11.11 Assembly

11.11.1 Introduction

In this section the final assembly of the SCT barrels and disks is described. The focus of work on large scale assembly has been to break down the overall task into individual steps, to identify and develop generic procedures for each of these steps and to establish the conditions under which assembly will take place. Details of the procedures outlined in this section are under development.

A high level of reliability is required during the assembly processes, which can only be achieved by enforcing a rigorous quality control system at every stage of manufacture. The general elements of the quality control systems are described in Chapter 1.3.3. The dominant activity during assembly becomes testing.

11.11.1.1 Testing techniques

Electrical checks at the assembly stage are intended to ensure that no damage occurs during handling. A detailed study of the component parts is already made during the component construction phase. The tests will include measurements of detector leakage and chip power supply currents. Test pulses read out via a DAQ system will also be used to ensure electronics functionality.

To establish that the assembly has proceeded correctly, checking procedures will include the use of Thermal Imaging (TI) and White Light Interferometric Profile Measurement, (WIPM - also known as Optical Coherence Radar). TI is a non-contact method for measuring the temperature profile across an object, using a commercially available infra-red camera system. It will be used, for example, to check for poor thermal contact at the module cooling contacts. WIPM is a non-contact method for measuring the surface height across an object with micron scale accuracy. It is based on the localization of so-called 'white light' fringes in an imaging Michelson interferometer when illuminated with a collimated, but broad band light source [11-93, 11-94, 11-95]. The height of the object can be determined by scanning the reference mirror position along the interferometer axis, whilst searching for the white light fringes on an individual pixel basis and tagging the reference mirror position at which this occurs for each pixel. This entire operation takes place under computer control in a single scan. WIPM will be used, for example, to check for excessive out-of-plane distortion (such as bowing, twisting or tilting) of the detectors in relation to the reference mounting surfaces on the completed modules, before and after assembly into local supports.

A fine focus X-ray scanning system will be used for detailed survey and cross-calibration with the FSI system. This is discussed in detail in Section 9.2.2.

11.11.1.2 Barrel local support assembly

Five sub-assemblies will be delivered to the local support assembly site:

- Modules;
- Mechanical support sub-assembly;

- Power and DAT sub-assembly;
- DC monitoring system sub-assembly;
- DCS sub-assembly.

Each of these will have a set of handling, inspection and checking procedures defined. For example, a typical procedure for the modules might be:

- On arrival, inspect and check functionality of modules in handling container, then store cold and powered until required.
- Re-check functionality in handling container, transfer to clean environment and attach to local handling jig.
- Cool to operating temperature and while powered check geometry with WIPM.
- Load into the local support assembly jig.

The first stage of local support assembly will be to attach the mechanical support sub-assembly onto a handling frame, to which it will remain attached until it is fixed to the barrel. This frame will ensure that the local support will remain undistorted during all subsequent handling, assembly, inspection and checking processes.

The power, DAT, DC monitoring and DCS sub-assemblies will then be attached to the mechanical support to produce an un-populated local support. Low-mass cable and fibre-optic pigtails (some ~4m long) will be protected by plastic reels that are fixed to the handling frame.

The un-populated local support will then be mounted in an environmental chamber and subjected to several thermal cycles from $25°C$ to $-15°C$. The operation and calibration of the DCS temperature, pressure and humidity monitors (for the alignment system, where fitted) will be verified. The optical link and electrical harnesses will be retested, in particular to verify the connector functionality during the thermal cycling. Assembly of the unpopulated local support will not be a precision process and will largely be done manually.

The next stage of assembly will be the attachment of modules to the local support, which will require a high precision. However, the final module positions will be fully determined by the positions of the hole and slot in each module, dowel pins in the local support and the datum mounting surfaces on the modules and local support. The precision will not depend on the module placement process.

An initial design for the module placement jig is depicted in Figure 11-107. The main parts are as follows:

- A long travel, low precision linear translation stage for positioning the local support under the module.
- A loading tray for receiving the module.
- A teflon coated vacuum chuck for picking up the module.
- An extension to the vacuum chuck for holding the module pigtail.

