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Study of FES/CAST/HGS

by

Gary L. Workman Ph.D.
Principal Investigator,

Rick Cummings
and Brian Jones

Materials Processing Laboratory
Center for Automation & Robotics
University of Alabama in Huntsville
Huntsville, Alabama 35899

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INTRODUCTION

The microgravity materials processing program has been instrumental in providing the crystal growth comunity with an experimental environment to better understand the phenomena associated with the growing of crystals. In many applications one may pursue the growth of large single crystals which cannot be grown on earth due to convective driven flows. A microgravity environment is characterized by neither convection or buoyancy. Consequently superior crystals are able to be grown in space. On the other hand, since neither convection nor buoyancy dominate the fluid flow in a microgravity environment, then lesser dominating phenomena can affect crystal growth, such as surface driven flows or diffusion limited solidification. In the case of experiments that are to be flown in space using the Fluid Experiments System (FES), diffusion limited growth should be the dominating phenomenon.

The use of holographic and schlieren optical techniques for studying the concentration gradients in solidification processes has been used by several investigators ove the years. The HGS facility at MSFC has been a primary resource in researching this capability. Consequently scientific personnel have been able to utilize these techniques in both ground based research and in space experiments. An important event in the scientific utilization of the HGS facilities was the TGS Crystal Growth and the CAST experiments that were flown on the IML mission in March of this year. The preparation and processing of these space observations are the primary experiments reported in this work.

This project provides some ground-based studies to optimize on the holographic techniques used to acquire information about the crystal growth processes flown on IML. Since the ground-based studies will be compared with the space-based experimental results, it is necesary to conduct sufficient ground based studies to best determine how the experiment in space worked. The current capabilities in computer based systems for image processing and numerical computation have certainly assisted in those efforts. As anticipated, this study has certainly shown that these advanced computing capabilities are helpful in the data analysis of such experiments.

Experimental Approach

The Holographic Ground System (HGS) is a ground support facility for the Fluid Experiment System (FES). It consists of a Mach-Zhender holography system, which can be modified for several uses including schlieren, microscopy, shadowgrams, hologram construction and reconstruction, and other minor holographic analysis techniques.

This year a series of tasks was completed, the first being the cleaning of the optical components of HGS. The cleaning involved the removal of each component from its mount and implementation of the cleaning procedure obtained from the original systems integrator, TAI Corporation. This procedure is attached in the Appendix 1. Total time for completion of this task was approximately four weeks.

After all the optical components were reinstalled, an exhaustive realignment of the HGS optical bench was necessary to restore the system to functionality. When the alignment was completed, interference fringes which were not present in the original alignment were observed. In an attempt to correct the situation, the collimating lens was switched with a supposedly identical focusing lens. However, this arrangement further intensified the condition. The lenses were switched back, and the fringes were reduced by rotating each lens separately until the fringes were minimized. The optical bench alignment procedure used here was included in the report from the previous effort.

Optical cleaning and realignment of the optical bench was completed just before the HGS received the flight film. The holographic film from all three cameras was downloaded into canisters with the film from each camera was divided into two canisters each, to minimize the possibility of accidental exposure. This began the lengthy development process.

The film development procedure was altered slightly from the previous one by the use of a new fixer. The new brand was Clayton Rapid Fixer™ in lieu of the usual Kodak brand. Thus, the fixing time was shortened to three minutes. Also changed was the brand of methanol used to bleach the blue dye from the developed holograms. However, this new methanol formed a granular substance when mixed

with water. After it was determined that this was no threat to the integrity of the holograms, the new 70mm development procedure was followed for all the IML film.

During the course of this research there was a general concern that very expensively obtained flight holograms may become compromised by the safelight used in the ground processing. Hence, a suggestion was made that the safe light in the dark room should be tested for possible exposure of the flight film. By holding an unexposed piece of test film directly in front of the light, the determination was that the light posed no threat to the flight film.

In order to get correct development time for different types of exposures, a development box, which uses infrared intensity detectors to determine the darkness of the film, was used. A preliminary analysis of settings for the development box was needed before a full scale development process could take place. The correct settings were determined by a simple trial and error method. Each test hologram was developed at different levels of intensity. The development box (see Appendix 3) has essentially two dials that are used for calibration. The third dial is not used for calibration purposes; its only function is to control the LED intensity. Dial 1 controls the sensitivity of the optical sensor. Dial 2 controls the response time of that sensor. The method used to set dial 1 is invariant: insert a neutral density filter in the development tank while dial 2 is at a preset value. Dial 1 is then adjusted until the LED light indicated correct exposure darkness. The best negatives were produced by first setting the response time to 3.0, calibrating the sensitivity, and then reducing the response time to 2.0. The development times varied depending on the type of hologram. Single exposures took about two minutes, doubles took one and a half minutes, and diffuse usually required two and a half minutes in the developer box.

