20.09.2002

Module assembly
in
Oslo.

Version. 1.0

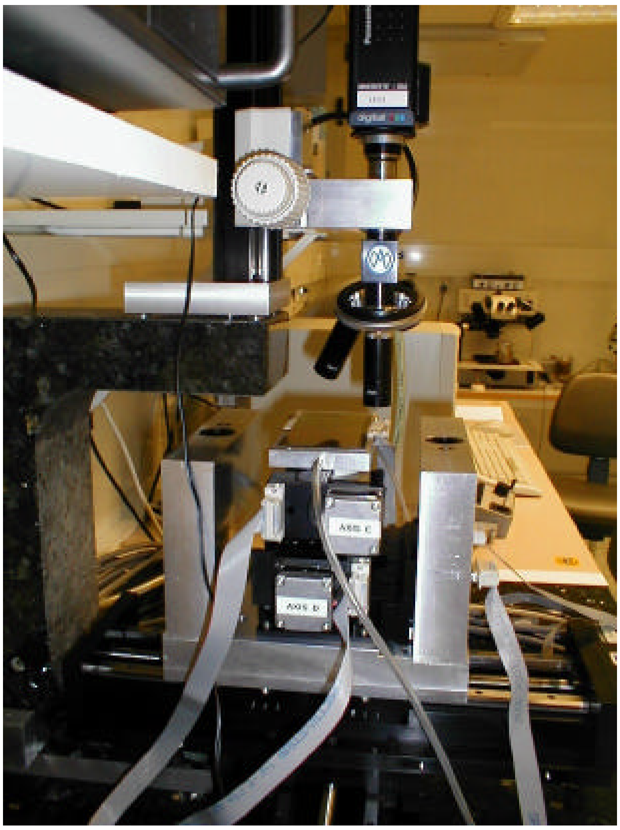
Introduction.

This document describes the detector alignment procedures at the University of Oslo. It contains a description of the set-up and software, as well as a brief discussion of the general principles. A more detailed description of all the steps is left to the operator manual.

The set-up.

The equipment consists of an alignment jig, a number of pick-up jig sets, step-motors to move the alignment jig, a control box for the step-motors, a camera with a monitor, and a computer to control the system.

The alignment jig consists of a solid aluminium frame in a u-shape, that is a bottom plate and two walls. In each of the walls there is a hole with ball-bearings fitted for steering pins. These steering pins are never removed, so they can be regarded as fixed. On the bottom plate two units of step-motors are mounted. The units are identical and consist of three step-motors on top of each other. The two lower ones move linearly and are oriented orthogonal, and the top one rotates. On top of the rotating motor a vacuum chunk to hold the detector is mounted. When the detector is placed on the vacuum chunk it can move in the x- and y-directions and rotate independently. With two of these units mounted on the u-shape frame, two detectors can be aligned next to each other, and be controlled in any direction. The alignment jig shown in picture 1.



Picture 1

The two steering pins define a coordinate system. The y-axis can be defined to be parallel to the line between the centres of the steering pins. The x-axis is normal to the y-axis. The origin is defined to be the centre point between the steering pins. The principle of the alignment is that the detectors should be aligned with the centre of the two detectors in the origin. The line between the centre points of the detectors should have a 20 milliradians angle relative to the x-axis. To measure the positions of the centre of the steering pins is time consuming, and the results are not precise. Therefore pieces of silicon with special marks are mounted near each steering pin. The positions of these marks can easily be measured with high precision. These marks will be referred to as reference points one and two. Adding vectors to the positions of the reference points will give the positions of the steering pins (figure 1).

