Computer Generated 3D Animated Holographic Stereograms

Brandon Ian Reed, BSc (Eng), Cape Town

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Abstract

This thesis describes the process of creating and displaying a computer generated 3D animated holographic stereogram.

The objective of the project was to create a computer generated 3-dimensional model and animate it to perform some action using an animation program. This animated object would then be transferred to holographic film in the form of incremental component views of that object, resulting in a holographic stereogram that displays both parallax as well as animation.

Five broad areas were covered:

1. <u>The development of a computer generated 3-dimensional model of the object to be animated and the subsequent animation of that object</u>.

   The model chosen for development was a piston-crankshaft-conrod assembly. This was modelled using solid modelling techniques and the resultant wireframe model rendered to give a realistic representation of the physical object. This rendered model was then animated to perform the action or process that it would carry out under normal operating conditions. In this case, the animation involved having the model follow a 4-stroke combustion cycle. The animation was transferred to colour reversal film, by photographing each frame of the animation as it appeared on the screen, with a single-lens reflex camera. The film now contained the information needed for generation of the holographic stereogram.

2. <u>The development of the holographic optical components and systems required for the generation of the stereograms as well as the method used to control these components</u>.

   The basic optical layout required for the stereograms was determined and the various optical components designed and built. These components were controlled using a custom designed computer software program that could operate all the components

simultaneously. This computer interaction was required to automate a series of operations that required high accuracy.

3. <u>The creation of the first generation master transmission holographic stereogram</u>.

The slide images generated from the photographs of the animated object and the computer controlled optical components were used to create the master stereogram. This is a sequential process where each frame from the original animation is transferred to the holographic film in the form of a transmission hologram. The holographic film itself is masked off to a slit 10mm wide to prevent the incremental holograms overlapping. After each animated frame has been exposed, the slide film is advanced by one frame and the holographic film is advanced by the width of the slit and the process repeated.

4. <u>The generation of the transfer transmission holographic stereogram using the white-light rainbow transmission technique</u>.

The real images of the Master holographic stereogram are used to generate the Transfer stereogram using the white-light rainbow transmission technique. This technique allows the final stereogram to be viewed using a white-light source as the reconstruction beam by reconstructing the various wavelengths of the light into different horizontal planes. As for the creation of the Master hologram, the Transfer hologram is made using an incremental approach where each real image from the Master is systematically transferred to the Transfer hologram to build up the final holographic stereogram.

5. <u>The display of the holographic stereogram</u>.

The resultant holographic stereogram can be displayed in one of two ways depending on the viewers requirements. With the stereogram formed into the shape of a cylinder, and the entire stereogram visible, it is possible to move around the stereogram with the sensation that one is observing the model move in the centre of the cylinder.

The alternative to this is to remain stationary in front of the stereogram that has been masked to show only a single view of the model. The stereogram is then rotated and the model appears to move as one observes it from a stationary viewpoint.

Computer generated animation was successfully combined with conventional holographic stereogram techniques and a realistic sense of parallax was achieved with the animated stereographic image.

The project was a success in terms of the objectives of the theses. There are some areas where further work can be undertaken to develop this process into a useful visualisation tool. These include:

- Reworking the technique used to transfer the animated image from the computer monitor for use in generating the Master holographic stereogram.

- The adaptation of the optical layout to enable the Master and the Transfer optics to be used as a unit, simplifying the complex set-up procedure between operations.

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Chapter 1. Introduction

Holographic stereograms are hybrids of photography and holography that retain some of the characteristics of their basic form but add some unique elements of their own. Most people at one time or another have looked at geographical photographs of topographical terrain using stereoscopic glasses. These glasses allow one to view the image in three dimensions with a startling sense of realism. It is this principle that is taken forward and developed to form the holographic stereogram in the form that it has today.

Many technological advances have come about by accident when a researcher has been looking for one thing and stumbles onto something else. Holography itself is such an example, it arose out of the attempt to improve the resolution of electron microscopes. The holographic stereogram, on the other hand, was not something that arose by chance. This was an example of a determined effort by researchers to overcome the size limitations of holograms and make holograms of larger objects and objects out in the open.

To generate such holograms, and employ some of the techniques used in stereoscopic photography, it was necessary to use the principle of multiplexing. Holographic multiplexing involves a technique that is analogous to that used in the communications industry, ie. sending many signals simultaneously down a coaxial cable and distinguishing them by using different transmission frequencies. For holography, this principle was extended to allow two successive images to be captured on one piece of holographic film. These images are differentiated from each other by the way in which they are encoded in the film's emulsion. The two different images are displayed by light being reconstructed in different directions. If one now looks at this pair of reconstructed images, each eye will only see one of the images. The result will be that the combined image is seen autostereoscopically.

This is all very well if one wants a single view of an stationary object in one orientation. If one wants to view that same object from a different view point, it is necessary to have another stereoscopic pair of images from this new direction. This can be extended to the point where there are many sets of views of the stationary object from different positions. The principle behind the making of a holographic stereogram is to capture these various pairs of images on a piece of holographic film so that they can be reconstructed to form a view of the object from various different directions. One generally views an object by moving past it with one's head in a stationary vertical plane. A holographic stereogram mimics this simplified motion as the views of the object are given from a single horizontal plane. In practice, the views of the object are not generated in special stereographic pairs, but in equal steps in a straight line past an object. This allows each holographically recorded view of the object to be able to be used with its neighbouring view to form a stereoscopic view of the object from that direction.

All that is required to accomplish this is a set of slide photographs taken from equally spaced points along a path past the stationary object. These slides will give incremental views of the object from changing perspectives. The slides can then be sequentially transferred onto the holographic film in the form of component holograms. When all the views have been recorded, there is a final multi-image stereogram that has more parallax than the two-image stereogram since the stereo effect occurs between all pairs of adjacent images. Moving slowly past this hologram results in one observing a jerky form of parallax.

With the advent of powerful desktop computers and animation software programs, the possibility now manifests itself, to use these computer animation tools, to construct the views of an object needed to create a stereogram. In fact, one could go one step further and create an entire autostereoscopic object that could never have existed, using a computer to create it in the first place.

With these animation tools it is possible to add motion to an object so that over and above creating the incremental views of the object needed for the stereoscopic reconstruction, each view of the object could show it in a slightly different physical location. The result of this is to have not only views of this object from various orientations, but to also have the object performing some independent action. An example of this would be someone performing some repetitive task such as jogging on the spot. This person can be considered the object. As the viewer moves past the object, they will see progressively around that object, however each view will carry with it the addition of the effect of the jogging.

There is scope for use of this kind of stereogram from the immediately apparent novelty aspect in amusement parks and other places of entertainment to other more technical applications.

One of the technical applications of interest is to take an object that has been designed using a computer aided drawing (CAD) program and animate it to perform the task that it was designed to carry out. By creating a holographic stereogram of this design in operation, it is possible for the designer to get a true feeling of the aesthetics of the design during the prototyping process. This form of visualisation would not be possible if one could only watch the animation take place on the screen because, in order for there to be any sense of realism, there has to be parallax. Parallax requires that each eye has a different view of the object and this is not possible by simply viewing the two dimensional image that appears on the screen during an animation.

The aim of this project is to create a computer generated 3-dimensional model and animate it to perform some action using an animation program. This animated object must then be transferred to holographic film in the form of incremental component views of that object. This will result in a stereogram that displays both parallax as well as animation.

1.1. Structure of the Report

The report is structured in such a way as to give the reader all the basic information pertinent to the project. In order to keep the report as concise as possible, detailed calculations and supplementary material will be presented in the appendices.

A detailed literature review will first be undertaken. A critical analysis will be made at the end of each item discussed and a decision made on the usefulness of each item with regard to the project. This literature survey will be completed in two parts. The first will concentrate on the work done to date on the production of holographic stereograms and the second will cover the topic of computer generated animation.

The main body of the report will begin with a chapter dealing with the creation of the animated model from which the holographic stereogram will be made. This chapter will describe in detail the process used to generate the animation using a 3 dimensional animation package.

The following chapter will begin by giving an overview of the holographic components to be employed. This will be greatly expanded later by a discussion of each optical component and the work required in developing that component. Detailed design drawings will be presented in the appendices.

The control of the various components will follow and this will deal with all aspects of control but specific emphasis will be placed on the use of a computer to control the advancement of the holographic film. The programming code used in this control process will be briefly explained, but as with all supplementary material, it will be covered fully in the appendices.

All the previous chapters will be brought together by a chapter describing the actual generation of the holographic stereogram using the Master/Transfer holographic technique. Following this chapter will be one where the display of the stereogram is discussed.

The last chapter in the body of the report will focus on a discussion of the practical problems that were discovered during all stages of the project, from the initial generation of computer animation to the final display of the holographic stereogram.

The report will be completed by a chapter of concluding statements to be followed by a series of recommendations for future work.

Chapter 2. Literature Review

2.1. Multiplexed Holographic Stereograms

In the world of multiplexed holography, there are two distinctly different methods of achieving a similar result. The first was developed in 1969 by Dominic DeBitetto and is described in his paper *Holographic Panoramic Stereograms Synthesised From White-Light Recordings* [1] while the second was developed in 1973 by Lloyd Cross and presented at the Society of Photo-optical and Instrumentation Engineers (SPIE) as an unpublished paper [2].

2.1.1. Holographic Panoramic Stereograms

DeBitetto's method employs a technique analogous to that used by the communications industry, ie. sending many signals simultaneously down a coaxial cable and distinguishing them by using different transmission frequencies. He extended this principle to holography by capturing successive images on one piece of holographic film. The images were differentiated from each other by the way they are encoded in the film's emulsion. Different images are displayed by light being reconstructed in different directions.

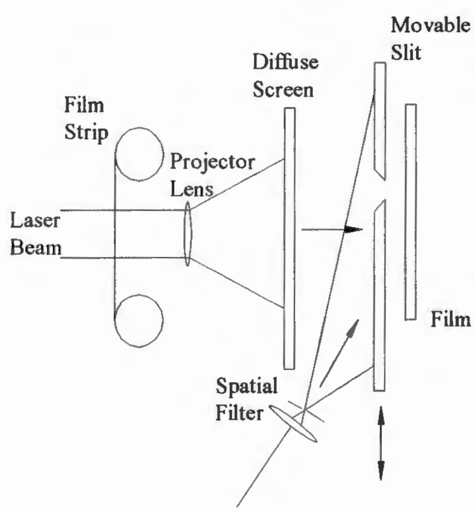

Figure 2.1 - DeBitetto's Panoramic Stereogram Technique

To do this, he projected 2D transparencies onto a ground glass diffusion screen from the rear with the light from a laser (shown in Figure 2.1). He recorded each projection through a movable vertical aperture. The aperture was moved a distance equal to its width and the subsequent 2D view was exposed [3]. After development, each strip hologram corresponded to the original camera position and angle.

A problem with this approach is that one of the specifications for employment of his method is that the incoherently recorded two-dimensional photographs must be taken from a series of equally spaced positions along a horizontal line [4] (see Figure 2.2). This does not lend its self to be used as a visualisation tool of a fully 3D object. Further development has been done to reduce this limitation and Kasahara, et al [18] have shown how this technique can be extended to a cylindrical format.

2.1.2. Cross Multiplexed Holograms

Cross took a different approach to DeBitetto. His technique involved having all the successive images' information focused onto consecutive narrow strips. By moving ones plane of view, different images are reconstructed, ie. the viewer looks through a narrow strip hologram at a virtual image of the slide at the centre of the hologram [5]. This occurs because, where the former set-up has a "camera" moving past the subject while following a horizontal path, here the camera remains stationary while the object rotates (see Figure 2.2).

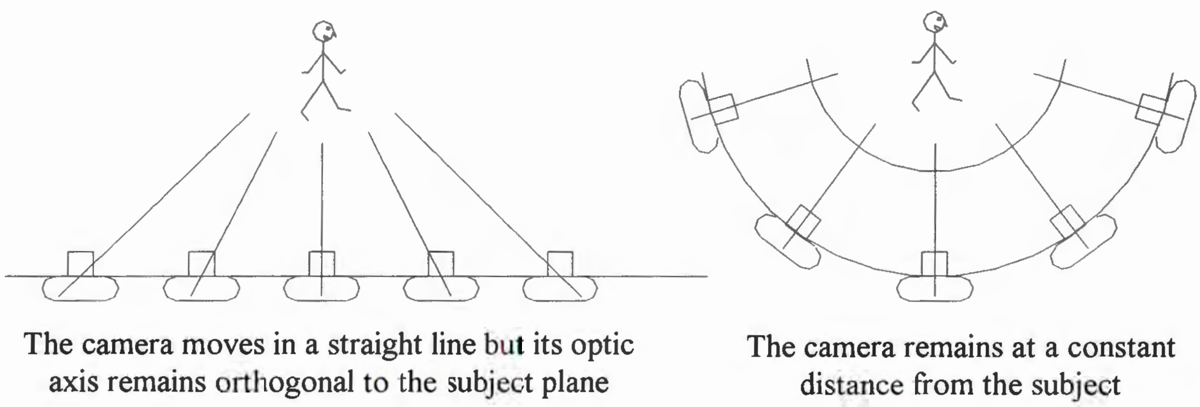

Figure 2.2 - DeBitetto's and Cross's Specifications for Slide Recordings

Aspects of both Cross's and DeBitetto's techniques will be used for the creation of the animated holographic stereogram for this project. This opens up a range of opportunities for practical use of this method as a visualisation tool since one can show a full 360^{0} of parallax with good dimensional accuracy being maintained. The rest of this review will focus on various aspects of both Cross and DeBitetto holographic stereograms and in particular how other peoples research can be adapted and implemented in producing holographic stereograms with a base image constructed through computer generated animation.

2.2. Cross Multiplexed Holograms

Lloyd Cross never published his work as he made a very successful business out of selling Cross Multiplex Holograms and therefore there is only third party information as to his methods and the implementation of his ideas. In two papers, one by Benton (*Three Dimensional Holographic Displays*) [6] and the other by Fusek et al (*Use of a Holographic Lens for Producing Cylindrical Holographic Stereograms*) [7] his techniques are outlined. What follows is a brief description of the optical components required to create a multiplexed hologram and is taken from the aforementioned paper by Fusek et al and illustrated in Figure 2.3.

The beam from a laser is split into an object and reference beams by a beamsplitter. The object beam is passed through a spatial filter and collimated to illuminate a single slide frame uniformly. Anamorphic optics (two cylindrical lenses at 90^{O}) are used in place of a projector lens to separate the image into vertical and horizontal image planes. The horizontal rays are focused to a point near the location of the reconstructed image, usually near the plane of the cylindrical lens.

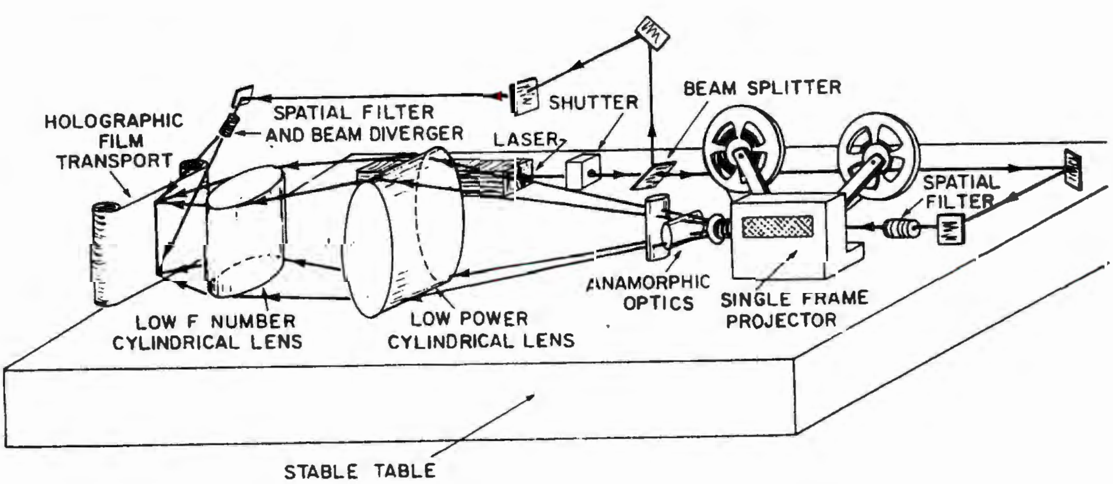

Figure 2.3 - Optical Components Required to Make a Multiplexed Hologram

The vertical image rays are focused in the plane of the holographic film and a large cylindrical lens is used to converge the rays to a point about 1m from the film (the nominal viewing distance for the reconstructed hologram). These vertically focused rays form the "virtual" slit that is required to produce a rainbow hologram that can be viewed in white light.

It must be borne in mind that the location of this point of convergence can radically alter the vertical viewing angle of the hologram as this is still essentially a rainbow hologram one is viewing.

One of the most critical components utilised in the apparatus is the low f/number cylindrical lens that is used to focus the vertical image rays to a slit on the film. A variety of different approaches have been proposed to optimise this problem and these are detailed below.

2.2.1. Plano-Convex Cylindrical Lens

One of the major stumbling blocks encountered while setting up the optics of the system is the construction of the cylindrical lens. A good and cheap alternative to using a ground glass cylindrical lens is to use a lens constructed of a perspex shell and filled with an optically clear refracting liquid. This is the ideal solution since the plano-convex lens surface created by a curved piece of perspex is one dimensional and it is optically flat. Perspex also has the property that when it is compressed by applying a force to its edges, the shape that it assumes is that of part of the arc of a circle [8].

One potential problem with this type of lens is that it suffers from a phenomenon known as astigmatism. This condition occurs when rays that emanate from point objects lying at a considerable distance from the axis of the lens fail to meet at a common image point thus not satisfying von Seidel's third lens condition [9]. In the case of a cylindrical lens, this is caused by one surface of the lens being so much closer to the object than the other. In order to eliminate this effect as much as possible, it is important to keep the curvature of the surface as small as possible. To reduce spherical aberration to an acceptable level, a plano-convex lens should be used with the flat side facing the laser [10].

2.2.1.1. Simple Liquid-Filled Lenses

Saxby [8] has covered the topic of liquid filled lenses in detail and gives a comprehensive guide for constructing a variety of lenses. His calculations for designing the lens use the assumption that a plano-convex cylindrical lens will have a focal length that is approximately equal to twice its radius of curvature [11] and he uses a carpenters cramp to hold the perspex body of the lens and the lens surface in position during gluing.

His method of construction is not ideal since he relies on judgement by eye for positioning the lens surface relative to the frame. It is extremely important however for the lens to hold its curved shape accurately to minimise lens aberrations as much as possible and by simply gluing the lens together and sighting its position by eye, this accuracy can not be obtained to any great degree.

Sandy McCormack has attempted to overcome the difficulty of accurate construction as well as the resultant lens aberrations of a fixed focus lens by proposing a tuneable liquid filled lens [12].

2.2.1.2. Tuneable Cylindrical Lens

McCormack's lens consists of two separate pieces of perspex for the lens surfaces. The glycerine is contained in a vinyl bag which is glued to the perspex in such a way as to still allow light to pass through the lens. The sides of each piece of perspex has an angled section of aluminium attached to it which acts as the tuning arm. This whole assembly is then clamped between two pieces of aluminium to hold the lens curvature that is chosen.

McCormack recommends tuning the lens by loosening one tuning arm at a time and pivoting it slowly while watching the resultant image on a section of white card. This is to continue until a suitable image is produced.

The principle of being able to tune the lens is a sound one, but in practise it proved to give a highly unsatisfactory resultant image even after many hours of delicate fine tuning, a process described by McCormack as a "Zen-like experience [13]".

2.2.1.3. Holographic Optical Elements (HOE's)

Fusek et al took Cross's technique one step further by suggesting the use of a holographic lens in place of the low f/number, large aperture cylindrical lens described above.

This was done for a number of reasons, the primary reason being that the only way they could find to increase the image width and to reduce distortions was by building lenses of higher quality and precision. They decided to rather use a simple transmission, off-axis, focusing holographic optical element (HOE) because of the difficulty in producing an accurate liquid filled lens. What follows is a description of how they produced their HOE.

"Subject beam rays are caused to converge to a point congruent with the desired focal point of the HOE (see Figure 2.4). A collimated reference beam is directed toward the holographic film at the desired angle of incidence. A hologram is then made by recording the interference of these two wave fronts. After developing, the hologram is used as a lens by illuminating the hologram with the original reference beam. The reference beam rays will then be diffracted toward the point of convergence of the original subject beam, thus forming the focal point of a simple lens." [14]

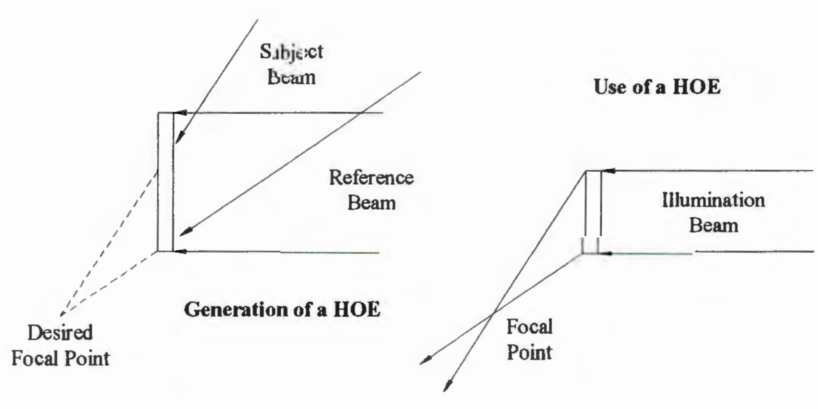

Figure 2.4 - Optical Scheme for Making and Using a Simple Off-Axis Transmission HOE

The main thrust of this technique was to replace the cylindrical lens with a HOE which has many of the characteristics of a simple lens but fewer aberrations, specifically astigmatism. One significant difference between a HOE and a lens is that the image from a HOE is not in line with the incident beam and this can cause complications in optics alignment.

2.2.2. Shortcomings of Cross's Multiplexing Technique

The idea of a one-step white-light rainbow hologram is very appealing but there are unfortunately a number of optical and other shortcomings related to this technique. Saxby details some of these in his chapter "*Improving the Image*" [15]. Of some importance is the fact that there is a marked lack of sharpness in the vertical aspect, the images are sickly green and the whole image is overlaid with vertical lines (known as the "picket-fence effect").

More importantly from an engineering point of view however, is the fact that there is serious distortion towards the edge of the image due to a complication known as time smear. This effect is caused by the images being nested so close together. When one looks at the outside of the image area, one is in fact looking at an image made just before or just after the one in the centre. As such, the image is taken (and meant to be viewed) from a different viewpoint. Any movement the object makes compounds this distortion and this seriously affects the ability to use this method as a means to introduce animation into the stereogram.

Benton describes the technical limitations of this technique clearly when he says that "because the image seen from one point is actually a composite of many nearby perspective views, the spatial image becomes seriously distorted away from the hologram centre" [16]. Clearly for an engineering application, distortion of an image is not ideal and a different technique of recording must be found.

2.3. Holographic Panoramic Stereograms

The chronological development of the principles of Holographic Panoramic Stereograms will now be presented with discussion taking place in two parts. The first will deal with the classic generation of stereograms which are only viewable with a coherent source of light and the second will present a discussion on white light viewable transmission holographic stereograms.

Throughout the discussion certain aspects will be highlighted where the principles will be applied directly to this project.

2.3.1. Early Stereogram Development

DeBitetto's ground-breaking work was published in his paper *Holographic Panoramic Stereograms Synthesised From White-Light Recordings* [1] and the following information is based on this paper.

The method previously used for obtaining holograms of three-dimensional objects illuminated in white light was to use an $n \times n$ element fly's eye lens [17]. DeBitetto's paper presents "a new and simple alternate method for synthesising a composite hologram from a horizontal sequence of n incoherently recorded two-dimensional photographs such as might be taken for constructing panoramic stereograms".

As described in Section 2.1.1, DeBitetto's first step involved taking a series of incoherently lit two-dimensional photographs of a three dimensional object on a fine grained reversal film. These photographs could be taken either sequentially or simultaneously from a series of equally spaced positions along a horizontal line (illustrated in Figure 2.2).

His second step was to sequentially project the component two-dimensional transparencies onto a translucent screen (see Figure 2.1) using a beam of collimated coherent light as the projection source. A stationary high-resolution photographic plate was located at least 25cm behind the screen.

For this process the slit width must be chosen with care and DeBitetto maintains that it should be chosen to be equal or smaller than the normal aperture of the eye. This restriction is imposed so that the parallax changes that the eye perceives, appears continuous as the viewer changes their position behind the composite hologram. It must be remembered at this point that the stereogram created in this manner is only viewable with a coherent light source that is generally of the same type as used to create the hologram. DeBitetto suggests that slit widths of less than 0.5 mm be avoided as they can result in serious reduction of horizontal resolution.

Further work on this issue has been performed and will be discussed in the following section.

In his closing statements, DeBitetto maintains that the final reconstructed image still exhibits some residual characteristic granularity when viewed directly due to the diffuse scattering by the diffuse screen. This is a very valid observation and details of the screen used in this project will be discussed later in Section 4.1.5 entitled *Opaque Focusing Screen*.

2.3.2. Master Hologram Slit Width

A number of researchers took the principles proposed by DeBitetto further and investigated various techniques surrounding them. One such group was Kasahara, et al who did work on reconstructing objects holographically in 3 dimensions that could not be seen with the naked eye [18] such as x-rayed internal organs.

Their research was directed at the possibility of getting numerical data concerning the spatial distribution of the reconstructed object in the object space. Most of their paper was directed at the reconstruction of radiographic x-ray images using the technique of holographic stereograms to show an object in 3D. Included in this discussion is an investigation of the permitted width of the Master hologram slit to avoid a discontinuous sensation when viewing the final hologram. A brief description of their results is shown below. Figure 2.5 defines the nomenclature used for their equations and Figure 2.6 gives a graphical representation of their results.

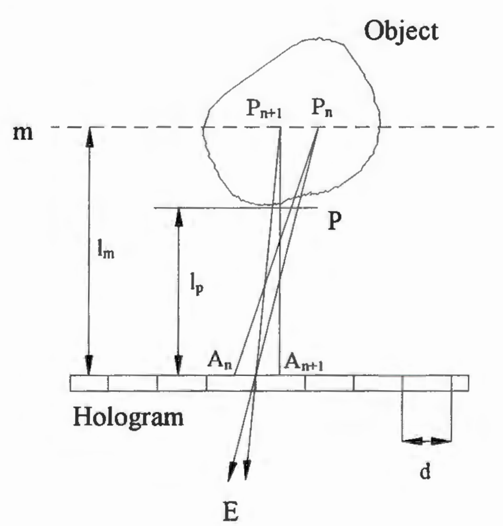

Figure 2.5 - Nomenclature used to Determine Minimum Slit Width

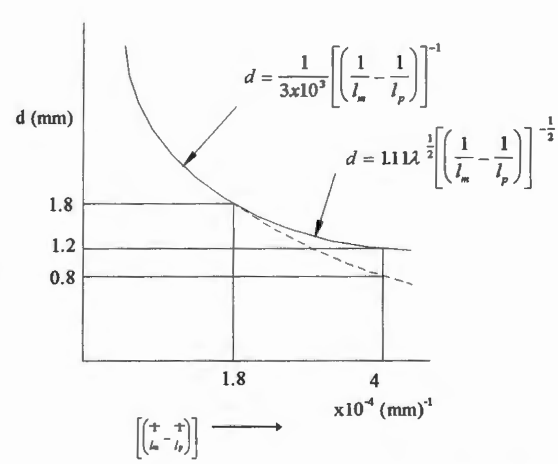

Figure 2.6 - Graph Showing Permitted Slit Width Vs Depth of Object

In brief, Figure 2.6 shows the effect when the sampling interval (slit width) is reduced below about 1.8mm. Here the width of each elementary hologram acts as a finite aperture and the variable of the diameter of the pupil of the observers eye is replaced by the width of the component hologram. When this happens, the observed image quality is blurred by the diffraction of the edge of each hologram and thus larger sampling intervals are suggested.

Their paper goes on to discuss the interrelationship between the sharpness of the reconstructed image and the depth of the reconstructed space. Formulae are developed relating the width of the elementary hologram to the diameter of the aperture of the photographic objective and the pupil diameter of the observers eye. This relationship is shown below in Equation 1 where d denotes the hologram width, D the diameter of the aperture and α the diameter of the pupil.

$$d < 0.61\frac{D^2}{\alpha}$$

Equation 1 - Equation relating the width of the elementary hologram to the diameter of the aperture of the photographic objective and the pupil diameter of the observers eye

It was further shown that when the diameter of the aperture of the photographic objective has nearly the same value as the width of the elementary hologram, the observer would not perceive the discontinuity of flickering. This relationship did not however apply to the present case as the slides were destined to be generated as a series of two-dimensional frames from an animation and not a solid object displaying parallax. The use of single frames eliminates the blur associated with depth of focus of the photographic objective at the marginal plane of the object space.

2.3.3. Recording the Subject

William Molteni has given guidelines for how best to record the subject [19] and develop the photographic slides. He maintains it is critical there be good registration between the camera and the film. In this way one avoids displacement of each perspective relative to the rest. A lack of tight registration can lead to wavy horizontal lines and vertical jitter in the final hologram. He advocates that very good care be taken of the film as it is essentially ones object. After processing, the object should have a solid colour with many tones. If the background to the scene isn't black enough on the film, then it can cause the surface of the final hologram to glow and reduce its overall contrast.

Molteni's recommendation for the Master slit width is between 1mm and 4mm. His reasoning is similar to Kasahara, et al [18] save that their lower limit is in the region of 1.8mm (see Figure 2.6) and he illustrates the use of an overhead reference beam for creating the Master hologram.

At this stage it is important to define the difference between area and angle multiplexing in the recording of the holographic stereograms. This is a concept applicable only to the Master hologram stage and is of importance as it defines how the hologram is encoded in the emulsion and replayed after development.

2.3.3.1. Angle Multiplexing

In essence, angle multiplexing consists of projecting a series of horizontally scanned perspective views sequentially onto a rotating plate with the reference beam also rotating. When illuminated, all the views are reconstructed simultaneously and are viewable from their respective angles to produce a 3D image. Ones eyes have to be placed at just the right height and distance to see the entire image. The image brightness and contrast are degraded as the number of superimposed exposures increases.

2.3.3.2. Area Multiplexing

Area multiplexing stems from sequential images being recorded side by side as vertical strips. In this case the reference beam remains stationary and the holographic strip can be viewed either flat [4] or formed into a cylinder [18] to allow the possibility of a 360^{O} view.

If the reference beam is very much stronger than the image (or object) beam during creation of the stereogram, the fringe contrast will be greater where the image is brighter. Once the stereogram has been developed and is illuminated, the hologram will diffract more light from that brighter area and reproduce the image to an eye placed at the resultant focal point.

The information presented above is useful in determining the requirements for creating the Master holographic stereogram if that hologram is to be replayed with the coherent reference beam that was used to create it. A technique still had to be found to enable these stereograms to be viewable with an incoherent source of light.

2.3.4. White Light Reconstruction of Transmission Holograms

Around the same time that DeBitetto was developing his panoramic stereograms, Steven Benton was pushing the boundaries of holography by describing a technique whereby he could sacrifice vertical parallax resulting in a hologram that could be replayed using an incoherent vertical line source of light [20]. At the time of this development he was looking for a way to reduce the information content of the hologram to allow a relaxation of the reconstruction requirements. The long-term goal of this investigation was to enable transmission of a holographic television signal [21], a task he subsequently found impossible to achieve.

The two-step technique that he developed is shown in Figure 2.7 and can be described as follows: The subject for the Transfer hologram is a real image of the object projected by a narrow horizontal strip of the Master hologram. The Transfer hologram is now illuminated to reconstruct a real image of the original Master hologram. The entire field of view becomes visible when the eye is positioned at the image of the strip.

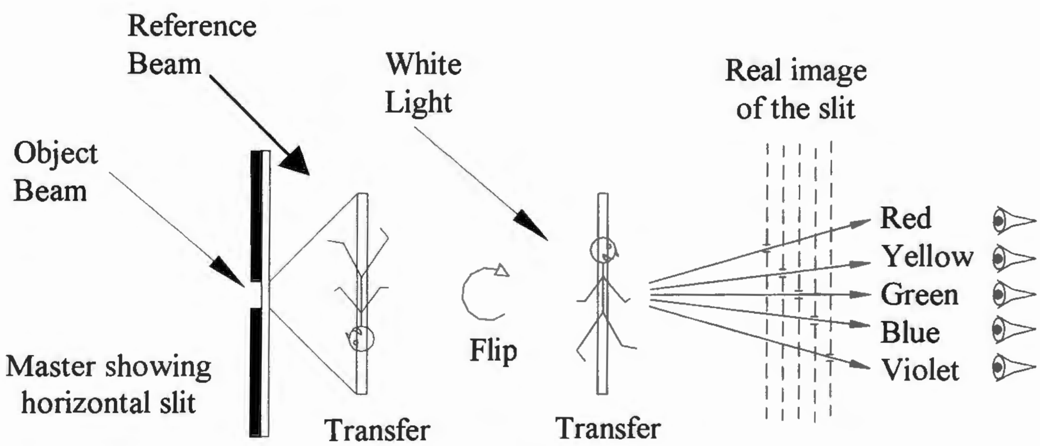

Figure 2.7 - Optical Layout for Producing Rainbow Holograms

The fringes, which normally provide vertical parallax, are replaced by an optically generated diffraction grating [22] which disperses the white light into a spectrum in the vertical plane. This means that at any particular elevation, the eye receives a narrow band of wavelengths from red at the top to violet at the bottom.

One is in effect viewing the holographic image through a real image of the slit. By viewing the hologram in a light with many frequencies, one is simply seeing a different view of the object for each wavelength of light at a different height.

With transmission holograms now viewable in white light, it was not long before this technique was combined with DeBitetto's panoramic stereogram to create the white light viewable holographic stereogram.

2.3.5. Early White Light Viewable Stereograms

The techniques pioneered by both DeBitetto and Benton provided stimulus for further development of panoramic stereograms to be undertaken. A number of researchers took the amalgamation of these two techniques further and enhanced the development state of the stereogram.

Benton has published two papers, the first in 1976 [23] and more completely in 1982 [24] where he describes the then current state of holographic stereogram development. The information he presents is largely covered in previous sections but in his discussion he has brought up a number of other topics worth mentioning.

In his first paper he has outlined some requirements to be fulfilled in order for the quality of the final display to be acceptable. These requirements include the fact that the "image luminance is determined by the diffraction efficiency of the hologram as well as by its illuminance". This simply means that for hologram display illumination, ideally one needs high-power multi-mode lasers but since these are prohibitively expensive, other sources of illumination are required. Since non-laser illumination must now be used, restraints are placed on both the depth and parallax content of the image as the illumination intensity levels are subsequently lower.

In his second paper, apart from presenting a survey of the present state of holograms, he also makes the observation that stereograms cannot mimic all the imaging properties of a true hologram. This is because the resolution and depth of focus of the synthetic image is limited to that of its component images. It is however possible to produce "convincingly solid quasiholographic three-dimensional images" viewable by the unaided eye at normal viewing distances.

2.3.6. Modern White-Light Transmission Holographic Stereograms

By the mid 1980's, Stephen Benton had taken the work pioneered by DeBitetto further as he was dissatisfied with the number of optical and other shortcomings related to Cross's multiplexing technique (see Section 2.2). Another concern of his was the fact that many of the modern day techniques used in Cross's Stereograms were of a proprietary nature and thus protected by various patents. By reworking DeBitetto's original ideas he developed the present-day standard for flat stereograms. With this development came a flurry of advances in techniques resulting in the ability to create achromatic and multicolour stereograms as well as introducing animation that was optically defined and dimensionally accurate.

In his paper entitled Photographic Holography [25], Benton describes in detail his concepts of white light transmission stereograms. Most of these concepts have been presented above but since they are the foundation of the work to follow, a few of them have been repeated here as concluding statements regarding holographic stereograms.

Holographic diffraction lenses can overlap in any number and simultaneously redirect light from a single area to any number of positions. It is this concept that is so important in creating holographic stereograms. The number or density of perspective views needed for parallax to appear continuous will depend on the depth and degree of animation shown by the object. This is however ultimately determined by the size of the projector lens needed to sharply display the real image of the slide on the diffuse screen.

All the relevant literature on the subject of white light transmission holographic stereograms has now been presented. What follows is a discussion of computers and their previous application to the topic.

2.4. Computer Control

Sandy McCormack has spent time computerising [26] many aspects of the control of her automatic holographic stereogram printer and this allows her to change various parameters during printing such as: "exposure time, holographic film spacing, ratio of holograms to movie frames printed, settling time and beam ratio [27]". The testing of an optical arrangement is no longer time consuming since the computer can alter parameters very precisely.

2.5. Animation in Holographic Stereograms

William Molteni published a paper in 1985 called *Computer-Aided Drawing of Holographic Stereograms* [28] wherein he discusses what he calls "a personal computer-aided drawing system dedicated to the production of holographic stereograms".

His process of creating the slides necessary for forming the stereogram is handled in a crude and simplistic fashion if one takes into account what is available today as far as animation packages are concerned. He creates two 2D line drawings at differing depths and then gets the computer to connect the drawings linearly by "tweening" or creating a series of intermediate drawings. He uses a process called autographic stereography to view these images. This technique requires practice but means that extra viewing aids such as polarising glasses are not needed.

Both Benton [25] and Saxby [29] recognise the advantages to be gained from computer generated creation of the component perspective slides though neither give any details of work they may have done on the subject.

McCormack also saw the possibilities that emerge when one starts creating computer-generated scenes. She discusses how cinema and video techniques [30] can be utilised to record and mix imagery and under a heading *Computer Graphics* she states, "The significance of holographic stereograms is that they are the only way to see three dimensional computer graphics in 3D." That is no longer strictly true since the evolution of Stereo Lithography (Rapid Prototyping) but there are still no other ways of seeing computer generated, animated objects in motion.

2.6. Conclusion

To date, the technology of holographic stereograms has remained limited in part to graphic and artistic displays. The techniques and processes described in the various sections above will now be extended and used for visualisation in a purely technical sense. It is this extension to current stereogram technology that will move the technique out of the realm of simple display holography to that where it can have some practical engineering benefit.

Chapter 3. Computer Generated 3D Animation

3.1. Introduction

Until a few years ago, the production of complex 3D animated graphics could only be tackled by large specialist organisations because of the time and computing power required to produce them. However, with increased computing power dropping in price, this ability to produce complex 3D animated images, complete with transparency, reflections and shadows, has left the realm of broadcast television and has become available for use in a variety of new technologically innovative applications.

There are now a host of 3D computer animation packages available on the market, but for state of the art performance and power there is still little to rival Autodesk's 3D Studio. Autodesk has just released a 32 Bit version for Windows 95™ called 3D Studio Max.

3.1.1. 3D Modelling

Conceptually, 3D modelling works as follows: First, one must model the object to be created. When that is completed, this object must be given a surface texture. The object must then be illuminated by an array of lights and the virtual camera must be set into position. It is this camera that will show the view that the observer will see. The modelling package facilitates effortless handling of these complex tasks. When all the above has been specified, the scene must be rendered. This, in real terms, means that one begins the rendering process and the computer works out what the scene will really look like given all the lighting, objects and texture information that has been specified.