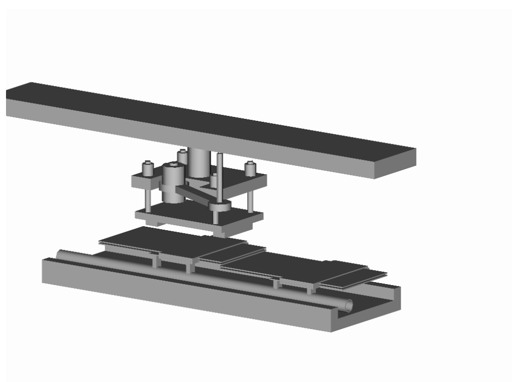

Figure 11-107 Module Placement Jig.

- A manually operated mechanism for raising and lowering the vacuum chuck.
- A 'soft landing' arrangement will prevent damage to the module when it is lowered onto the local support.
- A manual two-axis translation stage for fine adjustment of the position of the module within its plane and a manual rotation stage for fine adjustment of the module angle within its plane.

The translation stage for positioning the local support will have a series of 'detent stops', one for each module position. The translation and rotation stages on the module placement unit will allow the module to be located over the local support with sufficient accuracy to enable the precision hole and slot of the module to mate with the precision dowel pins on the local support, as it is lowered into place. The module will be secured by a single screw.

The un-populated local support will first be fitted into the mounting jig. The following sequence of operations will then be repeated for each module, first for the lower three modules and then for the upper three:

- The module will be placed manually into the loading tray in its handling frame and picked up by the vacuum chuck.
- The local support will be moved into the correct position under the module, and the module will be lowered over the dowel pins onto the datum surface of the local support.
- The module will be fixed loosely in place, the vacuum chuck raised and the local support translated clear of the vacuum chuck.
- The module fixing screw will then be tightened to the correct torque.
- The module wiring pigtail will be connected to the local support wiring harness.
- The basic operation of the module electronics will be verified.

After a local support has been populated, it will be extensively tested. It will be mounted onto a cooling pipe in the environmental chamber and a full set of electrical tests will be performed warm. In particular these tests will include verification of the correct operation of the redundancy scheme. The assembly will then be cooled to –15°C , powered and tested briefly again. WIPM measurements will be made to ensure the modules remain in their correct locations and that there are no distortions.

11.11.1.3 Local support to barrel

Once tested, the local supports can be attached to fully equipped carbon fibre barrels. The attachment will be via six precision support brackets pre-mounted onto the barrel. These will be attached using a precision jig in which the cylinder will be rotated and the brackets translated into position, and then fastened manually by screws.

Before the local supports are fixed to the barrels, the cooling pipes and manifolds must be installed and leak tested. At the same time, the thermometry associated with the cooling system will be installed and tested. Parts of the FSI alignment system will also be mounted and tested prior to attaching the local supports.

If necessary, the barrels will remain stationary during the attachment of the local supports. They will be pre-stressed into their final shapes, by mounting a complete set of dummy local supports of the same mass. These will be removed one at time, immediately prior to mounting each real local support. This will minimise the stresses in the completed structure.

The barrels will be mounted in turn into a support frame via a pair of discs attached to the flanges at each end. These discs will support the barrel as for the final interlink wheels and will be adjustable, so that the axis of the barrel can be accurately adjusted to be coincident with the axis of the support frame. There will be an external circular rail system at each end of the support frame, on which a pair of linked radial arms will move around the barrel, as indicated in Figure 11-108. A series of indexed stops will allow the arms to be located at the correct ϕ angle for each local support. The two arms will be linked by a strut, which will be capable of adjustment to the radial position of each barrel. This strut will carry a linear rail system, along which a carriage will move along the z direction. It will be possible to locate this carriage at either of two z positions, one for each set of local supports at each end of the barrel.

The carriage will support a rotating and sliding 'mounting head' assembly onto which the local supports will be attached one at a time. This movable mounting head will manoeuvre each local support into the correct position for fixing to the barrel. A pair of pins at each end will allow each local support to be swung into position along a trajectory that ensures no contact with any other module or local support.

Figure 11-108 Cylindrical Mounting Frame, Arm

A set of precision fine adjustment screws will manoeuvre the local support into its final position, so that the dowels are correctly aligned with their corresponding holes and slots. This will be done in a similar way to the alignment of the modules onto their local supports. As in the case of module attachment, the dowel pins will be recessed so that they will be tolerant of small tilt errors until the fixing screws have been fully tightened. There will be a similar lowering and soft landing arrangement as for the local support assembly jig to finally engage the local support onto the dowel pins.