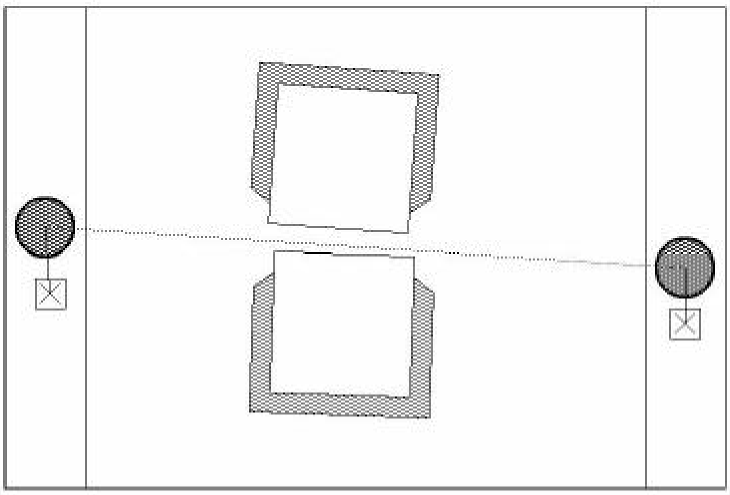


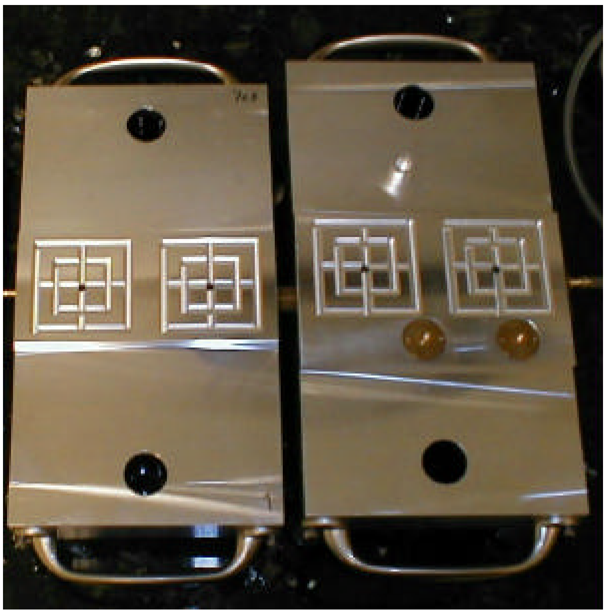
Figure 1

The alignment jig is mounted on two long-range linear step-motors. They are aligned such that the bottom one moves parallel to the direction of the walls on the alignment jig. The other step-motor is mounted on top of this one and is aligned normal to the bottom one. They are referred to as the A and B stages, and they define a new coordinate system. The step-motor positions can be read out in terms of step numbers, and this can be converted to millimetres if the step length is known. In this case there are 250 steps per millimetre, and this is assumed to be constant. This is of course not the case, but for this purpose it will not affect the performance. It is the repeatability that is important. When stage A is positioned with step number a, and stage B is positioned with step number B, the coordinates of the alignment jig are (a, b). The step motor control system resets the coordinate system every time it is turned off, so the program must control the absolute values of the coordinate system by storing the positions on file. In addition, the step motors are also shifted a few micrometers every time the system is initialised, so it is best to operate with relative coordinates only.

Above the alignment jig a fixed camera is mounted. Using the AB stages the alignment jig can move under the camera. With a lens magnifying 320 times, the camera gives images to the pattern recognition system so that the positions of certain fiducial marks can be measured with great precision. By definition the point in the centre pixel of the image is assigned the coordinates of the AB stages. Other points in the image can also be assigned AB coordinates by transforming pixel size to step size, or by transforming the AB coordinates to millimetres, and the pixel coordinates to millimetres and then adding them together. This will give a new coordinate system, the XY-system (not to be confused with the xy-system). The calculations are simplified by assuming that the pixel size is constant, and that the axes of the pixel coordinate system are parallel to the AB stages. Ideally, the position of any point in the image will be the same as if this point were moved to the centre pixel, using the AB step motors, and measured again. The errors will be negligible for positions near the centre pixel.