The holograms are encoded for identification after the flight experiment with an alpha-numeric annotation. The first digit indicated the mission number. The second identified the experiment. The third gave the run number. The fourth digit identified the camera. The fifth, sixth, and seventh identified the hologram number for that sequence. For example: 2C2P158 means second mission (IML-1), CAST experiment, second run, primary camera, 158th hologram. The last five digits were obtained from a LED dot matrix binary pattern that is encoded on each hologram

during the flight exposure. A diagram for further simplification is included in Appendix 4. The first two digits are implied, and used only for filing purposes.

The first holograms that were developed consisted of the first TGS (triglycine sulfate) experiment in which the crystal growth chamber contained approximately 5000 polystyrene spheres of three different sizes: 199 microns, 468 microns, and 646 microns. These sphere were used to observe convective flow of the solution due to thermal gradients and to shuttle maneuvers that could cause minute acceleration changes. It was anticipated that the use of various sizes would contrast different buoyancy characteristics due to convective flow.

In performing the experiments to determine HGS requirements, a series of ground runs for the Casting And Solidification Technology (CAST) experiment were performed. The next task completed was the development of the ground experiment holograms. The development of the flight holograms was put on hold until the ground holograms were developed. The ground test was a complete replication of the flight experiment.

One one occasion, a meeting was held to discuss an existing problem with the drive mechanism and with the Holographic Optical Elements (HOE's). The drive mechanism did not fully advance during a portion of the CAST experiment, which resulted in overlapped holograms. It was decided that overlapped images should still be saved for possible data recovery at a later date. The discussion mainly focused on the HOE's, which allowed two separate angular views of the TGS crystal. A problem occurred because the HOE portion of the hologram image was less intense than the central portion. Different development times were used to determine optimal transmission through the HOE's. It was found that the same development time would be continued.

Experimental Results

During the performance of this research study, we have developed 821 holograms, which included 281 CAST holograms, 314 TGS primary camera holograms, and 226 TGS transverse camera holograms. SSL Lab developed about 150 other holograms from the TGS primary camera.

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After completion of hologram development, Polaroid photographs were taken to pass on to MetroLaser for their analysis. The Polaroid photographs were to be used for velocity vector analysis. Two Polaroids were taken from five holograms, one at five and one at sixty second exposure times. The negatives for the Polaroid film required a solution of sodium sulfite to remove the coating.

After all flight holograms were developed, the HGS table was reconfigured for hologram reconstruction. The acquisition of a three-axis camera mount was used for viewing and recording during reconstruction. Motor drive movement had to be determined and Unidex step units had to be calibrated. Precision calipers were used to determine a drive movement of 1000 microns per revolution, and Unidex step units of 5 microns per step.

As part of its role in supporting the IML space mission, the HGS is continuing to acquire images of the TGS 1B experiment for future particle velocity vector determination during microgravity shuttle maneuvers. In run 1B, there are 62 holograms to be analyzed. In order to include all relevant data, 36 images of each hologram are stored from 3 separate vertical planes over the crystal. Appendix 4 shows a schematic of the location of images for the system used here. Each image was made to overlap by approximately 10 percent. Images were given names according to their position over the crystal. Values along the x-axis were numbered consecutively. The y-axis value was given the stepper motor position. The z-axis was labeled A, B, and C for each vertical plane. The filename of an image, for example, could be 3150.1C, meaning stepper motor position 3150, first column, and in the C plane. The crystal center is under the 0.2B image. Refer to appendix 5 for a complete procedure on image acquisition. The Unidex is controlled and images were acquired using the Computerized Holographic Image Processing (CHIP) program written by Dr. Howard Brooks, DePauw University. Dr. Brooks has been very active in supporting the HGS facility with software to analyze FES holograms.

