent 150 module run, with two prior to that.

The 150 module run provided, for the £rst time, usable statistics on the placement accuracy of the sensors in

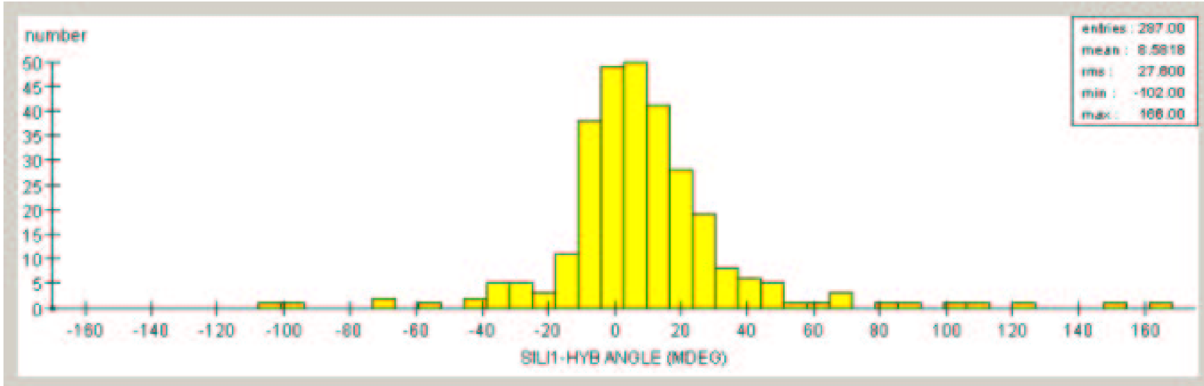

Figure 22: Results for the angle of the hybrid with respect to the nearest sensor for all modules built at UCSB.

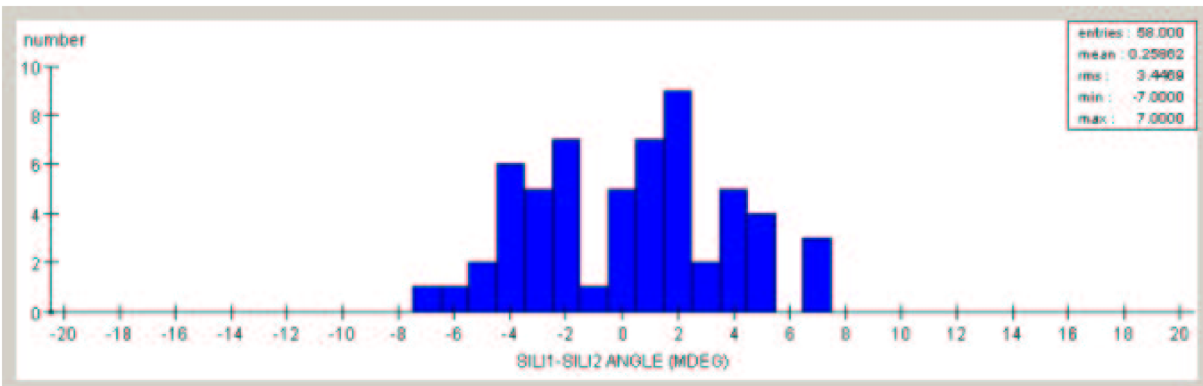

Figure 23: Results for the angle between sensors for most recent 58 modules built.

individual positions on each of the £ve assembly plates used. It appears that subtle differences in the assembly plates lead to trends in the £nal accuracies of the assembled modules which are unique to each individual plate, and to each position on that plate. Prior to this, approximate correction factors to the positions of the sensors, based mainly on data obtained from 'dry' runs, had been implemented. Now, a new set of correction factors have been derived, including – for the £rst time – corrections to the rotations. Early indications are that these lead to noticeable improvements and should lead to all modules being mechanically within speci£cations (Fig. 23).

6.2 Bonding

The pull strength of a wirebond is the main criteria in determining its quality. The CMS speci£cations call for a pull strength of > 6g and only a small number of lift-offs. Extensive pull testing was carried out to determine a set of standard parameters for each type of bonding surface.