3.1.2. 3D Animation

At this stage it is possible to add the fourth dimension, time. In this way, one can create, not only a stationary scene, but animate it as well. The degree of animation varies enormously, but in its simplest form, it means that after creating a 3D "world", one sets a flight path for the virtual camera to follow. Instead of a single 2D snapshot of the scene, one ends up with a short video of what happens as the camera flies by.

More complex 3D animation techniques include setting a timeline for objects and having them twist, move and distort while the camera remains stationary. At this stage, keyframe animation becomes important and this will be fully dealt with in Section 3.6 entitled *3D Animation using the Keyframer*.

3.2. Solid Modelling Processes

The process of creating a 3D object is called solid modelling and the various methods of achieving this will be discussed below.

3.2.1. Extrusion

Solid modelling essentially involves an action called extrusion. Extrusion simply means pulling up the sides of a 2D object so that it becomes 3D. For example, a circle, when extruded will form a cylinder. This effect is illustrated in Figure 3.1.

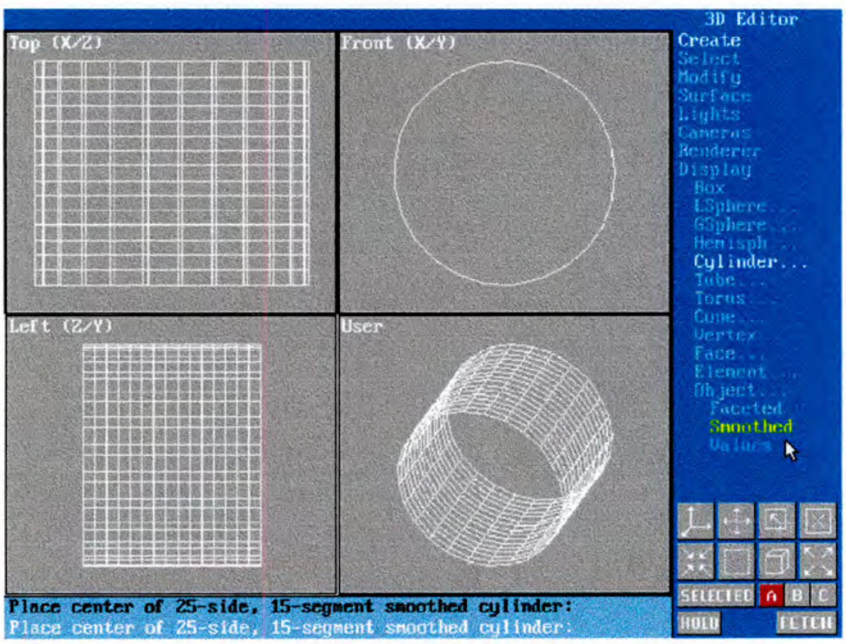

Figure 3.1 - Solid Modelling using Extrusion

The next step up in complexity is called path extrusion. In this process, the extrusion is given a set path to follow and the circle above can be turned into a 90^{O} elbow. The shape has been altered, but the cross-sectional area remains the same.

3.2.2. Lofting

Lofting is similar to extrusion, except that one changes the cross-section along the way with a smoothing effect from one to the other. An example of this is if one wanted to create a wine bottle, then one could quite easily loft a cylinder as before but add a narrower cross-section where one wanted the shoulder of the bottle to narrow to the neck. Figure 3.2 shows an eyeball being similarly lofted to the correct shape.

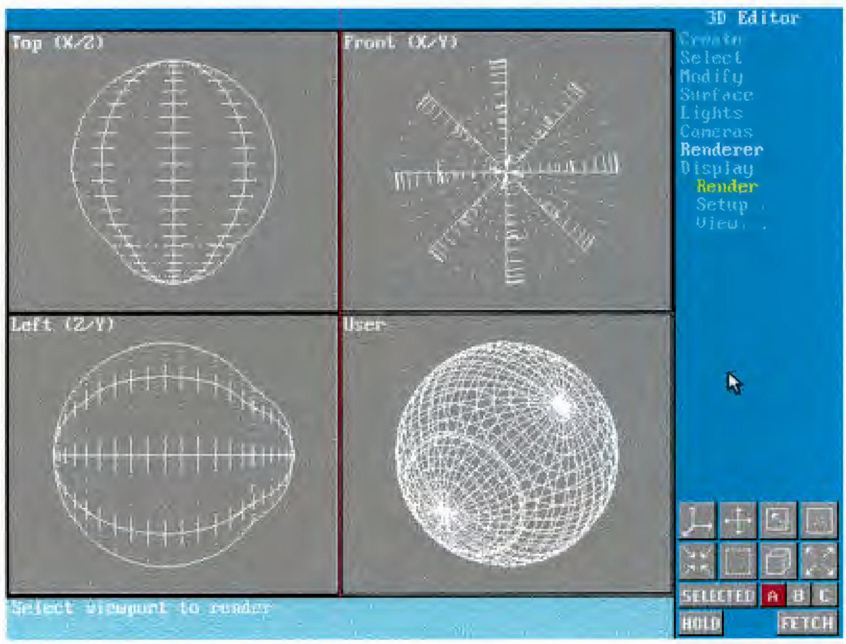

Figure 3.2 - Solid Modelling using Lofting

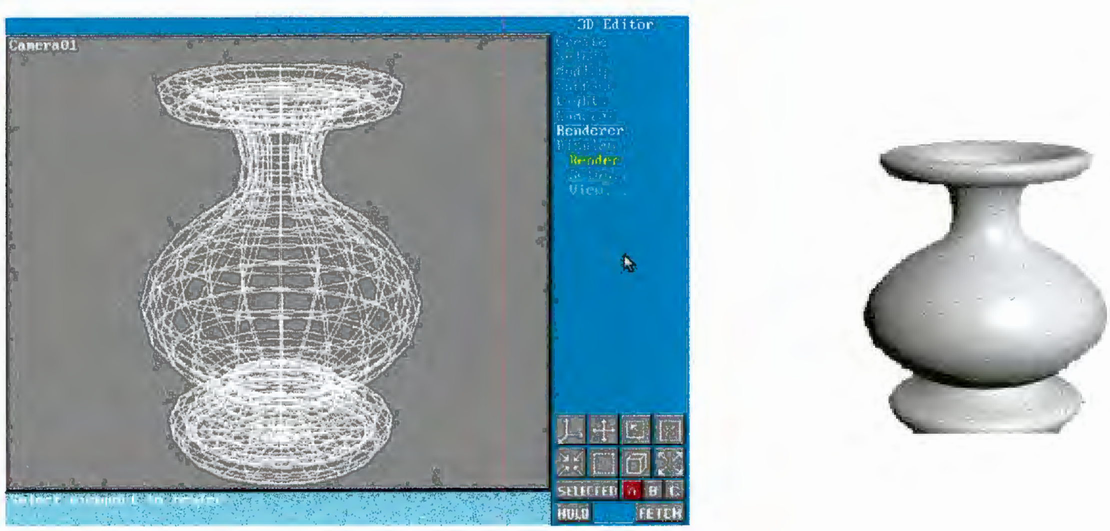

Figure 3.3 - Solid Modelling using Latheing. The rendered vase is shown on the right.

3.2.3. Latheing

Latheing differs from extrusion in that here one takes a 2D object and spins it through 360^{O} to create the model. The best example of this is the creation of a vase (illustrated in Figure 3.3). It is quite possible to create a vase through lofting, but by drawing a simple line of half its profile, it can be spun to form a perfect vase.

3.2.4. Spiralling

Spiralling is a simple way of creating complex shapes and forms by combining the effects of both extruding and latheing. A spring can be made by extruding a circle into a cylinder and then pulling that cylinder out along a circular path that lifts slightly as it goes. If one then lathes that effect, one can create a spring of any length one likes.

3.3. Model Conceptualisation and Creation

Before one begins to model an object, it is important to think ahead and plan ones approach. Many complex forms can be created from simple shapes that have been copied and repeated.

When creating holographic stereograms, it is recommended that the image fill the entire height of the frame, but should fill no more than one third of the width of the frame [31]. This places a constraint on the dimensions of the object and should be born in mind when creating the model.

For this project is was decided to model the crankshaft/con-rod/piston assembly of a four-stroke internal combustion engine since Engineering Model Visualisation is one of the central issues of this project.

With 3D Studio's software, one can not draw dimensionally accurate figures as it was developed for use by graphic artists. Fortunately, there is a way around this problem by drawing in Autodesk's AutoCAD and then importing these drawings into 3D Studio. The AutoCAD export format crosses the application boundary seamlessly and one can then extrude dimensionally accurate models.

Once the basic objects have been drawn and extruded, it is possible to use Gaussian addition and subtraction to create more complex shapes. For example, to produce a hollow piston it was possible to subtract a smaller cylinder from a slightly larger one to form a tube with one end closed. This process of addition and subtraction is fundamental to solid modelling and one can save much time by planning the different sections that are to be created.

A variety of primitives (ready made shapes) are available for use and shortcuts can generally be found by adding and subtracting them to generate new complex objects.

Through the process of extruding, lofting and latheing, a wireframe 3D skeleton of the model was created that was dimensionally accurate in every sense (See Figure 3.4). The next step in the process was to choose a surface texture and colour to be applied to the model.

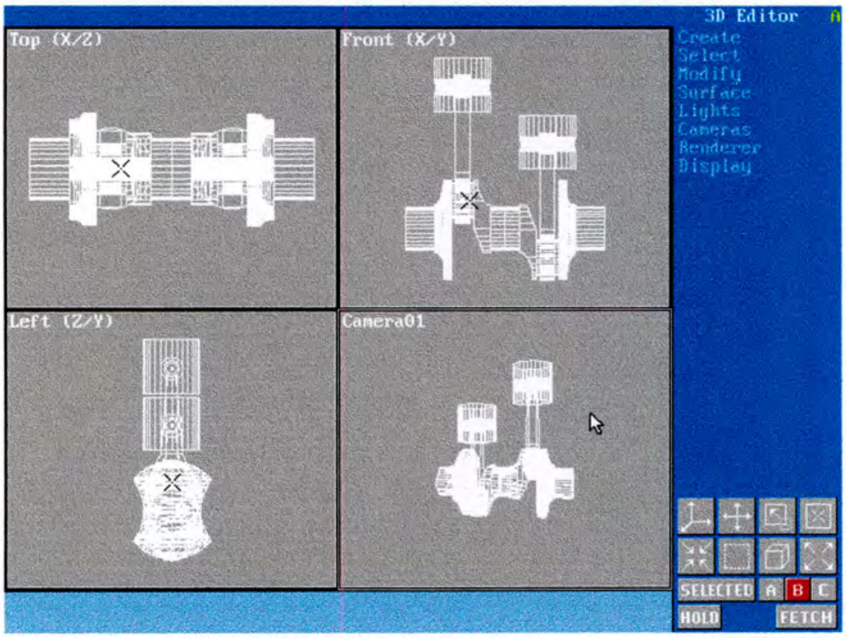

Figure 3.4 - Wireframe Model of Object

3.4. Surface Materials and Mapping

3.4.1. Surface Mapping

There are a number of surface mapping types available but only the most important ones will be described as the others have no use for the application at hand.

The most common forms of surface mapping are decal mapping and shape mapping. Decal mapping is analogous to sticking a flat label onto a surface only in this case it would be a bitmap image. Shape mapping takes that same label and stretches it in such a way as to take into account the shape of the object.

If one wants to apply an uneven texture to simulate the surface of an object, then on must apply what is known as bump mapping. This is the 3D equivalent of embossing.

Since the object being modelled was a crankshaft/con-rod/piston assembly of an engine, the surface was mapped with a flat untextured surface of a colour to be decided below.

3.4.2. Surface Materials

3D Studio has a specific materials section called the Materials Editor where one can create and edit surface materials. In the Materials Editor, one can combine such properties as colour, shininess and transparency as well as apply texture maps and create special effects.

To create colours it is possible to use one of two systems. The first allows one to adjust the primary light colours (Red, Green and Blue or RGB) to create the desired shade. The other system involves adjusting the hue, luminescence and saturation (HLS) to create the same effect as above.

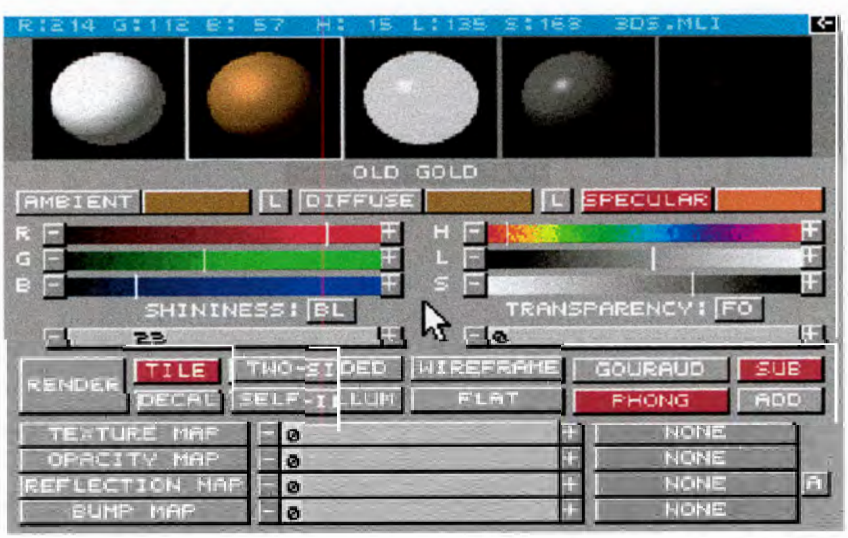

Figure 3.5 - Materials Editor showing "Old Gold"

For the production of holograms it is unnecessary to create some intricate colour scheme as the HeNe laser only has one wavelength and as such all the extraneous colour will be lost. For this model an old-gold colour was developed as shown in Figure 3.5 and applied to the model. The preliminary work in creating the 3D model had now been completed and all that was required was to render the scene.

3.5. Rendering Techniques

Rendering is the process of creating the final form of the 3D object as will be seen by the observer. There are three things that are required before a scene can be rendered and they are lights, camera and surface finish.

3.5.1. Lights

Lights are a critical part of any scene since they can create a mood and enhance a situation by adding shadows and other such lighting effects. For this project, mood enhancement was not a priority so the lights were arranged in such a way as to provide ambient light under all conditions. The lights illustrated in Figure 3.6 are shown as four stars in each view.

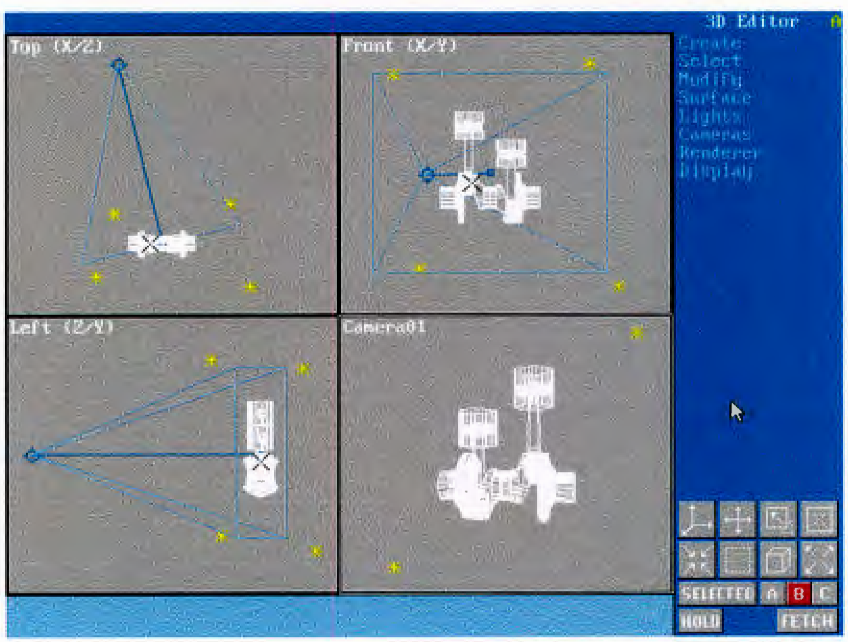

Figure 3.6 - Wireframe Object Showing Lighting and Camera Positions

3.5.2. Camera

One has full control over the camera in 3D Studio, which allows complex camera angles to be used. Initially the camera was situated in such a way as to give maximum exposure to the model (Shown in Figure 3.6) but this was adjusted later when animation was introduced.

3.5.3. Surface Finish

One has a variety of options as far as surface finish is concerned from wireframe and flat shading to ray tracing. The main differences between them are the assumptions that they make about the surface finish of the object and thus how they compute complex lighting effects.

3.5.3.1. Flat Shading

Flat shading, which is the simplest of the techniques (after the simple wireframe), looks for a central pixel of a polygon (the basic building block of any 3D object), checks to see where the light is coming from, and then colours the whole polygon based on that information. This gives a rough surface finish and is primarily used as a method of initially checking the model before using a more complex rendering technique.

3.5.3.2. Ray-Tracing

Ray-tracing is at the other end of the rendering spectrum. Here one creates photorealistic results but the time taken to create them is an order of magnitude larger than the other methods since the technique involves beaming imaginary rays through every pixel of the model. Every piece of information is calculated including surface colours, texture maps and shadows.

Where an object is said to be transparent or reflective, secondary rays are sent out from each pixel to every other object in the scene to see what should be visible through it or what should be reflected onto it. The same process is used to determine shadows and other complex lighting effects.

3.5.3.3. Phong Shading

As a compromise between the two, since ray-tracing was not necessary for this application, phong shading was chosen for rendering. This method reduced the time taken to render and gave an acceptable surface finish.

Phong shading uses a technique called normal vector interpolation shading. This means that every pixel in a polygon is assigned a colour based on the pixel's surface and lighting information. Even though with this method, transparent materials and some reflecting surfaces cannot be handled, this was of no concern as there were none of these surfaces involved. (See Figure 3.7 for the result of this rendering)

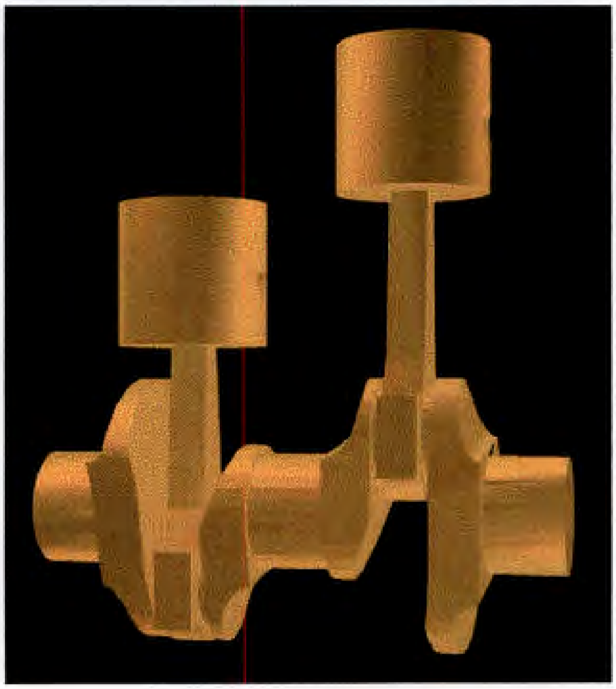

Figure 3.7 - Object in Final Rendered Form

3.6. 3D Animation using the Keyframer

The next step in creating the slides needed for creation of the holographic stereogram is to simulate the movement of the object to be filmed in front of the camera. This is where the superiority of 3D Studio is clearly evident as it has an animation studio called the Keyframer (See Figure 3.8). In this environment, one has all the tools necessary to create the most complex paths for the camera to follow as well as the ability to have the 3D model alter its shape with time and many other animation tools.

To recreate the subject alignment necessary to create stereograms [32] (see Figure 2.2), 3D Studios' 2D Shaper was used to create a circular camera path and this is illustrated in Figure 3.9. This enabled the condition that the camera remain stationary and the subject rotate (or vice versa) to be met. This approach can be extended to any application of this type.

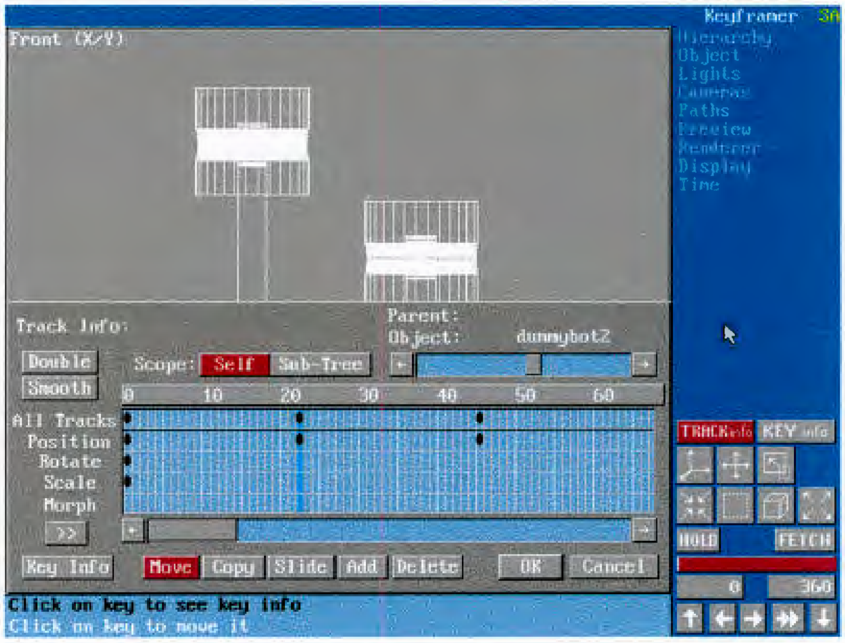

Figure 3.8 - The Keyframer

Next it was necessary to adjust the position of the crankshaft/con-rod/piston assembly to give it the appearance of rotary and linear motion while the camera moved past it. Since 3D Studio version 2 was used for animation and not version 4 or later, the simulation of this motion was a fairly complex task.

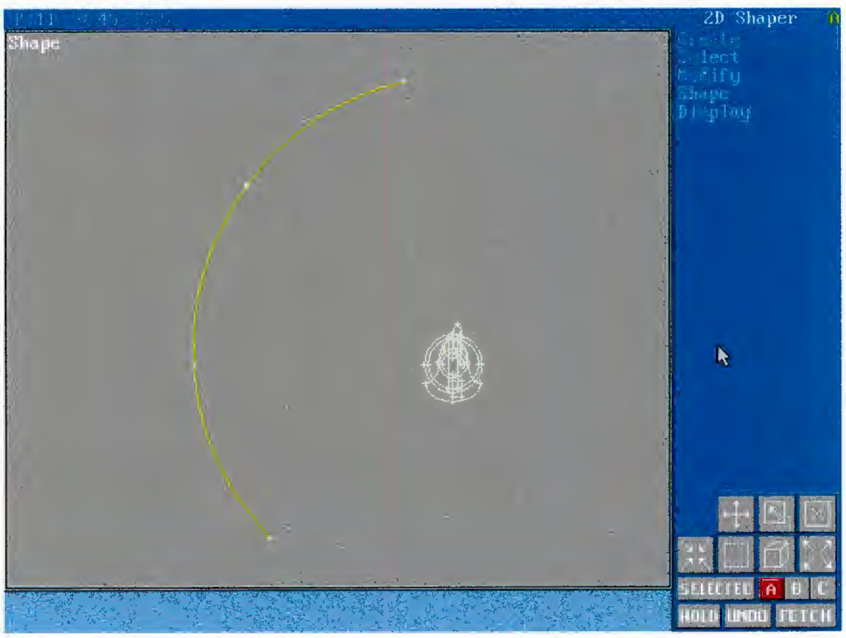

Figure 3.9 - Creating a Camera Path in the 2D Shaper

In version two, a hierarchical parent-child relationship can be set up between various linked objects. For example, if one considers the human shoulder to be the parent, then the arm can be linked to the shoulder as a child. Now the hand can be linked to the arm and then the arm is considered to be the parent to the hand. Now, if one moves the shoulder of the animated arm, the motion is passed down through the children and the arm and the hand move as well.

This has been changed in version 4 of the product by the introduction of a feature called inverse kinematics. With this feature one can now "take hold" of the animated hand as described above, move it, and the shoulder will follow. In this way kinematic information can now be passed both up and down the hierarchy of objects.

In the keyframer, the animation was set up to produce 360 frames for 120^{O} of camera motion. This allowed for 3 views of the object for every degree of rotation and was enough to fulfil any requirement as laid out in Section 2.3.2 entitled *Master Hologram Slit Width*.

With the camera path now described and the motion of the crankshaft/con-rod/piston assembly programmed to vary its position with time, the computer was left to carry out the rendering process which required 13 hours on a 386DX40 PC with a maths co-processor and 8MB of RAM.

3.7. Rendered Model Transferral to Film

After the creation of the different views of the animated object on the PC, is was necessary to transfer this sequence of frames onto slide film. Colour reversal film is necessary, as one needs a positive of the image and not a negative. It is possible for a specialist graphics bureau to create individual slides directly from computer graphics files, but with 360 slides used for 120^{O} of rotation, it is costly!

An alternative process was used which was rather simple but proved to be surprisingly effective.

Heed was taken of the relationship developed in Section 2.3.2, Equation 1 where the camera aperture was related to the diameter of the pupil and the eventual Master hologram slit width. However, since the photograph was being taken of the screen and not of a solid object displaying parallax, the aperture could be set fully open to allow as much light as possible from the screen. This was done without loss of depth of focus of the photographic object at the marginal plane of the object space.

The best alternative is to simply photograph the screen using a macro lens on a single-lens reflex camera. Ordinary colour slide film was used and a variety of test photographs at various shutter speeds and F-stops were taken. Under normal circumstances, unless the camera has a fairly wide aperture (> f/1.5), then one will not be able to see the object stereoscopically as there will be insufficient parallax. However, this was not relevant here as the photographs were to be taken from a flat screen of a series of animated frames showing no parallax.

After few test exposures were made, it was found that the ideal camera settings for this case were a ¼ second exposure time with the film 450mm away from the computer monitor but this will vary depending on both the colour chosen for rendering the object as well as the brightness and contrast chosen for the monitor. Fuji RD - 123 colour slide film was used. The F-stop was adjusted so that the aperture was completely open to allow as much light into the camera.

Specific instructions were given to the processing laboratory not to do any enhancement with their automatic development machines to ensure repeatability of the results. Instructions were also given not to cut or mount the slide film. The developed film now contained all the information that would be needed to create the holograms of the object and was ready to be loaded into the Film Advancer.

Chapter 4. Holographic Optical Systems and Component Control

This Chapter will deal with the components used to create the holographic stereogram by describing the holographic optical components used and will detail how some of those components can be controlled using an integrated computer software interface.

4.1. Holographic Components

4.1.1. Basic Holographic Optics

This section will deal briefly with standard holographic optical components, while the following section describes specific components that were developed for the creation of the stereograms.

4.1.1.1. Light Source for Holography

The helium-neon (or HeNe) laser is the most common type of gas laser. It consists of a tube containing helium gas at one torr and neon gas at 0.1 torr. The main purpose of the helium is to supply a continuous source of energy to the neon through electrical discharge [33].

The HeNe laser used for this project operates at a wavelength of 632.8nm and is rated at 60mW. It does however only have a practical output power in the region of 30mW with a coherent length of 150mm.

4.1.1.2. Spatial Filters

The use of spatial filtering is necessary if one is to "clean" up the expanded laser beam and this filtering is illustrated in Figure 4.1.

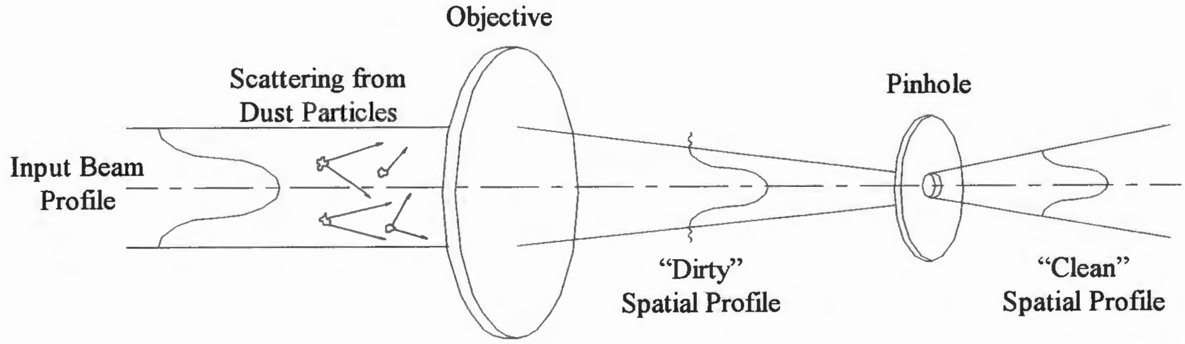

Figure 4.1 - Schematic of a Spatial Filter

The swirls and clamshell type markings shown in the unfiltered beam as in Figure 4.1 are the result of interference of parts of the beam that have been diffracted by optical imperfections in the laser and the microscope objective used to expand the beam. Dust is another major cause of such patterns.

If one places a pinhole at the precise focal length of the objective lens, the pinhole filters out the Newtonian Rings that are formed by the various diffractions and one is left with the beam as illustrated in Figure 4.2 that is the optical transform of the undiffracted beam. The pinhole is typically made from a platinum-iridium alloy and has a hole diameter ranging from 0.005 - 0.01mm.

The spatial filtering is important since a “dirty” beam will lead to uneven illumination of the object. This will result in beam intensity ratios between the object and reference beams varying, leading to a poor image.

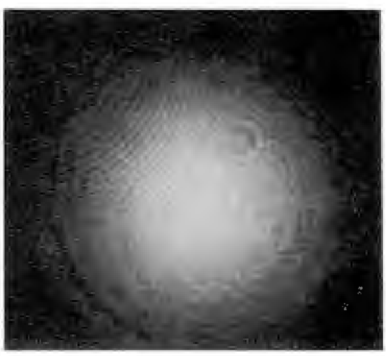

Figure 4.1 - "Dirty" Expanded Laser Beam

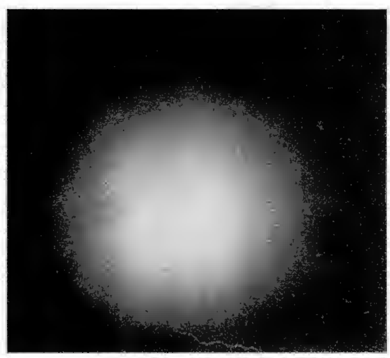

Figure 4.2 - Expanded Beam Cleaned by a Spatial Filter

The spatial filter used for this project had the following characteristics:

Objective Magnification	40X
Focal Length (mm)	6.3
Pinhole Diameter (μm)	5 - 10

4.1.1.3. Beam Splitter

There are a variety of beamsplitters available from the reasonably inexpensive fixed-ratio plain glass cubes to the very expensive variable-polarisation disk.

A variable-ratio beamsplitter was used for this project. It consists of a rotatable disk that is metalised in the form of a broad ring. This ring is graded and calibrated for various ratios and simplifies the task of adjusting beam intensities.

4.1.1.4. Front-Surface Coated Mirrors

The use of front-surface coated mirrors is very important in holography. The extra material (illustrated in Figure 4.4) the laser beam would have to travel through if it were to first pass through glass to get to the mirrored surface and then back through the glass to get out would diffract the beam from its original path and reduce the efficiency of the reflection. There would also be reflections from the extra surfaces that the rays traverse.

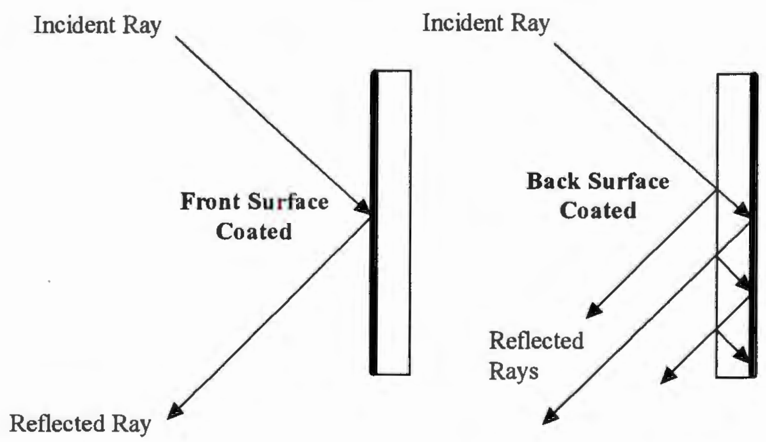

Figure 4.4 - Schematic Showing the Reflection Characteristics of a Front vs a Back Surface Coated Mirror

On the other hand, with the mirror coating on the front surface of the glass one can get a reflectance of up to 99.8% of the light ray incident on the mirrored surface [34].

There are a variety of front surface coatings available, including metallic and dielectric coatings. Metallic mirrors are by far the most common as they represent a good mixture of performance and economy with a nominal reflectance of 85%. They are relatively insensitive to wavelength, angle or polarisation of incident light. To obtain the best performance from metallic coatings, only very gentle cleaning of the surface may be performed.

4.1.2. Spatial Filter Collimator

For the process of making holographic stereograms, it is necessary to pass "clean", collimated light through the image slide. It is not necessary to use a corrected lens for this collimation process as the image from the slide will still be passed through a projector lens to correct for any aberrations present. It is thus possible to use a simple lens to collimate the laser.

An ordinary magnifying glass lens was chosen with a focal length of 200mm. This focal length was chosen so that as little expanding light as possible from the spatial filter would be lost before it was collimated. The lens was attached to the slide advancer in a position just before the slide (see Section 4.2.1). This allows accurate collimated illumination of the slide.

4.1.3. Projection Lens

One of the most critical optical components used is the projector lens. The projector lens creates a real image of the slide on the opaque focusing screen (see Section 4.1.5). This image is free from any distortions because the projector lens is a compound lens (see Figure 4.5) and thus well corrected for aberrations such as astigmatism, coma and distortion [35].

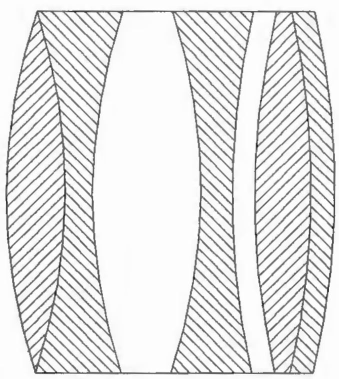

Figure 4.5 - Schematic of a Compound Lens

4.1.4. Fixed Focus Ray-Traced Plano-Convex Cylindrical Lens

The use of a cylindrical lens is optional. It has both advantages and disadvantages associated with it as indicated in the following discussion.

The type of Master holographic stereogram that was required to be made in the study can loosely be described as a "stationary slit" Master, ie. one where the slit is stationary and the film moves relative to the slit before the next exposure is made. Under these circumstances, it can be advantageous for the expanded, collimated reference beam to be squeezed by a cylindrical lens to prevent the loss of beam due to overspill [36].

One of the disadvantages of this method is that the cost of purchasing the large cylindrical lens needed for this collimation is prohibitive. To overcome this problem it is possible to use a lens constructed of a perspex shell that is filled with an optically clear refracting fluid. This technique has been covered in Section 2.2.1 under the title *Plano-Convex Cylindrical Lens.*

The use of this liquid filled lens creates a new set of problems as it suffers severely from astigmatism as illustrated in Figure 4.1. Notice that the rays fail to meet at a common point, which is indicative of this aberration.

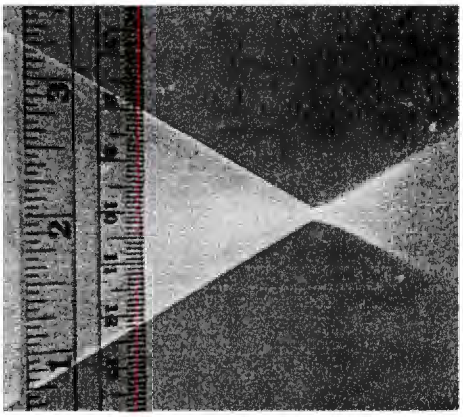

Figure 4.1 - Focal Region formed by a Liquid Filled Lens

After a variety of other methods (see Section 2.2.1) had been tested, it was decided the only way to achieve a reasonable image quality from a liquid filled lens was to use ray trace techniques to determine the radius of curvature needed for a specific focal length. The equations used to generate these surfaces are developed in Appendix A entitled *Design of the Fixed-Focus Cylindrical Lens.*

Once the ray tracing formulae had been developed, a spreadsheet was used to optimise the various lens design parameters. The result of this analysis was to develop a plano-convex cylindrical lens development tool with the ability to generate a lens based on specified parameters. A sample of the output of this tool is illustrated in Figure 4.7.

Lens Development Tool for a Liquid Filled Cylindrical Lens					
Refractive index - Air	1		Height of ray		Focal Length
Refractive index - Glycerene	1.4788				
Refractive index - Perspex	1.19		50		128.88
Refractive index - Glass	1.52		40		134.99
			30		139.50
Thickness of Perspex	1.5	mm	20		142.60
Thickness of Glass	2	mm	10		144.42
Thickness of Glycerene	77	mm	5		144.87
			2.5		144.98
Radius of curvature (r1)	96	mm			
		Ray Trace at height 50 - 2.5			
		Max	144.98		
		Min	128.88	Avg	140.03
		Difference	16.10	Ave Dev	4.78
		% Diff	11.50%	Std Dev	6.11

Figure 4.7 - Lens Development Tool for a Liquid Filled Cylindrical Lens

As an example of the output from the spreadsheet, here are the results of a lens that can be used to collimate a beam of light where the aperture has to be 100mm. Notice that the spreadsheet only describes rays to a height of 50mm due to symmetry of the lens. Notice also the effect of astigmatism illustrated by the 11.5% difference between the focal lengths of the 2.5mm and the 50mm ray. However, the larger the radius of curvature (r_1) the less severe is this effect.

The first lens surface has a radius of curvature of 96mm and a focal length of 140mm. It has a 100mm clear aperture for film illumination. The radius of curvature was specified to be as large as possible so as to eliminate lens aberrations as far as possible and these were further reduced by using a glass pane for the lens surface closest to the point source.

The gain in localised reference beam intensity by using the cylindrical lens was heavily outweighed by the poor optical characteristics obtained by the lens even after extensive work had been done to correct for this. During the final stages of this project, it was decided not to use this lens due to the inherent restrictions associated with it and a simple collimating lens was used in its place.

4.1.5. Opaque Focusing Screen

The opaque focusing screen is used as a screen for the image of the slide projected by the projector lens. Since this screen forms the real image for the creation of the Master, it must be of the highest quality possible.

There are special proprietary "Bright™" screens available but as the cost of these are well over R1 000 for a 4" x 5" plate, an alternative was sought in what is referred to as a BT focusing screen. This screen is used by professional photographers to focus the image before the 4" x 5" film pack is slid on for exposure. The price of a second hand BT screen is more reasonable at R650 but this was still considered to be too costly.

Ferric Sulphate was used in an effort to chemically etch an existing 4" x 5" clear glass plate but was found to be most unsatisfactory as the surface texture obtained in this manner was not uniform.

The method finally employed consisted of using a simple carborundum grinding paste on a clear 4" x 5" glass plate 2mm thick. This proved satisfactory and a bright image of the slide was visible when projected onto the screen.