The procedure for mounting a local support onto a barrel will be as follows:

- The cooling contact grease will be applied to the cooling blocks on the modules.
- The dummy local support used to pre-stress the barrel will be removed.
- A local support will be mounted onto the mounting head at its loading position.
- The radial arms and carriage will be manoeuvred into the correct ϕ and z position.
- The local support will be guided and adjusted into its final position, engaged with the dowel pins, screwed loosely in place.
- The cable and fibre-optic pigtails will be transferred to a temporary fixing on the barrel support frame near to the end of the local support.
- The handling frame will be removed from the local support, and the local support fixing screws will be tightened to the specified torque.

Once both local supports forming a complete line in z have been attached, the central electrical bypass connections will be made manually. The barrel will then be cooled to $-10°C$ by cooling the environment and the pair of local supports observed using a WIPM system which will be mounted onto a strut fixed to a second pair of rotating arms. Measurements will be automatically made along the full barrel length. The cooling system will be turned on and WIPM used to look for abnormal shape changes which would indicate bad mechanical connections. The electronics will then be powered up and WIPM again used to look for distortions. At the same time TI will be used to look for hot spots. In combination, these tests will give a high degree of assurance that the local supports have been correctly mounted and have good cooling contacts. In addition to measuring the most recent pair of attached local supports, the previous four pairs of local supports will also be measured during the cool down of the barrel; in this way each local support will be studied through five complete thermal cycles.

11.11.1.4 Forward modules to disks

This section describes a conceptual scheme for the assembly of modules onto the forward SCT disks together with a suitable placement machine and the sequence of tests during the assembly. After a disk has been fully machined it is placed in a frame where it is kept until it has been surveyed, fully assembled with modules and other components and finally tested. Such a frame with a "naked" disk in it can be seen in Figure 11-109. In addition to what is shown in Figure 11-109 a), each frame provides connections for all cooling and module services so that it can be easily connected to a cooling system or a module readout system. Services which have to hang from the disk permanently, for example optical fibre links can be temporarily attached to the outside of the frame**.** The disk is attached to the frame at the same locations at which it will be held inside the space frame. The frame itself does not have to be machined with great precision since one of the attachment pins to which the disk is fixed is adjustable in position with respect to the other pin. A frame will be a relatively cheap component and therefore one frame for each disk can be fabricated. The frame is also used to insert a disk into the space frame as described in Section 11.11.1.6. The disks are also surveyed, tested, transported and stored inside their frames.

The assembly of modules to the disks is performed with the disk hanging in its frame and an assembly tool fixed to the frame as shown in Figure 11-109 b) and c). In this position the assembly tool can be used to assemble all modules on one side of the disk. If it is necessary to assembly modules onto both sides of the disk in parallel a second assembly tool can be mounted onto the other side of the frame.

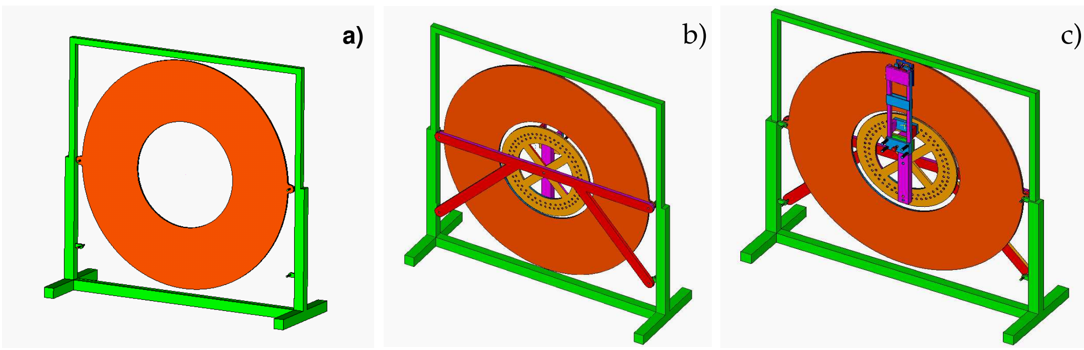

Figure 11-109 Disk support frame (a), together with rear (b) and forward (c) views of the module attachment tools.

The assembly tool consists of a bridge fixed to the frame on the same pins that hold the disk to the frame. It is therefore automatically aligned to the disk. The bridge holds a locator wheel in the centre of the disk to which an arm is attached. The arm is held with a bearing on a shaft in the centre of the locator wheel. The arm has a module pick up and placement unit on its end and can be rotated around the centre of the disk to the ϕ position of each module. It is locked in this position by inserting two dowel pins into corresponding location holes in the locator wheel. These dowel pins have a spring mechanism which holds them in the “inserted” position unless they are pulled back and rotated by 90^0 so that they get locked in the “not inserted” position. The locator wheel has two sets of locator holes which specify the ϕ positions of the modules in the outer and the two inner rings (modules on the two innermost rings have identical ϕ positions).