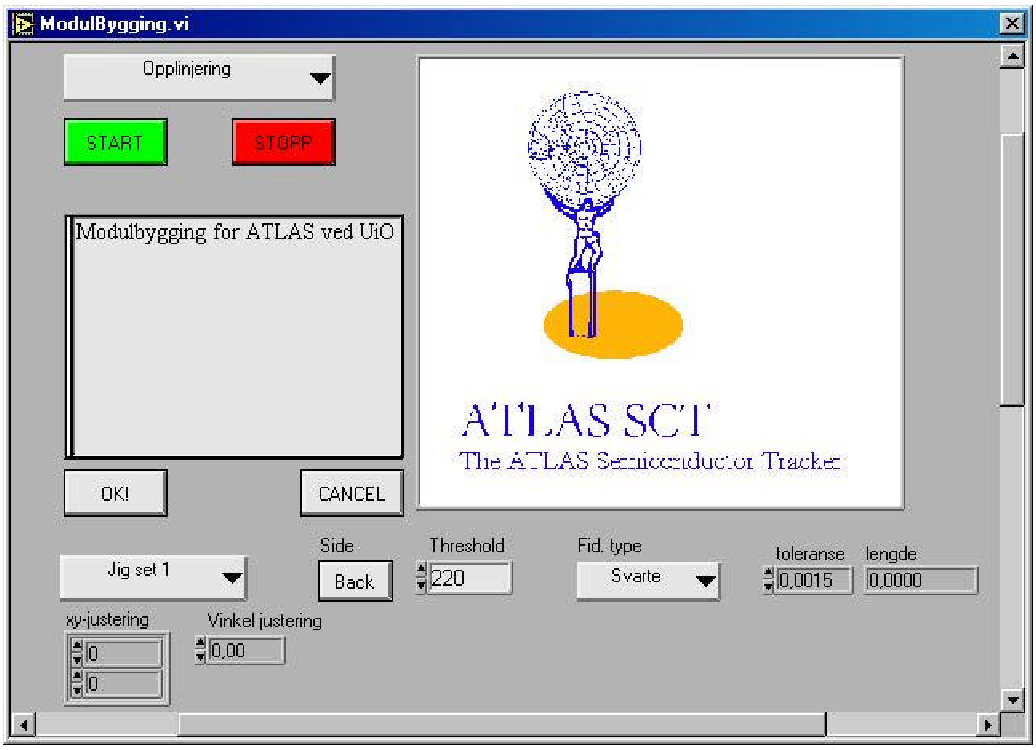
Two detectors are aligned on the alignment jig at certain positions relative to the steering pins on the jig. These must be transferred to the pick-up jig without loosing their coordinates. The pick-up jigs are the jigs used for gluing the detectors to the baseboard. They have holes with ball-bearings fitted for the steering pins on the alignment jig, and a hollow pattern for the vacuum to hold the detectors in place. One can introduce the same coordinate system here as on the alignment jig, with the y-axis between the centre of the two holes and the origin in the mid-point between the holes. Reference marks, similar to the ones on the alignment jig, are glued to the pick-up jigs too, so that instead of measuring the positions of the holes, the positions of the reference marks are measured.

One must distinguish between the pick-up jig for the backside detectors and the jig for the front-side detectors. The backside pick-up jig has steering pins for the baseboard mounted. These steering pins can be screwed down and out of the jig for two reasons. First, the diameter of the precision holes on the baseboards vary slightly, so it is desirable to have steering pins with different sizes too. Second, when the pick-up jig is lowered down on the alignment jig to transfer the detectors, the pins must be screwed down not to obstruct the jig from coming all the way down on the detectors. The front side jigs do not have these steering pins, but otherwise they are identical. A backside pick-up jig and a front-side pick-up jig make up a jig set. To build modules with the required precision, jigs from different sets must not be used together.



Picture 2

The alignment system is computer controlled with a LabVIEW program. The program communicates with the step-motor control box, the camera and the operator. The detailed description of the program is left to the operator manual, but a brief account of the main features is given here. All LabVIEW programs consist of a front panel and a diagram. The front panel is the interface to the user, while the actual program is implemented in the diagram. The main intention for the program, except for aligning detectors, is to be as simple and intuitive as possible. A message box on the front panel gives instructions to the user, who responds by pressing the OK or CANCEL buttons. The picture box displays the images from the pattern recognition system so the user easily can adjust different parameters if it fails. The most important parameter is the threshold value, which is used when transforming the 8-bit image into a binary image. From the menu the user can execute the different options of the program. The three main options is the "detector alignment", the "measure detector" option and the "measure detectors on pick-up jig" option. The latter option is used to control that a pair of aligned detectors that has been transferred to the pick-up jig has kept its coordinates after the transfer. Measuring the corner of the detectors relative to the reference points on the jig does this. However, since the positions of the detectors are defined by the positions of fiducial marks on the detectors, and not by the corners, the relative positions of the fiducial marks to the corner must be measured too. This is done by the "measure detector" option. The front panel is shown in picture 3.



Picture 3

Measuring the detectors.