4.2. Holographic Component Control

This section will deal with the components that were designed and built to facilitate the creation of the stereograms as well as the computer software that was written to control these components. Any detailed specifications will be dealt with in the Appendices with just the essential information being presented here.

4.2.1. Slide Advancer

One of the key themes in the generation of the holographic stereograms is the concept of sequentially exposing one slide at a time. It is important that there be good registration from one slide to the next to ensure no erratic shifting of the final image. In Section 4.1.2 the lens used to collimate the light coming from the spatial filter was described. It was also stated that the lens was positioned in a permanent position just before the slide by being integrated into the slide advancer.

The discussion below relates to the drawings found in Appendix D.1 entitled *Design Drawings of a Frame Advancer*. Drawing 1 shows an assembly of the **frame advancer** and Drawings 2 through 6 show detailed views of the **housing**, **shaft**, **base**, **film mask** and **feet & lens holder** respectively. A photograph of this design is shown in Figure 4.8.

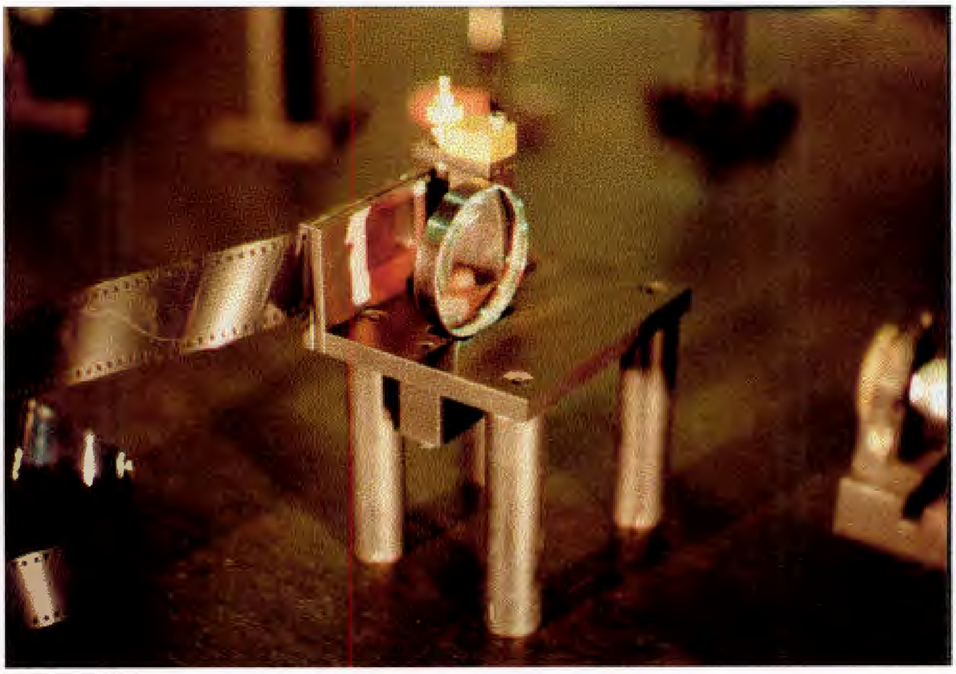

Figure 4.8 - Photograph of the Slide Frame Advancer

The height of the unexpanded laser beam is 143mm above the plane of the holographic table and a simple lens was positioned at this height to collimate the expanding beam before it reached the slide.

The strip of slide film was given a fabric lined slot to pass through with guides to keep it centred at the height of the laser. The film passed by a "window" having the dimensions of a single slide and this window was in turn illuminated by the collimated light coming from the lens. This arrangement allowed the image of a single slide to be projected into space and finally, via the projector lens, onto the opaque focusing screen.

The slide film was advanced sequentially by using the roller-sprocket common to a 35mm camera. A spring loaded register ball was used to ensure precise positioning of the film as well as the facility to shift the advancing sprocket to the left or right by 4mm. This was required to allow centring of the slide image in the window since slide misalignment can occur when one first loads the film. The number of holes from the leading edge of the film to the first frame is not always constant and one can get the condition where the tooth of the sprocket has engaged the wrong hole.

Consideration was given to controlling the rotation of the sprocket via a computer connected to a stepper motor. This idea was rejected because the holding torque required by the stepper motor, to remain in a fixed position, would result in vibration of the holographic table.

Computer control would however be implemented to control the two devices described below.

4.2.2. Exposure Control

The automation of the exposure process is advantageous when one has to expose few dozen slides during the creation of the stereogram.

Saxby has presented an elegant way of achieving this [37] by using a voltmeter to create an electromagnetic shutter. All that is required is to remove the scale from the voltmeter and drill a hole at the 0V position just large enough for the laser beam to pass through. One now attaches a small circular piece of card to the pointer to cover this hole when no voltage is applied. As soon as a few volts are applied, the needle moves and the laser beam is allowed to pass unhindered through the voltmeter.

This technique can be taken a step further by deriving the voltage source to drive the voltmeter from the parallel port of a computer. Here one has the ability to toggle between 0V and 5V simply by adjusting the bit value sent to that address (This concept is taken further in Appendix B.3 entitled *Computer Control*).

Through the computer control it was possible to set any exposure time by varying a parameter in the computer control interface discussed in Sections 4.2.4 and Appendix C.2.1

4.2.3. Holographic Film Spacing

Accurate registration of the component's holograms is a critical element in the creation of stereograms. This is true for the creation of both the Master and the Transfers although for different reasons.

During the creation of the Masters, it is important to keep the parallax angle the same as that used to create the original slides of the object. For example, if the slides show a view of the object every 10^{O} then the slides must be projected onto the master every 10^{O} and this is easily achieved by using a cylindrical system to record incremental perspective views. If accurate registration does not occur, then the perspective will appear to be either exaggerated or reduced and the image may appear to roll as the viewing angle is changed [38].

When producing the Transfer holograms, it is important to have the Master illuminated from exactly the same position as the original reference beam used when creating it. A slight shift from this angle will result in the projected real image loosing intensity. This is of particular concern when one has many sequential images to record because if the final image has a number of weak frames, then the image will flicker as one moves past it. This problem can only be avoided by accurate registration of each Master segment to be projected.

There are a variety of indexing methods available and the one described below is best suited to the creation of cylindrical stereograms of the type being made for this project. The design of the indexing tool will be discussed first, followed by a section describing the method used to drive this indexer.

4.2.3.1. Indexing Turntable

Due to the inherent advantages of using a cylindrical indexing method, an investigation was undertaken to discover the simplest means of accomplishing this. A rotating table that could be adapted for use was found in the Departmental Workshop. This formed the base of the indexing turntable as it had degree graduations as well as a vernier type handle that could be rotated to give very accurate increments in angular position.

The description of the turntable that follows refers to drawings that can be found in Appendix D.2 entitled *Design Drawings of the Indexing Turntable.* A number of components were developed to enable the rotating table to be used as an indexer and these will be described in turn. The words in bold that appear in the following sections, refer to particular drawing titles found in the aforementioned appendix.

As an overview and to aid in conceptualising the design, a photograph of the assembly is shown in Figure 4.9.

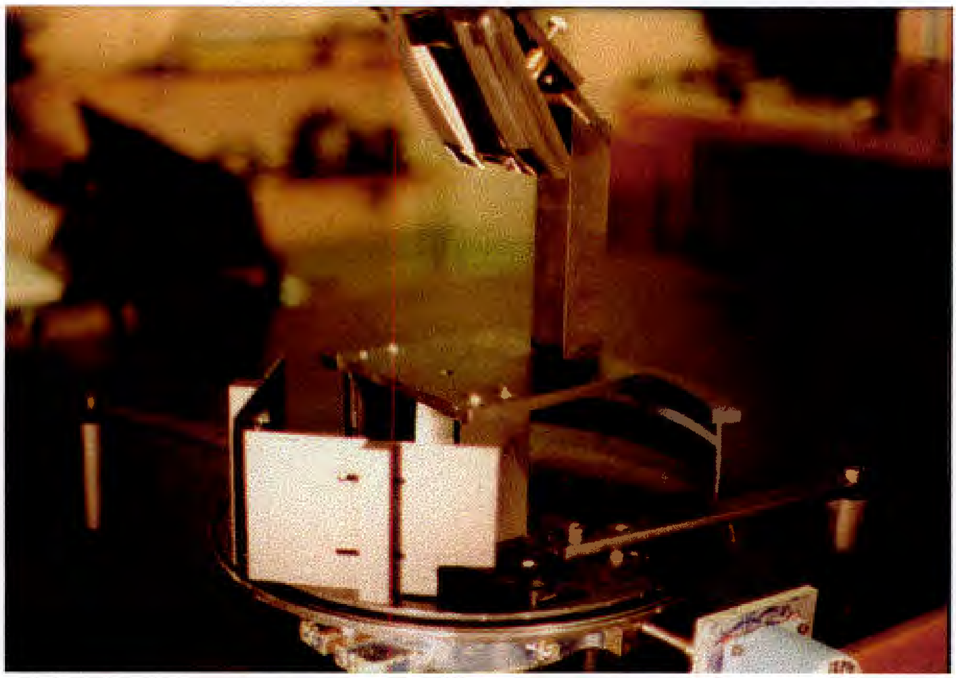

Figure 4.9 - Photograph of the Assembly of the Turntable

The indexer can be broken up into six distinct sections with the whole assembly being mounted on a **Base Plate**.

- The basic **Turntable** is an aluminium plate 8mm thick with a diameter of 410mm. There is a 4mm wide groove at a radius of 200mm used to position the two pieces of perspex that sandwich the film during use.
- The **Turntable** is attached to the **Rotating Table** by means of a **Locator**. The use of this locator is two fold. First, it is used to position the **Turntable** at the required height

above the holographic table. Secondly, it is used to house the bearing that will interface with the **Supporting Shaft**.

- This **Supporting Shaft** is fixed securely to the base and is located at the top by passing through a bearing housed in the **Locator**. The shaft continues through a hole machined in the **Turntable** and protrudes four millimetres. The result of this assembly is a **Rotating Turntable** with a stationary central area. This stationary area is required to hold the **Stationary Frame**.
- The use of the **Stationary Frame** varies depending on the process. During the generation of the Master, the frame holds a **Mask** which shields the holographic film from stray laser light. When making the Transfers, there is a separate assembly that attaches to this **Frame** to direct the reference beam to the film from the correct angle. This will be described in the next section.
- The final piece of the assembly is a pair of magnetic **Stabiliser Arms** that are attached to the **Frame** and in turn anchor on the holographic table. This ensures that the **Frame** remains absolutely steady during exposure of the film.

4.2.3.2. Reference Beam Director

The **Reference Beam Director** consists of 4 components and design drawings of these can be found in Appendix D.3. An illustration of this assembly is included in Figure 4.9. There is a **Base** that attaches to the **Stationary Frame** as described above. Attached to this are two **Upright Supports** which hold the **Top Plate** in position. This **Plate** has dimensions such that it can, through use of a **Mirror Support**, position the reference beam mirror in the correct position required redirecting the reference beam down onto the film from the correct angle. The **Upright Supports** are situated in such a position as to allow uninterrupted passage of the light from all required directions.

4.2.3.3. Indexer Control

Advancing the film after each exposure has been made is achieved through the use of a stepper motor. This stepper motor is attached to the **Indexing Turntable** via an aluminium **Coupling** and is fixed to the same **Base** through the use of an **Angle Support Bracket** and a **Stepper Base** as illustrated in Figure 4.9.

The stepper motor is controlled by a translator module, which is in turn controlled by the computer. The specification and design of the various components are described in detail in Appendix B and only the basic design details will be described below.

A modular translator that interprets signals from the parallel port of a computer drives the stepper motor at 200 steps per revolution. It is possible to control a variety of parameters of the stepper motor by sending logic computer high's (5 Volts) or low's (0 Volts) to the translator. It is possible to simultaneously send these high's and low's via the parallel port by sending a binary number to that port in the form of an array of high's and low's. All that is still needed is a means of getting the required information to the parallel port. This required the creation of control software.

4.2.4. Software Control Interface

Microsoft's Visual Basic® Version 4 Professional Edition was used to create the control interface between computer and stepper motor. What follows is an overview of the concepts of the software program. The details of the development of the software, as well as a guide to its use, will be given in Appendix C. A listing of the code used to generate the software will be given in Appendix E.

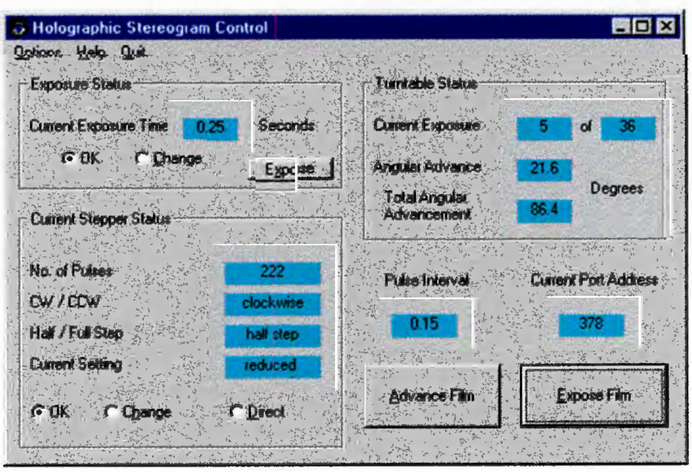

Figure 4.10 - Screen Display of the Software Control Interface

A "screen" display of the main control interface is shown in Figure 4.10. It is seen that the interface is divided into three main windows with two execution buttons and above these buttons, two outputs giving current hardware settings.

The window in the top left quadrant, entitled Exposure Status, is used to set the exposure time required for the holograms.

Below that is a window entitled Current Stepper Status where all the control variables required by the stepper motor are defined. The stepper motor needs to know how many steps to take and this is determined by how far the Indexing Turntable must advance before the next exposure is made. The three settings below this value determine the motion characteristics of the stepper motor. The Reduced Current option was disabled for this project, as variable torque was not required.

If the Direct option button is selected, a different part of the program is enabled where direct control the stepper motor away from the environment of holographic stereograms is obtained. This feature is especially useful in order to pre-set the position of the film prior to beginning the exposure process.

The window to the top-right is titled Turntable Status. It is the control centre of the process as it displays the status of the stereograms. The exposure number is recorded alongside the total number of exposures to be made. Below that is a measure of the Angular Advance. This is determined by the number of steps taken by the stepper motor and after each exposure, the Total Angular Advancement is recorded.

The two buttons in the lower right quadrant are used to implement the conditions set up in the first two sections, ie. to either Advance the film or Expose the film. The software has error checking to ensure that an exposure is not made without first advancing the film to the next position.

The two hardware settings displayed above the buttons are there to ensure that the correct hardware options are used. Although most computers have the same parallel port address, if another address is used then the software must be told to send its information to this new destination. The second setting is used to determine the time between the pulses that are sent to the stepper motor. This effectively determines the speed at which the Indexing Turntable rotates.

Chapter 5. Creation of a Holographic Stereogram

The creation of a stereogram is a two step process. The first step involves the creation of a Master (or H1) hologram and the second is the making of the Transfer (or H2) from this Master. This Chapter details the steps taken to produce the Master hologram and then the Transfer.

5.1. First Generation (Master) Transmission Holograms

The first generation Master hologram is simply a transmission hologram that has been processed in a certain way. As such, the first part of this discussion deals with the principles of transmission holography to be followed by an explanation of the requirements to specifically create the Master hologram.

5.1.1. Principles of Transmission Holograms

5.1.1.1. Optical Considerations

The underlying principle of holography is based on the fact that when a wavefront is refracted by a transparent object (or reflected by an opaque object), the object has diffracted the light and the resultant wavefront contains all the information about the object [39]. The undiffracted reference beam is optimally incident on the film at an angle of approximately 38^{O} from the same side of the film as the object. This results in interference fringes of the order of $1\mu m$ being formed on the film's emulsion.

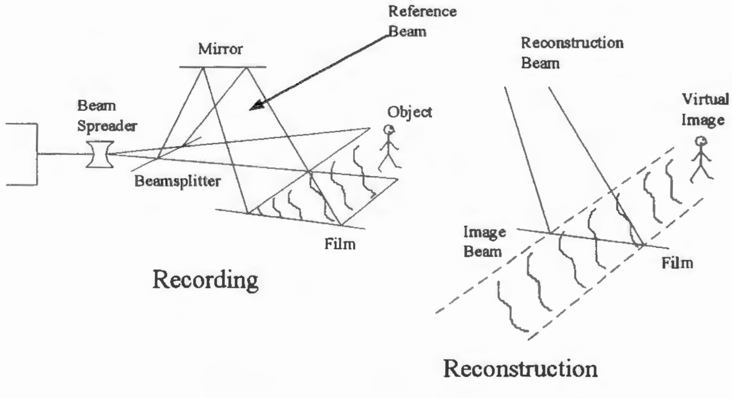

Figure 5.1 - Basic Arrangement for Transmission Holography

To reconstruct the image after developing, all that is necessary is to relocate the transmission hologram in the frame where it was made (see Figure 5.1) and direct the reference beam (now called the reconstruction beam) onto it from the same direction.

As one now looks along the reconstructed path of the object beam, one can see an image of the object in the position of the original object. If the hologram was made from an opaque object then the image would be autostereoscopic with full parallax. The image that one sees is known as a virtual image (see Figure 5.2) as the light doesn't actually pass through the image space but only appears to have originated from it. This is the same type of image that one sees when one looks into a mirror.

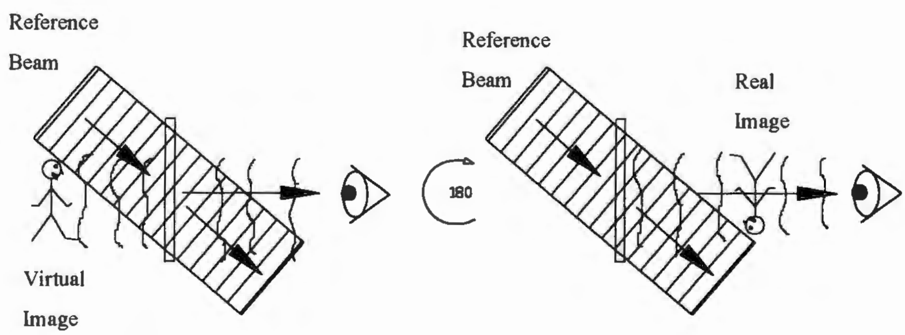

Figure 5.2 - Real and Virtual Images

To generate a Transfer transmission hologram, it is not the virtual image that is required from the hologram, but the real image as illustrated in Figure 5.2. In the case of the real image, the light actually passes through the space occupied by the image. The reason for this image being of importance is that it can be replayed onto a screen placed in the plane of the image and it is this property that is fundamental in the concept of a master hologram. The emulsion on the film has a finite thickness and because the object and reference beams are incident on the film at approximately equal angles, the interference

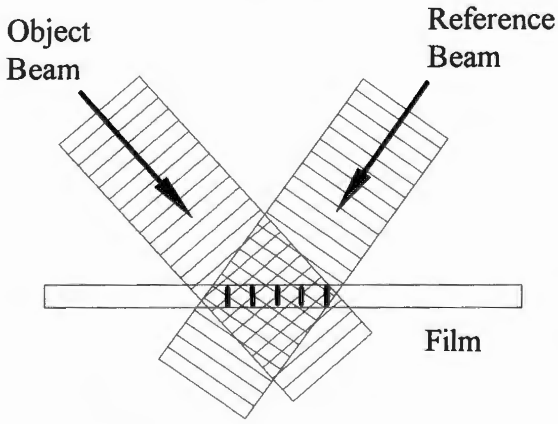

Figure 5.3 - "Plane" Hologram

fringes running through the emulsion are at right angles to the emulsions surface. This is illustrated in Figure 5.3.

To make a rainbow transfer hologram only a thin slit of the order of 7 - 10 mm of the original master is required, and as such, it is not necessary for one to use the entire height of the film. All that is needed is a thin strip (greater than 10mm) of film to be exposed. For this project, 35mm Agfa 8E75 holographic film was used. This extra 25mm width allows the viewpoint of the rainbow Transfer to be altered after the first test H2's are made.

Another important criteria in determining the optical layout of the table is that it is necessary to allow enough space for the expanded and collimated reference beam to bypass the object unimpeded on the way to the film. This requirement can restrict the angle of incidence of the reference beam on the film.

5.1.2. Optical Set-up and Component Alignment

The basic layout used in the creation of the H1's is shown diagramatically in Figure 5.4 and photographically in Figure 5.5. The following description details the procedure used in positioning and aligning the components.

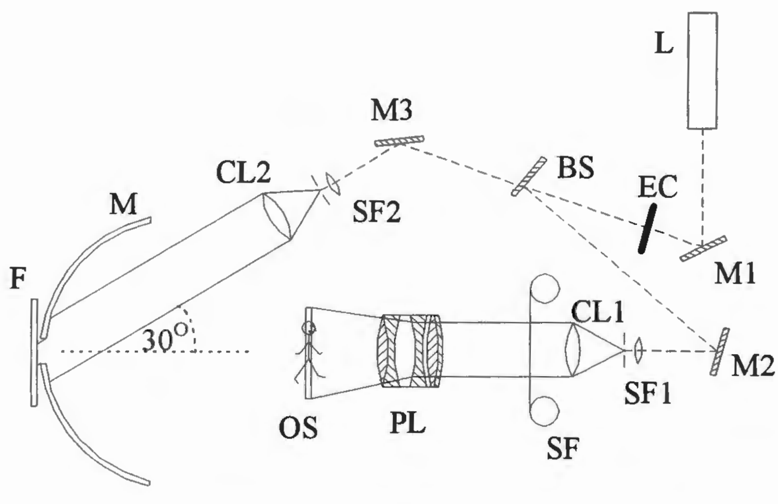

Figure 5.4 - Optical Layout for Master Holograms

The automatic exposure controller (EC) was placed in the position illustrated in Figure 5.4 to control the exposure of the film.

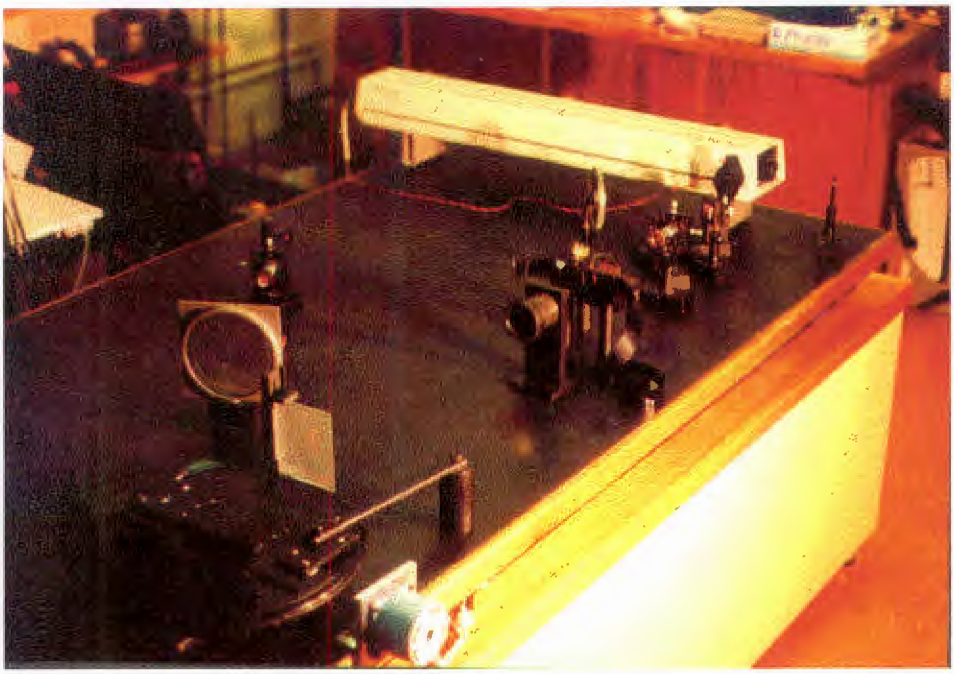

Figure 5.5 - Photograph Showing the Optical Layout for Creating Master Stereograms

A metalised variable beamsplitter (BS) was placed in the position shown to split the HeNe laser into the object and reference beams. It must be borne in mind that the initial placing of the basic components for the object and reference beams occurs simultaneously to enable the path lengths to be matched. For clarity, the two different paths will be dealt with in turn.

5.1.2.1. The Object Beam Optical Arrangement

The object beam path was first determined by reflecting the unexpended laser beam off the adjusting mirror (M2) to fall onto the centre of the opaque focusing screen (OS) where the slide image was to be projected. This allowed one, firstly to measure the path length of the laser from the beamsplitter to the screen and secondly to centre the beam before other optical components were introduced.

A spatial filter (SF1) was introduced to clean up the beam (see Section 4.1.1.2) and to expand it to the collimating lens (CL1). It was important to adjust the illumination from the beam expander so that it was uniform over the diameter of the lens. Built into the housing of this collimating lens was the slide film (SF) positioning mechanism (described in Section 4.2.1) which in turn projected a collimated image of the object onto the diffuse screen (see

Section 4.1.5). The quality of the image at this stage was not acceptable as it suffered from the effects of lens aberrations caused by the simple collimating lens.

The collimated image was now passed through the projector lens (PL) of a 35mm slide projector (see Section 4.1.3). This lens configuration is well corrected and resulted in a crisp, well-defined real image at its focal plane. The focal plane was adjusted by moving the projector lens either towards or away from the opaque focusing screen until a crisp image was formed on the screen (see Section 4.1.5). The simplest way of accomplishing this was to temporarily place a piece of white card behind the diffuse screen on to which to focus the image. Another way of achieving the same effect was to leave the screen in position and then view the image on the downstream side of the screen by means of a mirror in the appropriate reflective position. The former method was employed for simplicity as it was found to be difficult to successfully adjust the projector lens while simultaneously holding the mirror in position.

With the above optical components and equipment aligned correctly, the "object" part of the set-up needed for the creation of the Master transmission hologram was complete.

5.1.2.2. The Reference Beam Optical Arrangement

The path of the laser beam from the metalised variable beamsplitter to the film will now be considered. The initial process of centring the beam was similar to before, in that one had to first determine the reference beam path, free from the cluttering of the various optical components.

This was achieved by reflecting the unexpended laser beam off the adjusting mirror (M3) to fall onto the centre of the space that the holographic film (F) would occupy. This allowed one to measure the path length of the laser beam from the beamsplitter to the film and match it to the length of the object beam. Although the coherent length for this HeNe laser is 150mm, for holography one aims at a difference in path lengths between the two beams of less than 10mm.

A spatial filter (SF2) was introduced as before to clean up the beam and expand it to the collimating lens (CL2). It was just as important as before to adjust the illumination from the beam expander so that it was uniform over the diameter of the lens. The fact that the reference beam was expanded and then collimated was crucial when one came to the creation of the Transfer hologram and this will be dealt with in Section 5.2 entitled *Second Generation (Transfer) Transmission Holograms.*

The collimated reference beam was now directed at the slit that was formed by the mask (M). As this project uses "stationary slit" mastering, it was possible at this point to use a cylindrical lens to prevent overspill as discussed in Section 4.1.4 (*Fixed Focus Ray-Traced Plano-Convex Cylindrical Lens*). Once the angle of incidence was reduced from the optimum 38^O to 30^O, the reference beam bypassed the object (opaque screen, OS) on the way to the film without obstruction.

All the various components were now positioned to create the H1's. All that remained was to attach the computer, make a few test exposures to optimise the object/reference beam ratios, exposure times and then proceed to create the stereogram Masters.

5.1.3. Computer Interfacing of the Components

With the optical components aligned, the computer interface could be attached. The first step was to attach the stepper motor that controlled the Indexing Turntable to the circuit isolator. This isolator served to isolate the computer from the components that it controlled. The stepper motor was powered through a transformer. The power signal required by the Exposure Controller was taken from the isolator and connected to the controller taking care not to switch polarity on the voltmeter. The isolator was connected via a Centronics printer cable to the computer's parallel port.

Figure 5.6 shows from left to right, the stepper motor transformer, the translator, the circuit isolator and the circuit isolator power supply. Note the red and black twisted wire running from the isolator. This wire provides the 0V/5V to the Exposure Controller.

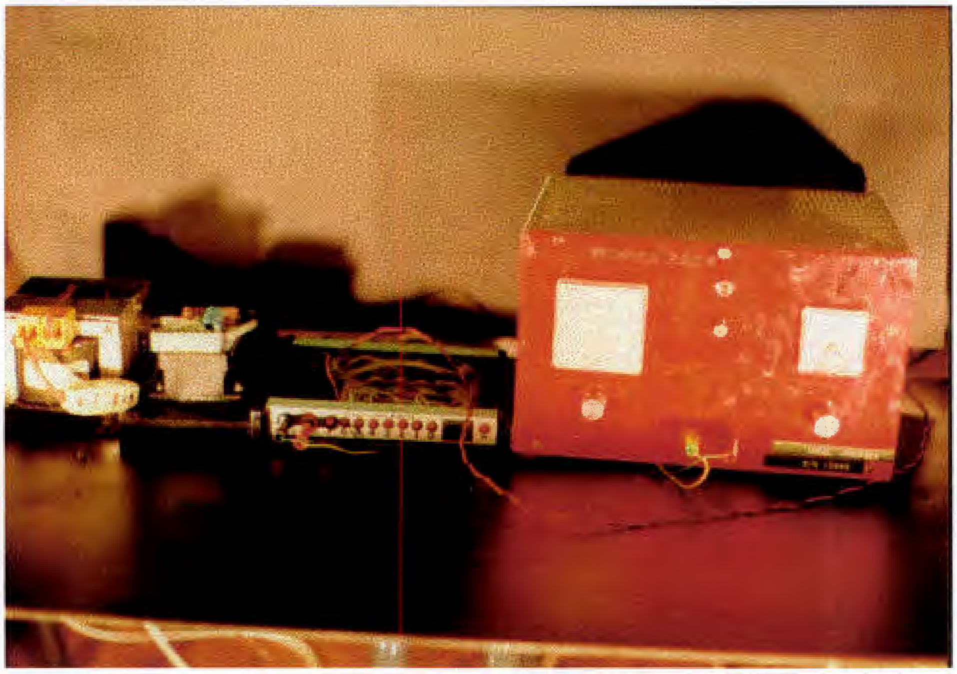

Figure 5.6 - Photograph of Control Components

5.1.4. Test Exposures

The category "test exposures" is very broad. There are many variables involved and it is necessary to approach the task systematically to ensure that the process does not become too complex. The test exposures made were initially single exposures. The computer control was only brought in once these exposures had been optimised. The method used to create the single exposure does not differ from the process used to create the final strip of exposures, and it will be dealt with as part of Section 5.1.7, Final Stereogram Masters.

The object/reference beam ratio is recommended in various references to be between 3:1 and 8:1 for transmission holography [40] with the reference beam having the greater intensity. As a first approximation, the variable beamsplitter was adjusted to a ratio of 180^{O} (see Section 4.1.1.3). An exposure time of one second was chosen as a base and a hologram was attempted.

At this stage the hologram had to be developed. Since this process will be dealt with in the following section, it will be assumed here that the Masters were successfully produced.

On the basis of the quality and brightness of the hologram after development, the beam intensity ratio was either increased or decreased. After many iterations it was found that for the chosen optical arrangement, the optimum image quality was obtained when the beamsplitter was set to 120^{O}. This corresponded to a beam intensity ratio of approximately 4:1.

It must be remembered that a strict analysis of the beam intensities was not followed but the method used in this type of analysis will be described below for completeness. The effective beam ratios are measured by directing a light meter (such as an OPT-110 Optical Power Meter produced by Oi Electric Co) along the bisector of the angle of the two beams and using a polarising filter with its polarising axis parallel to the direction of the polarisation of the reference beam [40]. Even when one uses this technique to find a starting point, it is still necessary to run through various iterations before arriving at the desired ratio.

Once the beam intensity ratios had been determined, it was necessary to optimise the exposure time. Once again, this exposure time is integral with the development process. During development one requires the film to reach a density of around 2.5 on completion of the specified development time [41] which is in turn determined by the development conditions (this will be discussed in the next section). By adjusting the exposure times it is possible to alter the development times. A number of test exposures were made and an exposure time of ¼ second was found to be optimal.

5.1.5. The Development Process

The development requirements for creating Masters, as compared to those in making Transfers, are quite different as it is advisable for Masters to use a technique that does not remove any material from the emulsion. The ideal holographic developer should combine the following properties:

1. maximum fringe contrast
2. maximum emulsion speed
3. minimum chemical fog

Unfortunately, chemical fog is related to the first two characteristics and one has to compromise on them to keep the fog level [41] in the region of 0.3 - 0.6. A small quantity of Bromide is added to the developer to retard the onset of this fog.

The chemical composition used for developing the Master hologram is shown below in Table 1. Although this particular developer can be reused if one increases both the exposure and development time by 5% per film developed, since repeatability was desired, fresh chemicals were used after every two developments.

De-ionised Water	700 ml
Ascorbic Acid	20 g
Metol	5 g
Anhydrous Sodium Carbonate	20 g
Sodium Hydroxide	6.5 g
Potassium Bromide	1 g
Water to make	1000 ml

Table 1 - Chemical Components of the Master Developer

The development time for this developer was determined predominantly by the temperature of the developer, the density and fog level required. For $20^{o}C$, the development time can be between 6 and 12 minutes. In practice, this was found to be excessive with 4 minutes giving an acceptable density level.

Because only small amounts of developer were being used at a time, it was recommended that one pre-soaked the emulsion in water containing a wetting agent. This wetting agent can be any commercial dish washing liquid such as Sunlight Liquid made by Lever Brothers which gave excellent results.

It was mentioned at the beginning of this section that one of the requirements for developing Master holograms is to follow a procedure that does not remove any material from the emulsion. This is particularly important when one bleaches the hologram after development.

5.1.6. Bleaching the Master

Due to the criteria mentioned above, the only bleach considered suitable for master holograms is a rehalogenating bleach. This is a bleach that does not remove any silver from the emulsion. The best bleach for transmission masters, of the type created above, is one based on ethylenediaminetetraacetic acid [42]. This acid is more commonly referred to by its acronym EDTA and is used in the form of its ferric salt.

The bleach bath for master holograms is shown in Table 2:

De-ionised Water	700 ml
EDTA (disodium salt)	30 g
Ferric (iron(III)) Sulphate Crystals	30 g
Potassium Bromide	30 g
Sodium Hydrogen Sulphate Crystals	30 g
Water to make	1000 ml

Table 2 - Chemical Components of the Master Bleach

Before placing the developed holographic film into the bleach bath, it is important to rinse the emulsion briefly in (tap) water to remove excess developer. This action extends the effective life cycle of the bleach. As soon as the film had been placed in the bleach, the lights could be turned on.

The film must be rocked gently back and forth in the bleach until all traces of dark silver have disappeared. One way to determine this more clearly is to look at the back of the film for spots of unbleached silver. To ensure that the bleach had completed the process, the film was left in the bath for an extra minute after all visible traces of silver had gone.

One of the characteristics of this particular bleach is that it leaves some microscopic silver bromide crystals resulting in a bluish haze on the film. This haze is due to the effect of Rayleigh scattering of the incident light and is not apparent when the film is exposed to laser light. Since this film was not intended for display, no effort was made to remove the haze.

5.1.7. Final Stereogram Masters (H1's)

This section will describe the final method employed in generating the Master holograms.

Using 36 slides for 120^{O} of rotation, corresponded to one slide every 3.3^{O} at a radius of 200mm. This equated to a slit width of 11.64mm. Thus, in order to fit 36 slides onto the film, each slide could occupy no more than 11.64mm.

To accomplish this, and to ensure that there was no overlap of exposures, the Mask on the Indexing Turntable was adjusted to 10mm. This introduced a 1.5mm spacing between exposures as it was found during testing that this small gap reduced the possibility for overlap of one real image by the subsequent one during reconstruction. The overlap is due to a small unmasked part of the following exposure being illuminated by the reconstruction beam.

The 35mm holographic film was held in position between two perspex sheets mounted in an aluminium frame. The frame was secured in position on the turntable by locating in a groove cut at a radius of 200mm.

The parameters used by the software control program were set as follows.

- The stepper motor was set to advance 222 steps. One revolution of the stepper motor is 200 steps and results in a 3^{O} advance of the turntable. Thus, 222 steps equated to the 3.3^{O} needed to advance the film the distance of 11.64mm, needed for the next exposure.
- The exposure interval was set to 0.25 seconds.
- The time between stepper motor steps was adjusted to 0.15 seconds. For 222 steps, this amounted to approximately 30 seconds.
- The memory address of the computers output port was Hexadecimal 378.

The strip of slides was fed into the Frame Advancer and the first slide was centrally positioned using the spindle positioning screws (see Section 4.2.1). It is important to load the slides correctly as they have to be inverted in the Advancer in order for the image to be upright when projected onto the opaque focusing screen. It is also important that the slides be fed in from the correct direction as this will determine whether the slides are inverted left-to-right relative to the original animation.

Once the parameters were set, the process of obtaining the sequential exposures could begin. The following paragraphs relate to the method used to accomplish this.

The first exposure was made by sending a 5V pulse to the Exposure Controller, via the software interface, for 0.25 seconds. As soon as this was completed, the turntable advancing routine was initiated. This is a process which by its very nature is incongruous to holography as it sets up serious vibrations on the holographic table. It is well known that any vibration of the table must be avoided during exposure of the hologram and as such a suitable period had to elapse for damping to occur. Interferometric tests using the Michelson set-up were performed on the vibration induced by the stepper motor. It was found that within 5 seconds the fringes on the interferometer had stabilised to the extent that the system could be assumed vibration free. To ensure that the table was damped and vibration free before the next exposure was made, the table was left for 60 and not just 5 seconds.

During this 60 second settling time, both the object and reference beams were checked to make sure that the illumination from the beam expanders were still uniform over their respective areas. This is a crucial step as during the stepping motion of the turntable, there is a possibility that the alignment of these critical components can be offset.

To perform this inspection, cardboard masks were placed in front of the expanding beams and their profiles inspected. There is a control button available in the software interface to allow continuous exposure to take place for any set period. Only rarely did any adjustment have to be made. However, if his adjustment was not performed, the image quality of the resultant holograms would be seriously degraded.

The Frame Advancer was used to advance the slide strip to the next frame.

There was a period of approximately 20 seconds after these two tasks had been completed before the next exposure was made. This settling time allowed for any additional vibrations that may have been induced to die out.

The exposure-advancement process was repeated until each slide had been exposed in turn. The average time taken for each exposure routine was 2 minutes and the entire process took just under 1½ hours to complete. Because of this lengthy process it is clear why such care must be taken to ensure that every exposure is performed with the slide fully illuminated and the table completely damped. Any mistake will show up only after development of the strip resulting in an unwanted repetition of the process.

The hologram was developed in the same chemicals as described previously except that in this instance, a Paterson Super System 4 development tank for 35mm film was used to process the film instead of flat development trays. The bleaching of the hologram was also performed in the same tank.

The Master holograms that were created using the above process gave very crisp and well defined real images. These images would now form the object used in the generation of the rainbow Transfer holograms that were to follow.

5.2. Second Generation (Transfer) Transmission Holograms (H2's)

The optical layout of the procedure used in creating the stereogram is similar in process but completely different in execution to that for the Master. Generation of these Transfers still uses the transmission holographic approach but here one adds not only the white light rainbow effect but also an overhead reference beam for display purposes.