The arm of the assembly tool consists of two parts, a solid, central bar extending to the inner radius of the disk and an outer arm extending to the radius at which the module will be placed. The arm and the bar are connected to each other via a connection plate which is a part of the outer arm. A detail of the connection between the outer arm and the central bar can be seen in Figure 11-110. The outer arm is made of two square aluminium extrusions connected with cross plates in several places to give a lightweight and torsion-stiff structure. The radial position of the module placement unit can be adjusted to the three module radii.

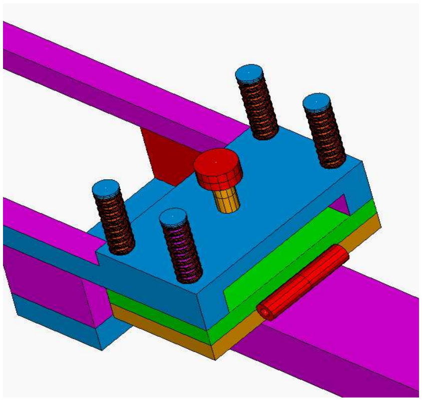

Figure 11-110 Connection Detail.

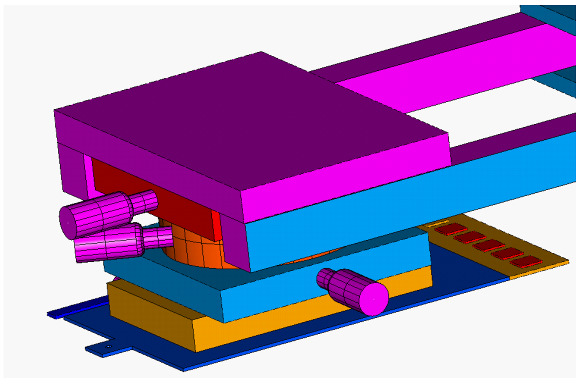

Figure 11-111 Module Placement Unit.

A z-movement of the outer arm is facilitated by a set of four linear bearings in the outer arm receiving four shafts from the connection plate of the outer arm. These shafts are loaded with springs pushing the outer arm towards the connection plate. The height of the outer arm above the surface of the disk is then adjusted by a screw above the centre of the connection plate which pushes the outer arm away from the connection plate and thus from the inner bar. The module placement unit itself is shown in Figure 11-111 and consists of:

- A teflon coated vacuum chuck holding the module.
- Two variable extensions of the vacuum chuck holding the pigtail of the module.
- Manually adjusted linear stages for fine adjustment of the module position in the x and y coordinate and also rotation.
- A stage adjusting the module ϕ angle.

The module placement unit allows the module to be located on the disk with sufficient accuracy for precision dowel pins to be inserted through the precision hole and slot of the module into the corresponding holes in the connection blocks on the disk. Microscope objectives are used to check whether the module holes are aligned with those in the connection blocks. The dowel pins are secured in the connection blocks by grub screws and the module is secured to the connection blocks by an additional, short 1 mm screw in each block.

It is possible to tilt the outer arm away from the disk by 90 degrees with a hinge in the connection plate which is also shown in Figure 11-110. If the arm is tilted away from the disk and rotated to the $\phi=180^0$ position as shown in Figure 11-112[1], the placement and pick-up unit will be in a horizontal position and a module in its transport and test box can be located underneath the unit. Using the adjustments of the vacuum chuck the module can be picked up from its box and the arm is then “loaded”. After loading the arm it is rotated into the next ϕ position and tilted back towards the disk for placement of the module.

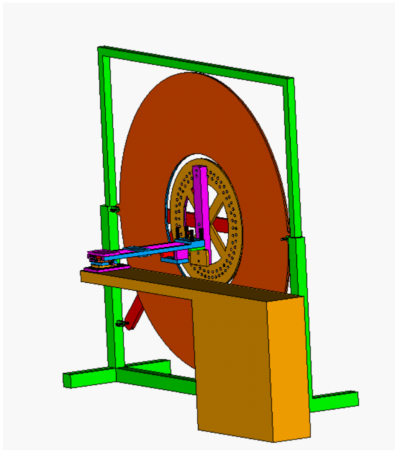

Figure 11-112 Module Loading Position.