The FES experiments can produce a huge amount of data. The predicted number of images includes the 2232 images from run 1B as explained above, 768 images from run 1A in which the cap did not raise, and one interferogram from each of the 62 holograms in run 1B. The total number of images will be 3662 images, and

each images requires approximately one quarter of a megabyte of disk space, therefore images are currently being transferred over the ethernet to Space Science Laboratory for storage on Bernoulli cartridges. Appendix 6 contains several images obtained from the procedures followed here in processing holographic images from IML. The flight principal investigators are performing the analysis of these images, however, the ground processing procedures have proved to work very well.

Conclusions

This research task has produced a number of qualified procedures for processing and analyzing holographic images obtained from FES flight experiments. The analysis of the current data obtained from IML is still undergoing analysis; however, film processing procedures have been worked out for the first iteration with computer analysis procedures being worked through the first iteration. Finalization of the work on computer analysis is probably the next series of work to be accomplished.

Appendix 1
Optical Cleaning Procedure Used in this Work

Handling and Cleaning of Coated Optical Components:

Handling

Any component whose surface quality is critical should be handled in such a way that no foreign matter, particularly grease, touches the surface. They should be held only by the edge with a clean cloth, rubber gloves or finger cots previously cleaned with alcohol or detergent and water. Holding by the edge with bare fingers leaves grease on the edge and usually on the edge of the optical surface.

Components should also be protected as much as possible from dust. While providing a completely dust free environment may not be feasible; a cover directly over the component should be used as most dust travels straight down.

Cleaning

Normally the best advice on cleaning optical components is "DON'T" unless a slightly "dirty surface" has an appreciable effect on the performance of the component. (Any cleaning operation has some associated risk of damage.)

Excess dust can often be removed by blowing with an ear syringe. Care should be taken that the ear syringe is clean and dry and is not spraying water, etc.

A more effective method of removing dust is with compressed gas (such as Oriel's Microfilter Duster #4905.) The can must be held STRICTLY UPRIGHT to avoid liquid from being released.

If cleaning becomes necessary the following materials are recommended:

1) Clean Lens Tissue

2) Good quality Porous Cloth (Oriel #4908)

3) Box of Cotton Pads (Oriel #4910)

4) Microfilter Optics Cleaner (Oriel #4902)

5) Microfilter Duster (Oriel #4905)

6) Finger Cots or Clean Gloves

7) Acetone, Reagent Grade

8) Alcohol: This should be 95% pure distilled ethyl alcohol available
from laboratory supply houses or from your local liquor store (190
proof). Do not use 100% pure or "reagent grade" which has the last
5% of water removed by absorbents. The absorbents leave a residue.

9) Dispensers for both Acetone & Alcohol: You must use a dispenser
designed so that Alcohol, or Acetone, does not return to the main
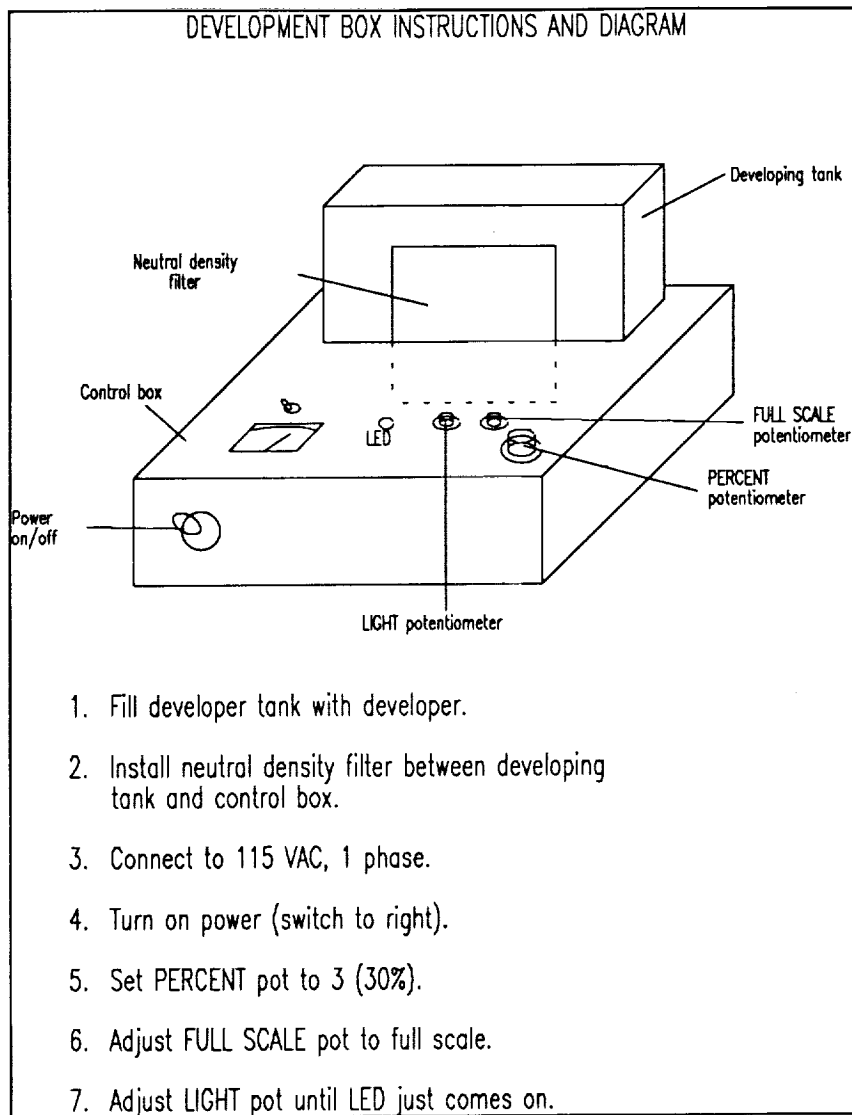reservoir. This is to prevent contamination.