The first step is to measure the relative position of the corner to the fiducial mark on the detector. This is done on only one detector per side. In the menu on the front panel the option "measure detector" is chosen. The detector is placed on a pick-up jig rather than directly on the alignment jig, because there is a mirror on the pick-up jig that gives good contrast to the corner for measuring its position. The pick-up jig is placed on the alignment jig, and the AB-stages are driven to the position where the fiducial mark on the detector is centred in the camera. The position is measured, and the camera is driven to the corner to measure its position. This is repeated five times to give some statistics in case of a bad measurement. The vector from the fiducial point to the corner is calculated, as shown in figure 2, but the rotation of the vector depends on the rotation of the detector on the jig. The detector orientation must be measured so the vectors can be normalized. Measuring a fiducial point at the other end of the detector does this.

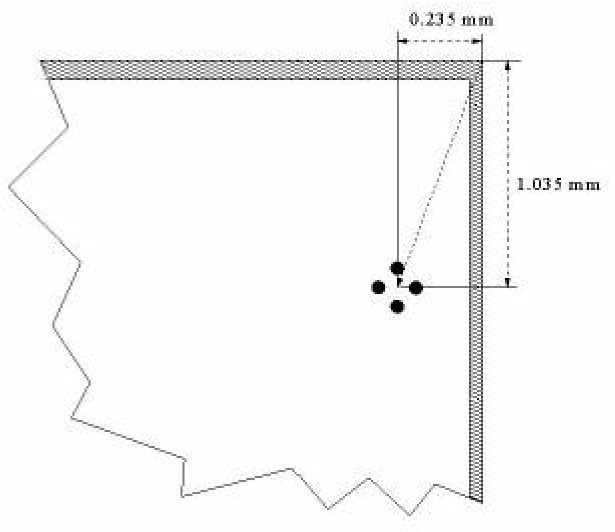


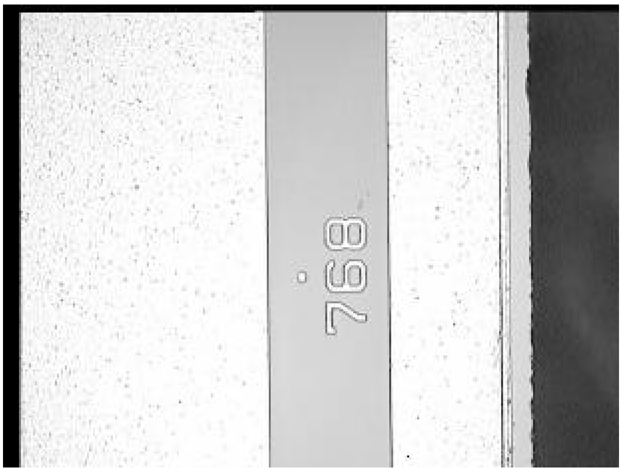
Figure 2

Detector alignment.

Choosing the “detector alignment” option from the menu starts the detector alignment. A detector is placed on each vacuum chunk on the alignment jig. The measured detector is placed on the right-hand side so that it will end up near the reference point on the pick-up jig. The orientation of the detectors can be checked by eye by controlling the position of the scratch pads. An inspection routine is also integrated in the program to make sure that the module is not assembled the wrong way.

With the detectors on the chunks, the alignment can begin. The detectors will be aligned relative to the reference points on the alignment jig, so these positions must be measured first. When this is done, the correct positions of the detectors are calculated. These positions, however, depend on which pick-up jig that is to be used. Therefore there is a different pair of offset vectors for each individual jig. The jig is indicated on the front panel by choosing jig set and side. In addition the operator has the possibility to fine tune the positioning by using the adjustment controls on the front panel. With these controls the alignment can be rotated and displaced in the xy-directions. This is more convenient than to change the offset vectors. The reason for doing this fine-tuning is that a pair of offset vectors that work one day may not be optimal another day. It is the positions of the detectors on the pick-up jig that matters, and the transfer from alignment jig to pick-up jig is not one to one, but can be a little unpredictable.

Assuming that the correct jig set and side is chosen, the correct detector positions are now calculated. Before the alignment begins, the inspection routine, mentioned earlier, to control the orientation of the detectors is done. The camera is driven to a position where the strip number of the detector should be visible. The correct orientation of the detector is by definition such that strip number 768 is under the camera, shown in picture 4. If strip number one appears, the detector must be re-placed. This test is done for both detectors, and the operator has to confirm that the detectors are orientated correctly. In the case that the strip number is out of reach for the camera, a search panel appears so the user can search for the number manually.