The above attachment procedure does not rely on accurate jigs and automated placement because the only position that has to be determined with high accuracy - the position of the module location unit - is adjustable. The module position is determined by the position of the holes in the module and the connection blocks and does not depend on the module placement process.

After a module is placed onto the disk its elementary electrical functions are tested. For this reason the placement arm will be equipped with a set of readout cables and connectors which leave the arm near the centre of the disk (cables are not shown on the figures).

After the installation of each ring of modules, the disk is connected to a "docking station" which provides all cooling connections and electrical and optical connectors for a complete disk. The modules are powered and clocked and test pulses will be read out.

11.11.1.5 Barrel interlinking

The assembly of the four barrels into the final structure will be a complex operation. This is because each barrel will have long pigtails of services and the interlink structure which holds them together will have to be threaded onto these whilst the barrels are maintained in their correct positions. The details of this process are still preliminary.

The general scheme is depicted in Figure 11-113. First, the smallest barrel will be mounted onto an assembly jig, which will be cantilevered from a support frame at one end. The next barrel will then be manoeuvred into position, supported by a similar cantilevered frame attached to the other end which will be mounted onto a carriage which can roll along rails fixed to the floor. The outer barrel will then be temporarily attached to the inner barrel with adjustable struts at both ends and the mobile support frame will be retracted. The service pigtails will be protected with a handling frame. The position of the outer barrel will then be adjusted into its final posi-

1. in the $\phi=180^0$ position the arm would be hanging vertically down if it was not tilted away form the disk.

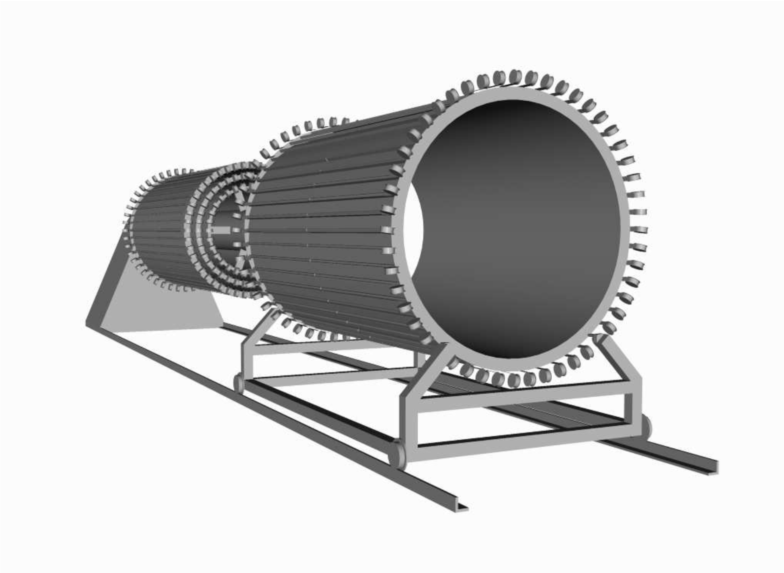

Figure 11-113 Barrel Assembly Scheme.

tion, and checked using the FSI alignment system. Both barrels will then undergo a full series of electrical and cooling checks to ensure functionality.

This process will then be repeated for the remaining barrels. Finally the services at the free end will be fed onto a special jig and passed through the holes in the interlinking wheel, which will then be manoeuvred into its final position and attached to the four barrels. The temporary support struts will then be removed at that end and the complete assembly will then be supported from this interlink wheel and a new temporary support at the other end so that the cantilevered support frame can be removed. The procedure will then be repeated for the second interlink wheel at the other end.

The services will then be laid out along the interlink wheels and attached to them. The completed SCT barrel assembly will then be inserted into its active insulation jacket and temporary end covers installed. The cooling system will be connected, the electronics powered up and all systems tested at the final operating temperature. It will then be surveyed once more at the operating temperature, using both FSI and the X-ray scanning systems.

Finally, the entire SCT barrel assembly will be installed inside the TRT barrel and the services attached to the TRT support structure. After a final set of checks to verify the service connections for both the SCT and TRT, the complete assembly will be installed into ATLAS, as discussed elsewhere.

11.11.1.6 Disks to spaceframe

This section describes conceptually the mounting process of disks into a space frame section of arbitrary length. It assumes the use of disk hanging points for handling during installation. Before the disks are installed into the space frame all services will be pre-installed to the outside of the space frame.