5.2.1. Optical Set-up and Component Alignment

The discussion that follows refers to the optical arrangement illustrated in Figure 5.7 and shown photographically in Figure 5.8. As was the case for the discussion of the Masters, the paths of the object and reference beams will be dealt with individually.

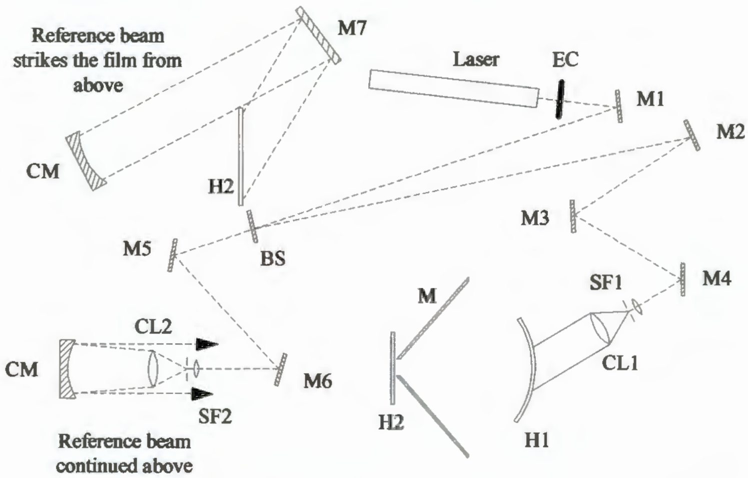

Figure 5.7 - Optical Layout for Transfer Holograms

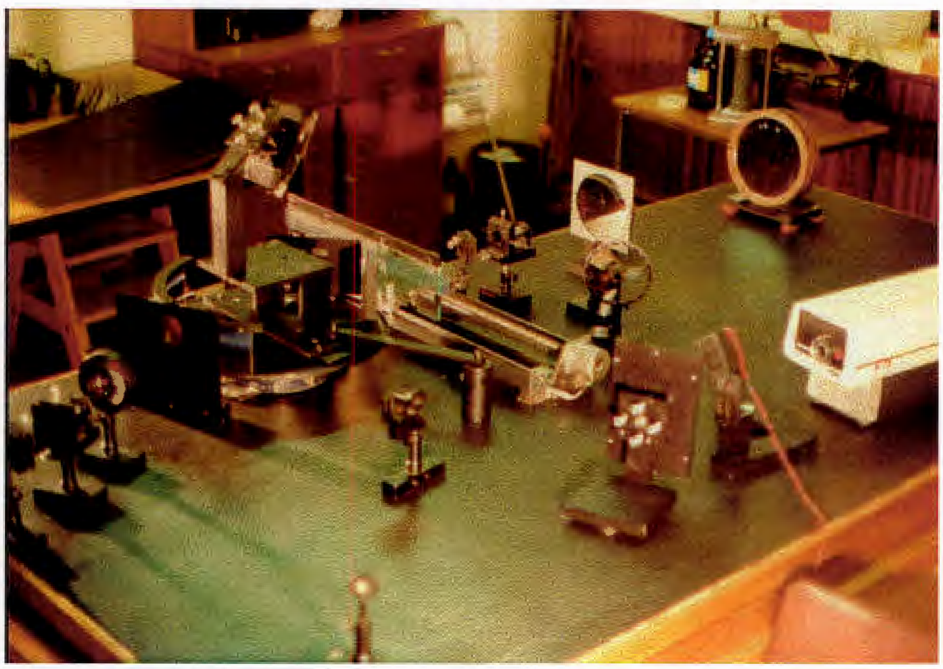

Figure 5.8 - Photograph Showing the Optical Layout used for the Transfers

5.2.1.1. The Object Beam Optical Arrangement

From the beamsplitter (BS), the laser beam is positioned by mirror M2, M3 and M4 to be incident on the Master hologram (H1). This is done without the spatial filter (SF1) and the collimating lens (CL1) present, in order to align the object beam to be incident on the H1 from the same angle as the reference beam used to create it. One must be careful at this stage not to expose the H1 to the unexpanded laser beam for an extended period as this will cause a phenomenon known as spot-out where the beam leaves a small spot on the film where the laser has been incident.

The Master is held in position by sandwiching it between two 1.6mm perspex sheets. It was essential to use perspex as it is optically clear. The perspex was anchored in position by placing the sheets in two support brackets, one in the form of a groove in the turntable and the other in the form of a milled aluminium groove of the same diameter as the groove in the turntable. This arrangement is illustrated in Figure 5.9.

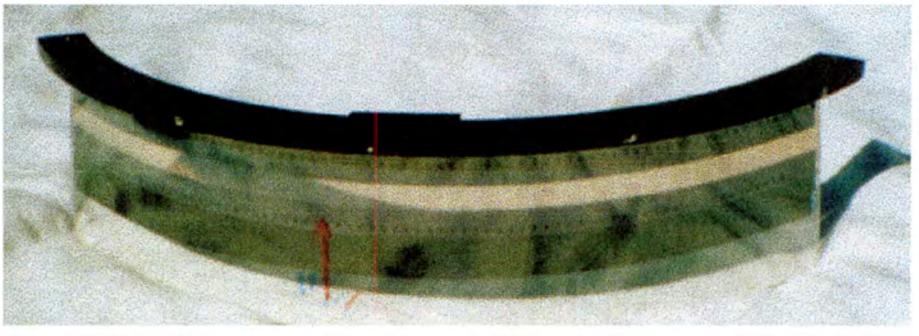

Figure 5.9 - Photograph Showing the Master Held in Position

It has been stated previously in Section 5.1.2.2 that the reference beam used to create the Master must be collimated. The reason for this is that, in order to reconstruct a geometrically correct (though pseudoscopic) real image from the Master, one needs to illuminate the flipped Master with the conjugate of the reference beam. Although a hologram is not the same as a lens, it still focuses an image and obeys the lens laws. Thus, if one changes the divergence of the beam illuminating the Master, then the real image will be shifted and magnified relative to its original position.

A spatial filter and collimating lens are introduced to fulfil the illumination requirements described above. A simple lens with a focal length of 100mm was used to collimate the light. This lens was chosen specifically because of its short focal length as it ensured no loss of light from the expanding beam. A secondary mask was introduced to restrict the collimated light to the width of each incremental image. The secondary mask was positioned as close as possible to the Master as the refraction effect caused by the light passing by the edges had to be reduced to the lowest level possible.

The theory of white light rainbow transmission holography, described in Section 2.3.4, requires that only a narrow slit of the master be exposed. This was achieved by placing two strips of black insulation tape on the inside curve of the perspex used to house the Master. The image slit width was set to 10mm to allow the restricted real image to be as bright as possible without sacrificing clarity in the final stereogram.

With the collimated beam now incident on the Master, the real image was projected to the plane of the holographic film. In order to check that the real image was positioned correctly, a frosted glass plate was placed in the position of the film and the quality of the projected (real) image was observed on the downstream side. If the image was not focused then it was possible to adjust the position of this focal point by adjusting the degree of divergence of the object beam as discussed above.

With all these criteria met, the requirements of the object beam for generating white light rainbow transmission holograms were fulfilled and the reference beam had to be established.

5.2.1.2. The Reference Beam Optical Arrangement

It must be remembered that the set-up is not as clear-cut as "object beam path first followed by the reference beam path" as it is an incremental process just as for the Master set-up. The rough layout is done first to optimise path lengths and once that has been completed the other components are added sequentially.

The layout of the reference beam differs markedly to that used for the generation of the Masters, in that the reference beam had to be positioned to be incident on the film from above. This requirement was determined by the manner chosen to reconstruct the stereogram. It is desirable that the reconstruction light be a single source placed at the centre of the stereogram, at a position far enough below the holographic strip that the light does not shine into the observers eyes.

In order to achieve this, the beam can only have its elevation off the table changed in one plane. If the beam is skewed away from the vertical when reflected from mirror M6, then there will be a discrepancy in the directions of the polarisation vectors where the reference beam intercepts the object beam and the quality of the final hologram will be degraded.

In order to maintain constant polarisation vectors, the following optical components were employed. The reference beam was directed by mirrors M3 and M4 onto a collimating mirror (CM1). This collimating mirror reflected the beam via M5 down to the film. Note that from M4 to the film, only the elevation of the beam is altered and not its angular position.

Once the object/reference beam path lengths had been adjusted, the beam expansion optical components were introduced.

A spatial filter was positioned just after M4 in order to clean and expand the laser beam. The focal length of the collimating mirror was 1m and as such, to obtain collimated light from it, would have to be placed 1m from the spatial filter. There were two problems with this. Firstly, the holographic table was not long enough. Secondly, and more importantly, to expand the beam over a length of 1m before attempting to collimate it would result in significant loss in intensity of the collimated reference beam. To overcome this constraint, a secondary simple lens (CL2) with a focal length of 300mm was placed in position between the spatial filter and the collimating mirror. This served to shorten the effective focal length of the collimating mirror. In practice it was necessary to move the lens back and forth until the reference beam was collimated.

The mirror M5 directed the collimated reference beam down onto the film. The mirror was held in position by the support shown in Figure 5.9, which was designed in such a way as to direct the reference beam onto the film at an angle of incidence of 38^{O} (previously been stated to be the optimum for transmission holograms). This layout was used to generate test Transfer holograms.

5.2.2. Test Exposures

The generation of the Transfer hologram involved a great many variables and it was once again necessary to approach the task systematically.

Initial tests were performed using 4" x 5" film sheets attached to a glass plate using White Spirits as an index matching fluid. However, since 35mm roll film was to be used for the final hologram, the object/reference beam ratios and exposure time variables had to be checked against this stock film.

Unfortunately, the 35mm strip was pre-curved due to being rolled during storage. This led to it not remaining attached to a single pane of glass with index matching fluid. To overcome this problem, the film was sandwiched between two glass plates. Initially, black paper was placed between the substrate and the downstream glass plate to eliminate internal reflections and remove the need for the index matching fluid. This proved to be unsuccessful and the following work was done using index matching fluid in place of the black paper.

With the 35mm film sandwiched between two plates of glass and index matching fluid, it was necessary to optimise the object/reference beam ratios and exposure time for this arrangement. In order to do this, a beam bracketing technique was developed which worked as follows. At a fixed beam ratio, five holograms were produced alongside each other with no overlap. Each hologram had a different exposure time and in this case, ½, 1, 2, 3 and 4 seconds were chosen. The object/reference beam ratio was then changed, first by +50% and thereafter by -50% from the first setting and the exposure process repeated.

When one now compared the three sets of holograms, it was quite clear whether the +50% or -50% gave a better image. One could at this stage also see which order of magnitude exposure time was the best.

For the second iteration, the 5 exposure times were bracketed around 3 seconds at 2, 2.5, 3, 3.5 and 4 to begin homing in on the correct value. The process of generating 3 sets of holograms was repeated. This bracketing process continued until a point was found, where beyond it, there was a rapid decrease in quality of the image.

The result of this iterative process was an object/reference beam ratio equivalent to 50^{O} (approximately 4:1) on the variable beamsplitter and an exposure time of 4 seconds.

The computer interface and control will be dealt with in Section 5.2.4 where a description is given of the method used to generate the final Transfer holograms.

5.2.3. The Development and Bleaching Process

The development and bleaching requirements for a Transfer hologram were also quite different to that for a Master. Here, one did not have to be concerned with removal of material from the emulsion during the bleaching stage and therefore it was not essential to use a rehalogenating bleach as a solvent bleach gave acceptable results.

Three different development/bleaching processes were tested to determine the optimal one. This choice was based on the inter-relationship of the variables defined in Section 5.1.5, namely the fringe contrast, emulsion speed and chemical fog levels of the film during development.

Firstly, use was made of the same chemicals that were used for developing and bleaching the Master. This resulted in an acceptable hologram but with the characteristic bluish haze caused by Rayleigh scattering. This haze could be removed by placing the emulsion in an ascorbic acid/water solution in the presence of a powerful light (greater than a 12V, 20W Halogen).

The second process used was the one known as the Pyrochrome process. This is a forgiving process as it will tolerate large errors in exposure and processing time. The developing agent is pyrogallol with metol in a highly alkaline solution. It produced a stain image which suppressed the Rayleigh scattering with limited shrinkage by hardening the emulsion. The developer is a two-part solution with both parts being mixed in equal quantities just prior to use (necessary as both oxidise rapidly in the presence of air).

The third developing process used, employed a simple X-ray developer from Agfa (shown in Figure 5.10) known as G 127 c. This developer gave the same quality results as those obtained via the Pyrochrome process but without the additional two part mixing requirements. Due to the simplicity of this approach, this developer was chosen in the production of the rest of the Transfers.

Figure 5.10 - Photograph Showing the Development Baths and the Agfa Developer

The bleach used with both the Pyrochrome based developer and the X-ray developer is known as a solvent (or reversal) bleach as it removes the negative fringes leaving the silver bromide unchanged. This is accomplished by converting the silver to soluble silver sulphate which is then washed away. The chemicals used for this process are shown below in Table 3.

De-ionised Water	700 ml
Potassium Dichromate	5 g
Sodium Hydrogen Sulphate Crystals	15 g
De-ionised Water to make	1000 ml

Table 3 - Chemical Composition of a Solvent Bleach

The combination of this development and bleaching process gave good, crisp, bright transmission transfer holograms.

5.2.4. Final White Light Viewable Stereogram Transfers

Once the object/reference beam ratios and exposure times, along with the development and bleaching processes had been optimised, the control systems could be implemented and the final holograms were produced.

The control interface parameters of the computer were set to be the same as they were during the generation of the Masters. This would ensure that each image would be positioned correctly during exposure. Therefore:

- The stepper motor was set to advance 222 steps which equated to the 3.3^{O} needed to advance the film 11.64mm needed per exposure.
- The exposure interval was set to 4 seconds.
- The time between stepper motor steps was set at 0.15 seconds.
- The memory address of the computers output port was Hexadecimal 378.

To accurately position the holographic film for the image from the Master to be recorded onto it, the film was indexed by rotating the Advancing Frame's worm drive through 11 revolutions per exposure. This advanced the film 22mm resulting in one view of the object every 6.3 degrees at a radius of curvature of 200mm.

The image from the Master hologram was focused at the plane of the Transfer by moving the collimating lens CL1 (see Figure 5.7) towards or away from the Master. This changed the divergence of the object beam resulting in a change in the real image's focal plane.

The procedure used to create each incremental hologram can be described as follows:

With the image from the Master focused at the plane of the film, the Exposure Controller was sent a 4 second exposure pulse which in turn exposed the film for 4 seconds. When this was completed, the turntable advancing routine was initiated and the film advanced to its next position.

To ensure that the table was vibration free before each exposure was made, a delay of 60 seconds was observed. During this settling time, both the object and reference beams were checked to ensure that the light from the beam expanders still uniformly illuminated their respective areas.

This exposure/advancement routine was repeated until the full length of the Transfer film had been exposed to the incremental real images from the Master.

The 35mm strip film was then developed in a Paterson Super System 4 development tank using the development procedure described above.

In order to view the resultant white light hologram, a white light reconstruction beam was projected onto the film from the correct direction and position. This was accomplished using the display box, as described in the following Chapter.

A sample of the hologram produced, with the respective slide that was used to produce it, can be found on the inside back cover of the thesis. In order to successfully view the hologram it is important to position it with the light incident from the correct orientation. One corner of the black supporting frame has been removed. With this corner in the bottom left hand corner, the light must be incident at 38^{O} from below and on the opposite side to the viewer. If however, the removed corner is in the top right hand position, then light must be incident at 38^{O} from above.

A high intensity white light must be used for reconstruction purposes. A 50 Watt halogen lamp (described in Chapter 6 – *Procedure used to Display the Holographic Stereogram*) of the kind often found in interior lighting will perform optimally. Using a conventional 100W incandescent spotlight will be sufficient, but will result in a poorer grainy image due to the characteristics of the white light produced.

To view the stereogram pair, position the hologram in such a manner as to give the brightest (green) image. Because of the narrow field of view of each component, it is possible to position oneself such that each eye can only see one image at a time. When one changes one's plane of focus away from the plane of the hologram to a point approximately 200mm past the hologram, the two component images overlap stereoscopically and form a single image.

Chapter 6. Procedure Used to Display the Holographic Stereograms

One of the fundamental requirements of the reconstruction beam used to illuminate the holographic stereogram includes the need for the reconstruction beam to be the conjugate of the reference beam used to create it. This simply means that the white light illumination source must be incident from the same angle as the original reference beam but from the opposite side of the stereogram. An alternative to this (shown in Figure 2.7) is to have the reconstruction beam incident from the same side and angle as the reference beam, but with the stereogram rotated out of its plane about a horizontal axis (flipped) through 180^O.

The Transfer hologram was generated with the reference beam incident from above at 38^O to the film. The reason for this was to enable the stereogram's reconstruction beam to be incident from below when the hologram was flipped through 180^O. The positioning of this light source was important as it had to be far enough below the level of the hologram that it was not visible during viewing.

The layout for viewing the cylindrical holographic stereogram is as follows:

- A strip of 1.5mm thick cast perspex was formed into a cylindrical shape with a diameter of 400mm.
- The hologram fixed to the perspex using double sided tape after ensuring that it was in the correct orientation.
- A 50 Watt, 12 Volt halogen lamp was used to illuminate the stereogram. It was important to ensure that the filament of the lamp was in a vertical orientation due to the restriction imposed by the rainbow slit used to create the Transfer. The lamp was positioned in the centre of the cylinder 160mm below the centre of the holographic stereogram.

There are two different ways of displaying the final stereogram. The choice of display depends on the use intended for the hologram. There are a variety of different cone angles available for the halogen lamp used as the reconstruction beam. Choosing the correct one is vital to the success of the display.

The first method of display is to shield the light source from the viewer's eyes, but to leave the entire holographic stereogram exposed to view. Because of the narrow field of view of each component hologram in this stereogram, it is possible to position oneself such that each eye can only see one image at a time. When one changes one's plane of focus away from the plane of the hologram to the centre of the cylinder, the two component images overlap stereoscopically and form a single image.

Once the image has stabilised, one can move around the cylinder and systematically recreate the object. This form of motion results in a very realistic viewing sensation as it is equivalent to the real life situation where an object is performing some action and the viewer moves either past it or around it.

There are a few practical disadvantages associated with this technique. First, it requires some practice to be able to view the stereogram successfully in this manner as one has to concentrate on a spot in space while moving about and not be distracted by the transition of the images from one to the next.

The maximum cone size of these halogen lamps is in the region of 40^{O} which means that it is not possible to use a single lamp and place it in a vertical orientation to simultaneously illuminate the entire 120^{O} hologram. To overcome this limitation, one must use as many lamps as required to uniformly illuminate the stereogram. These lamps can then be directed at the hologram.

The viewer does not see the animation that is experienced while moving around the stereogram as a smooth motion. Although being difficult to perceive smooth animation, this method does allow one to study the individual views from various orientations and view the impact this motion has on the various components in the object.

In order to view the stereogram in this manner, a viewing platform was constructed (shown in Figure 5.1) with the various elements described above placed in their respective positions. Since only 120^{O} of motion around the object was generated, the platform only required a viewing area of 120^{O}.

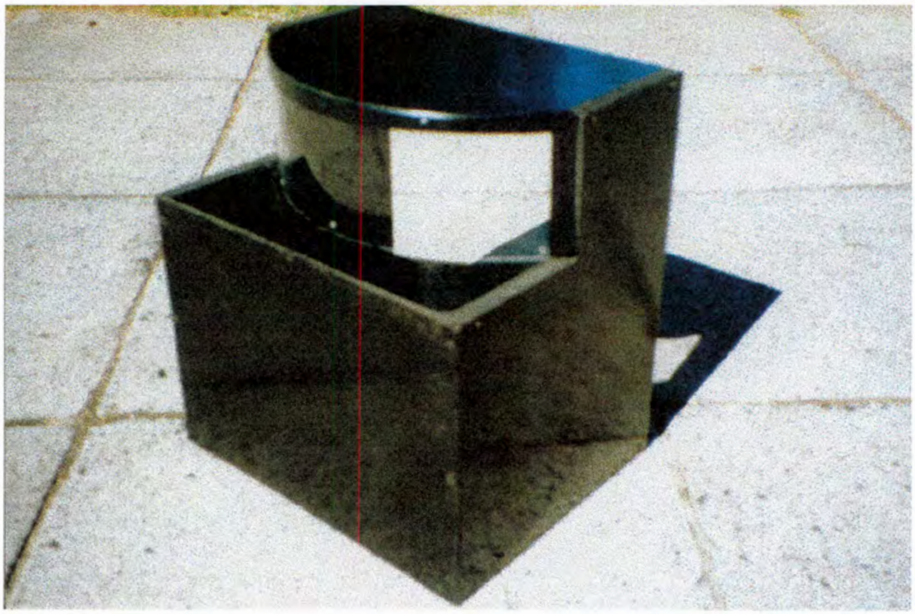

Figure 6.1 - Photograph of the Stereogram Viewing Chest

The second method of display is to view the stereogram in the form of an animated holographic motion picture.

The principle is similar to before, in that one still generates a stereoscopic view of the object by looking through two images of that object. The difference here is, the rest of the images are shielded from view and only come onto the scene as the stereogram is moved relative to the observers stationary position. This is accomplished by rotating the perspex cylinder with the stereogram attached to it, past a viewing window.

This display technique gives a sequence that is similar in appearance to an animation shown on a computer screen except in this case there is the added sense of realism due to the stereoscopic effect of viewing two images simultaneously.

The display of the animation in this form was accomplished by constructing a viewing case (shown in Figure 6.2) with a window just large enough to display two sequential holograms simultaneously.

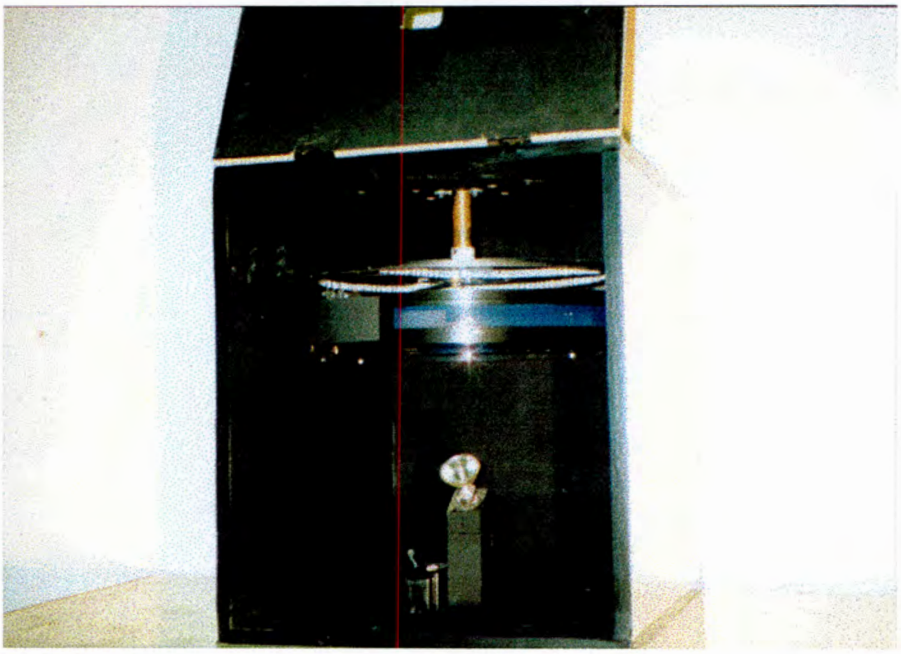

Figure 6.2 - Photograph of the Holographic Movie Display Case

Inside the case, the perspex cylinder/stereogram assembly was attached to a 12 Volt windscreen wiper motor. This motor could have its speed adjusted simply by varying the voltage that powered it.

A 50 Watt, 12 Volt halogen lamp was used to illuminate the stereogram. Here it is not necessary to illuminate more than two frames of the stereogram at a time and subsequently, a single lamp can be used as the illumination cone is sufficient to illuminate the required frames.

There are technical limitations to this technique. Conventional animation is rated at a playback time of 25 frames per second. If one tries to play back the stereogram at rates anywhere close to this, the image appears as a blur to the viewer as the eye can not recreate the individual views quickly enough. At the other end of the scale, if the holograms are moved passed the viewing window too slowly, then there is a significant jump apparent from one view of the object to the next.

When the correct playback speed had been determined, a realistic three dimensional sensation was achieved.

Chapter 7. Discussion

This chapter will focus on a discussion of the practical problems that were discovered during the stages of this project, from the initial generation of computer animation to the final display of the holographic stereogram.

7.1. Animation

The introduction of computer generated animation was a primary requirement of this investigation. However, one must take care as to how this is implemented, as excessive animation over a short period of time will degrade the quality of the final stereogram. For a 120^0 stereogram, the motion should not last for more than approximately 5s, the time it takes to walk past it.

The parallax in the stereogram is generated by optically superimposing two adjacent images. If these images are of a stationary object then the component images will register optically with each other and form an autostereoscopic image. With the introduction of animation, the image from the first to the second frame has changed in some way and if this change is excessive then the two images will not successfully overlap. The result of this will be an image that does not have sharply defined edges giving a very blurry effect.

This is a fact that must be appreciated right from the start of the process as the animation must be implemented with exaggerated slowness. This slow motion will ensure that there are enough frames from the beginning to the end of the motion to ensure a gradual change from one to the other.

This slow motion will not be transferred to the final image as here one can change the rate of animation simply by adjusting the rate at which the reconstruction process is performed.

7.2. Image Size

The final display size of a 20mm wide image was a restriction that was placed on the image due to the availability of holographic film. The final image height had to be small enough to fit onto a 35mm film strip. A further restriction was that this strip had a usable size of 25mm due to the advancement notches similar to those found on standard 35mm photographic negative.

In order for the maximum height of the image to be 25mm, the corresponding width of the image was 20mm. To achieve this, each Master was made of an image 20mm wide.

7.3. Diffuse Focusing Screen

Various sized Master/Transfer relationships were used, from images 40mm high down to the final 20mm high image. The process of transferring the slide images to the Master involved projecting them onto a diffuse glass plate. A variety a diffuse screens are available for use and these were described in Section 4.1.5. The screen that was used for the project was not of the highest quality commercially available and the result of this was to introduce speckle noise onto the image of the Master. This noise manifested itself during the generation of the Transfer in the following way:

The smaller the final image the more noticeable was the level of noise as the relative size between the speckle and the image was larger. The final 20mm image that was produced did have an appreciable noise present, which was less severe in the 40mm test image.

7.4. Projected Master Slit Size

When generating the Master, each incremental view of the image must be recorded as an individual strip hologram. In order to use 36 slides to generate an image around 120^{O} of a circle, 3.3^{O} per slide is required. With a circle diameter of 400mm, this equates to 11.64mm per slide. Thus each hologram can occupy a width of 11.64mm of the Master hologram.

In order to generate the rainbow effect necessary to create a white-light viewable stereogram, the Master needs to be reduced to a horizontal slit of the order of the diameter of the pupil. The result of this is an exposed square of the Master strip 11.64mm x ±7mm. In practice, this restriction lead to a dull projected real image and correspondingly increased exposure times.

In order to increase the real image's brightness, the horizontal slit was increased to 10mm resulting in a 30% increase in surface area. This brightened the real image dramatically and enabled a brighter Transfer to be made. The width of the horizontal slit also determines the purity of the colours and the sharpness of the image in the vertical direction. A narrow slit gives a sharper image but introduces more speckle. The tests that were performed at various slit widths showed no perceivable change in sharpness from the 7mm slit to the 10mm slit.

The benefits achieved by increasing the slit width far outweighed the slight potential loss in sharpness and the speckle that is evident on the Transfer is influenced more by the size of the image and the diffuse screen used to generate the Master.

7.5. General Film Exposure

The time taken for the film to have all the incremental holograms exposed on it is substantial. In the case of the Master, it was just under two hours for 36 exposures and the Transfers took in the region of 1 hour. During this time, the film is out in the open, subjected to any light incident on it. Even though holographic film by its very nature is slow, 2 hours, even in minimal light conditions, is significant.

Care must be taken to ensure that excessive light is shielded from the film and wherever possible, the aperture of the laser should be closed. Most of the control of this Master-Transfer process takes place by computer and this requires user input under certain circumstances. The monitor's output must be reduced to a minimum and well shielded from the film.

7.6. Transfer Curvature

During the testing procedure, the Transfers were generated with the film in the shape that it was to be displayed in. However, in an attempt to simplify the procedure, strip transfers were generated with the film mounted flat. After processing, the film was curved to the shape that it would have for display, a radius of 200mm.

The result of this was to reduce the field of view of each individual hologram by a few degrees. This reduction did not impact on the ability to view the resultant stereogram and in fact improved the transition from one hologram to the next. This was most apparent when larger images were captured on the film as there was a reduction in image overlap on transition from one image to the next.

7.7. Display

Using a stepper motor to drive the holographic movie for display would appear to be desirable as one then has full control over the speed and positioning of the stereogram through the use of a computer. This is however not the ideal solution. The stepper motor has 200 steps per revolution. To control the speed of rotation, one controls the time between steps and not the time of the steps.

This can lead to complications if the motor is supporting a heavy frame to hold the stereogram in position. If this is the case then the inertia of the frame can be enough to break holding torque during each step, resulting in an erratic motion of the stereogram.

When a lightweight frame is used, then the inertia does not overcome the holding torque but there is no damping of the impulse rotation caused by each step. During stepping this can cause problems if the stepper motor wants to step forward at the instant that it is vibrating in such a way as to be moving in the opposite direction.

This vibration can be overcome by using a rubber band (in this case a section of motor car tyre tube) positioned to damp the forward and backward oscillation of the supporting frame during and after the stepping of the stepper motor.

Chapter 8. Conclusions

Based on the findings of this project, the following conclusions may be drawn.

- **Animation**. There is scope for computer generated 3D animation to be used in conjunction with the conventional holographic stereogram. The visual effect of this animation gives a much more realistic viewing experience than by simply viewing an animation on a computer monitor.
- **Parallax**. The sense of parallax can still be achieved with an animated image as long as the degree of animation is carefully planned and implemented. In general, this requires the animation to be implemented with exaggerated slowness to improve the optical registration process from one frame to the next.
- **Optical Set-up**. The layout and alignment of the various optical components must be undertaken with great care as the actual exposure process can last a long time. Mistakes only become evident after development, and the process has to be repeated.
- **Curved Transfers**. In order to simplify the process of making the Transfer holograms, it is possible to make them using a flat film and then curve the film to the required radius after development. This post-curving does alter the field of view for each component hologram, but in fact improves the transition from one hologram to the next.
- **Display**. Different methods of stereogram reconstruction are possible allowing a variety of different displays of the final product.

Chapter 9. Recommendations

There is scope for this technique to be developed into a useful tool for utilisation in a variety of technical and educational fields. In order for this to happen, there are a number of changes to the basic stereogram that could be performed to streamline the process of generating the holograms.

Included in these are the following:

The technique that is used to transfer the animated image from the monitor is presently performed using a camera. The camera produces a slide image which is then used as the basis for the holographic image.

This is a convoluted process that results in a less than ideal transfer mechanism. A solution to this is to replace the entire object beam optics with a colour LCD (liquid crystal display) screen. This is possible as the optics are only present in order to generate an image on the diffuse glass screen.

The LCD screen will provide the image in a much more elegant fashion as it will dramatically reduce the number of components needed to create it. It will remove the need to accurately focusing the image onto the screen using the projector lens. Each successive image will also be perfectly indexed with the previous one, as there would be no intermediate step to advance and line up the individual slides.

Another avenue for improvement is in the layout of the Master hologram. For this project, the Master was created with the film having a curved profile the same as that used to display it. Since this hologram is never meant for display in this form, it can be made with the film flat. This modification removes much of the difficulty that was encountered during alignment and indexing of the curved film. The indexing can now be performed using a screw threaded drive which removes the need for a rotating turntable.

With the requirement of a projector lens and ancillary focusing optics removed, it is possible for a combined integrated set-up to be developed that can be used for generating both Master and Transfer holograms with out the need to change the set-up for each process. This in itself will streamline the process to the extent that it becomes commercially viable.

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Appendix A. Design of the Fixed-Focus Cylindrical Lens

This section deals with the design of the fixed-focus plano-convex cylindrical lens. The first part presents the derivation of the equations that are needed to trace the path of any ray incident on the cylindrical lens. The materials selection and equations were placed in a spreadsheet and the various parameters varied until a lens was found having a minimum of aberrations at the focal length required. The result of the spreadsheet analysis was used to develop a functional lens.

A.1. Refraction At A Spherical Surface

The governing equations for the design of the lens were obtained from Hardy, et al [43]. The following convention of signs was adopted as illustrated in Figure A.1:

1. Draw all figures with the light incident on the reflecting or refracting surfaces from the left.
2. Consider the *object distance* s = PV positive when P is at the *left* of the vertex.
3. Consider the *image distance* s' = VP' positive when P' is at the *right* of the vertex.
4. Consider the *radius of curvature* R = CV positive when the centre of curvature lies at the *right* of the vertex.
5. Consider slope angles positive when the axis must be rotated counter-clockwise through less than $\pi/2$ to bring it into coincidence with the ray.
6. Consider angles of incidence and refraction positive when the radius of curvature must be rotated counter-clockwise through less than $\pi/2$ to bring it into coincidence with the ray.
7. Consider distances normal to the axis positive when measured upward.

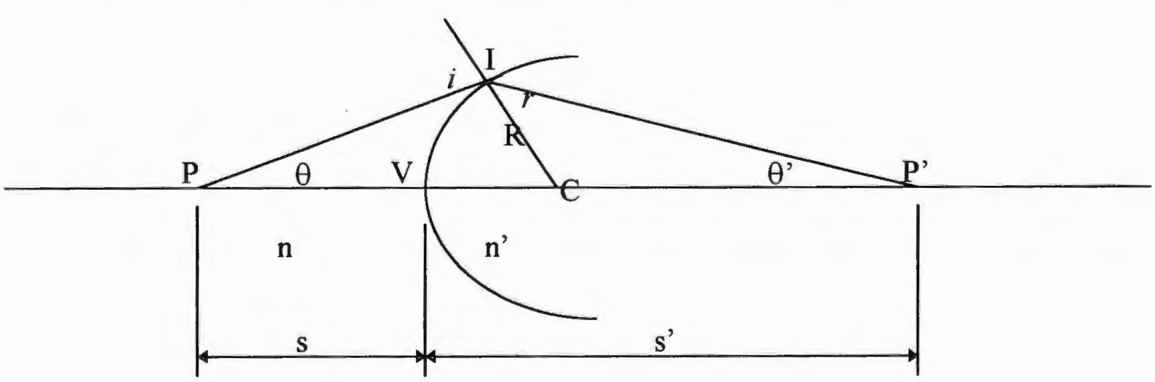


Figure A.1 - Refraction at a Spherical Surface

From Figure A.1 it can be shown that, using triangle PIC and the sine rule,

$$\sin i = \frac{R+s}{R}\sin\theta$$

Equation 2

The angle of refraction r can be found using Snell's law and rewritten in the form

$$\sin r = \frac{n}{n'}\sin i$$

Equation 3

Solving for θ' in triangle PIP' (remember that θ' is negative according to the sign convention shown above)

$$\theta' = r + \theta - i$$

Equation 4

To find the distance s' = VP', consider triangle P'IC. Using the sine rule gives

$$s' = R - R\frac{\sin r}{\sin\theta'}$$

Equation 5

The equations shown above are all that are necessary to find the point P' for any ray in the object space whose slope angle and intercept are known.

For the case when the refracting surface is plane, R = ∞ and the formulas shown above become indeterminate. For this situation the following equations can be derived

$$\sin\theta' = \frac{n}{n'}\sin\theta$$

Equation 6

and

$$s' = -s\tan\theta\cot\theta'$$

Equation 7

For the lens being designed, parallel rays are going to be incident on the lens resulting in point P being at infinity and PI being parallel to PV (See Figure A.2). If the height of the ray incident on the refracting surface (PI) is h above the axis, then

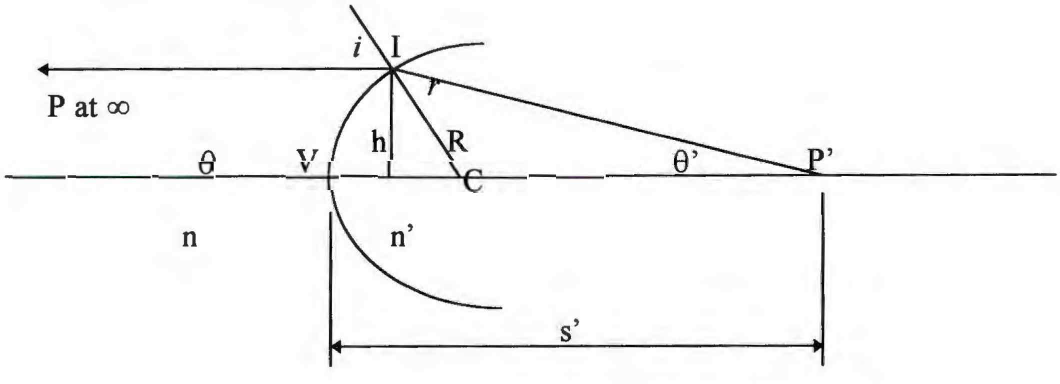


Figure A.2 - Special Case of Figure A.1 with PI parallel to PV

$$\sin i = \frac{h}{R}$$

Equation 8

Using and triangle P'IC, recognising that the exterior angle at C equals i.

$$\theta' = r - i$$

Equation 9

Equation 5 applies in this case just as it does in the general case.

A.2. Development of Lens Parameters

The equations that were described above are now ready to be used to ray-trace the lens to be designed. Figure A.3 shows the surfaces that constitute the various refracting surfaces under investigation.

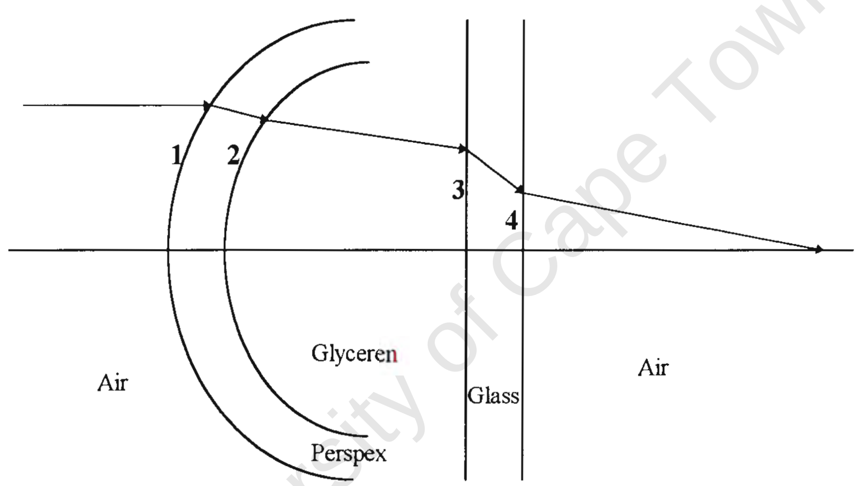


Figure A.3 - Schematic of Cylindrical Lens Showing the Various Refracting Surfaces

The various lens surfaces (1 to 4 above) will be dealt with in turn with the relevant equations shown under each sub-heading.