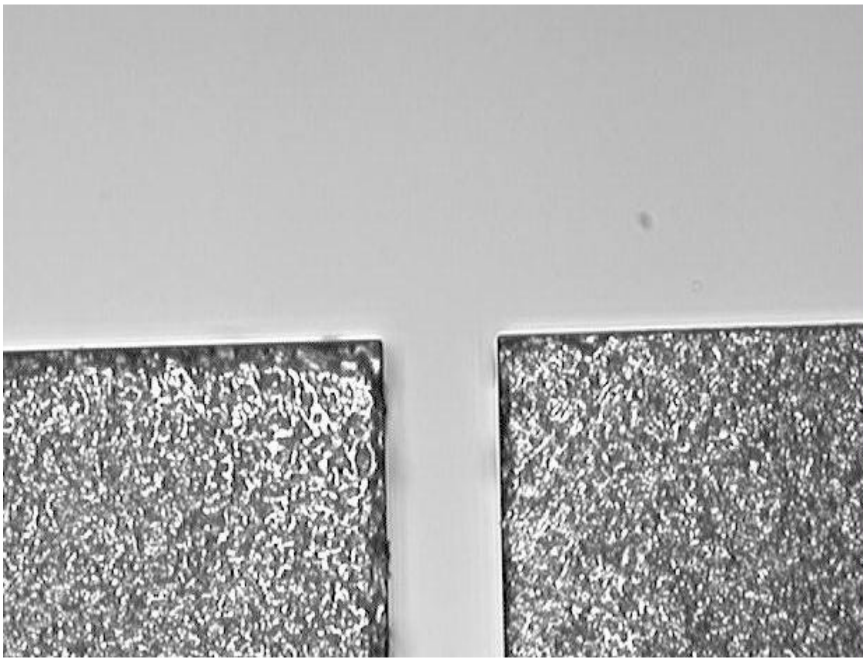


Picture 4

Now the system must measure the initial positions of the detectors. The position of a detector is defined by two fiducial marks, and it is the position of the fiducial marks that must be measured. The detectors are put on by hand, so this step involves some manual searching. The camera is driven to a position in the area of the fiducial mark, and a search panel appears. The operator can move the alignment jig under the camera using this panel, and when the fiducial mark appears in the camera its position can be measured. This is repeated for all four fiducial marks. Now the system knows the initial positions and the desired positions, so the rest is done automatically. If the system discovers that the right hand detectors initial position is interfering with the desired position of the left detector, the right hand detector is moved to a safe position. The left detector is aligned first, and this prevents it from crashing into the other detector.

The alignment of a detector is an iteration process. A cycle of movements is followed by a measurement of the detector position. If the deviations from the desired positions are bigger than the given tolerance, a new cycle of movements is done. This is repeated until the deviations are within the tolerance. The tolerance is set to one micrometer for each fiducial mark. A cycle of movements is a rotation followed by a shift in the y-direction and a shift in the x-direction. The left detector is aligned first, and when this is accepted, the right hand detector is aligned. At the end, a short rapport appears on the message board showing the deviations for each fiducial mark, and the distance and angle between the calculated positions of the steering pins.

Before the detectors are transferred to the pick-up jig, it could be useful to check the separation of the detectors. This is also done with the detectors on the pick-up jig, and the two results must be compared to see whether the detectors have moved relative to each other. The separation is measured by measuring the vector between two corners next to each other. The separation is measured on both sides. Since different detectors can have slightly different cut-edges, it is important to measure these vectors while the detectors are on the alignment jig, because here they are by definition positioned correctly with respect to each other. The separation between the detectors is shown in picture 5.



Picture 5

With both detectors placed correctly relative to the reference points, and therefore to each other, they can be transferred to a pick-up jig. Steering pins that are fixed on the alignment jig do this. The pick-up jig has holes with ball-bearings to match the steering pins, so it can be lowered onto the detectors. At this point the detectors are in contact with both the vacuum chunks on the alignment jig and the pick-up jig. The vacuum on the alignment jig is switched of, and the vacuum on the pick-up jig is switched on. The detectors are now transferred to the pick-up jig, and it can be raised from the alignment jig.

Measuring the detector positions on the pick-up jig.

The pick-up jig with the pair of aligned detectors is put back on the alignment jig with the detectors on the topside. Choosing the "measure detectors on jig" option will start the measuring procedure. Based on the vector measured between the fiducial and the corner of the detector, one can calculate where the detectors should be on the jig to give correct values for the midfx, midfy, mhx, mhy and stereo angle. These calculations are also based on previous modules that have gone through a complete metrology. Three measurements must be done. The position of the corner relative to the reference mark on the jig, the angle of the detectors relative to the jig and the separation of the detectors.