Suggested Procedure:

Step A) Clean top surface of table to remove grease and dust. Lay
several sheets of lens tissue, or cloth, on top of table.
(A good precaution in case component accidently drops).

B) Fold a cotton pad in 1/2 to form a rectangle and then in
1/2 again to form a square.

C) Using either the cleaning cloth or finger cots, pick up
component with surface to be cleaned facing you.

D) Spray Optics Cleaner directly on to a cotton pad. Using the
cotton pad "gently" rub surface until it is completely wet.

E) Use another clean and dry cotton pad to wipe component dry.
If there are still signs of dirt, repeat steps B thru E once
more.

F) If there still seems to be some grease or dirt on the surface,
try the following: (If not, go to step G)

1) Fold a cotton pad as outlined in Step B.

2) Dampen (do not saturate) the folded edge with acetone.
Starting at the top edge of the surface, slowly and
gently pull the pad down the surface in one motion.
You may have to repeat this several times. If heavy
streaks begin to appear, change to a clean pad and acetone.

3) Repeat Steps B thru E.

G) The final cleaning can be accomplished by either of the fol-
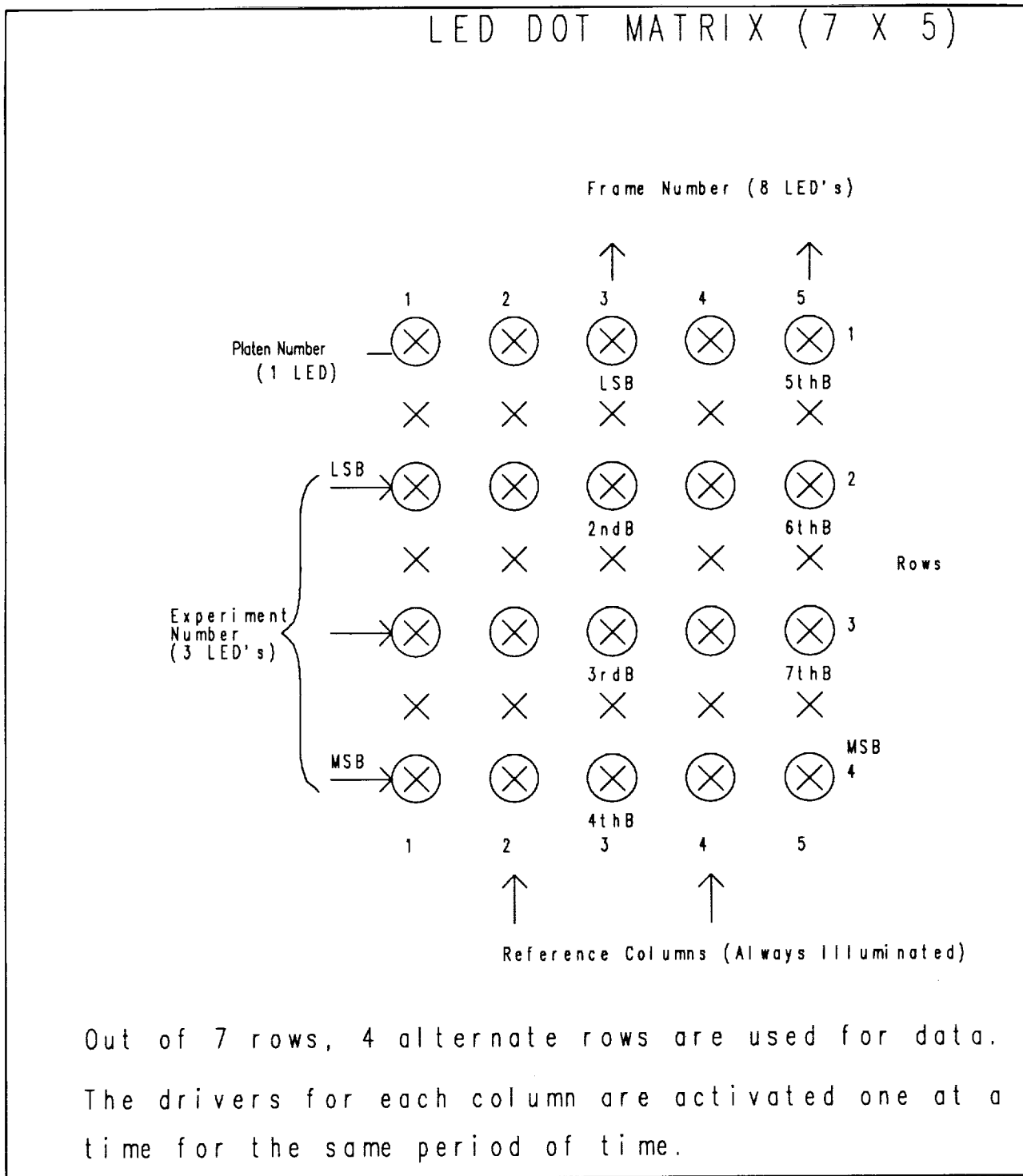lowing methods:

Method I   Follow procedure "F" except substitute the alcohol in place
            of acetone. The alcohol should remove any small streaks, or
            residue. Repeat if necessary.

Method II   A) Place a single sheet of lens tissue over the piece near
                one end of the tissue. Be sure that the other end of
                the tissue rests on more tissue, not on the table direct-
                ly to prevent dust pickup from table.

            B) Put a few drops of alcohol on the tissue directly on top
                of the component surface. This will spread to wet the
                entire component surface. Use only enough to wet this
                surface. Gently lift up the corners of the tissue
                slightly to check that the entire surface is wet.

            C) Grasp the near corners of the tissue and slowly and gent-
                ly slide (pull) the lens tissue off the component. Pull
                parallel to the surface so that the entire surface of
                the component is in contact with the tissue. During this
                sliding you will see that a dry area is created at the
                far side of the component which slowly creeps towards you
                until the whole piece is dry. The sliding action should
                be done in one motion, not stopping until the entire sur-
                face is dry. Then the balance of the tissue can be lifted
                off.

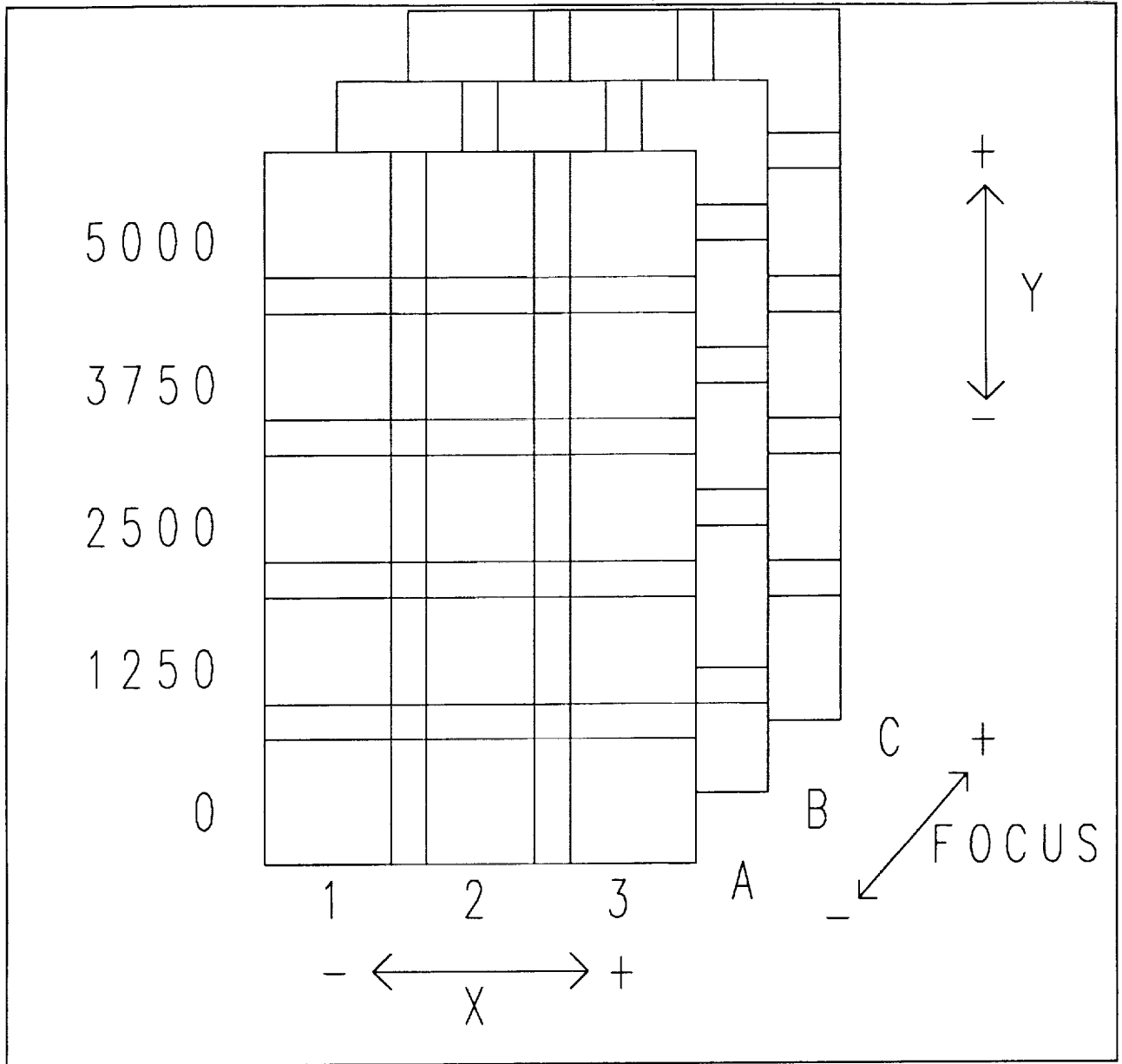   D) Repeat if necessary.

Appendix 2
Development Box Diagram

DEVELOPMENT BOX INSTRUCTIONS AND DIAGRAM

1. Fill developer tank with developer.

2. Install neutral density filter between developing
   tank and control box.

3. Connect to 115 VAC, 1 phase.