A.2.1. First Refracting Surface

As can be seen in Figure A.3, the rays are incident on this refracting surface in a parallel orientation. Beginning with Equation 8 above,

$$i_1 = \arcsin\left(\frac{h_1}{R_1}\right)$$

$$r_1 = \arcsin\left(\frac{n_a}{n_p} x \frac{h_1}{R_1}\right)$$ from Equation 3

$\theta''_1 = r_1 - i_1$ Remember that θ' is negative when following the sign convention

$$s'_1 = R_1 - R_1 \frac{\sin r_1}{\sin \theta''_1}$$ from Equation 5

A.2.2. Second Refracting Surface

The rays refracted by the first surface now pass through the thickness of the perspex (t_p)to the boundary of the perspex and glycerine. Thus, $\theta_2 = \theta''_1$ since the slope angle θ_2 for the second surface is identical to θ'_1

$$s_2 = s'_1 - t_p$$

$$i_2 = \arcsin\left(\left(\frac{R_2 + s_2}{R_2}\right)\sin \theta_2\right)$$ from Equation 2

$$r_2 = \arcsin\left(\frac{n_p}{n_{gly}} \sin i_2\right)$$ from Equation 3

$$\theta''_2 = r_2 + \theta_2 - i_2$$ from Equation 4

$$s'_2 = R_2 - R_2 \frac{\sin r_2}{\sin \theta''_2}$$ from Equation 5

A.2.3. Third Refracting Surface

This is a plane refracting surface with its equations described by Equation 6 and Equation 7

$$\theta_3 = \theta'_2$$

$$\theta'_3 = \arcsin\left(\frac{n_{gly}}{n_g} \sin \theta_3\right)$$ from Equation 6

$$s_3 = s'_2 - t_{gly}$$

$$s'_3 = -s_3\left(\frac{\tan \theta_3}{\tan \theta'_3}\right)$$ from Equation 7

A.2.4. Fourth Refracting Surface

These equations are similar to those shown for refracting surface 3 but will be detailed below for completeness.

$$\theta_4 = \theta'_3$$

$$\theta'_4 = \arcsin\left(\frac{n_g}{n_a}\sin\theta_4\right) \qquad \text{from Equation 6}$$

$$s_4 = s'_3 - t_g$$

$$s'_4 = -s_4\left(\frac{\tan\theta_4}{\tan\theta'_4}\right) \qquad \text{from Equation 7}$$

A.3. Material Selection

Before any optimisation of the lens can be undertaken, the availability of the various materials must be ascertained and their properties and characteristics investigated.

A.3.1. Material to be used for the Curved Surface

Perspex was chosen over the cheaper ultra-high impact resistant acrylic (UHIRA) because the UHIRA was not optically clear.

1.5mm thick perspex was selected because it could be made to hold its curved profile with little force being needed to hold it in position.

The refractive index of perspex was specified by Cape Plastics to be 1.490 at 20°C.

A.3.2. Refractive Liquid

A variety of substances such as medical-grade liquid paraffin or mineral oil are suitable, but the best is glycerine although it is also the most expensive. All of the liquids mentioned are fully transparent to HeNe light [44].

Saarchem Holpro Analytic has certified that the refractive index of their glycerol is 1.4788 at 20°C.

A.3.3. Glass Backing Lens

A 2mm glass was chosen for the backing pane. The glass has a refractive index of 1.5.

A.4. Lens Parameter Optimisation

The basic equations and other constants are now ready to be used to optimise the lens parameters. This was done using a spreadsheet and varying the inputs until a suitably dimensioned lens was obtained. The resultant spreadsheet is shown in Figure A.4. Note that ray heights 20, 10, 5 and 2.5 mm are not shown to avoid repetition.

Lens Development Tool for a Liquid Filled Cylindrical Lens				
Refractive index - Air	1		Height of ray	Focal Length
Refractive index - Glycerene	1.4788			
Refractive index - Perspex	1.19		50	128.88
Refractive index - Glass	1.52		40	134.99
			30	139.50
Thickness of Perspex	1.5	mm	20	142.60
Thickness of Glass	2	mm	10	144.42
Thickness of Glycerene	77	mm	5	144.87
			2.5	144.98
Radius of curvature (r1)	96	mm		

Ray Trace at height 50 - 2.5			
Max	144.98		
Min	128.88	Avg	140.03
Difference	16.10	Ave Dev	4.78
% Diff	11.50%	Std Dev	6.11

Height of collimated ray (h)	89 mm	Height of collimated ray (h)	50 mm	Height of collimated ray (h)	40 mm	Height of collimated ray (h)	
Lens Surface 1		Lens Surface 1		Lens Surface 1		Lens Surface 1	
i1	67.98463	i1	31.388166	i1	24.6243	i1	18.20896
r1	51.17474	r1	25.955635	r1	20.4959	r1	15.22469
Theta1'	-16.80989	Theta1'	-5.432531	Theta1'	-4.1284	Theta1'	-2.98526
s1'	354.6123	s1'	539.80722	s1'	562.902	s1'	580.0727
Lens Surface 2		Lens Surface 2		Lens Surface 2		Lens Surface 2	
Theta2	-16.80989	Theta2	-5.432531	Theta2	-4.1284	Theta2	-2.98526
s2	-353.1123	s2	-538.3072	s2	-561.4	s2	-578.573
i2	52.31913	i2	26.399176	i2	20.8362	i2	15.47235
r2	39.5586	r2	20.964562	r2	16.6325	r2	12.39642
Theta2'	-29.57043	Theta2'	-10.86714	Theta2'	-8.3321	Theta2'	-6.0612
s2'	216.455	s2'	273.839	s2'	281.159	s2'	286.626
Lens Surface 3		Lens Surface 3		Lens Surface 3		Lens Surface 3	
Theta3	-29.57043	Theta3	-10.86714	Theta3	-8.3321	Theta3	-6.0612
Theta3'	-28.69303	Theta3'	-10.56915	Theta3'	-8.1047	Theta3'	-5.89632
s3	-139.455	s3	-196.839	s3	-204.16	s3	-209.626
s3'	144.5689	s3'	202.52229	s3'	209.967	s3'	215.5312
Lens Surface 4		Lens Surface 4		Lens Surface 4		Lens Surface 4	
Theta4	-28.69303	Theta4	-10.56915	Theta4	-8.1047	Theta4	-5.89632
Theta4'	-46.86774	Theta4'	-16.18869	Theta4'	-12.374	Theta4'	-8.98335
s4	-142.5689	s4	-200.5223	s4	-207.97	s4	-213.531
s4'	73.10315	s4'	128.87818	s4'	134.99	s4'	139.4959

Figure A.4 - Liquid Filled Glycerine Lens Optimisation Tool

Note: This tool can now be used to create a lens with any desired specifications for use in laser beam collimation.

Appendix B. Design of the Indexing Turntable Interface

This section deals with the interface used to control the Indexing Turntable. A stepper motor coupled to a modular translator drives the turntable and the whole system is controlled using computer software.

B.1. The Turntable

The need for the turntable was discussed in Section 4.2.3. Design drawings of this construction can be found in Appendix D.2.

B.2. The Stepper Motor And Translator

Rotational control of the turntable is by means of a Slo-syn synchronous stepper motor, type M091-FD-8106 with 200 steps per revolution. This is in turn controlled by a Modular Translator Drive 430-TH. The specifications that follow are to be found in part in the *Instruction Manual for Slo-syn Micro Series Motion Controls* [45].

B.2.1. Modular Translator Drive 430-TH Specification

The designation T relates to the translator module and the H refers to the fact that it is bonded to a heat sink.

The 450-TH is a high efficiency bipolar chopper translator module which in this instance is being used with a 8-lead motor. It uses resistive current sensing to provide full- and half-step operation.

B.2.1.1. Logic and Voltage Conventions

- All logic functions are *low true logic.* A logic low or logic 0 will activate a function and a logic high, or a logic 1 will deactivate a function.
- In the cases where the function changes with a change in logic state, the low true (active) will be indicated with a bar. For example, in the case of $CW/\overline{CCW}$, (see Figure B.1), CW is active with no connection.
- When a pin is left *open*, it is clamped in a logic *high* (inactivated) state by the optical isolator.

- The stepper motor advances one step on a positive going (low to high) pulse edge.

B.2.1.2. Output Pin Assignments

Figure B.1 shows a schematic diagram of the translator module. The right hand side of the diagram shows pins 1 through 8 with their assigned outputs.

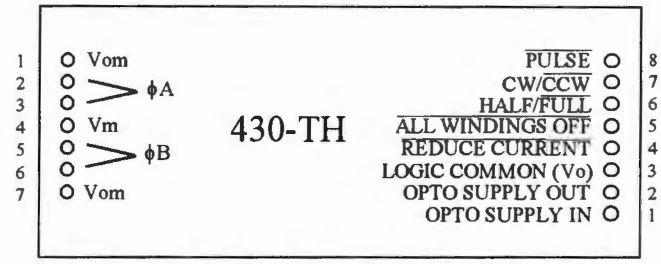


Figure B.1 - Translator Module Pin Assignments

B.2.1.3. Electrical Specifications

The following are the electrical specifications relating to the modular translator.

- Power and voltages

  Supply Voltage: 28VDC, nominal 24V min to 36V Max including ripple

  Supply Current: 4.0 Amps

- Polarity connections Vm = +

  Vom = Common

- Filter capacitor requirement

  A minimum of a 250 microfarad 50VDC capacitor is needed across Vm - Vom at the drive terminals.

B.2.2. Stepper Motor Specifications

The stepper motor is connected, via a seven-pin plug, to the translator's motor drive pins (see Figure B.1). The motor drive pins on the translator are arranged symmetrically around the centre Vm pin (pin 4 in Figure B.1). If the motor connector is inadvertently rotated 180 degrees when connecting the stepper motor, then the CW and CCW directions will be reversed.

The stepper motor type M091-FD-8106 (as mentioned above) is an 8-lead motor and is illustrated in Figure B.2. It was decided, after investigation of the speed/torque curves (see Figure B.3) that a parallel motor connection should be used. This is not critical as the motor is going to be used at very low speeds with very little torque required.

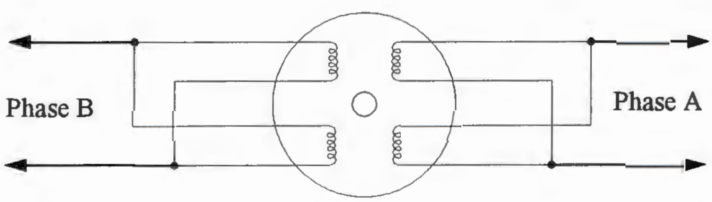


Figure B.2 - 8-Lead Stepper Motor Parallel Connection

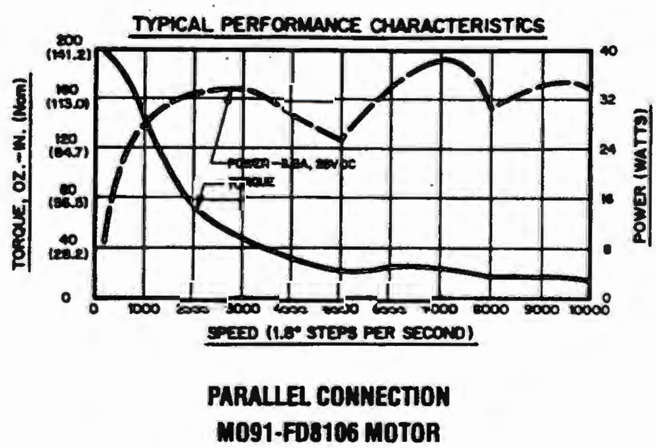


Figure B.3 - Parallel Connection Torque Curves

B.2.2.1. Electrical Specifications for Translator Output to the Stepper Motor

The following are the electrical specifications relating to the voltage and current output to the stepper motor.

- Output voltage to the stepper motor

  24V to 36V (max.) depending on the power supply

- Motor current per phase

  3.5 Amps peak for full current mode

  1.5 Amps peak for reduced current mode

- Motor voltage (alternating) per phase

  98 VA nominal at 28VDC, 3.5A supply input

It is recommended that the stepper motor phase pairs are twisted with 20 twists/metre to deliver maximum motor performance.

B.3. Computer Control

The following sections will show how the translator will be used to control the stepper motor via the computer. First there will be an explanation of the basics of control and details of the computer output port configuration. Thereafter the computer software developed to control the output port will be described.

B.3.1. Port Configurations and Background to Control

The translator uses logic input signals (see Section B.2.1.1) to control its signals to the stepper motor. This is convenient since the output signals from a standard DB-25S connector (more commonly known as a parallel printer port and shown in Figure B.4) are logic signals with a *high* of +5 Volts DC. This falls neatly between the power limits of 4.5-7 VDC required by the opto-isolators (pins) on the translator.

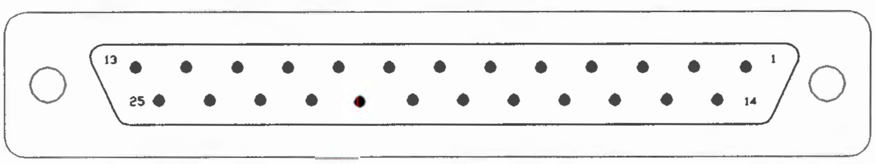


Figure B.4 - Schematic of a DB-25S Connector

Figure B.1 shows that there are 5 pins (pins 4 through 8) that can be used to fully control the motion of the stepper motor. The DB-25S connector was originally developed for the IBM PC as an output port for its printer and has the ability to output 1 byte (8 bits) of information simultaneously. This is achieved by sending data bit 1 through data bit 8 to pins 2 through 9 (see Figure B.4). Pins 18 through 25 are connected to ground.

The other pins are of no importance to this exercise as they carry information specific to printer operation.

All that is required now is to find some way of controlling pins 2 through 9 of the DB-25S connector and this is discussed in the next section.

B.3.2. Software Interface Design

The idea behind port control is relatively simple. All that is necessary is to know the address of the port in memory and then send an 8 bit **binary** word to that address. Due to the fact that the IBM PC set a standard for parallel port addressing, most computers have 378 (a **hexadecimal** number) as their first parallel port address.

In fact it is not necessary to physically send a binary word to that address. If one sends an **ASCII** character to the address, the computer will automatically convert the signal from ASCII to binary, for example:

Letter to be "Printed"	ASCII Character Number	Binary Equivalent
D	68	01000100

Table 4 - Binary ASCII Equivalents

Table 4 above shows that if the letter D is sent to the port in question then the binary equivalent (01000100) is what actually appears. In a conventional printer, this would then be converted back to ASCII and printed as a "D".

The translator does not need all 8 bits to control it but only 5 (see Figure B.1). Table 5 shows the relationship between the binary word and the pins on the translator.

Bit No.	1	2	3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8
Binary No	0	1	0	0	0	1	0	0
Translator				$\overline{\text{Reduce Current}}$	$\overline{\textit{All Windings Off}}$	Half/ $\overline{\textit{Full}}$	CW/ $\overline{\text{CCW}}$	$\overline{\textit{Pulse}}$

Table 5 - Relationship Between the Binary Word and the Translator Pins

Microsoft Visual Basic® Professional Edition Version 4 was used to create the software interface to control the port and hence to control the Indexing Turntable. The details of the development of this software, a listing of the code, as well as a guide to its use will be given in Appendix C, *Design of the Computer Software Interface* and Appendix E, *Computer Interface Software Code Listing*.

Appendix C. Design of the Computer Software Interface

This Appendix is presented in the form of a user manual for the software program created for the project.

C.1. Introduction

Stereo is the program written specifically to aide in the creation of holographic stereograms. It facilitates this process by presenting a graphical user interface, where all relevant parameters can be adjusted. The interface is illustrated in Figure C.1 and has the following features:

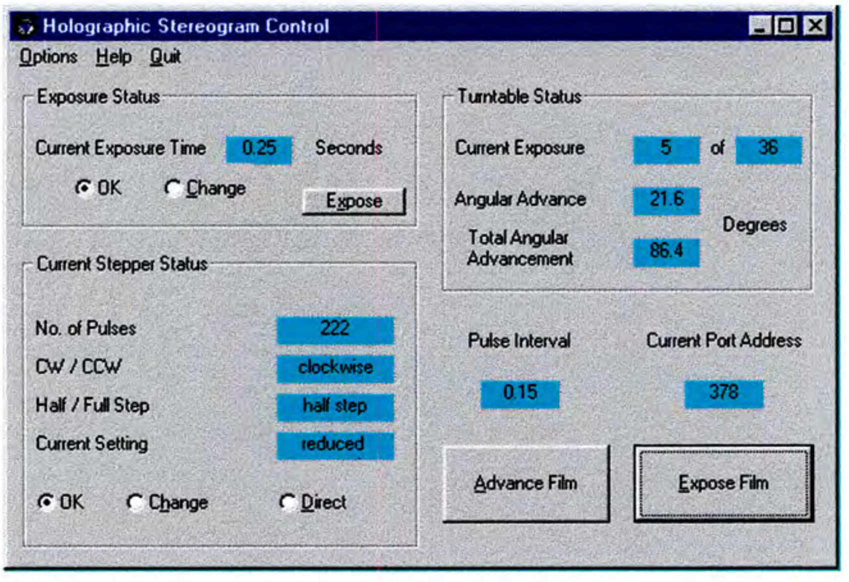


Figure C.1 - Photograph Showing the User Interface of the Software

- A comprehensive **Exposure Status** window where all the information relating to the duration of exposure and the total number of exposures can be specified. Test exposures can also be made.
- A **Current Stepper Status** window that allows the user to pre-set the operation of the stepper motor for use in advancing the film between exposures.
- A **Turntable Status** window where the status of the exposure and the advancement process specified in the previous two windows can be monitored.

- A **Direct Stepper Motor Control** window which allows one to manually control the stepper motor in isolation of the actual stereogram process. This is useful for pre-exposure positioning of the turntable.
- An **Options** button that enables one to set hardware conditions including the output port address and the interval between stepper motor steps.

C.2. Detailed Feature Description

The features presented above are dealt with more fully in the sections below. Each feature is accompanied by a photograph for illustration purposes.

C.2.1. The Exposure Status Window

This allows one to specify all the information relating to the exposures that are to take place during the creation of the stereograms. The **current exposure time** in seconds is shown in a box in the centre of the window (shown in Figure C.1).

By clicking on the **change** button with the mouse, the **duration** of the exposure can be altered. In the pop-up window (illustrated in Figure C.2), the **total number of exposures** can also be set. This information is updated on the main screen when **OK** is pressed. If **Cancel** is selected, no changes are made.

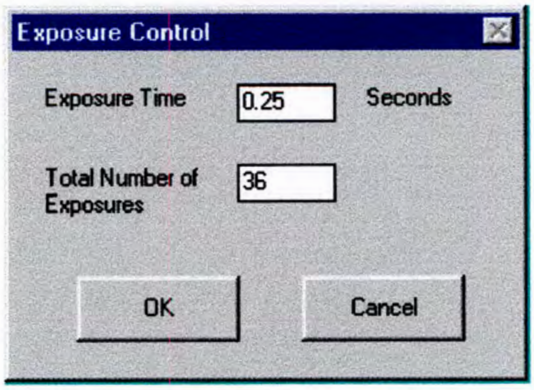


Figure C.2 - Photograph Showing the Exposure Control Pop-up Window

By clicking on the **Expose** button, the following message box is displayed, **Continuous Exposure?**. This allows one to open the shutter of the exposure meter in order to re-align the expanded beam or perform some other task that requires the beam to be available. Choosing

Yes, allows the laser beam through the shutter for the time specified in the duration box while **No** cancels the operation.

C.2.2. Current Stepper Status

The **Current Stepper Status** window allows the user to pre-set the operation of the stepper motor for use in advancing the film between exposures.

The four blue boxes (shown in Figure C.1) display the number of steps that the stepper motor must take, whether it must rotate clockwise or counter-clockwise, use a half or a full step and have either a full or reduced current setting. All four of these parameters can be set by choosing the **Change** option button. The pop-up window where these changes can be made is shown in Figure C.3.

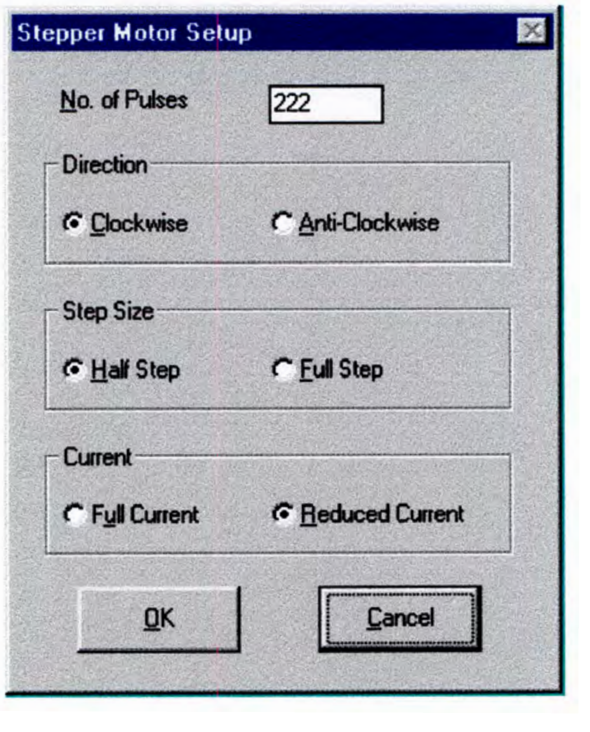


Figure C.3 - Photograph Showing the Stepper Motor Setup Pop-up Window

C.2.3. Turntable Status

The result of the parameters chosen in the two sections above are reflected in the Turntable Status window during operation of the program. The output of this window can be seen in Figure C.1. This output changes when either the **Expose Film** button or the **Advance Film** button is pressed. This action will be dealt with in Section C.2.6.

C.2.4. Direct Stepper Motor Control

This Pop-up window is useful for pre-exposure positioning of the turntable and is shown in Figure C.4.

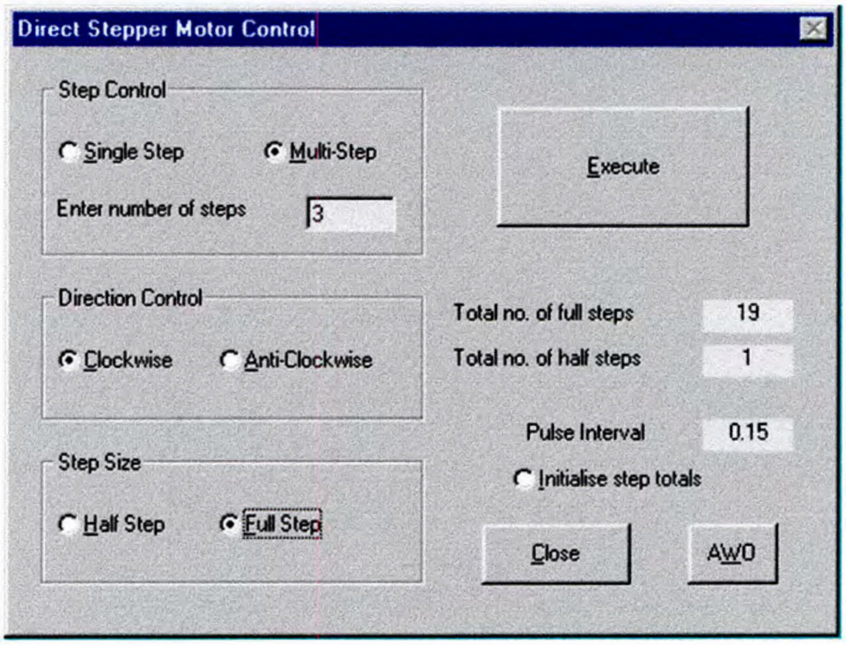


Figure C.4 - Photograph Showing Direct Stepper Motor Control Pop-up Window

When the Master has been placed in position on the turntable, it has to have its first slit hologram aligned. This window will allow one to manually adjust this hologram to its correct position relative to the reference beam. During the test procedure, one requires that various different views of the holograms are made. When this is complete, the Master can be repositioned in its start position, ready for the next iteration of exposures.

The three windows, **Step Control**, **Direction Control** and **Step Size** are used to control the output to the stepper motor. When the **Execute** button is pressed, these parameters are sent to the stepper motor and the cumulative status of the motor is shown alongside.

It is possible to reset this cumulative status by choosing the **Initialise step totals** button and the pulse interval is determined by the **Options** button described in Section C.2.5.

The **AWO** button is used to turn off the holding torque that keeps the stepper motor fixed in position. AWO is an acronym for All Windings Off and this is essential as this holding torque introduces vibrations to the holographic table which cannot be present during exposure of the hologram.

C.2.5. The Options Button

The Options pop-up window (shown in Figure C.5) appears when the **Options** menu is chosen on the main screen as shown in Figure C.1.

This window serves two functions. The first is to set the **Hexadecimal Parallel Port Address** of the computer that is being used to control the stepper motor and the second is to stipulate the **Pulse Interval** that is sent to the motor.

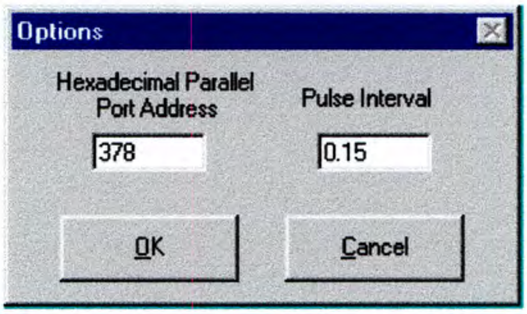


Figure C.5 - Photograph Showing the Options Pop-up Window

The results of the parameters set here will appear on the main interface screen below the pop-up window when that window is closed.

C.2.6. Program Execution

Once all the other parameters have been set, the Stereo program is now ready to participate in the generation of the holographic stereograms. This is done through the use of the two buttons labelled **Advance Film** and **Expose Film**.

The **Expose Button** is pressed first (as the film is presumably already in position) and this exposes the hologram for the duration set under the **Exposure Control** pop-up window. The **Turntable Status** will now indicate that the first exposure has been made and the highlighted button will switch to **Advance Film**.

When the **Advance Film** button is pressed, the stepper motor then moves by the number of pulses and in the direction set in the **Stepper Motor Set-up** pop-up window. The **Turntable**

Status will now show the incremental **Angular Advancement** and the **Total Angular Advancement** of the turntable to date.

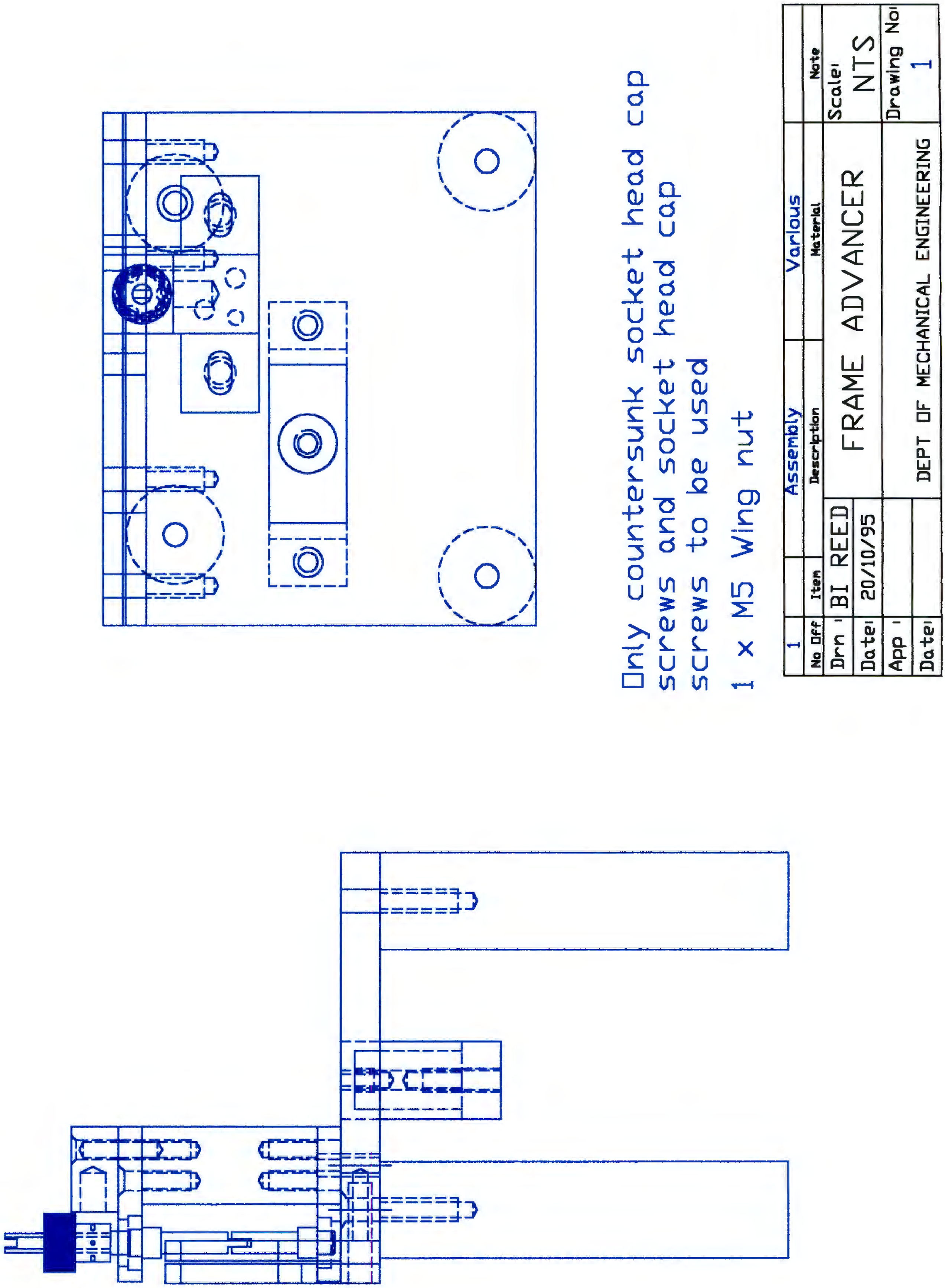
There is a built in safety feature that will prevent the same button being pressed twice. This is to prevent the case of exposing the same section of film twice in succession or advancing the turntable twice and having a dropped frame in the final hologram.

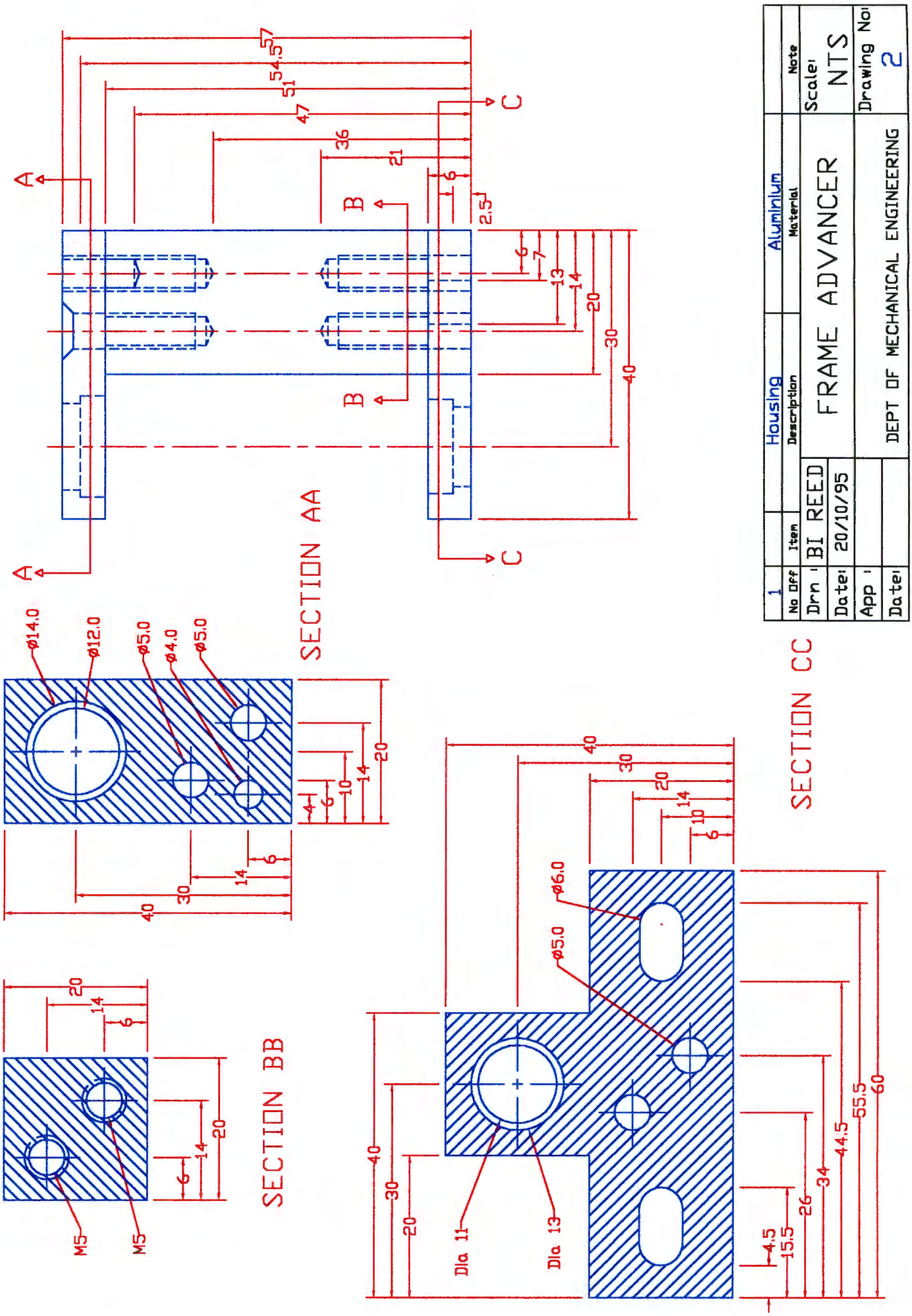
During both the exposure and advancement process, pop-up blocks will show that this is in process.

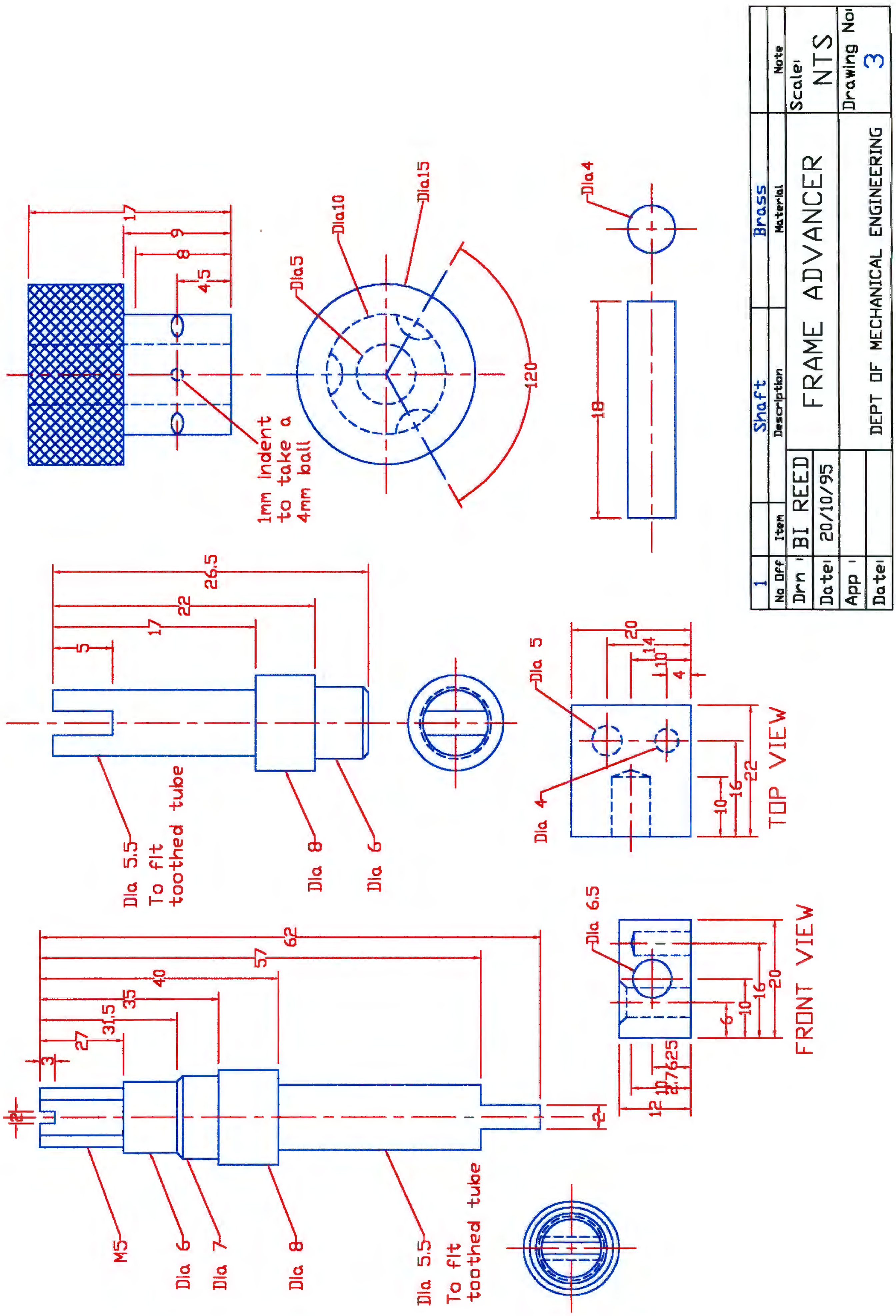
C.3. Software Code Listing

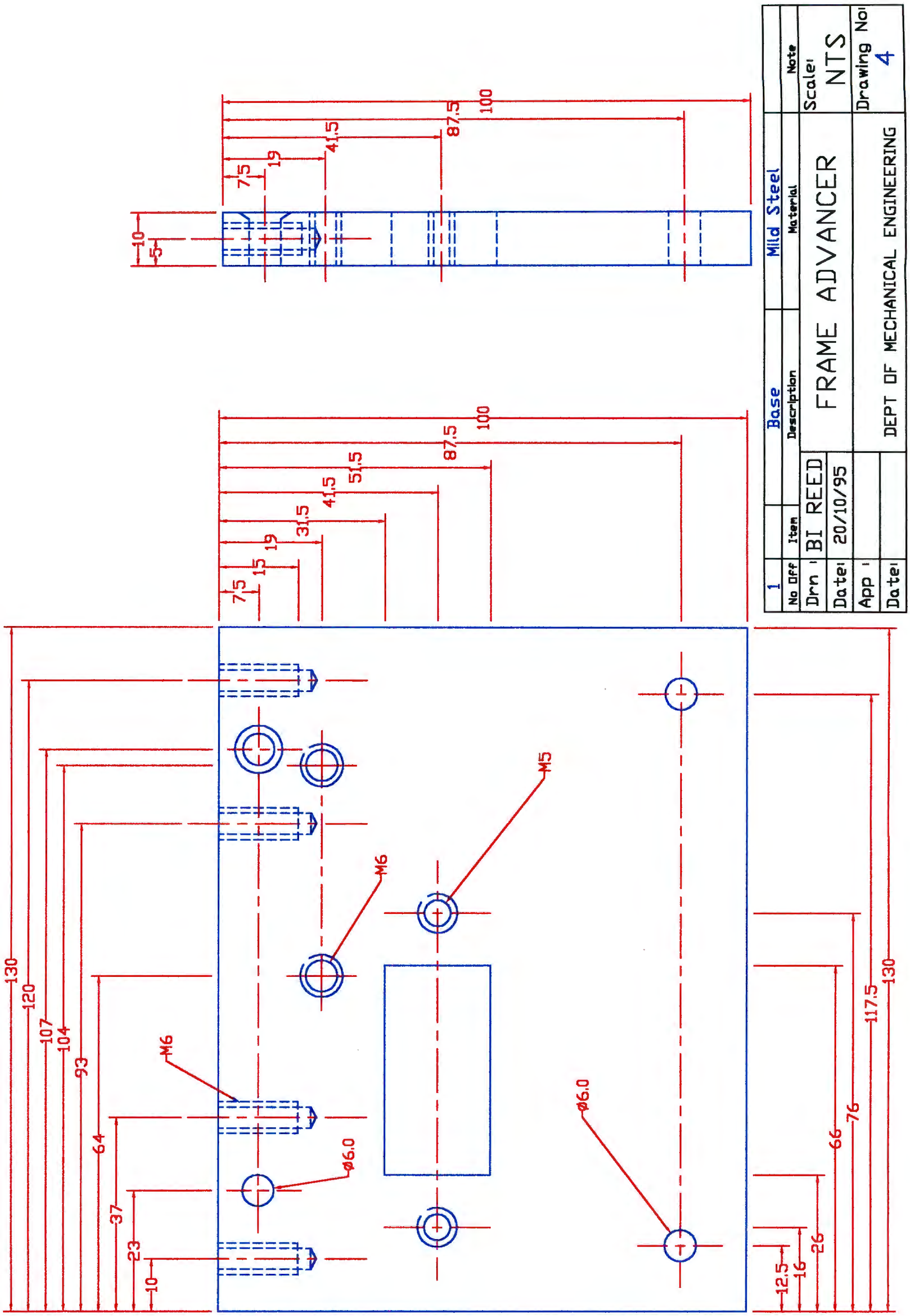
The software code listing for this program is presented in Appendix E.