The first test is done straight forward by measuring the position of the corner and the reference point on the jig three times. The angle is measured by first measuring the vector between two corners on the detector. Then the vector between two reference points on the jig is measured, and the angle between these vectors gives the result. Again this is repeated three times to avoid bad measurements. The final test is the separation test, which is done the same way as after the alignment. The separation vectors are compared to the ones measured on the front side.

If the deviations from the calculated, desired, positions are within some tolerances, the alignment is completed. If not, the detectors are put back on the alignment jig, and the alignment is done all over again. Here the fine tuning controls come in handy. If the detectors on the jig were ten micrometers off in the y-direction, the operator can shift the alignment ten micrometers by using the tuning controls. The most crucial parameters are the midfy and the midfx. The tolerances on the positions of the baseboard are bigger. Therefore the positions of the detectors on the backside jig are not that crucial. Shifting the front-side detectors can compensate a shift in either direction. This will result in a shift of the baseboard position, but the midfx and midfy parameters will not be affected.

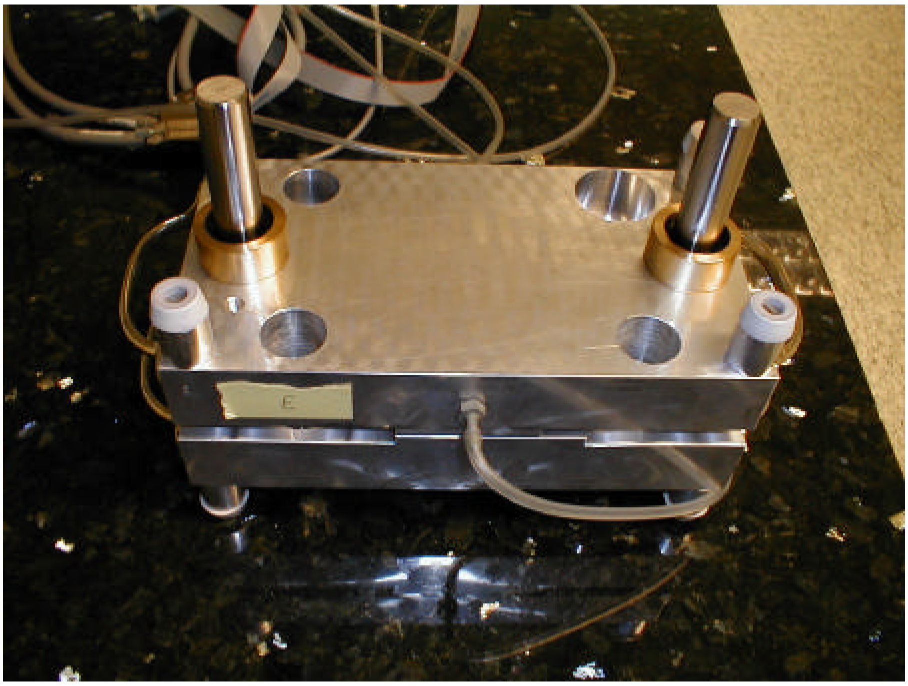
As a guide for the operator the following tolerances are used:

	X direction (µm)	**Y direction (µm)**	**Angle (mrad)**	**Separation (µm)**
Backside	±5	±5	±0,03	±4
Frontside	±4	±2	±0,03	±4

The front side tolerances refer to the compensated values. The separation should not deviate more than four micrometers from the separation measured on the front side.

Gluing the detectors to the baseboard.

The procedure is repeated for a new pair of detectors, so that two pairs of detectors are aligned on a set of pick-up jigs. On the pick-up jig for the backside detectors there are two steering pins for the positioning of the baseboard. A baseboard with glue is positioned on the detectors with these steering pins, using the precision hole and slot on the baseboard. The last step is to position the topside detectors on the baseboard to complete the module. Again this is done with steering pins. A steering pin is put in each of the two holes in the backside pick-up jig. Then the topside pick-up jig is lowered down on these pins onto the baseboard as shown in picture 6. A spacer is put between the jigs to fix the thickness of the module. The thickness of the spacer is calculated from the thickness of the baseboard.



Picture 6