4. Turn on power (switch to right).

5. Set PERCENT pot to 3 (30%).

6. Adjust FULL SCALE pot to full scale.

7. Adjust LIGHT pot until LED just comes on.

Appendix 3

LED Dot Matrix Diagram

LED DOT MATRIX (7 X 5)

Frame Number (8 LED's)

Out of 7 rows, 4 alternate rows are used for data.
The drivers for each column are activated one at a
time for the same period of time.

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Appendix 4

Schematic Showing Layout of Holographic Images

Appendix 5

Image Acquisition Procedure For The 1B TGS Experiment

The Computer Holographic Image Processing (CHIP) program is used to acquire 45 images of each hologram. The CHIP program may be used to control the UNIDEX, which drives the camera mount motors on the optical bench. The camera is attached to a 3-axis precision mount which can move vertical and horizontal and can focus.

It has been determined that 1 step of the motor is equal to 5 microns. By translating a known point in the image vertically across the monitor screen, the screen was found to be 2030 steps wide. By the same process the screen was found to be 1562 steps high. Each image is to overlap by 10% on the sides and by 20% on the top and bottom with the next image. Therefore it was determined that the vertical movement of the camera should be 1250 steps and the horizontal movement should be 1827 steps to get the correct overlap.

Before entering the CHIP program, a directory should be made to store the images in. The directory name should match the hologram code found on the sleeve. While in this directory, enter the program by typing "chip." Select INITIATE FRAMGRABBER, then B/W from the menu which appears. Then select CONTINUOUS. The image should now appear on the screen.