Appendix D.   Design Drawings of Control Components

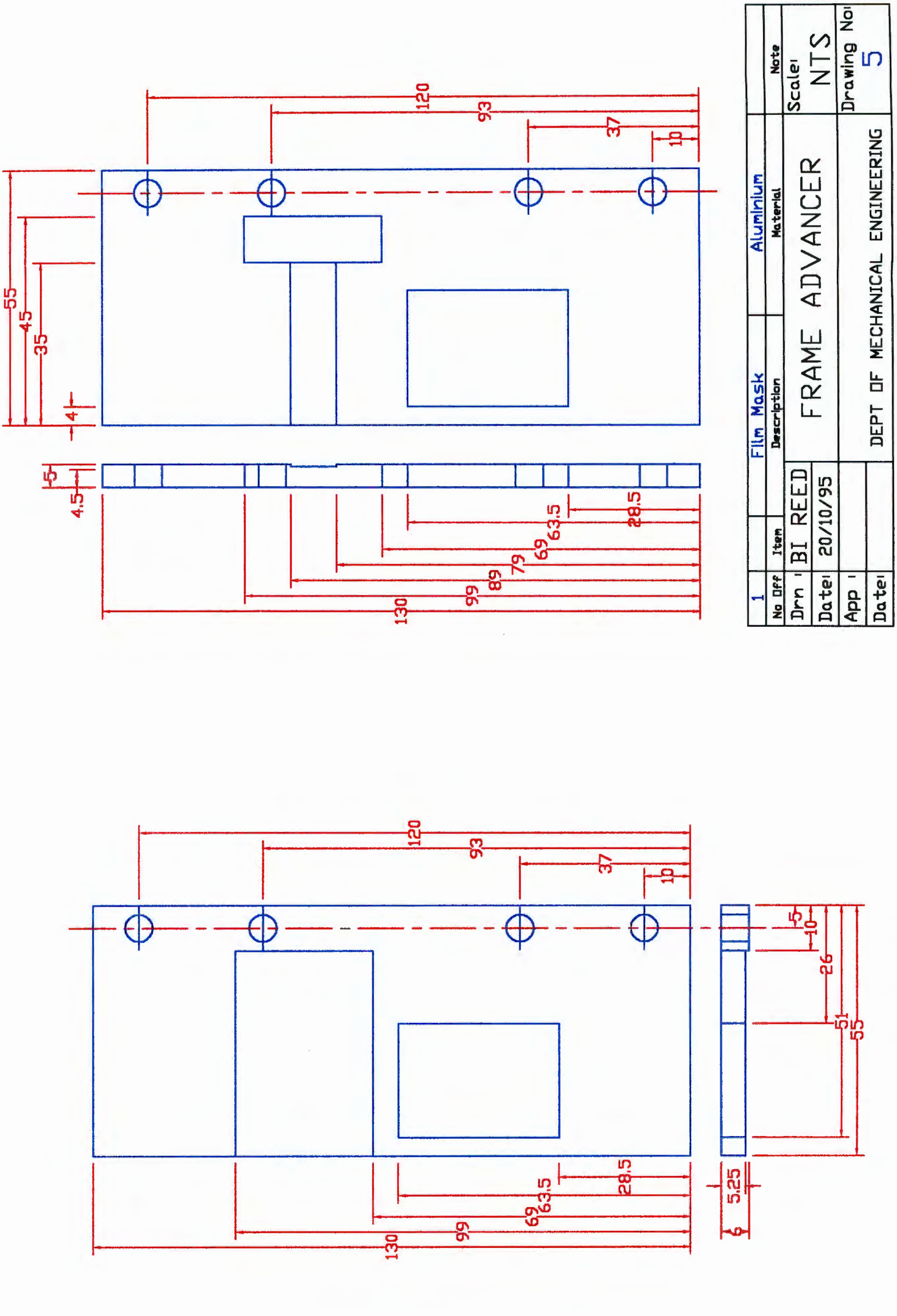

Only countersunk socket head cap
screws and socket head cap
screws to be used
1 x M5 Wing nut
1
Assembly
Various
No Off
Item
Description
Material
Note
Drn
BI REED
Date
20/10/95
App
Date
FRAME ADVANCER
Scale
NTS
Drawing No
1
DEPT OF MECHANICAL ENGINEERING

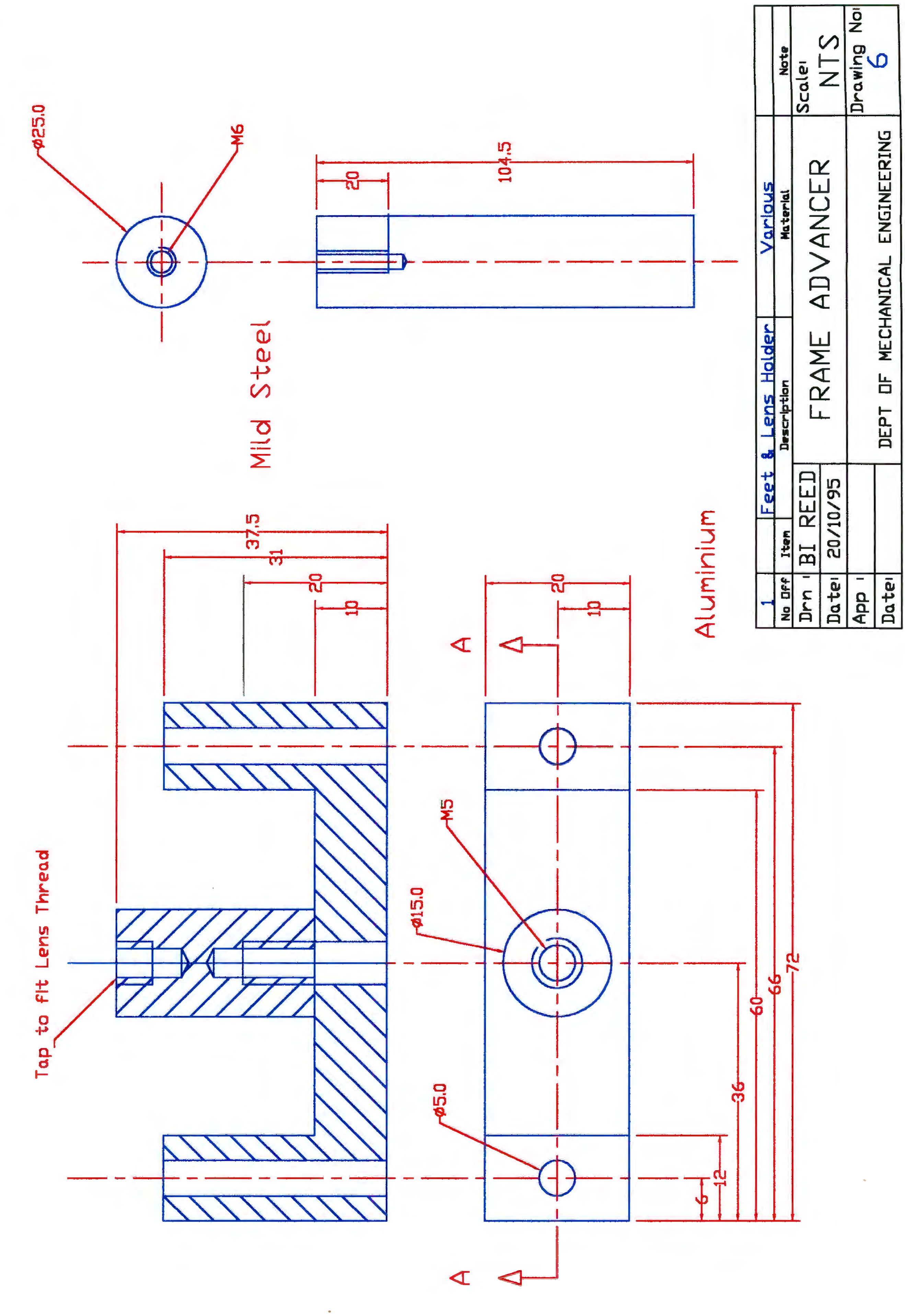

SECTION AA
SECTION BB
SECTION CC
ø14.0
ø12.0
ø5.0
ø4.0
ø5.0
ø6.0
ø5.0
M5
M5
Dia 11
Dia 13
1
Housing
Aluminium
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 20/10/95
App :
Date:
FRAME ADVANCER
Scale: NTS
Drawing No: 2
DEPT OF MECHANICAL ENGINEERING

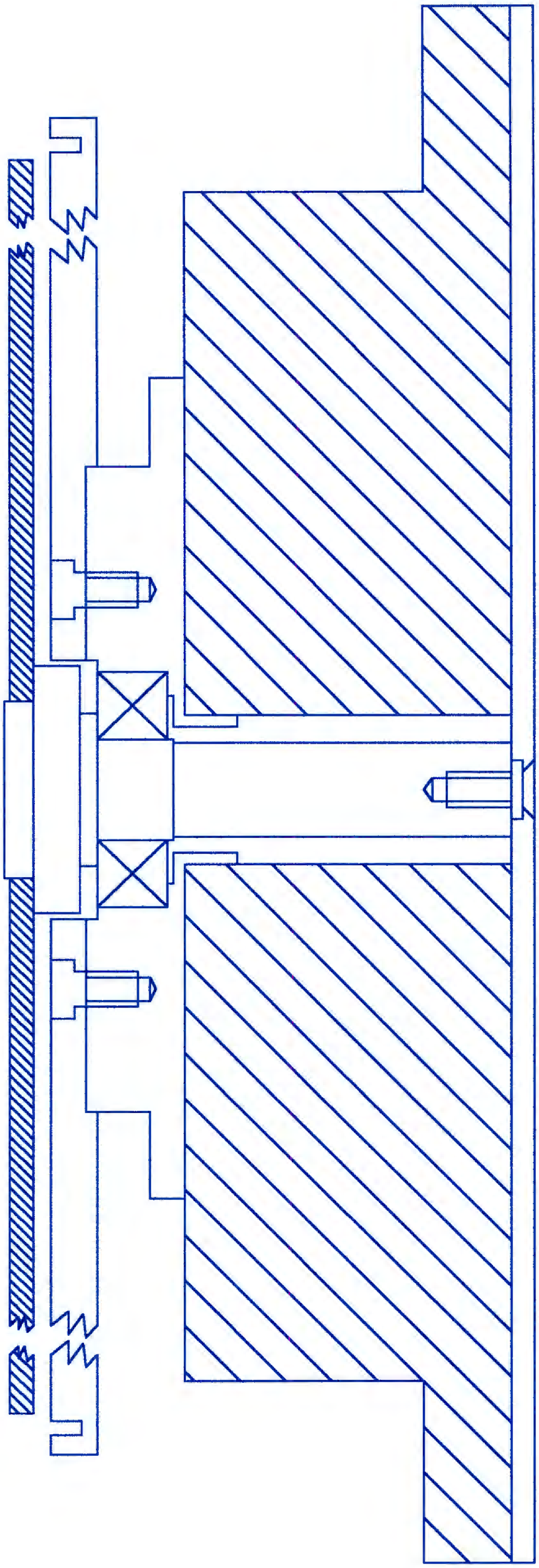

1
No Off
Item
Shaft
Description
Brass
Material
Note
Drn : BI REED
Date: 20/10/95
App :
Date:
FRAME ADVANCER
DEPT OF MECHANICAL ENGINEERING
Scale:
NTS
Drawing No:
3
TOP VIEW
FRONT VIEW
1mm indent to take a 4mm ball
Dia 5.5 To fit toothed tube
Dia 8
Dia 6
Dia 7
M5
Dia 5
Dia 4
Dia 6.5
Dia10
Dia15



1
Base
Mild Steel
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 20/10/95
App :
Date:
FRAME ADVANCER
Scale: NTS
Drawing No: 4
DEPT OF MECHANICAL ENGINEERING
M6
M5
ø6.0


1
Film Mask
Aluminium
No Off
Item
Description
Material
Note
Drn
BI REED
Date
20/10/95
App
Date
FRAME ADVANCER
Scale
NTS
Drawing No
5
DEPT OF MECHANICAL ENGINEERING


Tap to fit Lens Thread
ø5.0
ø15.0
M5
ø25.0
M6
Mild Steel
Aluminium
104.5
20
37.5
31
20
10
20
10
6
12
36
60
66
72
A
A
1
Feet & Lens Holder
Various
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 20/10/95
App :
Date:
FRAME ADVANCER
Scale:
NTS
Drawing No:
6
DEPT OF MECHANICAL ENGINEERING



Assembly Showing Main Components

No Off	Item	Description	Material	Note
		Assembly	Various	

Drn : BI REED

Date: 14/02/94

App :

Date:

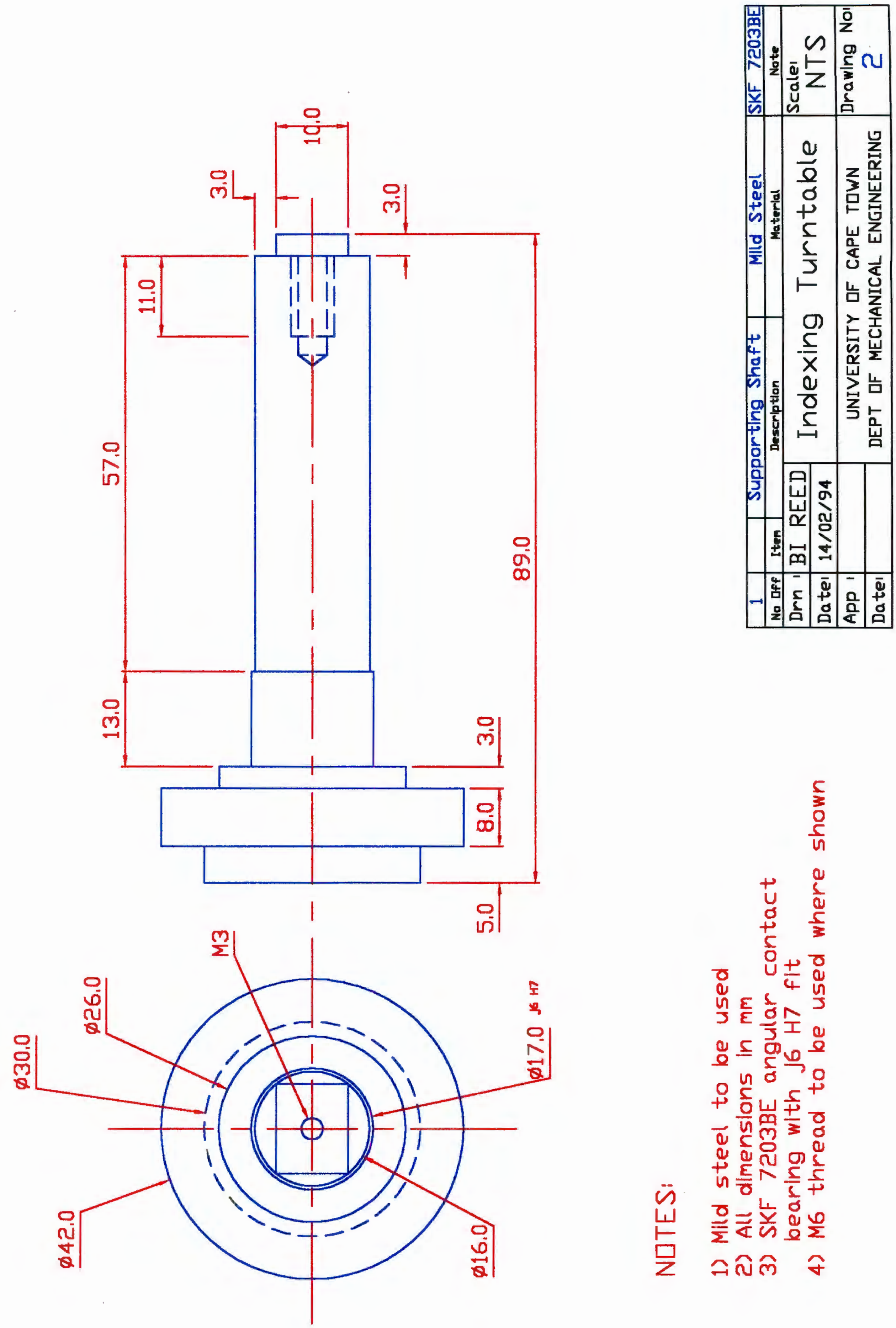
Indexing Turntable

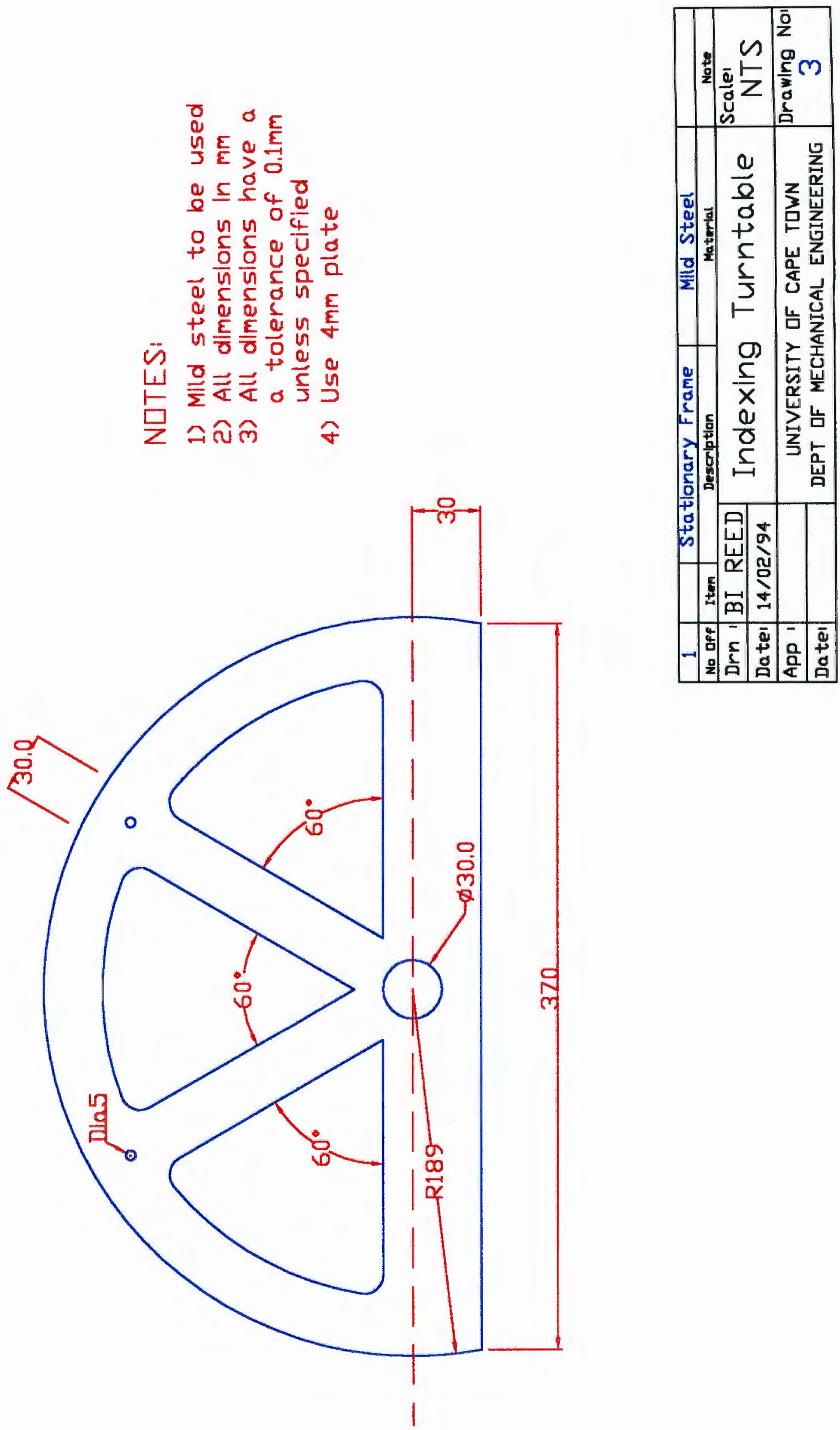
UNIVERSITY OF CAPE TOWN

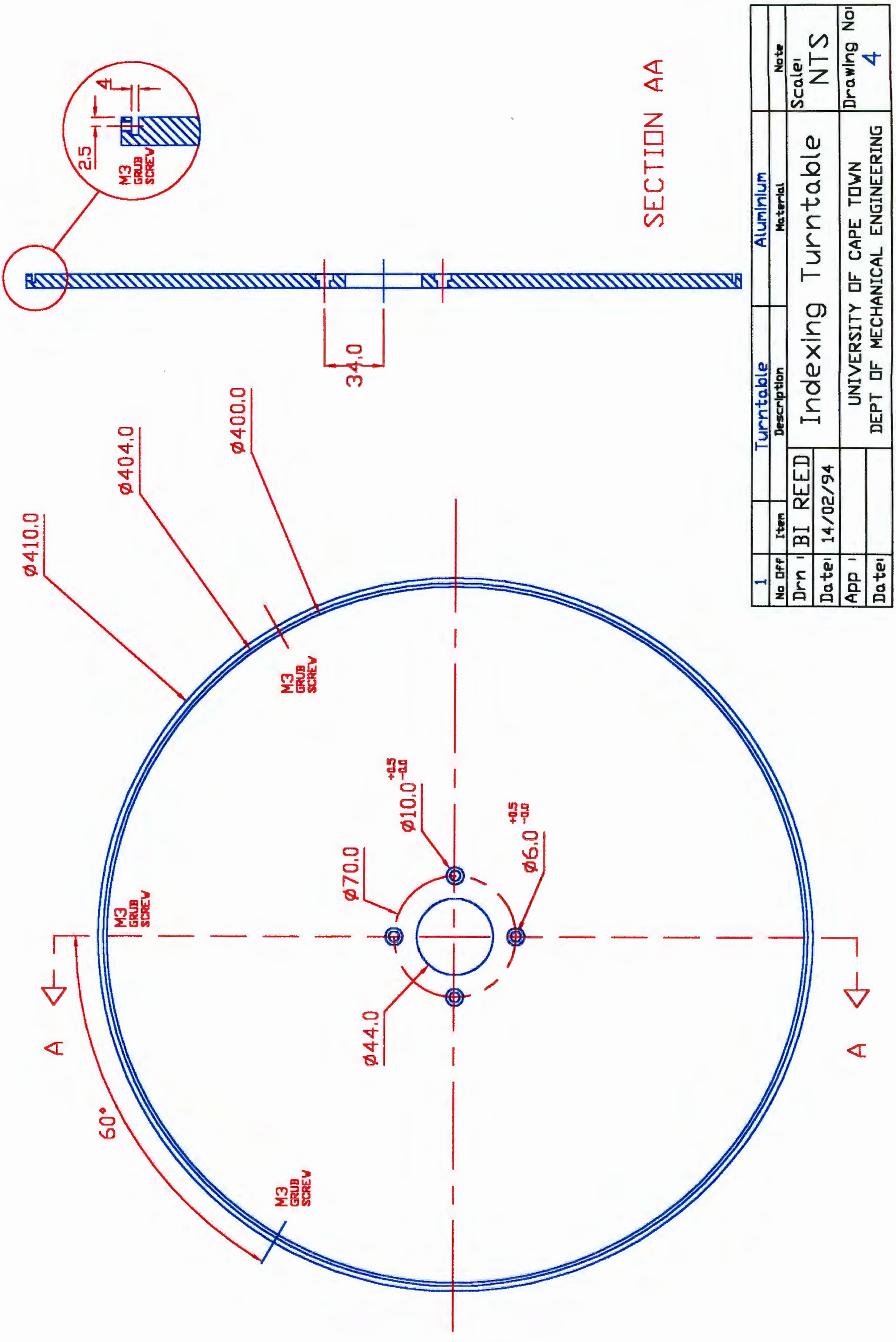
DEPT OF MECHANICAL ENGINEERING

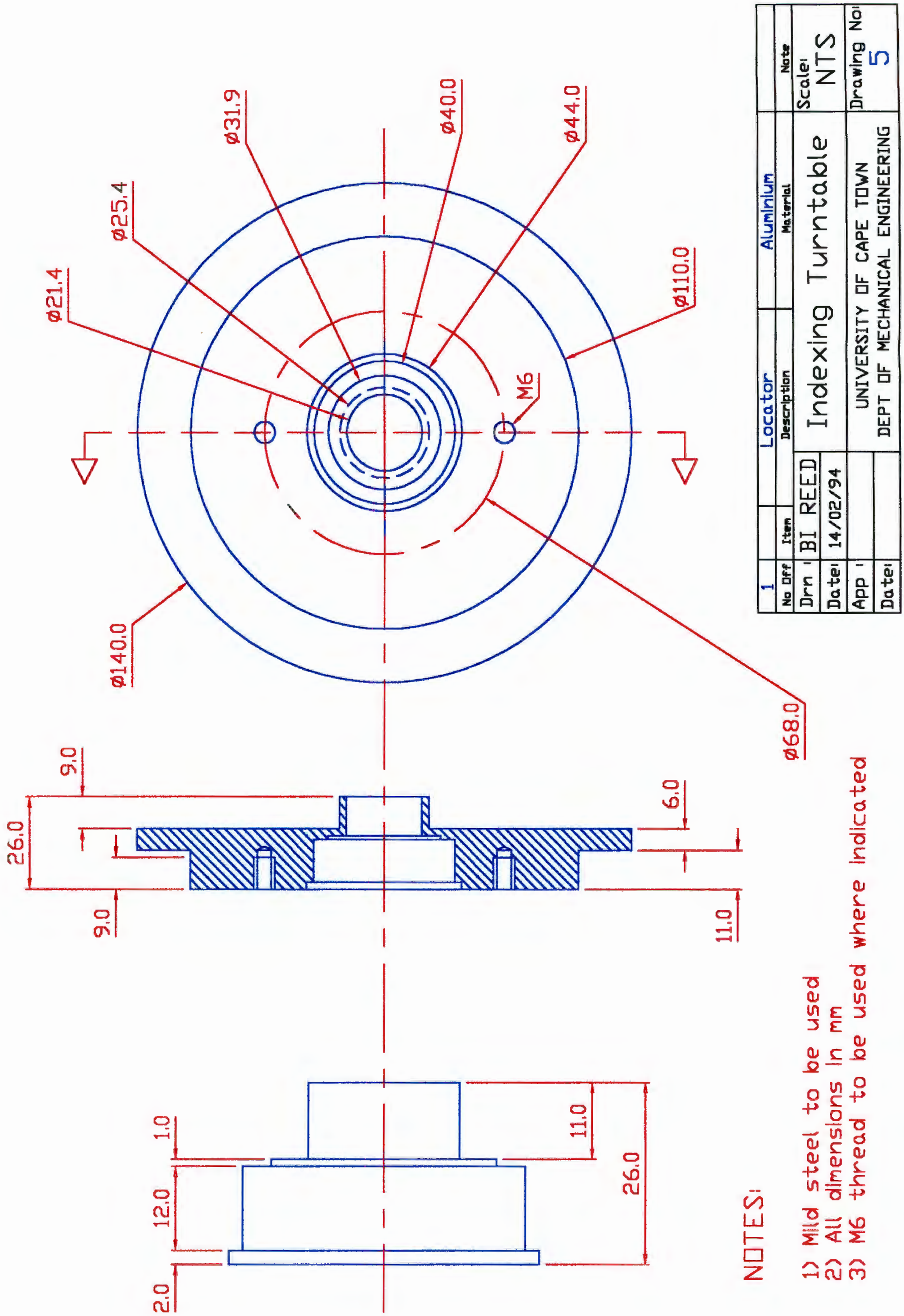
Scale: NTS

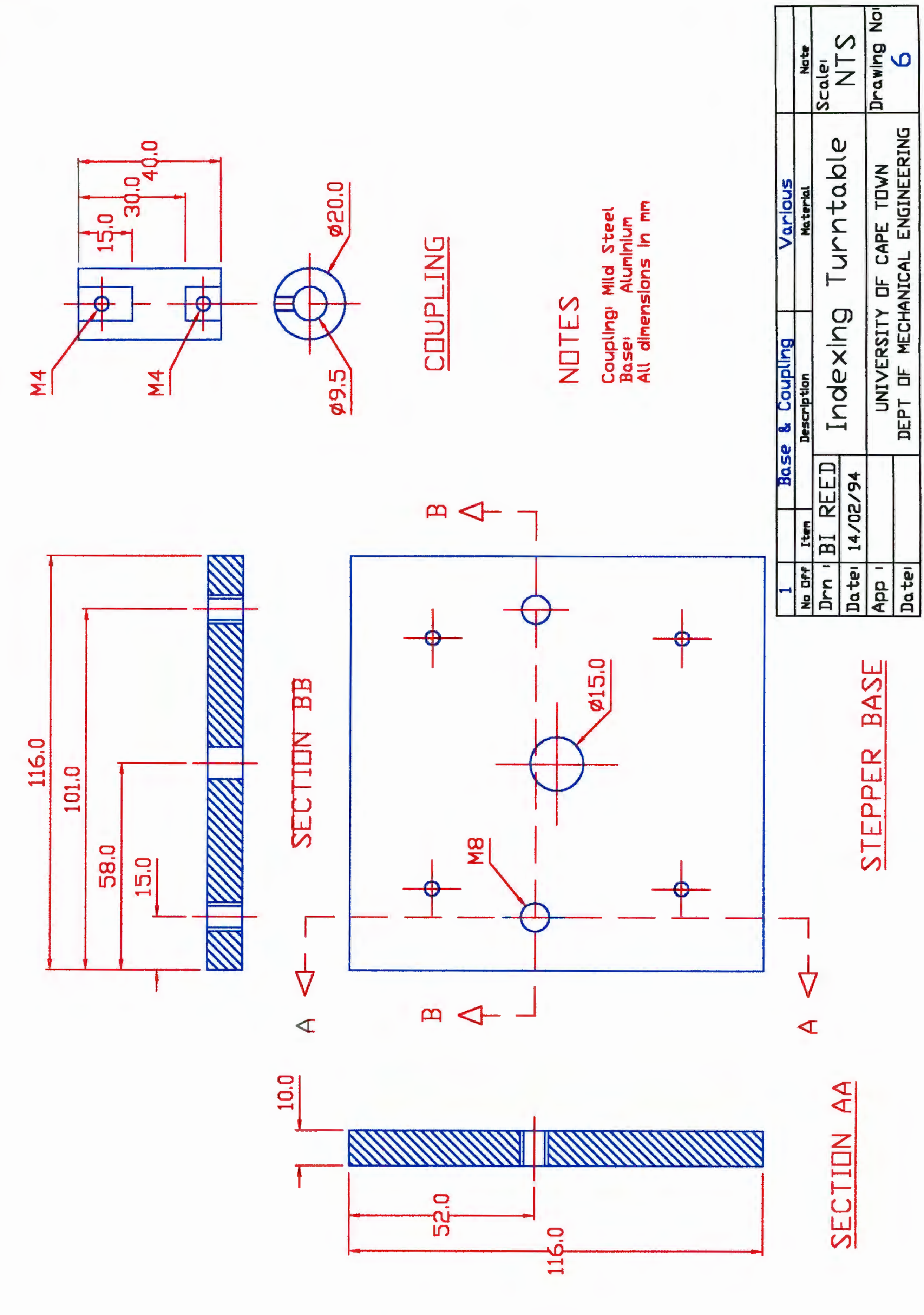
Drawing No: 1

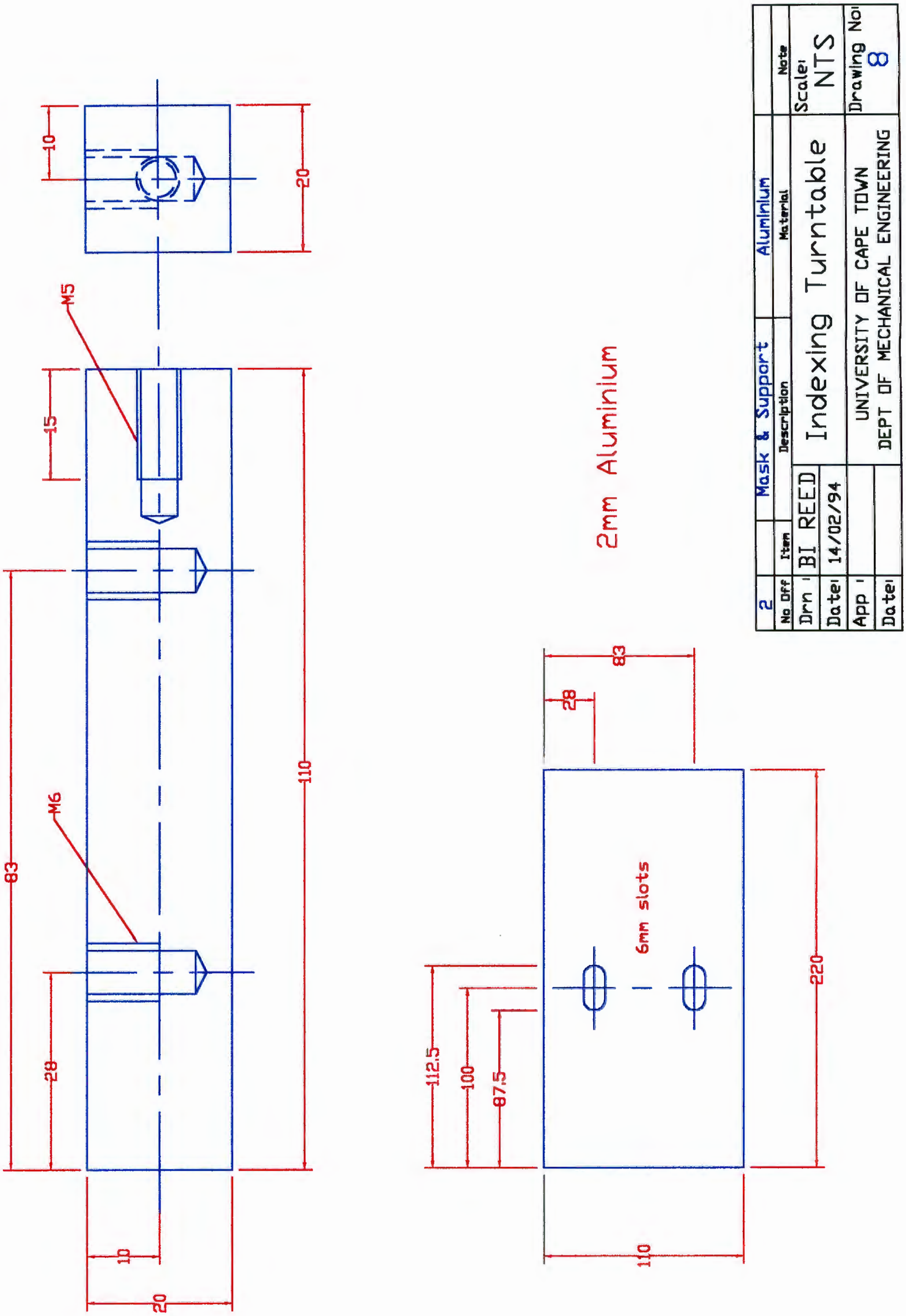

NOTES:
1) Mild steel to be used
2) All dimensions in mm
3) SKF 7203BE angular contact bearing with J6 H7 fit
4) M6 thread to be used where shown
Ø42.0
Ø30.0
Ø26.0
M3
Ø17.0 J6 H7
Ø16.0
13.0
57.0
11.0
3.0
10.0
3.0
89.0
3.0
8.0
5.0
1
Supporting Shaft
Mild Steel
SKF 7203BE
No Off
Item
Description
Material
Note
Drn: BI REED
Date: 14/02/94
Indexing Turntable
Scale: NTS
App:
Date:
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 2