During the installation process a temporary rail will be inserted into the space frame. This can be seen in Figure 11-114 from the top. The rail is held by arms which reach into the space frame

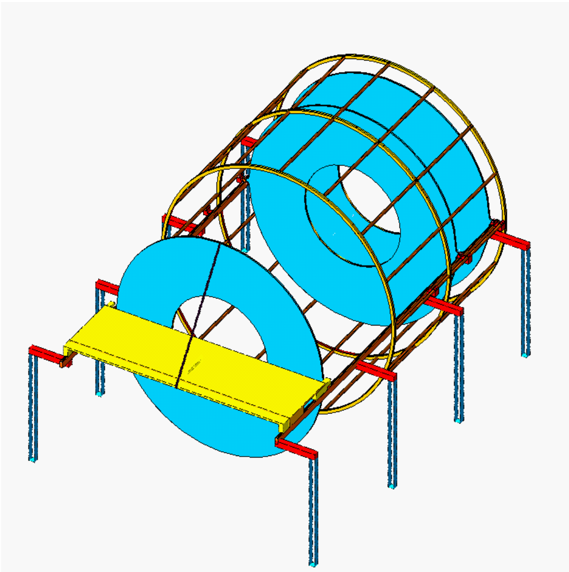

Figure 11-114 Temporary rail installation from the top.

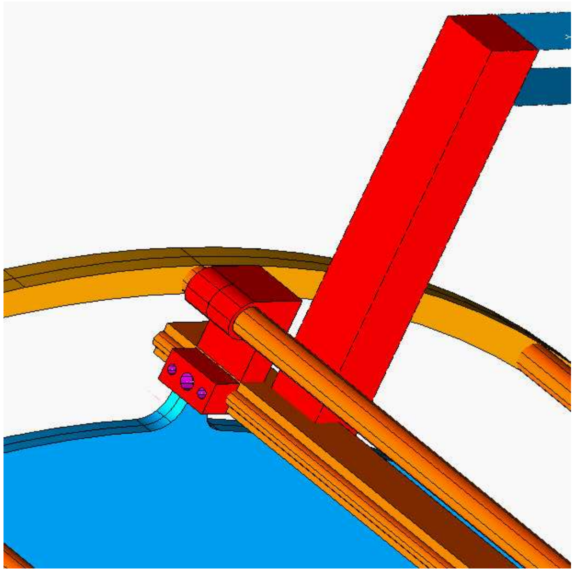

Figure 11-115 Detail of rail position and attachment points.

from the sides. These arms can be adjusted to allow the rail to become level with the disk attachment points on the space frame. A detail of the rail position with respect to the attachment points can be seen in Figure 11-115. In this figure the rail is already level with the attachment point. Once the rail is levelled the disks can be driven along the rail and over the attachment points. This makes use of the fact that the attachment is made using vertical connection pins and screws and that the joining surface between the space frame and the disks is horizontal.

Before the disk can be driven into the space frame it will be mounted on a car as in Figure 11-114. This car rests on the rails in four points and holds the disk in three points.

Once a disk is installed into the space frame all connections to external services are established. The complete frame is then covered with a temporary active insulation. The frame is then cooled to the operating temperature and the modules are again checked. During this operation the disk cooling system is also operating. This procedure will ensure that all connections are correctly established. After this test the position of the disk with respect to the space frame reference points is measured by a coordinate measurement system. The procedure of cold test and survey is repeated for each disk until the space frame section is fully equipped. Finally, the disk positions are again surveyed, the active insulation is installed onto the outside of the space frame covering all access to the services and the disks, and the section is operated using its own active cooling system.

11.11.2 References

11-93 T. Dresel, G. Hausler and H. Venzke; "Three-dimensional Sensing of Rough Surfaces by Coherence Radar", Appl. Opt. 31 (1992) 919.

11-94 M. Seeger, A. Gh. Podoleanu and D. A. Jackson; "Preliminary Results of Retinal Tissue Imaging using Coherence Radar Technique", Proc. Appl. Opt. Div. Conf., Reading, 16-19 September 1996, IOP Publishing, p64-68.

11-95 B. Bowe and V. Toal; "White Light Interferometer for Surface Profiling"; Proc. Appl. Opt. Div. Conf., Reading 16-19 September 1996, IOP Publishing, p211-215.