The first step in saving the images from the hologram to the hard disk is finding the reference point from which to start every time. To do this several steps must be followed. First, make sure the UNIDEX is set correctly. The Y-axis dial should be set to VERTICAL and the X-axis dial to HORIZONTAL. Press the reset button and then the slew button on the UNIDEX. The remote joystick may now be used to translate the image down to the vacuum tube where it meets the sting. This is found in the left HOE region. The X-axis should now be set to FOCUS. Move the joystick left and right to bring the edges of the tube into focus. When this is accomplished, switch the UNIDEX back to HORIZONTAL and find the left corner of the sting. Move the image left until the rounded corner of the sting is just at the edge of the screen. Then translate the image down until the top corner of the sting is just off the bottom edge of the screen. This is the reference point from which all images should be started.

The first image to be stored is to the left of the crystal. In order to get the camera positioned properly to save this image, several minor calculations were made. It was determined that for the screen to be placed on the center of the sting, the camera must be translated 1779 steps to the right of the reference point. For images to be acquired in three overlapping columns with the middle column centered on the sting, the first image should be taken 1827 steps to the left of this screen. This corresponds to a difference of -48 steps in the horizontal direction from the reference point. Also, images are to be acquired from three separate planes of focus. It was decided that the distance between the planes should correspond to the distance of horizontal travel from one column to the next, or 1827 steps.

The next step is to initialize the CHIP program for use. The RESET button should be pressed on the UNIDEX so that the display reads SYS RDY. Now select UDX ONLINE on the computer screen and AUTO UDX. This connects the program with the UNIDEX. Select HOLO CODE and

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enter the last 6 digits of the hologram code. Select ANGLE and enter 1a.

Because the program is not being used for its intended purpose, the ANGLE command does not seem to make any sense. The ANGLE is simply what the computer appends to the filename when it saves the images. The first image to be stored is in the first column and in the A plane. The file name is simply the vertical position of the camera. The lower row of images is in position 0. Therefore the first image will be saved as 0.1a. To move the camera into the "a" plane of focus, select INCX and type 1827. Switch the X dial on the UNIDEX to FOCUS. Then select GO. The image on the screen should not change position, only focus.

Now everything is set up to start acquiring images. Set the UNIDEX back to HORIZONTAL. Now select INCX and type -48, because the first image is -48 steps horizontally from where the camera is now situated as shown above. Select AUTO GRAB. This tells the program to capture and save the image after every translation. Select GO. The camera should move to the first image and save it as 0.1a. The file name of the last image saved appears in the box at the bottom of the computer screen. Select INCX and type 0, and select INCY and type -1250. Select GO 4 times. the images saved should be 1250.1a, 2500.1a, 3750.1a, and 5000.1a, consecutively. Next select INCX and type 1827. Then select INCY and type 0. Select ANGLE, type 2a and select GO. This should move the camera to column 2 and save the image as 5000.2a. Now select INCX and type 0. Select INCY and type 1250. Select GO 4 times. The crystal should now be seen on the screen, the camera on position 0.2a. Select INCX and type 1827. Select INCY and type 0. Select ANGLE and type 3a. Select GO. The camera should then be positioned on the 0.3a image. Select INCX and type 0. Select INCY and type
-1250. Select go 4 times. This should leave the camera on the 5000.3a image. This completes the "a" plane of focus.