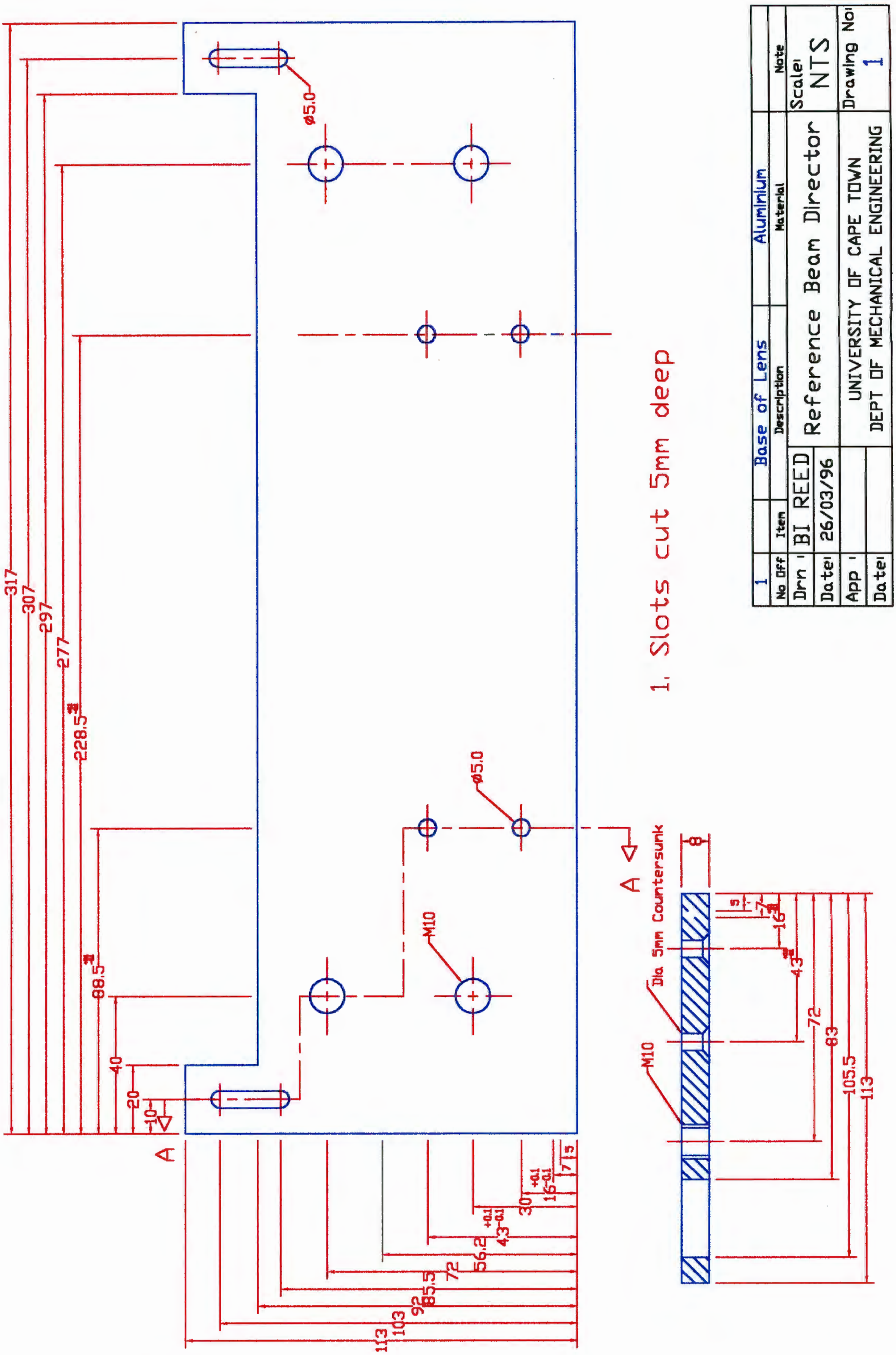

NOTES:
1) Mild steel to be used
2) All dimensions in mm
3) All dimensions have a
a tolerance of 0.1mm
unless specified
4) Use 4mm plate
30.0
Dia.5
60°
60°
60°
ø30.0
R189
370
30
1
Stationary Frame
Mild Steel
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 14/02/94
Indexing Turntable
Scale: NTS
App :
Date:
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 3

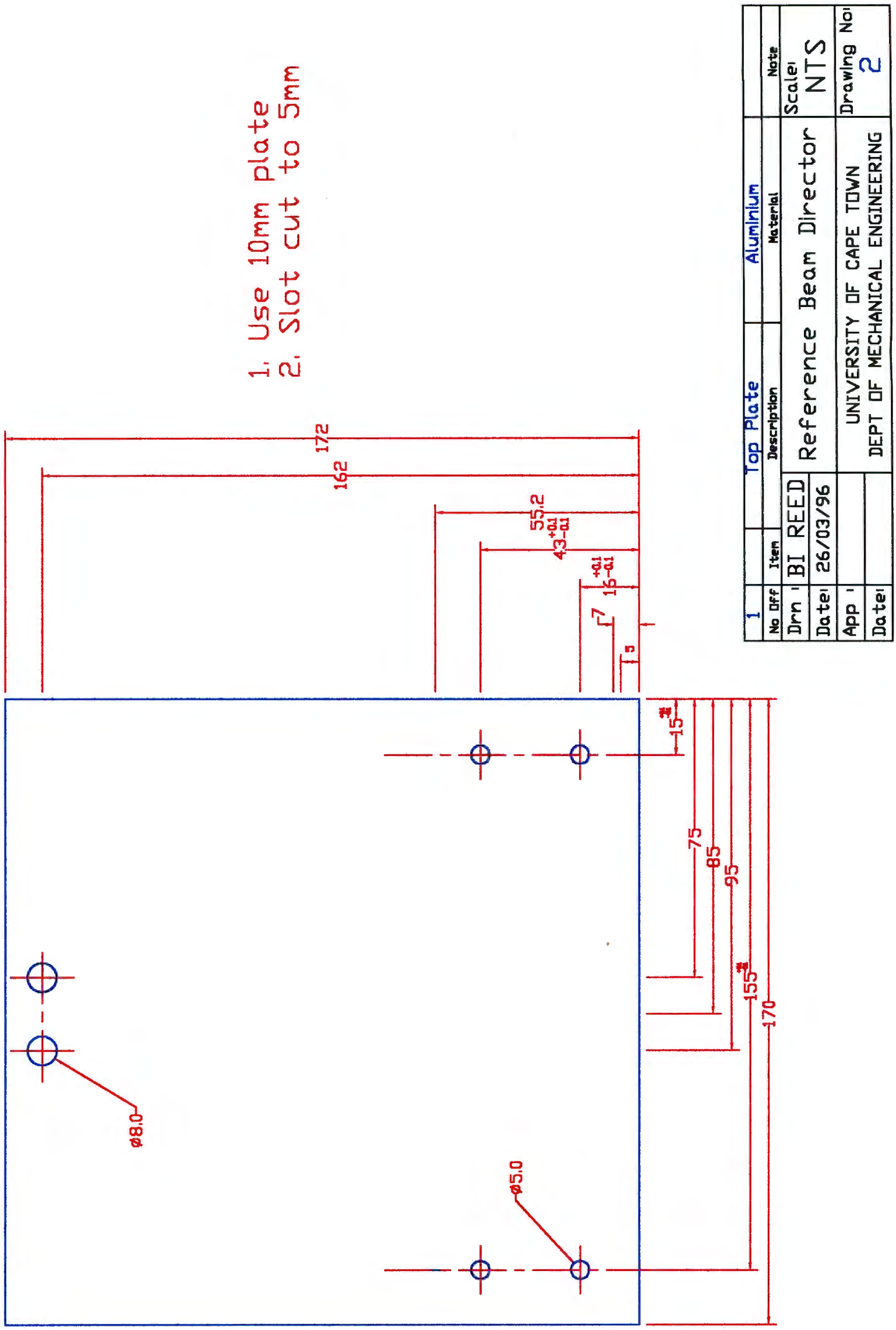

SECTION AA
Ø410.0
Ø404.0
Ø400.0
34.0
2.5
4
M3 GRUB SCREW
M3 GRUB SCREW
M3 GRUB SCREW
M3 GRUB SCREW
Ø70.0
Ø10.0 +0.5 -0.0
Ø6.0 +0.5 -0.0
Ø44.0
60°
A
A
1
Turntable
Aluminium
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 14/02/94
App :
Date:
Indexing Turntable
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Scale: NTS
Drawing No: 4

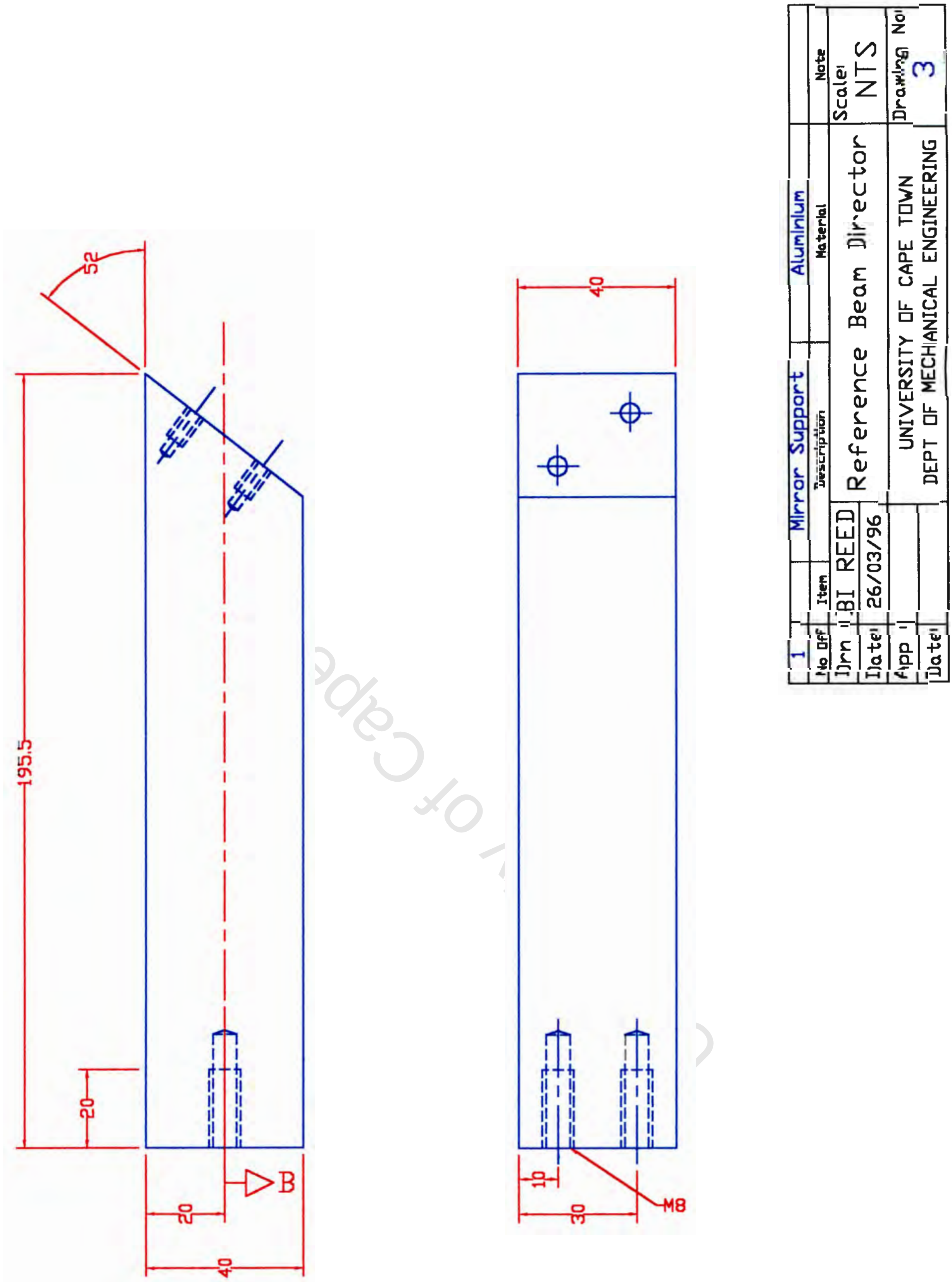

Ø21.4
Ø25.4
Ø31.9
Ø40.0
Ø44.0
Ø110.0
Ø140.0
Ø68.0
M6
9.0
26.0
9.0
6.0
11.0
1.0
12.0
2.0
11.0
26.0
NOTES:
1) Mild steel to be used
2) All dimensions in mm
3) M6 thread to be used where indicated
1
No Off
Item
Locator
Description
Aluminium
Material
Note
Drn : BI REED
Date: 14/02/94
Indexing Turntable
Scale: NTS
App :
Date:
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 5

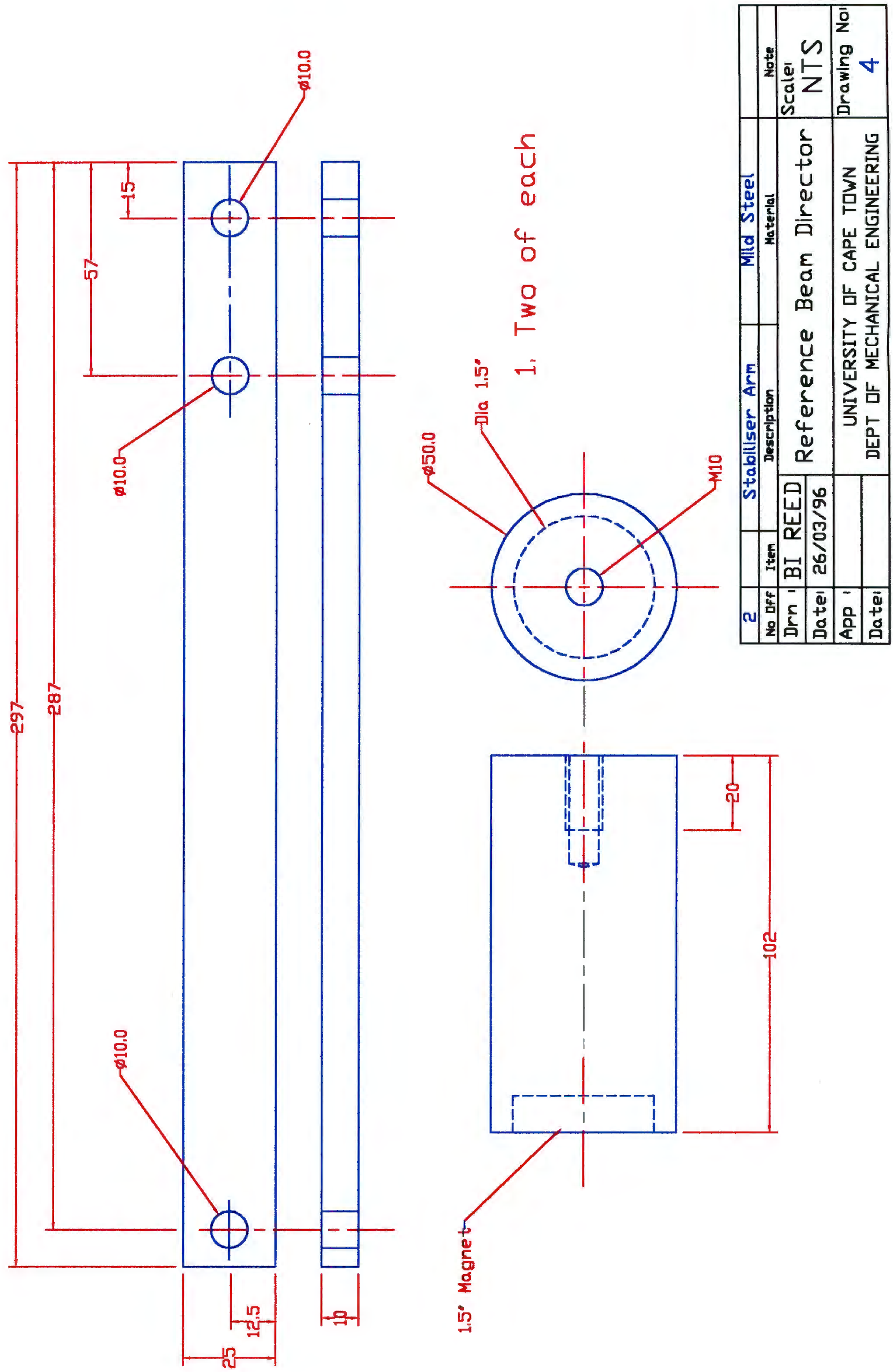

COUPLING
M4
M4
Ø20.0
Ø9.5
15.0
30.0
40.0
NOTES
Coupling: Mild Steel
Base: Aluminium
All dimensions in mm
SECTION BB
116.0
101.0
58.0
15.0
Ø15.0
M8
STEPPER BASE
SECTION AA
10.0
52.0
116.0
1
Base & Coupling
Various
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 14/02/94
App :
Date:
Indexing Turntable
Scale: NTS
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 6

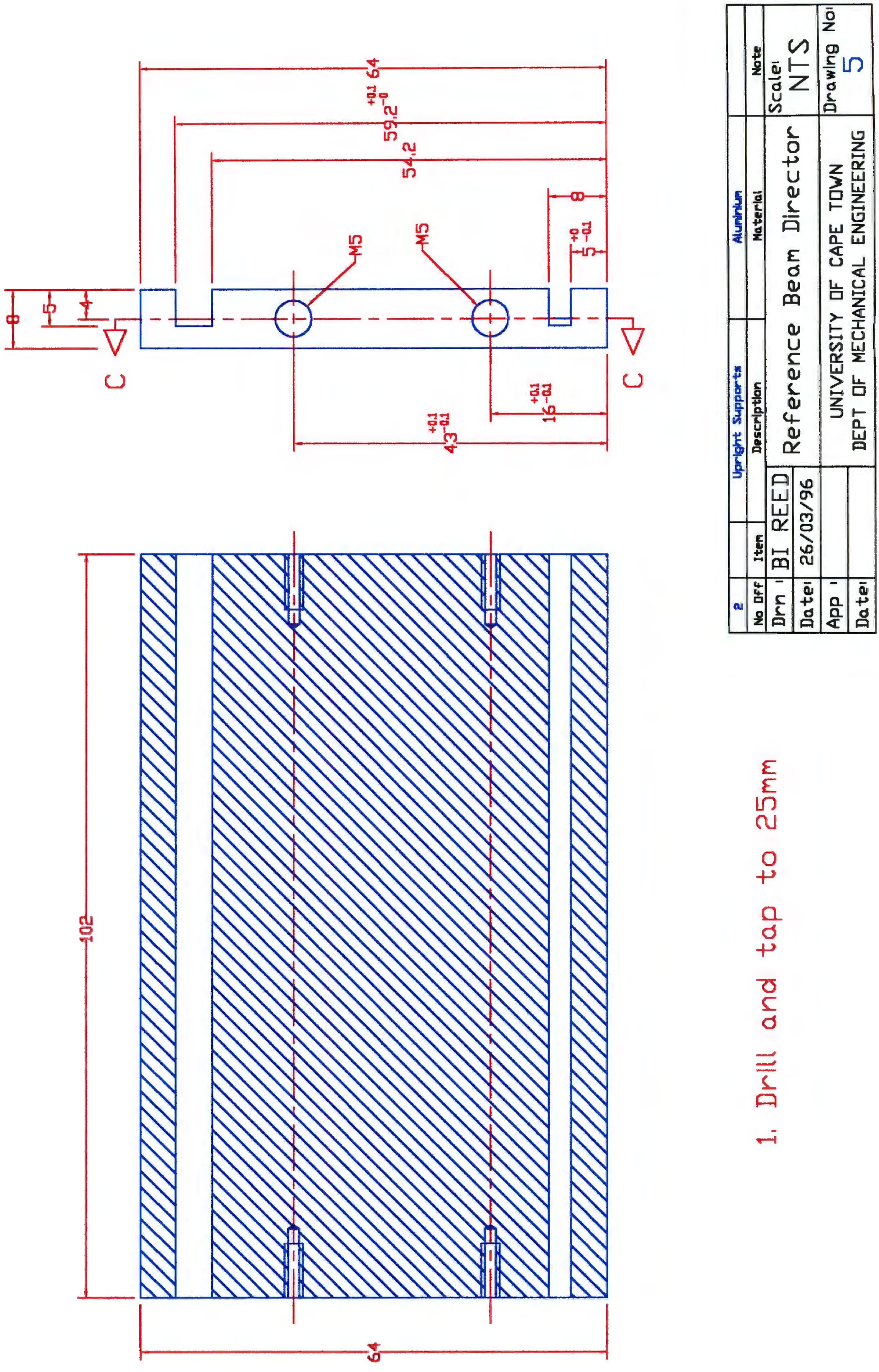

2
Mask & Support
Aluminium
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 14/02/94
App :
Date:
Indexing Turntable
Scale: NTS
Drawing No: 8
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
2mm Aluminium
6mm slots
M5
M6
10
20
15
110
83
28
10
20
83
28
112.5
100
87.5
220
110

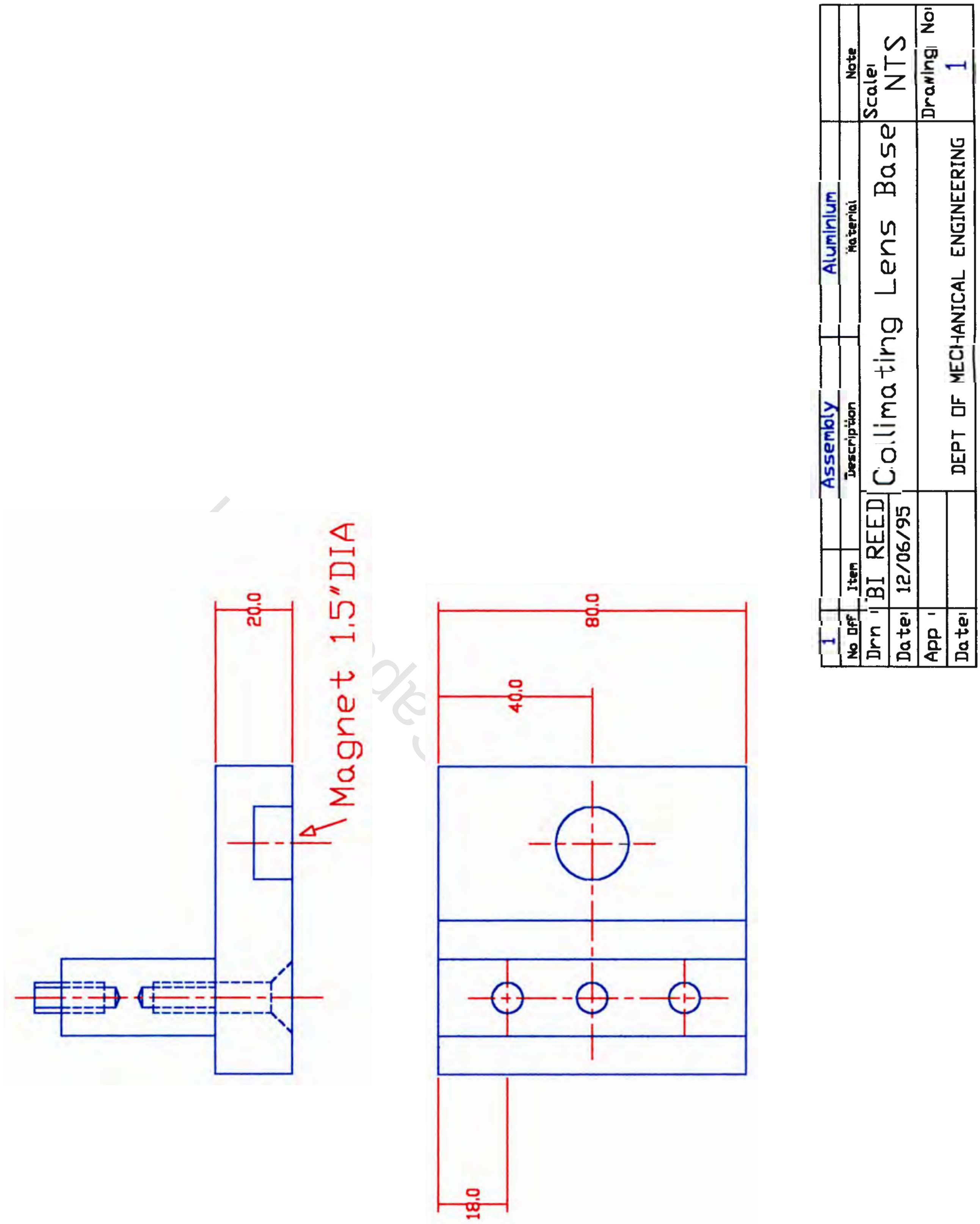

1. Slots cut 5mm deep
ø5.0
M10
Dia 5mm Countersunk
A
No Off 1
Item Base of Lens
Description
Material Aluminium
Note
Drn : BI REED
Date: 26/03/96
Reference Beam Director
Scale: NTS
App :
Date:
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 1

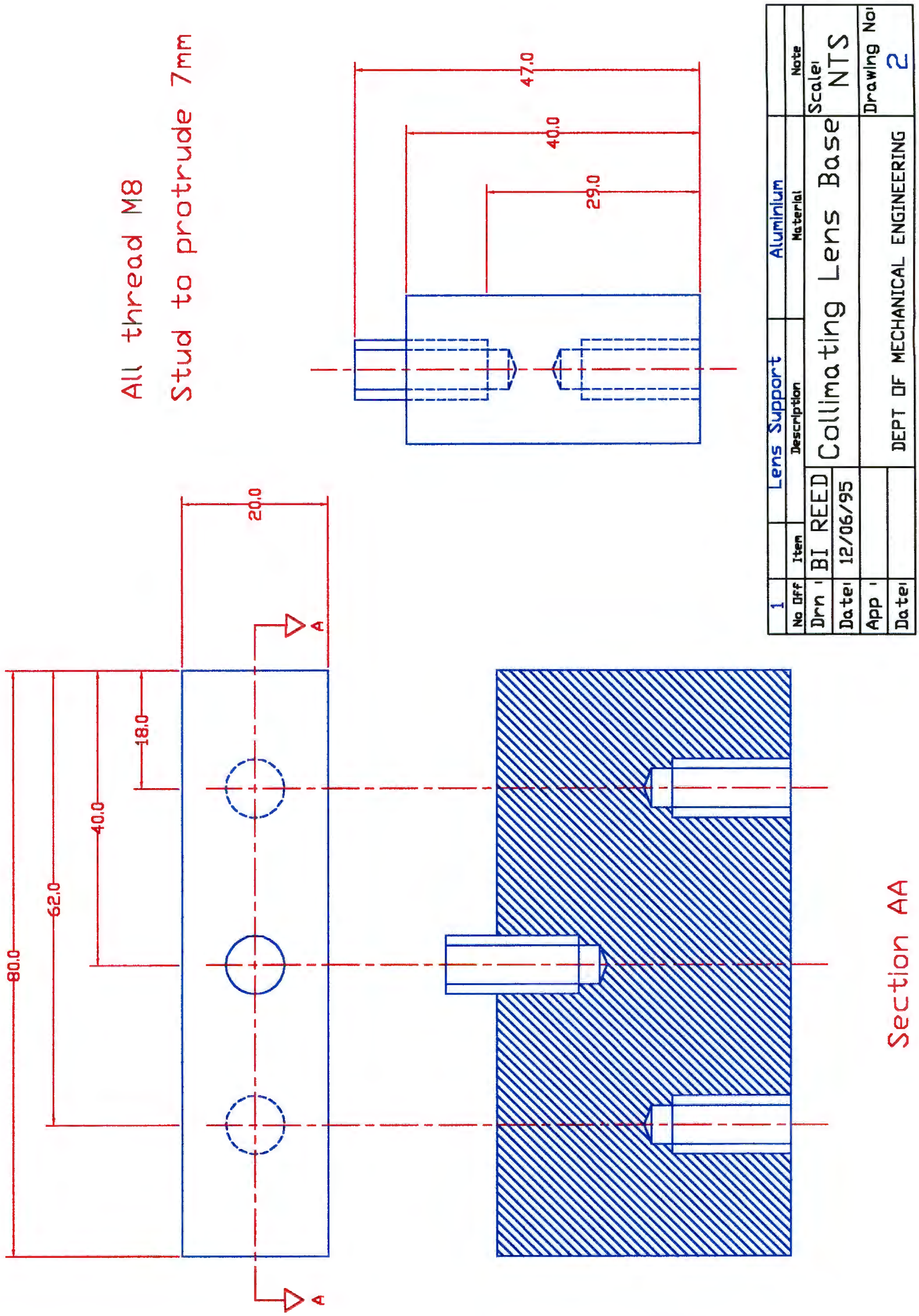

1. Use 10mm plate
2. Slot cut to 5mm
172
162
55,2
43
15
7
5
15
75
85
95
155
170
ø8.0
ø5.0
1
Top Plate
Aluminium
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 26/03/96
App :
Date:
Reference Beam Director
Scale: NTS
Drawing No: 2
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING

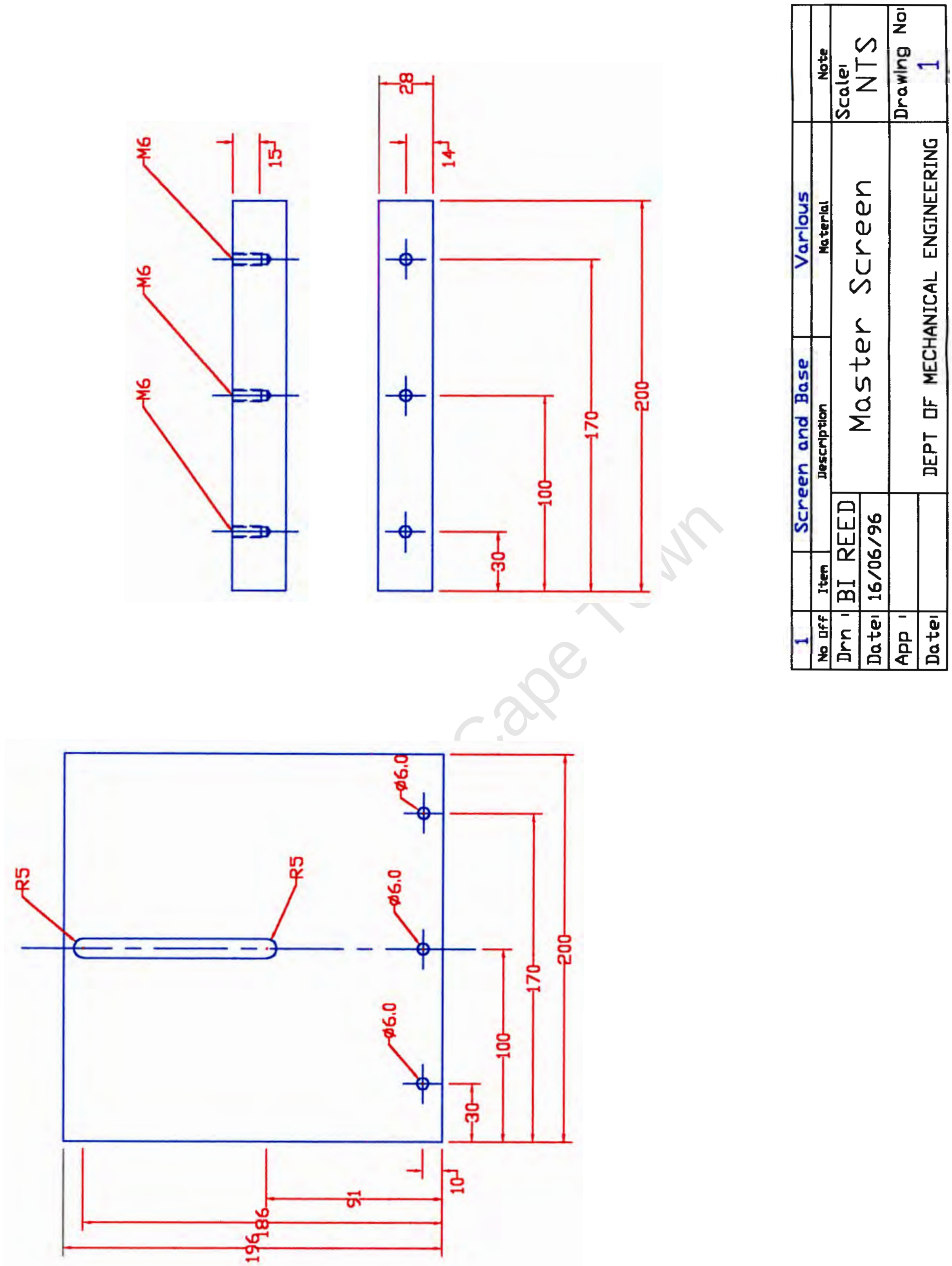

52
195.5
20
20
40
B
40
10
30
M8
1
Mirror Support
Aluminium
No Off
Item
Description
Material
Note
Drn
BI REED
Date
26/03/96
Reference Beam Director
Scale
NTS
App
Date
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No
3

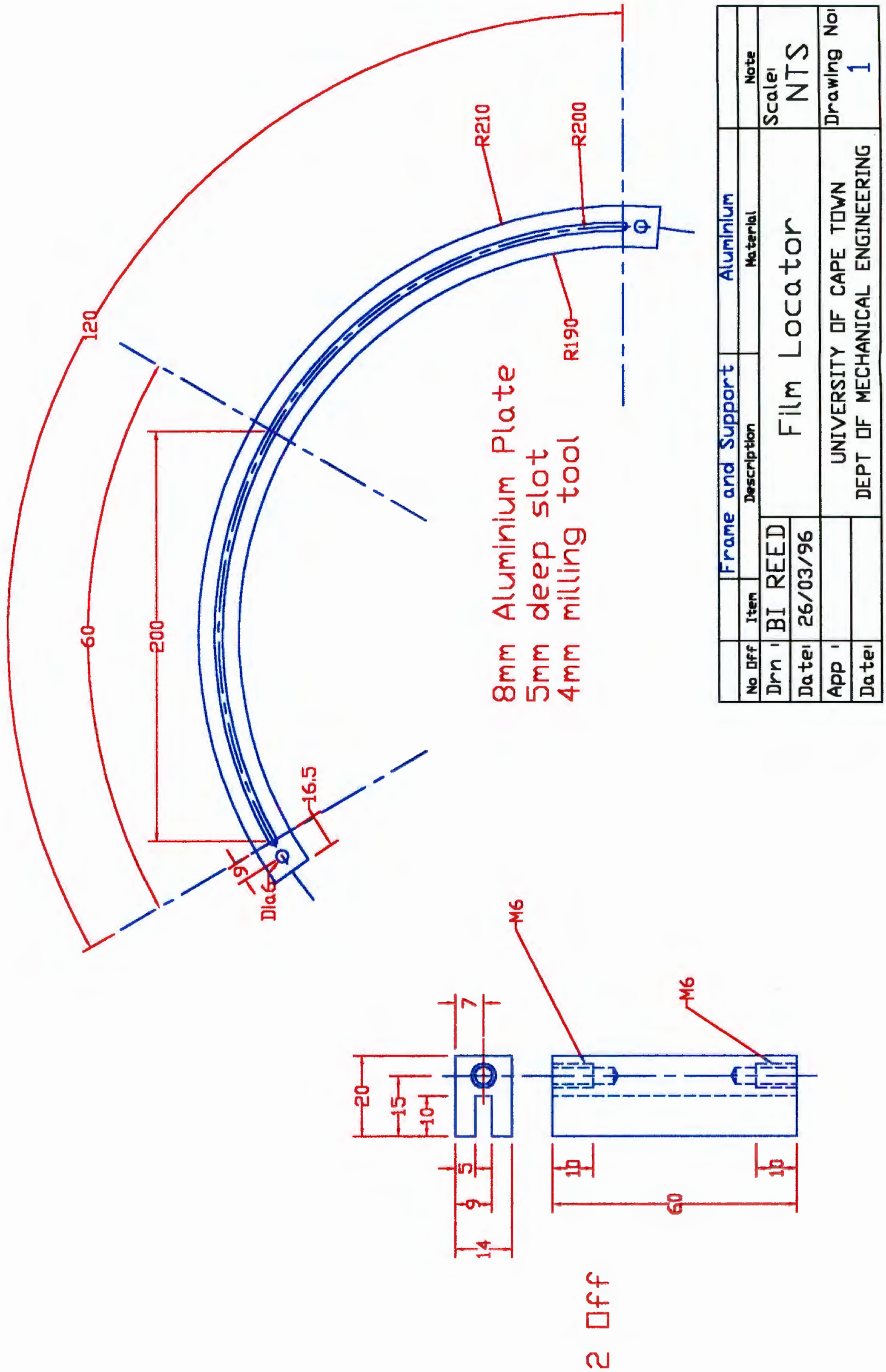

297
287
57
15
ø10.0
ø10.0
ø10.0
25
12.5
10
ø50.0
Dia 1.5"
M10
20
102
1.5" Magnet
1. Two of each
2
Stabiliser Arm
Mild Steel
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 26/03/96
Reference Beam Director
Scale: NTS
App :
Date:
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 4

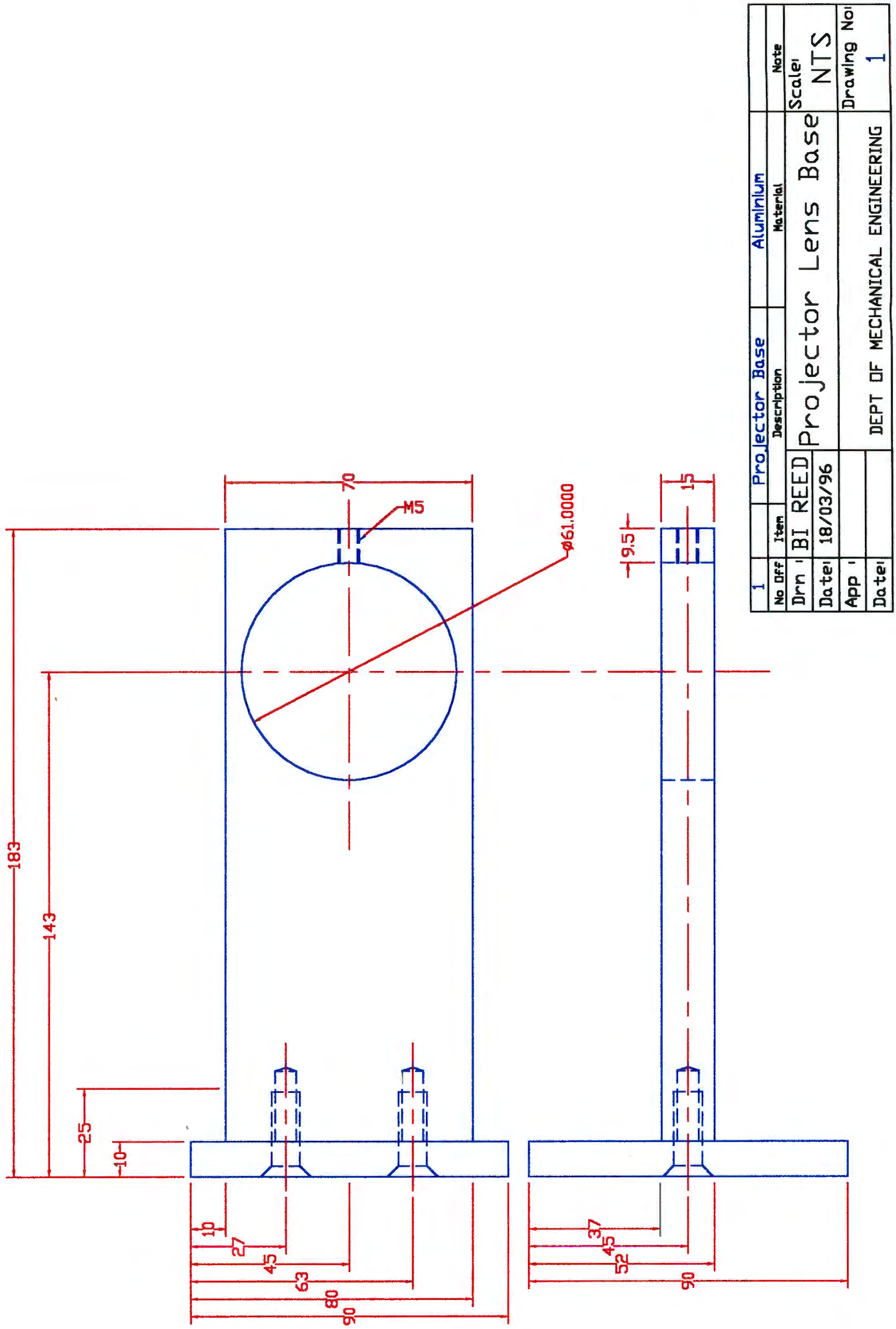

64
59.2 +0.1 -0
54.2
M5
M5
8
5 +0 -0.1
8
5
4
C
C
43 +0.1 -0.1
16 +0.1 -0.1
102
64
1. Drill and tap to 25mm
2
Upright Supports
Aluminium
No Off
Item
Description
Material
Note
Drn : BI REED
Date: 26/03/96
App :
Date:
Reference Beam Director
Scale: NTS
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Drawing No: 5