The wirebonds on the silicon are very consistent in bond strength and bond foot size. The average pull strength is measured to be 9.4 ± 0.5 g. Initially, bonding on the pitch adaptors was less consistent due to variable quality of the aluminization of the pitch adaptors manufactured by Reinhardt Microtech [15]. This meant that the bonding parameters had to be adjusted for every pitch adaptor, which was a very time-consuming process. Now, the pitch adaptors are being supplied by a new vendor (Planar Systems Inc. in Finland [16]) and are generally very consistent in their bondability, apart from one issue discussed below. Overall, the average pull strength of the PA–sensor bonds is measured to be 10.6 ± 0.8 g. With regard to hybrid bonding, no major problems have been observed and hybrid bond strengths are 10.3 ± 0.5 g.

All of the modules built have been wirebonded, along with over 600 hybrids. This corresponds to a total already topping 0.7 million wirebonds. Of these, a total of 67 faulty hybrid channels have been caused by wirebonding (0.022%). However, 41 of the 67 were bonds that failed to stick on a particular batch of Planar pitch adaptors. The PA's in this batch suffered from metallisation which adhered poorly to the glass substrate. The default set of bonding parameters, which had previouly been very successful, tended to lead to problems with bonds not sticking as the aluminisation pulled off of the PA. Eventually, a new set of bonding parameters were determined which eliminated this problem. With regard to modules bonding, a very low failure rate of only 15 channels total has been observed (0.005%). Of these, one was a pinhole, the rest opens.

During the £fteen modules per day production run, the wirebonding was able to keep pace with the production rate, with one technician needing about six hours to bond the modules on the 8090. This included pull testing of every 50th channel on every tenth module and eight test bonds on each pitch adaptor. This test was required of the £rst 20 modules of each type, subsequently reducing to a once a week frequency. Pull testing of bonds in the pitch adaptor is performed once every ten modules or when bonding parameters have been changed. The recent addition of the 8060 wirebonder removes a bottleneck in the bonding of the hybrids, and in recent production 28 hybrids were bonded in an eight hour period.

7 Conclusions

A substantial amount of work has been carried out at UCSB to prepare for CMS Tracker production. State of the art equipment has been purchased and set up to cater for assembly, wirebonding, inspection and repair. Numerous improvements have been made, and £xtures designed and built, in order to ensure that high quality modules can be produced at the required rate. In this context, it has been possible to absorb large increases in the scope of the tasks to be performed – for example, the addition of hybrid bonding and of TEC module assembly.

A signi£cant number of modules have been assembled over the past year. This has demonstrated the production capabilities and has also facilitated tuning of the process, leading to a high level of con£dence that all modules will meet the mechanical speci£cations. During the £rst substantial build, 4% of modules (8/150) were outside of the required accuracy, mostly due to angular misplacements of the sensors. Subsequent to the tuning based on the data obtained during that build, 58 further modules have been assembled which have all been well within the mechanical tolerances.

The wirebonding of these modules, along with large numbers of hybrids, has given very satisfactory results, with minimal faults introduced. The introduced failure rate for modules is just 0.005%. The corresponding rate for hybrid bonding is 0.022%, although over half the failures are attributable to one particular batch of problematic hybrids.

References

[1] **CERN/LHCC 98-6**, *"CMS: The Tracker Project: Technical Design Report"*, April 1998.
CERN/LHCC 2000-016, *"Addendum to the CMS Tracker TDR"*, February 2000.

[2] **CERN/LHCC 99-09**, L.L. Jones *et al.*, *"The APV25 Deep Submicron Chip for CMS Detectors"*, September 1999.

[3] Note on electronic testing at UCSB (in preparation)

[4] http://www.aerotech.com/products/gantries/ags10000.html

[5] http://www.ogpnet.com/na/ogpVideoSystems.jsp
http://www.bcmac.com/OGP/AvantZIP_400-600.pdf

[6] http://www.kulickesoffa.com/prodserv/pdfs/meg/8060.pdf

[7] http://www.kulickesoffa.com/prodserv/pdfs/8090.pdf

[8] **CMS Note 2002/005**, A. Honma *et al.*, *"An Automated Silicon Module Assembly System for the CMS Silicon Tracker"*, December 2001.

[9] http://www.festo.com

[10] http://www.pen-vac.com

[11] http://www.dage.de/download/ser3000.pdf

[12] *"Broken bonds and shipping modules"*, A. Cattai, http://agenda.cern.ch/fullAgenda.php?ida=a032055

[13] http://www.ij£snar.com/usa/details.asp?product=44

[14] *“ST sensor grading and pairing”*, E. Widl, http://agenda.cern.ch/fullAgenda.php?ida=a04390#s7

[15] http://www.reinhardt-microtech.ch

[16] http://www.planar.com