The next plane of focus is the "b" plane. Switch the UNIDEX to FOCUS and change INCX to -1827. Change INCY to 0 and ANGLE to 3b. Then select GO. The image saved should be 5000.3b. Switch the UNIDEX back to HORIZONTAL. Change INCX to 0 and INCY to 1250. Select GO 4 times. Keep track of the images being stored and make sure they are the correct ones. Change INCX to -1827 and INCY to 0. Change ANGLE to 2b and select GO. Change INCX to 0 and INCY to -1250. Select GO 4 times. Change INCX to -1827 and INCY to 0. Change ANGLE to 1b and select GO. Change INCX to 0 and INCY to 1250. Select GO 4 times. This should complete the "b" plane of focus and leave the camera on the 0.1b image.
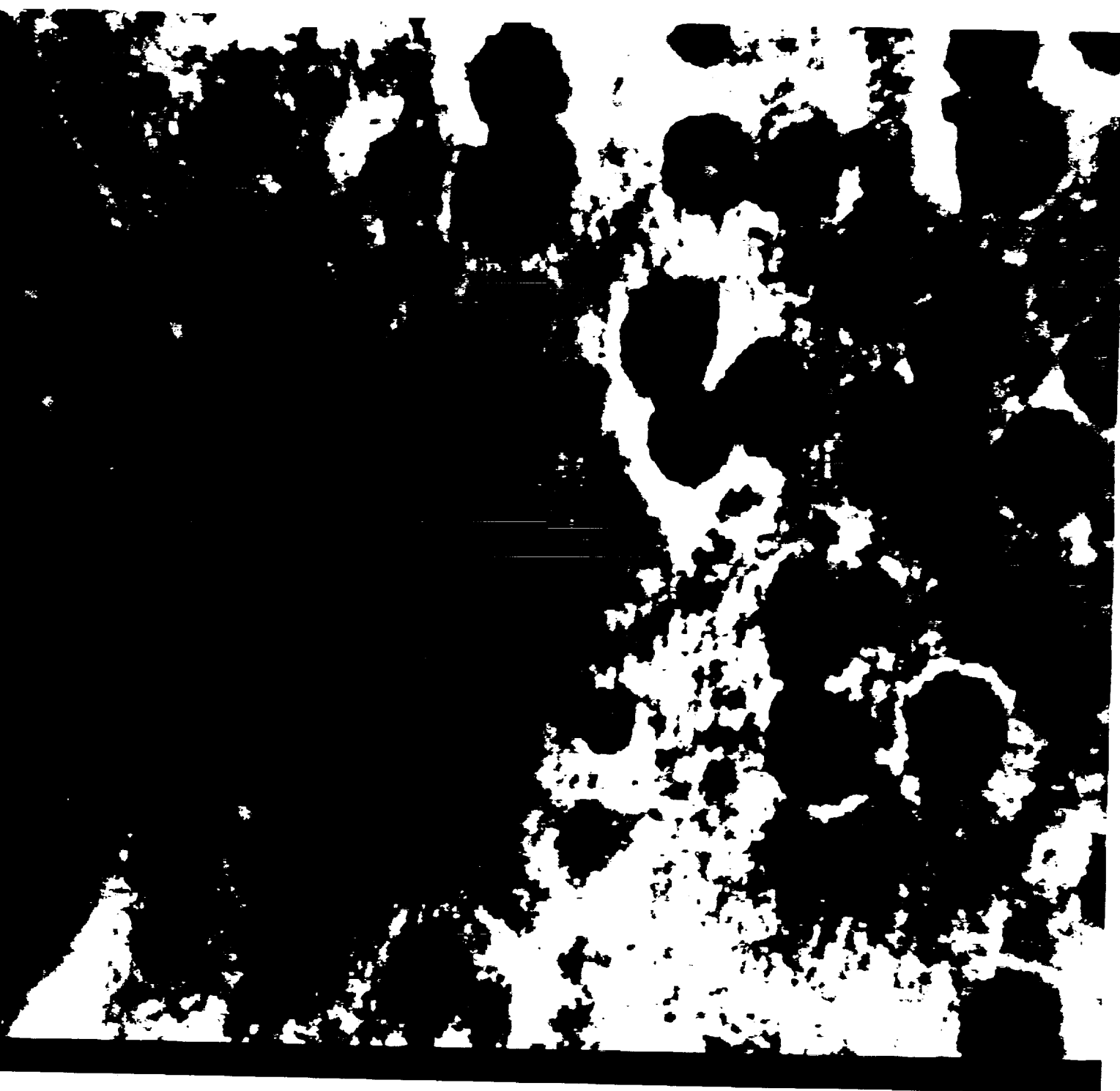
The last plane of focus is the "c" plane. Switch the UNIDEX to FOCUS and change INCX to -1827. Change INCY to 0 and ANGLE to 1c. Select GO. Switch the UNIDEX back to HORIZONTAL. Change INCX to 0 and INCY to -1250. Select GO 4 times. Change INCX to 1827 and INCY to 0. Change the ANGLE to 2c and select GO. Change INCX to 0 and INCY to 1250. Select GO 4 times. Change INCX to 1827 and INCY to 0. Change ANGLE to 3c and select GO. Change INCX to 0 and INCY to -1250. Select GO 4 times. This should complete the "c" plane and leave the camera on the 5000.3c image. Before beginning a new hologram, check the directory to make sure that the CHIP program saved all 45 images.

Appendix 6

Images of TGS Experiment Recorded from these Procedures