Magnet 1.5"DIA
20.0
80.0
40.0
18.0
1
Assembly
Aluminium
No Off
Item
Description
Material
Note
Drn
BI REED
Collimating Lens Base
Scale
NTS
Date
12/06/95
App
Date
DEPT OF MECHANICAL ENGINEERING
Drawing No
1


All thread M8
Stud to protrude 7mm
20.0
18.0
40.0
62.0
80.0
47.0
40.0
29.0
A
A
Section AA
1
No Off
Item
Lens Support
Description
Aluminium
Material
Note
Drn : BI REED
Date : 12/06/95
App :
Date :
Collimating Lens Base
Scale : NTS
Drawing No : 2
DEPT OF MECHANICAL ENGINEERING


M6
M6
M6
15
28
14
30
100
170
200
R5
R5
ø6.0
ø6.0
ø6.0
30
100
170
200
10
91
186
196
1
No Off
Screen and Base
Item
Description
Various
Material
Note
Drn : BI REED
Date: 16/06/96
App :
Date:
Master Screen
Scale: NTS
Drawing No: 1
DEPT OF MECHANICAL ENGINEERING


8mm Aluminium Plate
5mm deep slot
4mm milling tool
R210
R200
R190
120
60
200
16.5
9
Dia6
M6
M6
20
15
10
7
5
9
14
10
60
10
2 Off
No Off
Item
Frame and Support
Description
Aluminium
Material
Note
Drn : BI REED
Date : 26/03/96
App :
Date :
Film Locator
UNIVERSITY OF CAPE TOWN
DEPT OF MECHANICAL ENGINEERING
Scale: NTS
Drawing No: 1


1
No Off
Item
Projector Base
Description
Aluminium
Material
Note
Drn : BI REED
Date: 18/03/96
Projector Lens Base
Scale: NTS
App :
Date:
DEPT OF MECHANICAL ENGINEERING
Drawing No: 1
70
M5
ø61.0000
15
9.5
183
143
25
10
10
27
45
63
80
90
37
45
52
90

Appendix E. Computer Interface Software Code Listing

E.1. Form Holography

```
Begin VB.Form frmholography
Caption = "Holographic Stereogram Control"
ClientHeight = 4590
ClientLeft = 1185
ClientTop = 1950
ClientWidth = 7740
Height = 5280
Icon = "FRMHOLOG.frx":0000
Left = 1125
LinkTopic = "Form1"
ScaleHeight = 4590
ScaleWidth = 7740
Top = 1320
Width = 7860
Begin VB.CommandButton cmdexpose
  Caption = "&Expose Film"
  Height = 735
  Left = 5880
  TabIndex = 0
  Top = 3480
  Width = 1695
End
Begin VBX.IOPORT1 IOPORT1
  Left = 0
  Top = 0
End
Begin VB.CommandButton cmdnext
  Caption = "&Advance Film"
  Height = 735
  Left = 4080
  TabIndex = 1
  Top = 3480
  Width = 1575
End
Begin VB.Frame fraexposure
  Caption = "Exposure Status"
  Height = 1335
  Left = 120
  TabIndex = 16
  Top = 120
  Width = 3735
  Begin VB.CommandButton cmdContinuousExpose
    Caption = "E&xpose"
    Height = 255
    Left = 2640
    TabIndex = 34
    Top = 960
    Width = 975
  End
  Begin VB.OptionButton optok
    Caption = "OK"
    Height = 495
    Left = 480
    TabIndex = 18
    Top = 720
    Value = -1 'True
    Width = 615
  End
  Begin VB.OptionButton optchange
    Caption = "&Change"
    Height = 495
    Left = 1320
    TabIndex = 17
    Top = 720
    Width = 855
  End
  Begin VB.Label lbltime
    Alignment = 2 'Center
    BackColor = &H00FFFF00&
    Height = 255
    Left = 1920
    TabIndex = 21
    Top = 480
    Width = 615
  End
  Begin VB.Label lblexposure
    Caption = "Current Exposure Time"
    Height = 255
    Left = 120
    TabIndex = 20
    Top = 480
    Width = 2055
  End
  Begin VB.Label lblseconds
    Caption = "Seconds"
    Height = 255
```

```
    Left        = 2760
    TabIndex    = 19
    Top         = 480
    Width       = 855
  End
End
Begin VB.Frame frastepper
  Caption      = "Current Stepper Status"
  Height       = 2775
  Left         = 120
  TabIndex     = 8
  Top          = 1680
  Width        = 3735
  Begin VB.OptionButton opt2ok
    Caption     = "OK"
    Height      = 375
    Left        = 120
    TabIndex    = 11
    Top         = 2160
    Value       = -1 'True
    Width       = 615
  End
  Begin VB.OptionButton opt2change
    Caption     = "C&hange"
    Height      = 375
    Left        = 960
    TabIndex    = 10
    Top         = 2160
    Width       = 1215
  End
  Begin VB.OptionButton opt2direct
    Caption     = "&Direct"
    Height      = 375
    Left        = 2400
    TabIndex    = 9
    Top         = 2160
    Width       = 1215
  End
  Begin VB.Label lblcurrent
    Alignment   = 2 'Center
    BackColor   = &H00FFFF00&
    Height      = 255
    Left        = 2400
    TabIndex    = 26
    Top         = 1680
    Width       = 1095
  End
  Begin VB.Label lblstepsize
    Alignment   = 2 'Center
    BackColor   = &H00FFFF00&
    Height      = 255
    Left        = 2400
    TabIndex    = 25
    Top         = 1320
    Width       = 1095
  End
  Begin VB.Label lbldirection
    Alignment   = 2 'Center
    BackColor   = &H00FFFF00&
    Height      = 255
    Left        = 2400
    TabIndex    = 24
    Top         = 960
    Width       = 1095
  End
  Begin VB.Label lblpulses
    Alignment   = 2 'Center
    BackColor   = &H00FFFF00&
    Height      = 255
    Left        = 2400
    TabIndex    = 23
    Top         = 600
    Width       = 1095
  End
  Begin VB.Label lblpulsescaption
    Caption     = "No. of Pulses"
    Height      = 255
    Left        = 120
    TabIndex    = 15
    Top         = 600
    Width       = 1455
  End
  Begin VB.Label lbldirectioncaption
    Caption     = "CW / CCW"
    Height      = 255
    Left        = 120
    TabIndex    = 14
    Top         = 960
    Width       = 1455
  End
  Begin VB.Label lblstepsizecaption
    Caption     = "Half / Full Step"
    Height      = 255
    Left        = 120
    TabIndex    = 13
    Top         = 1320
    Width       = 1455
  End
  Begin VB.Label lblcurrentcaption
    Caption     = "Current Setting"
    Height      = 255
    Left        = 120
```

```
      TabIndex      = 12
      Top           = 1680
      Width         = 1455
    End
  End
  Begin VB.Frame fraturntable
    Caption         = "Turntable Status"
    Height          = 1935
    Left            = 4080
    TabIndex        = 2
    Top             = 120
    Width           = 3495
    Begin VB.Label lbltotaladvance
      Alignment       = 2 'Center
      BackColor       = &H00FFFF00&
      Height          = 255
      Left            = 1800
      TabIndex        = 29
      Top             = 1440
      Width           = 615
    End
    Begin VB.Label lblangularadvance
      Alignment       = 2 'Center
      BackColor       = &H00FFFF00&
      Height          = 255
      Left            = 1800
      TabIndex        = 28
      Top             = 960
      Width           = 615
    End
    Begin VB.Label lblcurrentexposure
      Alignment       = 2 'Center
      BackColor       = &H00FFFF00&
      Height          = 255
      Left            = 1800
      TabIndex        = 27
      Top             = 480
      Width           = 615
    End
    Begin VB.Label lbltotalexposures
      Alignment       = 2 'Center
      BackColor       = &H00FFFF00&
      Height          = 255
      Left            = 2760
      TabIndex        = 22
      Top             = 480
      Width           = 615
    End
    Begin VB.Label lblcurrentexposuretext
      Caption         = "Current Exposure"
      Height          = 255
      Left            = 120
      TabIndex        = 7
      Top             = 480
      Width           = 1575
    End
    Begin VB.Label lblangularadvancetext
      Caption         = "Angular Advance"
      Height          = 255
      Left            = 120
      TabIndex        = 6
      Top             = 960
      Width           = 1575
    End
    Begin VB.Label lbldegrees
      Caption         = "Degrees"
      Height          = 255
      Left            = 2640
      TabIndex        = 5
      Top             = 1200
      Width           = 735
    End
    Begin VB.Label lblof
      Caption         = "of"
      Height          = 255
      Left            = 2520
      TabIndex        = 4
      Top             = 480
      Width           = 255
    End
    Begin VB.Label lbladvancementtext
      Caption         = "Total Angular Advancement"
      Height          = 375
      Left            = 240
      TabIndex        = 3
      Top             = 1320
      Width           = 1215
    End
  End
  Begin VB.Label lblPulseInterval
    Alignment       = 2 'Center
    BackColor       = &H00FFFF00&
    Height          = 255
    Left            = 4440
    TabIndex        = 33
    Top             = 2880
    Width           = 735
  End
  Begin VB.Label lbl
    Caption         = "Pulse Interval"
    Height          = 255
    Left            = 4320
```

```
    TabIndex      =  32
    Top           =  2400
    Width         =  1095
  End
  Begin VB.Label lblcurrentaddress
    Alignment     =  2 'Center
    Caption       =  "Current Port Address"
    Height        =  255
    Left          =  5880
    TabIndex      =  31
    Top           =  2400
    Width         =  1695
  End
  Begin VB.Label lbladdress
    Alignment     =  2 'Center
    BackColor     =  &H00FFFF00&
    Height        =  255
    Left          =  6360
    TabIndex      =  30
    Top           =  2880
    Width         =  735
  End
  Begin VB.Menu mnuoptions
    Caption       =  "&Options"
  End
  Begin VB.Menu mnuhelp
    Caption       =  "&Help"
    Begin VB.Menu mnuhelpabout
      Caption     =  "About"
    End
  End
  Begin VB.Menu mnuquit
    Caption       =  "&Quit"
  End
End
Attribute VB_Name = "frmholography"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit

' Expose or Advance Film?
Public WhatNext As Integer

' Counter for the advancer window
Public Counter As Integer


Private Sub cmdContinuousExpose_Click()

Dim Msg
Dim Style
Dim Response
Dim Title
' Initialise the exposureoutput variable expose
Dim Exposure As Integer


Msg = "Continuous Exposure?"        ' Define message.
Style = vbYesNo + vbCritical + vbDefaultButton2 ' Define
buttons.
Title = "Continuous Exposure"
Response = MsgBox(Msg, Style, Title)
If Response = vbNo Then                    ' User chose Yes.

' Give Focus to the Exposure Button
Exposure = 0

' Send Condition to the Voltmeter
    Call modoutput.ExposureOutput(Exposure)



' Give Focus to the Exposure Button
cmdnext.SetFocus                              ' Return
Exit Sub
Else                              ' User chose No.



Exposure = 128

' Send Condition to the Voltmeter
    Call modoutput.ExposureOutput(Exposure)



' Give Focus to the Exposure Button
cmdnext.SetFocus                              ' Return
End If






End Sub


Private Sub cmdexpose_Click()


' Should it be Advance now ?
If WhatNext = 0 Then

Dim Msg
Dim Style
```

```
Dim Response
Dim Title
Msg = "Have you remebered to Advance the film ?"        ' Define
message.
Style  =  vbYesNo  +  vbCritical  +  vbDefaultButton2  '  Define
buttons.
Title = "Exposing the Film"
Response = MsgBox(Msg, Style, Title)
If Response = vbNo Then                 ' User chose Yes.

'  Give Focus to the Exposure Button
cmdnext.SetFocus

Exit Sub
Else                            ' User chose No.
                                ' Return
End If
End If




'  Initialise the exposureoutput variable expose
Dim Exposure As Integer



Exposure = 128

'  Send Condition to the Voltmeter
     Call modoutput.ExposureOutput(Exposure)


WhatNext = 0

'  Give Focus to the Exposure Button
cmdnext.SetFocus

End Sub



Private Sub cmdnext_Click()

Dim direction As Integer
Dim stepsize As Integer
Dim i As Integer
Static Exposure As Integer
Static angularadvance
Static totaladvance
Dim factor
Dim pausetime As Integer
Dim start
Dim finish

'  Should it be exposure now ?
If WhatNext = 1 Then

Dim Msg
Dim Style
Dim Response
Dim Title
Msg = "Have you remebered to Expose the film ?"         ' Define
message.
Style  =  vbYesNo  +  vbCritical  +  vbDefaultButton2  '  Define
buttons.
Title = "Advancing the Film"
Response = MsgBox(Msg, Style, Title)
If Response = vbNo Then                 ' User chose Yes.

'  Give Focus to the Exposure Button
cmdexpose.SetFocus

Exit Sub
Else                            ' User chose No.
End If
End If




'  Initialise the output variable Condition
Dim condition As Integer

'  Initialise stepper as firm
Call modoutput.output(8)

'Pause for 1 seconds to give stepper time to respond
   pausetime = 1  ' Set duration.
   start = Timer  ' Set start time.
   Do While Timer < start + pausetime
   Loop
   finish = Timer  ' Set end time.


'  Set the direction variable to the correct value
   If lbldirection = "clockwise" Then
      direction = 0
      Else: direction = 1
   End If
```

```
' Set the direction variable to the correct value
   If lblstepsize = "full step" Then
      stepsize = 1
      Else: stepsize = 0
   End If

' Set up Condition value
condition = 2 ^ 1 * direction + 2 ^ 2 * stepsize + 1


' Move a set number of pulses forward or fix if = 0

   If Int(lblpulses) < 1 Then
      MsgBox "Please enter a valid number of pulses", 48,
"Number of Pulses"

    Else:


    For i = 1 To Int(lblpulses)


' Start timer
frmadvancing.Show 1



        Call modoutput.output(condition)
        Call modoutput.output(8)

        Next

   End If


' Send an AWO signal to the stepper
        Call modoutput.output(0)

' Number of exposures so far
If Exposure = 0 Then Exposure = 1
Exposure = Exposure + 1
lblcurrentexposure = Exposure

angularadvance = Int(lblpulses) * 360 / 200
totaladvance = totaladvance + angularadvance

lblangularadvance = angularadvance
lbltotaladvance = totaladvance

WhatNext = 1
' Give Focus to the Exposure Button
cmdexpose.SetFocus

End Sub



Private Sub Form_Load()

' Expose or Advance Film?
WhatNext = 1

' Initialise the Current Stepper Status
lblcurrentexposure = "1"
lblpulses = "12"
lbldirection = "clockwise"
lblstepsize = "half step"
lblcurrent = "reduced current"
lbladdress = "378"
lbltime = "0.5"
lblPulseInterval = "0.5"
lblangularadvance = "0"
lbltotaladvance = "0"
lbltotalexposures = "?"

End Sub

Private Sub mnuhelpabout_Click()
frmeasteregg.Show 1
End Sub

Private Sub mnuoptions_Click()
frmoptions.Show 1
End Sub

Private Sub mnuquit_Click()
Dim Msg
Dim Style
Dim Response
Dim Title
Msg = "Are you sure you want to quit ?"        ' Define message.
Style = vbYesNo + vbCritical + vbDefaultButton2 ' Define
buttons.
Title = "Holographic Stereograms"
Response = MsgBox(Msg, Style, Title)
If Response = vbYes Then                ' User chose Yes.
   End                                  ' Quit the Application
Else                                    ' User chose No.
                                        ' Return
End If
```

```
End Sub

Private Sub opt2change_Click()

   If opt2change.Value = True Then

      ' This is a modal form
      frmstepperinit.Show 1

   End If

' give focus to the Next Slide button
cmdnext.SetFocus
End Sub

Private Sub opt2direct_Click()

' Bring up Direct Stepper Control form
   If opt2direct.Value = True Then

      ' Give option OK the check incase of X close
      opt2ok = True

      frmdirect.Show 1
   End If

' Give focus to the Next Slide button
cmdnext.SetFocus


End Sub


Private Sub optchange_Click()

   If optchange.Value = True Then

      ' Reset exposure status option in case X is chosen
      optok = True

      frmexposure.Show 1          'This is a modal form
   End If

' give focus to the Next Slide button
cmdexpose.SetFocus
End Sub
```

E.2. Form Stepperinit

```
Begin VB.Form frmstepperinit
   Caption         =   "Stepper Motor Setup"
   ClientHeight    =   4710
   ClientLeft      =   5250
   ClientTop       =   1755
   ClientWidth     =   4035
   ClipControls    =   0   'False
   ControlBox      =   0   'False
   Height          =   5115
   Left            =   5190
   LinkTopic       =   "Form2"
   MaxButton       =   0   'False
   MinButton       =   0   'False
   ScaleHeight     =   4710
   ScaleWidth      =   4035
   Top             =   1410
   Width           =   4155
   Begin VB.Frame fradirection
      Caption         =   "Direction"
      Height          =   855
      Left            =   240
      TabIndex        =   9
      Top             =   720
      Width           =   3495
      Begin VB.OptionButton optclock
         Caption         =   "&Clockwise"
         Height          =   375
         Left            =   120
         TabIndex        =   11
         Top             =   360
         Width           =   1215
      End
      Begin VB.OptionButton optanticlock
         Caption         =   "&Anti-Clockwise"
         Height          =   375
         Left            =   1680
         TabIndex        =   10
         Top             =   360
         Value           =   -1  'True
         Width           =   1575
      End
   End
   Begin VB.TextBox txtpulsesinit
      Appearance      =   0   'Flat
      Height          =   285
      Left            =   1920
      TabIndex        =   8
      Top             =   240
      Width           =   855
```

```
End
Begin VB.Frame frastepsize
  Caption      = "Step Size"
  Height       = 855
  Left         = 240
  TabIndex     = 5
  Top          = 1800
  Width        = 3495
  Begin VB.OptionButton opthalfstep
    Caption      = "&Half Step"
    Height       = 375
    Left         = 120
    TabIndex     = 7
    Top          = 360
    Width        = 1215
  End
  Begin VB.OptionButton optfullstep
    Caption      = "&Full Step"
    Height       = 375
    Left         = 1680
    TabIndex     = 6
    Top          = 360
    Value        = -1 'True
  Width        = 1215
  End
End
Begin VB.Frame fracurrent
  Caption      = "Current"
  Height       = 855
  Left         = 240
  TabIndex     = 2
  Top          = 2880
  Width        = 3495
  Begin VB.OptionButton optfullcurrent
    Caption      = "F&ull Current"
    Height       = 375
    Left         = 120
    TabIndex     = 4
    Top          = 360
    Width        = 1455
  End
  Begin VB.OptionButton optreducedcurrent
    Caption      = "&Reduced Current"
    Height       = 375
    Left         = 1680
    TabIndex     = 3
    Top          = 360
    Value        = -1 'True
    Width        = 1695
  End
End
```

```
  Begin VB.CommandButton cmdok
    Caption      = "&OK"
    Height       = 495
    Left         = 480
    TabIndex     = 1
    Top          = 3960
    Width        = 1215
  End
  Begin VB.CommandButton cmdcancel
    Caption      = "&Cancel"
    Height       = 495
    Left         = 2280
    TabIndex     = 0
    Top          = 3960
    Width        = 1215
  End
  Begin VB.Label lblpulses
    Caption      = "&No. of Pulses"
    Height       = 255
    Left         = 360
    TabIndex     = 12
    Top          = 240
    Width        = 1215
  End
End
Attribute VB_Name = "frmstepperinit"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit

Private Sub cmdcancel_Click()

' Unload the form
Unload frmstepperinit

' Return option to OK
frmholography!opt2ok = True

End Sub


Private Sub cmdok_Click()

' Send contents to current stepper status on the main form
frmholography!lblpulses = txtpulsesinit.Text

  If optclock = True Then
    frmholography!lbldirection = "clockwise"
    Else: frmholography!lbldirection = "anti-clockwise"
  End If
```

```
   If optfullstep = True Then
         frmholography!lblstepsize = "full step"
      Else: frmholography!lblstepsize = "half step"
   End If

' Close the stepper initialisation form
Unload frmstepperinit

' Return option to OK
frmholography!opt2ok = True

End Sub

Private Sub Form_Load()


' Get current stepper status from main form

   txtpulsesinit.Text = frmholography!lblpulses

   If frmholography!lbldirection = "clockwise" Then
      optclock = True
      Else: optanticlock = True
   End If

   If frmholography!lblstepsize = "full step" Then
      optfullstep = True
      Else: opthalfstep = True
   End If

End Sub

Private Sub optfullcurrent_Click()

If optfullcurrent.Value = True Then
   ' Warning that this doesn't exist
        MsgBox "This option is not presently supported", 48, "Full
Current"

End If

optreducedcurrent.Value = True
cmdcancel.SetFocus
End Sub
```

E.3. Form Direct

```
Begin VB.Form frmdirect
   Caption         =   "Direct Stepper Motor Control"
   ClientHeight    =   4695
   ClientLeft      =   1755
   ClientTop       =   1740
   ClientWidth     =   6690
   ControlBox      =   0   'False
   Height          =   5100
   Left            =   1695
   LinkTopic       =   "Form1"
   MaxButton       =   0   'False
   MinButton       =   0   'False
   ScaleHeight     =   4695
   ScaleWidth      =   6690
   Top             =   1395
   Width           =   6810
   Begin VB.CommandButton cmdawo
      Caption         =   "A&WO"
      Height          =   495
      Left            =   5520
      TabIndex        =   19
      Top             =   3840
      Width           =   735
   End
   Begin VB.OptionButton optdummy
      Height          =   195
      Left            =   5880
      TabIndex        =   18
      Top             =   3360
      Value           =   -1  'True
      Visible         =   0   'False
      Width           =   255
   End
   Begin VB.CommandButton cmdclose
      Caption         =   "&Close"
      Height          =   495
      Left            =   3840
      TabIndex        =   0
      Top             =   3840
      Width           =   1215
   End
   Begin VB.CommandButton cmdexecute
      Caption         =   "&Execute"
      Height          =   975
      Left            =   3960
      TabIndex        =   1
      Top             =   480
      Width           =   2055


   End
   Begin VB.Frame frastepcontrol
      Caption         =   "Step Control"
```

```
      Height        = 1455
      Left          = 240
      TabIndex      = 9
      Top           = 240
      Width         = 3135
      Begin VB.TextBox txtsteps
         BackColor     = &H00E0E0E0&
         Height        = 285
         Left          = 2160
         TabIndex      = 12
         Top           = 960
         Visible       = 0   'False
         Width         = 735
      End
      Begin VB.OptionButton opt1multistep
         Caption       = "&Multi-Step"
         Height        = 255
         Left          = 1800
         TabIndex      = 11
         Top           = 480
         Width         = 1215
      End
      Begin VB.OptionButton opt1singlestep
         Caption       = "&Single Step"
         Height        = 255
         Left          = 120
         TabIndex      = 10
         Top           = 480
         Value         = -1  'True
         Width         = 1455
      End
      Begin VB.Label lblsteps
         Caption       = "Enter number of steps"
         Height        = 255
         Left          = 120
         TabIndex      = 13
         Top           = 960
         Visible       = 0   'False
         Width         = 1935
      End
   End
   Begin VB.Frame fradirectioncontrol
      Caption         = "Direction Control"
      Height          = 1095
      Left            = 240
      TabIndex        = 6
      Top             = 1920
      Width           = 3135
      Begin VB.OptionButton opt2anticlockwise
         Caption       = "&Anti-Clockwise"
         Height        = 255
         Left          = 1440
         TabIndex      = 8
         Top           = 480
         Width         = 1575
      End
      Begin VB.OptionButton opt2clockwise
         Caption       = "&Clockwise"
         Height        = 255
         Left          = 120
         TabIndex      = 7
         Top           = 480
         Value         = -1  'True
         Width         = 1215
      End
   End
   Begin VB.Frame frastepsize
      Caption         = "Step Size"
      Height          = 1095
      Left            = 240
      TabIndex        = 3
      Top             = 3240
      Width           = 3135
      Begin VB.OptionButton opt3halfstep
         Caption       = "&Half Step"
         Height        = 255
         Left          = 120
         TabIndex      = 5
         Top           = 480
         Width         = 1215
      End
      Begin VB.OptionButton opt3fullstep
         Caption       = "&Full Step"
         Height        = 255
         Left          = 1440
         TabIndex      = 4
         Top           = 480
         Value         = -1  'True
         Width         = 1215
      End
   End
   Begin VB.OptionButton optinitialise
      Caption         = "&Initialise step totals"
      Height          = 255
      Left            = 4080
      TabIndex        = 2
      Top             = 3360
      Width           = 1575
   End
   Begin VB.Label lblinterval
      Alignment       = 2  'Center
      BackColor       = &H00E0E0E0&
```

```
      Height        = 255
      Left          = 5640
      TabIndex      = 21
      Top           = 3000
      Width         = 735
   End
   Begin VB.Label Label1
      Caption       = "Pulse Interval"
      Height        = 255
      Left          = 4200
      TabIndex      = 20
      Top           = 3000
      Width         = 1095
   End
   Begin VB.Label lbltotalhalfsteps
      Alignment     = 2 'Center
      BackColor     = &H00E0E0E0&
      Height        = 255
      Left          = 5640
      TabIndex      = 17
      Top           = 2400
      Width         = 735
   End
   Begin VB.Label lbltotalfullsteps
      Alignment     = 2 'Center
      BackColor     = &H00E0E0E0&
      Height        = 255
      Left          = 5640
      TabIndex      = 16
      Top           = 2040
      Width         = 735
   End
   Begin VB.Label lbltotalfullstepscap
      Caption       = "Total no. of full steps"
      Height        = 255
      Left          = 3600
      TabIndex      = 15
      Top           = 2040
      Width         = 1575
   End
   Begin VB.Label lbltotalhalfstepscap
      Caption       = "Total no. of half steps"
      Height        = 255
      Left          = 3600
      TabIndex      = 14
      Top           = 2400
      Width         = 1695
   End
End
Attribute VB_Name = "frmdirect"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit

Public totalhalfsteps As Long
Public totalfullsteps As Long

Private Sub cmdawo_Click()
' Initialise the output variable Condition
Dim condition As Integer

condition = 0

' Send Condition to the stepper motor
    Call modoutput.output(condition)
End Sub


Private Sub cmdclose_Click()

' Unload the form
Unload frmdirect

' Give option OK the check
frmholography!opt2ok = True


End Sub


Private Sub cmdexecute_Click()

Dim direction As Integer
Dim stepsize As Integer
Dim i As Integer
Dim numberofsteps As Long
Dim pausetime As Integer
Dim start
Dim finish

' Initialise the output variable Condition
Dim condition As Integer

' Initialise stepper as firm
Call modoutput.output(8)

'Pause for 1 seconds to give stepper time to respond
   pausetime = 1  ' Set duration.
   start = Timer   ' Set start time.
   Do While Timer < start + pausetime
   Loop
   finish = Timer  ' Set end time.
```

```
' Set the direction variable to the correct value
  If opt2clockwise = True Then
    direction = 0
    Else: direction = 1
  End If

' Set the direction variable to the correct value
  If opt3fullstep = True Then
    stepsize = 1
    Else: stepsize = 0
  End If

' Set up Condition value
condition = 2 ^ 0 + 2 ^ 1 * direction + 2 ^ 2 * stepsize + 2 ^ 3


' Move a single step forward
  If opt1singlestep = True Then

    ' Send Condition to the stepper motor

    Call modoutput.output(condition)
    Call modoutput.output(8)
    numberofsteps = 1

  Else: For i = 1 To txtsteps

  'Pause for specified seconds to give stepper time to respond
  pausetime = Int(lblinterval) ' Set duration from option
  start = Timer   ' Set start time.
  Do While Timer < start + pausetime
  Loop
  finish = Timer  ' Set end time.


      Call modoutput.output(condition)
      Call modoutput.output(8)

      Next

     numberofsteps = txtsteps

'Pause for 1 seconds to give stepper time to respond to next set of steps
  pausetime = 1  ' Set duration.
  start = Timer   ' Set start time.
  Do While Timer < start + pausetime
  Loop
  finish = Timer  ' Set end time.

  End If

' Keep a total of the number of steps and half steps to date
  If opt2clockwise = True And opt3halfstep = True Then
    totalhalfsteps = totalhalfsteps + numberofsteps
  ElseIf opt2clockwise = True And opt3fullstep = True Then
    totalfullsteps = totalfullsteps + numberofsteps
  ElseIf opt2anticlockwise = True And opt3halfstep = True Then
    totalhalfsteps = totalhalfsteps - numberofsteps
  ElseIf opt2anticlockwise = True And opt3fullstep = True Then
    totalfullsteps = totalfullsteps - numberofsteps
  End If

' Convert half steps to full steps
  If (totalhalfsteps / 2) - CInt(totalhalfsteps / 2) <> 0 Then
    totalfullsteps = totalfullsteps + (totalhalfsteps - 1) / 2
    totalhalfsteps = Abs((totalhalfsteps / 2 - CInt(totalhalfsteps / 2)) * 2)
  Else: totalfullsteps = totalfullsteps + (totalhalfsteps / 2)
     totalhalfsteps = 0
  End If


' Insert values into labels
lbltotalhalfsteps = totalhalfsteps
lbltotalfullsteps = totalfullsteps


End Sub


Private Sub Form_Load()
Dim Transition

' Insert values into labels
lbltotalhalfsteps = totalhalfsteps
lbltotalfullsteps = totalfullsteps
lblinterval = frmholography!lblPulseInterval
End Sub

Private Sub opt1multistep_Click()

' If the Multi-step Option is chosen
  If opt1multistep = True Then
    lblsteps.Visible = True
    txtsteps.Visible = True
  End If

' Give focus to text input
txtsteps.SetFocus
```

```
End Sub


Private Sub opt1singlestep_Click()

' If the Single-step Option is chosen
  If opt1singlestep = True Then
    lblsteps.Visible = False
    txtsteps.Visible = False
  End If

' Give focus to Execute button
cmdexecute.SetFocus

End Sub


Private Sub optinitialise_Click()

' Initialise Step Totals?
    totalfullsteps = 0
    totalhalfsteps = 0

' Show values on the form
lbltotalhalfsteps = totalhalfsteps
lbltotalfullsteps = totalfullsteps

' Clear the INIT option
    optdummy = True

' Give focus to the Execute button
cmdexecute.SetFocus

End Sub


Private Sub Timer1_Timer()

End Sub


Private Sub Timer_Timer()
Beep
End Sub
```

E.4. Form Options

```
Begin VB.Form frmoptions
  Caption       = "Options"
  ClientHeight  = 1815
  ClientLeft    = 5130
  ClientTop     = 4500
  ClientWidth   = 3735
  ClipControls  = 0 'False
  ControlBox    = 0 'False
  Height        = 2220
  Left          = 5070
  LinkTopic     = "Form1"
  MaxButton     = 0 'False
  MinButton     = 0 'False
  ScaleHeight   = 1815
  ScaleWidth    = 3735
  Top           = 4155
  Width         = 3855
  Begin VB.TextBox txtPulseInterval
    Height        = 285
    Left          = 2280
    TabIndex      = 5
    Top           = 600
    Width         = 855
  End
  Begin VB.CommandButton cmdcancel
    Caption       = "&Cancel"
    Height        = 495
    Left          = 2040
    TabIndex      = 3
    Top           = 1200
    Width         = 1335
  End
  Begin VB.CommandButton cmdok
    Caption       = "&OK"
    Height        = 495
    Left          = 360
    TabIndex      = 2
    Top           = 1200
    Width         = 1335
  End
  Begin VB.TextBox txtportaddress
    Height        = 285
    Left          = 600
    TabIndex      = 1
    Top           = 600
    Width         = 855
  End
  Begin VB.Label Label2
    Caption       = "Pulse Interval"
    Height        = 255



    Left          = 2160
```

```
    TabIndex      = 4
    Top           = 240
    Width         = 1095
  End
  Begin VB.Label Label1
    Alignment     = 2 'Center
    Caption       = "Hexadecimal Parallel Port Address"
    Height        = 375
    Left          = 240
    TabIndex      = 0
    Top           = 120
    Width         = 1695
  End
End
Attribute VB_Name = "frmoptions"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit

Private Sub cmdcancel_Click()
' Remove the options form
Unload frmoptions
End Sub


Private Sub cmdok_Click()
' Set up value of port
frmholography!lbladdress = txtportaddress.Text
frmholography!lblPulseInterval = txtPulseInterval.Text
' Close options form
Unload frmoptions
End Sub

Private Sub Form_Load()
txtportaddress.Text = frmholography!lbladdress
txtPulseInterval.Text = frmholography!lblPulseInterval
End Sub
```

E.5. Form Timer

```
Begin VB.Form frmtimer
  BorderStyle     = 1 'Fixed Single
  ClientHeight    = 1035
  ClientLeft      = 5265
  ClientTop       = 4245
  ClientWidth     = 3525
  ClipControls    = 0 'False
  ControlBox      = 0 'False
  Height          = 1440
  Left            = 5205
  LinkTopic       = "Form1"
  MaxButton       = 0 'False
  MinButton       = 0 'False
  ScaleHeight     = 1035
  ScaleWidth      = 3525
  Top             = 3900
  Visible         = 0 'False
  Width           = 3645
  Begin VB.Timer timerinterval
    Left          = 0
    Top           = 600
  End
  Begin VB.Label Label1
    Caption       = "Exposing"
    BeginProperty Font
      name          = "MS Sans Serif"
      charset       = 1
      weight        = 700
      size          = 24
      underline     = 0 'False
      italic        = 0 'False
      strikethrough = 0 'False
    EndProperty
    Height        = 615
    Left          = 600
    TabIndex      = 0
    Top           = 240
    Width         = 2295
  End
End
Attribute VB_Name = "frmtimer"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit

Private Sub Form_Load()
Dim DummyTime
DummyTime = Trim(CInt(Trim(frmholography!lbltime) * 1000))


timerinterval.Interval = DummyTime
End Sub

Private Sub Timer1_Timer()

End Sub

Private Sub timerinterval_Timer()
Unload frmtimer
End Sub
```

E.6. Form Advancing

```
Begin VB.Form frmadvancing
  BorderStyle    =  1 'Fixed Single
  ClientHeight   =  1065
  ClientLeft     =  5265
  ClientTop      =  4245
  ClientWidth    =  3510
  ClipControls   =  0 'False
  ControlBox     =  0 'False
  Height         =  1470
  Left           =  5205
  LinkTopic      =  "Form1"
  MaxButton      =  0 'False
  MinButton      =  0 'False
  ScaleHeight    =  1065
  ScaleWidth     =  3510
  Top            =  3900
  Width          =  3630
  Begin VB.Timer timeradvancing
    Left         =  0
    Top          =  600
  End
  Begin VB.Label lblcounter
    Alignment    =  1 'Right Justify
    Height       =  255
    Left         =  3120
    TabIndex     =  1
    Top          =  840
    Width        =  375
  End
  Begin VB.Label Label1
    Caption      =  "Advancing"
    BeginProperty Font
      name       =  "MS Sans Serif"
      charset    =  1
      weight     =  400
      size       =  24
      underline  =  0 'False
      italic     =  0 'False
      strikethrough = 0 'False
    EndProperty
    Height       =  615
    Left         =  600
    TabIndex     =  0
    Top          =  240
    Width        =  2295
  End
End
Attribute VB_Name = "frmadvancing"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit

' Counter for the advancer window
Public Counter As Integer

Private Sub Form_Load()
Dim DummyAdvancing


DummyAdvancing =
Trim(CInt(Trim(frmholography!lblPulseInterval) * 1000))
timeradvancing.Interval = DummyAdvancing
lblcounter = Counter
Counter = Counter + 1

End Sub


Private Sub timeradvancing_Timer()
Unload frmadvancing
End Sub
```

E.7. Form Exposure

```
Begin VB.Form frmexposure
  Caption        =  "Exposure Control"
  ClientHeight   =  2415
  ClientLeft     =  1320
  ClientTop      =  3930
  ClientWidth    =  3780
  ClipControls   =  0 'False
  ControlBox     =  0 'False
  Height         =  2820
  Left           =  1260
  LinkTopic      =  "Form1"
  MaxButton      =  0 'False
  MinButton      =  0 'False
  ScaleHeight    =  2415
  ScaleWidth     =  3780
  Top            =  3585
  Width          =  3900
  Begin VB.TextBox txtexposure
    Appearance   =  0 'Flat
    Height       =  285
    Left         =  1680
    TabIndex     =  0
```

```
    Top        = 240
    Width      = 735
  End
  Begin VB.CommandButton cmdok
    Caption    = "OK"
    Height     = 495
    Left       = 480
    TabIndex   = 3
    Top        = 1680
    Width      = 1215
  End
  Begin VB.CommandButton cmdcancel
    Caption    = "Cancel"
    Height     = 495
    Left       = 2160
    TabIndex   = 2
    Top        = 1680
    Width      = 1215
  End
  Begin VB.TextBox txttotalexposuresinit
    Appearance = 0 'Flat
    Height     = 285
    Left       = 1680
    TabIndex   = 1
    Top        = 840
    Width      = 735
  End
  Begin VB.Label Label1
    Caption    = "Exposure Time"
    Height     = 255
    Left       = 240
    TabIndex   = 6
    Top        = 240
    Width      = 1335
  End
  Begin VB.Label Label2
    Caption    = "Seconds"
    Height     = 255
    Left       = 2640
    TabIndex   = 5
    Top        = 240
    Width      = 735
  End
  Begin VB.Label lbltotalexposures
    Caption    = "Total Number of Exposures"
    Height     = 495
    Left       = 240
    TabIndex   = 4
    Top        = 840
    Width      = 1215
  End
End
Attribute VB_Name = "frmexposure"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Option Explicit
Private Sub cmdcancel_Click()

' Reset exposure status option
frmholography!optok = True

' Remove the exposure form
Unload frmexposure

End Sub

Private Sub cmdok_Click()

' Set up exposure status on main form
frmholography!lbltime = txtexposure.Text
frmholography!lbltotalexposures = txttotalexposuresinit.Text
frmholography!optok = True

' Close exposure form
Unload frmexposure

End Sub

Private Sub Form_Load()


' Get exposure status from the main form
txtexposure.Text = frmholography!lbltime
txttotalexposuresinit.Text = frmholography!lbltotalexposures

End Sub
```

E.8. Module Output

```
Attribute VB_Name = "modoutput"
Option Explicit


Public Sub output(step)

' Set Ioport.VBX Port Address
frmholography!IOPORT1.PortAddress = "&H" &
frmholography!lbladdress
```

```
' Send a clear signal to Ioport.VBX Port Data output
frmholography!IOPORT1.PortData = 8

' Set Ioport.VBX Port Data output
frmholography!IOPORT1.PortData = step

End Sub
Public Sub ExposureOutput(Exposure)
Dim pausetime As Integer
Dim start
Dim finish

' Set Ioport.VBX Port Address
frmholography!IOPORT1.PortAddress = "&H" &
frmholography!lbladdress

' Set Ioport.VBX Port Data output
frmholography!IOPORT1.PortData = Exposure

' Start timer
frmtimer.Show 1

' Set Ioport.VBX Port Data output to close shutter
frmholography!IOPORT1.PortData = 0

End Sub
```